Airport Asphalt Pavement Technology Program

Asphalt Paving Handbook

2025 Edition

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The Airport Asphalt Pavement Technology Program (AAPTP) is a cooperative agreement effort between the **National Asphalt Pavement Association** (NAPA) and the **Federal Aviation Administration** (FAA) to advance asphalt pavements and pavement materials. The AAPTP advances solutions for asphalt pavement design, construction, and materials deemed important to airfield reliability, efficiency, and safety. The program leverages NAPA's unique technology implementation capabilities with assistance from the FAA and industry to advance deployment and adoption of innovative asphalt material technologies.

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List of Abbreviations

AACP	Airfield Asphalt Certification Program
AAD	Average absolute deviation
AAPTP	Airport Asphalt Pavement Technology Program
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt cement
AR	Aged residue
ASTM	ASTM International
ATPB	Asphalt-treated permeable base
BMD	Balanced mix design
DoD	Department of Defense
DOT	Department of Transportation
EAP	Emulsified asphalt prime
ESAL	Equivalent single axle load
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FOD	Foreign object debris
GPS	Global Positioning System
HMA	Hot-mix asphalt
IC	Intelligent compaction
ICMV	Intelligent Compaction Measurement Value
IPF	Impacts per foot
JMF	Job-mix formula
LAS	Liquid anti-stripping
LJ	Longitudinal joint
LSL	Lower specification limit
MDL	Maximum density line
MOQ	Measure of quality
MSCR	Multiple Stress Creep Recovery
MTV	Material transfer vehicle
MUTCD	Manual on Uniform Traffic Control Devices
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal maximum aggregate size
OBC	Optimum binder content
OGFC	Open-graded friction course
OSHA	Occupational Safety and Health Administration
PCC	Portland cement concrete

PD	Percent defective
PG	Performance-graded
PLI	Pounds per linear inch
PMA	Polymer-modified asphalt
PWL	Percent within limits
QA	Quality assurance
QC	Quality control
RAP	Reclaimed asphalt pavement
RAS	Recycled asphalt shingles
RPE	Rapid penetrating emulsion
SMA	Stone matrix asphalt
TMD	Theoretical maximum density
TRB	Transportation Research Board
UFGS	Unified Facilities Guide Specifications
USACE	United States Army Corps of Engineers
USL	Upper specification limit
VFA	Voids filled with asphalt
VMA	Voids in the mineral aggregate
VPM	Vibrations per minute
VRAM	Void-reducing asphalt membrane
WMA	Warm-mix asphalt

1. Introduction

1.1 HANDBOOK PURPOSE AND ORGANIZATION

The purpose of this Asphalt Paving Handbook is to provide comprehensive technical information and best practices related to the paving of asphalt mixtures for both roadway and airfield projects. The goal is to keep the discussion focused on practical aspects that have the greatest effect on the quality and long-term performance of the finished pavement.

Asphalt paving success cannot be accomplished with simply good paving and compaction operations. Success also depends on appropriate structural design, proper materials selection, mix design, plant production, surface preparation, and quality assurance (QA). Using best practices in each of these phases results in asphalt pavements that are built to last.

The Airport Asphalt Pavement Technology Program (AAPTP), a cooperative effort between the National Asphalt Pavement Association (NAPA) and the Federal Aviation Administration (FAA), produced this Handbook for those involved in asphalt paving production, construction, and QA programs. This includes personnel representing the contractor, user agency or owner, and consultants. In particular, the target audience includes inspectors, project engineers, designers, superintendents, foremen, paving crews, plant operators, and testing technicians.

The Handbook's discussion of referenced specifications and test methods is current as of the publication date. Readers should review current specifications to ascertain any pertinent changes that may have occurred since that time.

This Handbook's target audience includes inspectors, project engineers, designers, superintendents, foremen, paving crews, plant operators, and testing technicians.

The first edition of this Handbook was published in 1991 by the Transportation Research Board with financial support from the American Association of State Highway and Transportation Officials (AASHTO), FAA, the Federal Highway Administration (FHWA), NAPA, and the U.S. Army Corps of Engineers (USACE). In 2000, the National Research Council appointed a committee of experts from agencies, producers, and contractors to update the Handbook. Since its inception, the Handbook has served as a longstanding, venerable reference used across the asphalt paving industry to promulgate good practices. This current edition provides a much-needed update to incorporate the latest technology, equipment, methods, and standards.

The organization of this latest edition has changed substantially from previous editions, now consisting of 12 chapters covering the process of an asphalt paving project from start to finish. This Handbook includes many “between chapter” references where topics have different aspects covered in multiple chapters. Referencing the discussion in other chapter(s) minimizes duplicate discussions.

Following this Chapter 1 introduction, Chapter 2 provides a brief review of project organization. The role of materials and the mix design relative to mixture behavior is covered in Chapter 3. A discussion of how the mix design performed in the lab will likely differ from the mix produced in the field also occurs in Chapter 3, including some discussion of the adjustments that will be needed.

Mix production at the plant is covered in Chapter 4 in a more abbreviated manner than previous editions of the Handbook to keep it proportional with other topics. Chapter 5 covers the proper preparation of the surface to be paved over, whether it be a new granular base or an existing asphalt or concrete pavement. This includes details on prime coats and tack coats. Delivery of the mixture from the plant to the jobsite is covered in Chapter 6, including equipment types and proper loading and unloading procedures.

Chapter 7 discusses mix placement on the jobsite. The chapter covers equipment, procedures, and grade and slope control, including automation. Chapter 8 is a thorough discussion on compaction of the mat, including roller types, factors that affect compaction, and establishing a rolling pattern. Both longitudinal and transverse joints are discussed in Chapter 9, with heavy emphasis on best practices for placing and compacting joints.

Chapter 10 has been added to provide a dedicated and more thorough discussion on the critical topic of segregation, including possible sources and corrective measures. Chapter 11 covers the complex topic of QA, providing essential fundamentals for the many ways an agency approaches quality control (QC) and acceptance in its specifications and procedures. Finally, Chapter 12 focuses on the many possible mat problems that may occur, in addition to segregation as covered in Chapter 10.

1.2 AIRFIELD PAVING

The earlier editions (1991 and 2000) of this Handbook focused on roadway paving. A major change in this new edition is greater emphasis on airfield paving, with additional discussion on practices unique to airfield work. The differences between roadway and airfield standard practices are covered on a topical basis as warranted throughout the Handbook, not necessarily as separate sections but as expanded discussion. References may be made to both the FAA and Department of Defense (DoD) airfield paving standards and specifications.

The FAA’s standard asphalt paving specification for airfields is Item P-401 found in advisory circular 150/5370-10H. The DoD’s standard asphalt paving specification for airfields is Unified Facilities Guide Specification (UFGS) 32 12 15.13. While these two airfield specifications have some similarities regarding materials, gradations, joints, etc., they also contain many differences, especially concerning QC and acceptance.

A major change in this new edition of the Handbook is that it places greater emphasis on airfield paving, with additional discussion on practices unique to airfield work.

For several reasons, airfield pavements provide unique challenges compared to roadway pavements, and these challenges affect the paving process.

First, the tire pressures of aircraft wheels are much greater than those of truck tires. Large commercial aircraft have tire pressures ranging from 150 to 250 pounds per square inch (psi), while large trucks have tire pressures ranging from 85 to 110 psi. Military fighter aircraft can have tire pressures that exceed 300 psi. These extremely high tire pressures, especially when combined with slow-moving or standing loads, can cause a newly paved asphalt surface to be prone to rutting, shoving, or scuffing unless the mix is designed, produced, placed, and compacted in a manner that ensures sufficient stability.

A second reason is that airfield pavements must be designed, constructed, and maintained in a manner that does not produce foreign object debris (FOD), a term very familiar to those involved in airfield pavements and operations. FOD is any debris that can be ingested in a jet engine and cause damage, leading to major flight safety concerns as well as costly engine repairs. Because of FOD concerns, airfield pavements must be kept at a higher serviceability level than highway pavements.

A third reason is that paving on airfields (shown in Figure 1) drastically disrupts airfield traffic operations compared to traffic disruption caused by roadway paving. For most highway paving, traffic can be diverted but remain open by closing one or a few lanes. For airfield paving, the entire runway or taxiway must typically be closed because closing partial width on a runway or taxiway to keep traffic open is not an option.

A fourth reason is that airfield specifications typically have very stringent smoothness requirements, so the paving process requires more attention than “everyday” roadway paving.

All these reasons and more explain why paving on airfields is referred to as the “high-wire act” of asphalt paving.

*The FAA’s standard asphalt paving specification for airfields is **Item P-401** found in advisory circular **150/5370-10H**. The DoD’s standard asphalt paving specification for airfields is Unified Facilities Guide Specification (UFGS) **32 12 15.13**.*

Source: Brian K. Wood

Figure 1. Roller Train Ensuring Compaction on a Runway Project

1.3 ASPHALT MIXTURES DEFINED AND CLASSIFIED

Asphalt mixtures consist of aggregate and asphalt binder that are precisely blended and mixed in an asphalt plant and then placed and compacted on the jobsite, typically in multiple lifts.

The term "asphalt mixtures" is used generically to include the many different types of aggregate and asphalt binder mixtures (also referred to as bitumen, asphalt, or asphalt cement) produced in an asphalt plant. Traditionally referred to as "hot-mix asphalt" (HMA), the change in terminology to "asphalt mixtures" was spurred by the introduction of warm-mix asphalt (WMA). WMA is a generic term for various products and technologies incorporated into asphalt mixtures that allow for decreased mix temperatures while maintaining the workability needed for mixing, paving, and compaction. Asphalt mixtures include HMA and WMA.

A wide range of mixture additives and binder modifiers can be used in a particular asphalt mix design. Both categories are discussed in Chapter 3.

Mixtures can be classified and produced with a wide range of aggregate types, sizes, and combinations, each having its own characteristics suited for a specific design application. Mix types vary depending on the performance demands of that layer (lift or course) in the overall pavement structure. Layer names or terminology can vary by agency, region of the country, etc. In general, base course refers to the bottom asphalt layer, intermediate course refers to a middle layer, and surface or wearing course is the top layer. Thinlay is a term used for a thin overlay of the surface. In general, larger aggregate sizes with lower binder contents are used in lower lifts, while smaller aggregate sizes with higher binder contents are used in lifts toward and at the surface. Mixes incorporating larger aggregates do not necessarily possess higher strength, as discussed in Section 3.3.1.

While each agency may have its own unique mix designations, several ways to categorize and name the various types of asphalt mixtures are common. The first is by designating the nominal maximum aggregate size (NMAS) of the aggregate used in the mix. This is covered in Chapter 3. The second is by gradation type, of which there are three: dense graded, open graded, and gap graded. Some agencies also include binder grade in their mix designation. An example of a mix designation for an agency is "12.5 mm Superpave with PG 64-22."

Dense-graded mixes use an aggregate gradation that is well-distributed throughout the entire range of aggregate particle sizes used, from coarse through fine, resulting in a "dense" aggregate packing structure. Superpave and Marshall are the predominant mix design methods (discussed in Chapter 3) that produce dense-graded mixes. Dense-graded mixes are by far the most common mix type used on roadways and airfields. A further way to categorize a dense-graded mix is by whether it is fine or coarse graded. This distinction is generally made by whether the gradation line falls above or below the maximum density line (MDL) on the 0.45 power curve, as discussed in Chapter 3. For example, a "19-mm fine" typically means the mix has a 19-mm NMAS with a fine dense gradation.

Open-graded mixes consist of an aggregate with primarily uniformly sized coarse particles and highly interconnected air voids. The primary purpose of these mixes is to serve as a drainage layer, either at the pavement surface or at the bottom of the structural pavement section. The surface drainage layer mixes are called open-graded friction course (OGFC) or permeable friction course. OGFCs are designed and placed as a surface course to provide a free-draining surface to prevent hydroplaning, reduce tire splash, and reduce tire noise. OGFC mixes typically have an NMAS of 12.5 mm or 9.5 mm. The second type of open-graded mix is called an asphalt-treated permeable base (ATPB). ATPBs are designed with low asphalt binder content and predominantly large-size aggregate, such as 25 mm or larger NMAS. ATPBs are placed at the bottom of the asphalt structure and tied to edge drains so any water that enters the structural pavement section, either from the surface or subsurface, can escape to the edge drains.

Gap-graded mixes consist of an aggregate gradation with larger and finer particles but little or no particles in the middle of the gradation band, which creates a "gap." Stone matrix asphalt (SMA) is a common example of a gap-graded mix. SMA mixtures function similarly to dense-graded mixes in that they provide dense, impervious layers when properly compacted. They are known to be highly rut resistant due to their stone-on-stone aggregate structure and for their increased durability due to a thicker asphalt film coating the aggregate.

Section 3.3.1 in Chapter 3 has a complementary and more extensive discussion on particle size distribution, including illustrations of these three mix types by gradation as well as by NMAS.

1.4 WORKMANSHIP

Several major construction factors directly affect the ultimate performance of asphalt pavements: the structural design of the pavement layers; the binder, aggregate, and mix design qualities; the construction procedures used to produce, transport, place, and compact the mix; and the workmanship or quality of construction. Poor workmanship can be one of the most significant factors leading to premature distress of an asphalt pavement.

To ensure pavements perform as expected, there is no substitute for careful adherence to best practices by all involved with asphalt paving in all phases of a project, as outlined in this Handbook.

Causes of poor workmanship frequently include failure to comply with specifications, poor construction techniques, and improper equipment setup and operation. Appropriate training of construction personnel is key to good workmanship as well. Mix plant and paving train personnel must understand fundamental processes and procedures, as well as the consequences of failing to perform these best practices. For example, failure of roller operators to observe temperature zones during compaction could result in pavement areas that have low compacted density and risk premature pavement failures, translating to FOD on airfields.

Project management decisions can also lead to poor workmanship. For example, if paving is allowed to proceed during inclement weather, inadequate compaction can result despite proper practice by equipment operators. Similarly, if the paving operation moves too quickly, it can exceed the rate of delivery of material. This results in frequent stops of the paving train, which in turn can cause unnecessary pavement roughness and nonuniform density.

Proper performance of all construction-related tasks, including testing and inspection, ensures that the asphalt mixture produced, placed, and compacted will perform as expected. QC and acceptance procedures, such as those described in Chapter 11 of this Handbook, will identify instances of poor workmanship. These instances should be corrected as soon as possible. Chapter 12 of this Handbook is intended to help identify the causes of mat problems and offers recommended adjustments to prevent continuation of the problem.

There is no substitute for careful adherence to best practices by all involved with asphalt paving in all phases of a project, as outlined in this Handbook.

1.5 CERTIFICATION AND ACCREDITATION PROGRAMS

Certification and accreditation programs are intended to increase the quality of construction by ensuring project team members and laboratories are knowledgeable about various topics in asphalt materials, sampling, testing, paving, QC, and acceptance. Certification applies to individuals, while accreditation or qualification applies to laboratories. Both are typically tied to an agency's specific requirements and standards.

There are various certification programs across the United States. Many State agencies have their own certification programs for the various individual roles involved in an asphalt paving project, from sampling and testing technician to inspector to mix designer.

One example of a national certification program that has been adopted for military airfield projects is the Airfield Asphalt Certification Program (AACP). The three certifications available under the AACP are Laboratory Technician, QC Manager, and Inspector. Essentially, the UFGS 32 12 15.13 specification requires a contractor to have at least one individual with each of these certifications on their QC staff, and the individual must actively participate in that respective role during project execution.

AASHTO and ASTM International both offer national laboratory accreditation and proficiency programs. These programs are intended to increase proficiency and accuracy and reduce variability on certain laboratory tests.

2. Project Organization

2.1 INTRODUCTION

The most essential part of project planning and organization is communication. While each agency may have its own detailed policy and procedures on how projects are organized, there are common aspects that can be highlighted. This chapter discusses five key aspects of project organization and how effective communication is a vital element of each.

1. Project documents are written instructions, produced before the project is advertised, that should describe the requirements clearly and in detail.
2. Preconstruction conferences initiate verbal communication between agency representatives and contractor personnel. This conference sets the tone for both the working relationship and direct communications during project execution.
3. Ongoing communication between the contractor and the agency is essential to ensuring high-quality work.
4. Ongoing records provide a means of tracking and communicating events, progress, test results, and overall performance. These records are typically produced daily.
5. Safety on the job requires good communication among all parties.

2.2 PROJECT DOCUMENTS

Project documents are developed by the design team and are part of the bid letting. These documents illustrate and describe the scope of work to be done under the contract. Specific definitions of these documents and other terms that apply directly to a project are normally included in the first section of the governing standard specifications. Project documents include the following:

- Plans—Drawings that show the project location and layout, cross sections of the pavement, dimensions of the work, roadway or airfield appurtenances, striping and traffic control, and other details of the work to be done.
- Standard specifications—Written technical documents that provide detailed technical requirements for the materials, products, and methods used to perform the work described in the plans. These specifications are designed to ensure that the pavement performs adequately for its intended use. Some may outline performance criteria for achieving the desired outcome. Standard specifications are usually published by an agency as a volume of many specifications that the agency owns and periodically updates. Categories of standard specifications include materials, construction, QA, and performance.
- Special or supplemental specifications—Approved additions and revisions to the standard specifications. These are typically newer specifications adopted since the last standard specification volume was published.

- Special provisions—Additions or revisions to the standard or supplemental specifications that are applicable only to an individual project.

Agencies often incorporate several other documents by reference into the standard specifications, supplemental specifications, and special provisions. Material specifications and test procedures from AASHTO and ASTM are often listed in the specifications and become part of the contract documents. Additional documents, such as the Federal Highway Administration's Manual on Uniform Traffic Control Devices (MUTCD) and Occupational Safety and Health Administration (OSHA) regulations, are treated in the same manner when referenced in the specifications. For airfields, AC 70/7460-1K Obstruction Marking and Lighting is an important document for construction equipment, etc.

Many of the material specifications and test methods written by AASHTO or ASTM for national use are modified by State or local agencies for their specific use. Governmental agencies often publish their own material specifications and test methods. These publications are also referenced in and become a part of the contract documents. Inspection manuals or guidelines are normally intended for use by the agency's representatives and are not part of the contract documents.

If a discrepancy exists between the instructions and specifications in any of the contract documents, the order of priority, from highest to lowest, is usually as follows:

1. Special provisions.
2. Plans.
3. Special or supplemental specifications.
4. Standard specifications.

This hierarchy corresponds to the documents' specific applicability to a project or contract.

Plans and specifications need to be accurate and complete, and they should leave little room for assumptions or interpretation. Accurate and complete contract documents result in comprehensive bids, save many hours of later discussion between agency and contractor representatives, and often prevent contract disputes that are expensive and time-consuming for all parties. To ensure that the full scope of the project is fully cataloged, pre-bid meetings and a time allowance for written pre-bid questions and official responses should be built into the bid-letting process.

If QA specifications are used, the requirements for the contractor to monitor its own work and for the agency or designated entity to do the necessary acceptance testing should be provided in detail. The project documents should clearly state testing methods and frequencies.

Chapter 11 is dedicated to the topic of QA, with sections on definitions, general types of specifications, QC plans, sampling methods, and QC at the plant and in the field, as well as acceptance.

2.3 PRECONSTRUCTION CONFERENCE

A preconstruction conference (or pre-paving meeting) should be held before work on a project begins, in time to allow for discussion, clarification, and any agreed-upon changes to be made. This conference is an opportunity to help all parties understand the responsibilities of the owner's representatives and the contractor's personnel. Details of the project should be covered so all affected parties understand the "who, what, why, when, where, and how."

Building a successful paving project is a partnership between all the parties involved, with the goal of delivering a top-quality result as a product of teamwork. Good communication is key, and the preconstruction conference sets the tone for future communication and cooperation. It is important that all aspects of the work be thoroughly discussed, potential problem areas be addressed, and any questions or concerns dealt with. All answers may not be available during the meeting, but action items can be assigned to provide the answers later when available. A good practice is to include a projected date by when each question should be answered to keep the questions from being forgotten.

Attendees at this meeting include key personnel representing the owner, contractor, subcontractors, testing firms, consultants, etc. Titles of key personnel include engineer, project manager, inspector, testing technician, superintendent, paving foreman, and plant manager. For airfield projects, airport management and airport operations should be represented to discuss airfield access, security, safety, etc. Lists of key personnel assigned to the project should be shared between the owner and contractor, with clear lines of authority and lines of communication delineated.

The agency is responsible for convening and conducting this preconstruction meeting. Agency personnel will outline the scope of the project, reviewing information provided in the contract documents. The agency representatives should also discuss any unusual aspects of the job—items that are not routine construction practices. The agency should review testing and sampling requirements to ensure everyone involved in the project understands the following:

- Purpose of all testing.
- Frequency of tests and taking of material samples.
- Responsibility for performing the tests and/or taking the samples.
- Location of tests or material samples.
- Details on handling, transporting, and testing of material samples.

- Timeframe and procedures for reporting test results and to whom they should be reported.
- Response to failing tests, including penalties, work stoppage, etc.

The individuals representing the contractor should be familiar with all aspects of the job and be able to speak with authority about their plans to accomplish the work. A progress schedule for the job should be presented and discussed with the agency representatives. Questions about the content in the contract documents should be raised and clarification requested. Because continuity of asphalt paving operations is critical to providing quality pavement, the contractor personnel should include items such as material sources, plant production rates, haul distances and routes, paving sequence, paving widths and speed, type and quantity of equipment to be used, etc.

The contractor QC plan is the process that the contractor will use to ensure that quality is controlled, and it should be discussed during the preconstruction conference as well. In particular, the testing that falls under QC should be covered, including how QC data is collected, reported, and perhaps used as part of acceptance. Chapter 11 discusses QC as part of QA.

Typically, on large projects and for all airfield projects, specifications require the construction of a test section prior to full asphalt mix production and paving operations. The purpose of the test section (also referred to as the control strip, test strip, etc.) is to evaluate the compliance of the job-mix formula (JMF), mix production, transportation, laydown, and compaction relative to the requirements in the project documents. When the project specifies this approach, full production should not begin until an acceptable test section has been constructed and accepted by the owner.

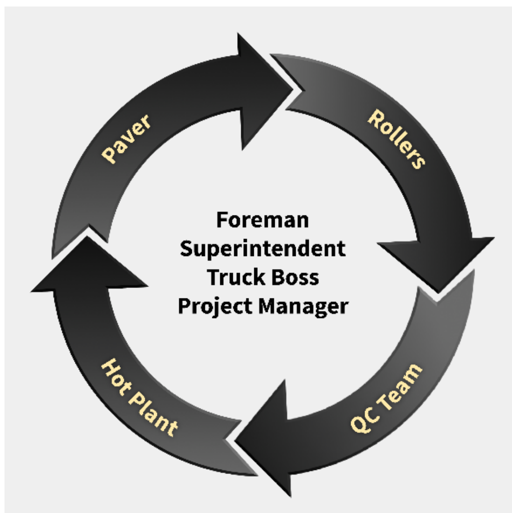
One of the most important items to be addressed at the preconstruction conference is job safety, a topic also covered at the end of this chapter. Safety is the responsibility of everyone involved with the project. Discussion of this topic should include not only the safety of those working on the job (contractor, subcontractors, and agency personnel) but also the safety of the traveling public and any traffic likely to operate in the vicinity of the work zone (e.g., airplanes). Clear responsibility should be delineated for maintenance of all traffic control devices, such as signs, pavement markings, and flagging. The name of the contractor representative responsible for safety should be provided to the agency so that rapid and clear communications can be accomplished should safety issues occur. For

A preconstruction conference (or pre-paving meeting) should be held before work on a project begins, in time to allow for discussion, clarification, and any agreed-upon changes to be made. This conference is an opportunity to help all parties understand the responsibilities of the owner's representatives and the contractor's personnel.

airfields in particular, an emergency response plan should be discussed since access to the site is usually tightly controlled compared to roadways.

2.4 ONGOING COMMUNICATION

Communication cannot stop once the preconstruction conference has finished. The quality of the paving work, along with the safety of those performing and inspecting the work, is directly related to the quality of the ongoing communication between all parties involved. It is important that the individuals in daily charge of the project for both the agency and the contractor meet periodically, on both a formal and an informal basis, to discuss the progress and quality of the work done to date and the schedule for future work. Clear lines of communication should be established, as illustrated in Figure 2, with regards to QC.



Source: NAPA

Figure 2. Lines of Communication for Quality Control

2.4.1 Formal Meetings

The frequency of formal update meetings depends on the scope and the size of the paving job. On a major project, these should be held at a regularly scheduled time at least once weekly, such as every Monday morning at the project office. Key personnel from both the agency and the contractor should be present, and an updated "look ahead" schedule should be presented and discussed so that all parties can properly plan and coordinate. The meeting should be conducted jointly by the agency and the contractor and serve as a forum for constructive input to the job. Written meeting minutes should be taken and distributed to interested parties.

The discussion should include such items as the quantity of work completed and test results obtained. The meeting should also focus on what has yet to be accomplished and the schedule for the coming weeks. Any changes in personnel, equipment, construction methods, and JMF should be discussed. Problems that have arisen and those that are anticipated should be communicated to both parties, with solutions explored. Safety should also be reviewed.

2.4.2 Informal Meetings

Informal meetings should be held daily between the individuals in charge of the job for the agency and the contractor. Ideally, these meetings should occur at a regularly scheduled time and can be held at the asphalt plant or at the paving site. The purpose of these informal meetings is twofold. First, occurrences the day before such as work completed, test results, and any problem areas encountered should be discussed and resolved, including overall safety issues. Second, the discussion should address what is expected to happen that day and over the next few days. Various aspects of the overall safety plan and specific project hazards should be included in these daily meetings. Providing key takeaways from any recent formal meetings is also important.

Asphalt paving projects, like many construction projects, are not always conducted as originally scheduled. Changes occur because of problems with material supply, equipment breakdown, contractor and subcontractor schedules, and weather conditions. When such changes occur, it is important that they be communicated between the contractor and the agency. Daily informal meetings provide a forum for the exchange of such information. The team also needs to appreciate that paving projects are uniquely dynamic: work zones are mobile and bustling with dozens of pieces of moving equipment, including trucks entering and exiting, and are often spread out over thousands of feet.

Section 2.6 includes additional discussion on daily safety briefings.

2.4.3 Communication Formats

Communications can be oral, electronic, and written. Much information can be communicated in oral form, but discussion of important information, including a change of conditions or contract modifications, should be in writing. Issues should be resolved quickly so they do not hamper the project schedule and risk project costs, efficiency, or safety.

Personnel for both the agency and the contractor should keep daily diaries and photographs of events that occur. Occurrences noted in a daily diary may need to be remembered later, and a written log can help keep the details accurate and complete. Section 2.5 contains a more thorough discussion of daily diaries.

Electronic project management tools are available to help with project communication and necessary project documentation.

2.5 ONGOING RECORDS

Accurate and complete records are needed for all construction projects. This is true both for the project engineer and staff and for the contractor's general superintendent, plant and paving superintendents, and all foremen. Trying to accurately reconstruct events later without proper notes, photographs, and complete test data is nearly impossible. Moreover, taking pictures and videos with time and date stamps, and possibly geolocations, to document a paving project can prove invaluable when the project is reviewed. Conflicting opinions about what happened are common with poor recordkeeping practices. One rule of thumb should always be followed: If in doubt about whether the information is important or beneficial, record it.

Workmanship is very important, as many problems are related to workmanship issues and are identified visually before they are determined by testing. Workmanship was covered in Section 1.4.

Taking pictures and videos with time and date stamps, and possibly geolocations, to document a paving project can prove invaluable when the project is reviewed.

2.5.1 Plant Reports

The results of all daily and periodic tests conducted at the asphalt plant should be recorded. A variety of different forms may be used for this purpose. Contractor personnel should complete and keep their own records, even if not required to do so by the agency.

Data that should be recorded include project number and location information, project material sources, JMF information, aggregate gradation and asphalt content test data, mix temperature, mix test results, material quantities (of aggregate, asphalt binder, and additives) used, number of tons of asphalt mix produced, daily weather conditions, and the pavement location where daily production was placed (see Figure 3). Agency specifications may require additional information, such as the moisture content of the individual aggregate stockpiles. Any such required data should be reported on the appropriate forms.

It is important to record the date, time, and location of all samples taken, as well as the name of the individual who took them, on the form. Any additional information that pertains to the sample should be noted. For example, if aggregate gradations are determined from samples taken at two different locations (e.g., from the cold-feed belt and from the extracted mix), those locations must be marked on the report. Failing test results should be highlighted on the form as well as the action to be taken.

Most forms should have a "Remarks" area. This portion of the form should be used to indicate any unusual occurrences or test results that took place during the day. Any corrective actions or changes to the materials, plant operating conditions, or test procedures should be indicated, as should the results of those actions or changes.

HMA Plant QC Report

Date: __________ Test Report No: __________ Project: ____________________ Time:__________ Lot No: __________
Sublot No: __________ Location Mix Placed: ____________ Sample Location (truck, paver, in-place): ____________

Asphalt Cement

Grade ____________ Source ____________ Design Content __________ Measured Content ____________

Test Method ____________

Aggregate

Source of Aggregate (stockpiles, cold feed, extraction, ignition): ____________

Washed or dry gradation? ____________

Sieve Size	JMF Percent Passing	Measured Percent Passing
37.5 mm	______	______
25 mm	______	______
19 mm	______	______
12.5 mm	______	______
9.5 mm	______	______
4.75 mm	______	______
2.36 mm	______	______
1.18 mm	______	______
0.6 mm	______	______
0.3 mm	______	______
0.15 mm	______	______
0.075 mm	______	______

Aggregate	Source	% Used
1	______	______
2	______	______
3	______	______
4	______	______
5	______	______

Fine Aggregate Angularity: ________

Coarse Aggregate Angularity: ________

Percent Flat & Elongated (5 to 1): ________

Mix Testing

No. of gyrations @ Nd: ____________ Laboratory Compaction Temp: ____________ Bulk Specific Gravity: ____________

Voids @Nd: ____________ Voids filled @ Nd: ____________ VMA @ Nd: ____________

% Gmm @ Ni: ____________ % Gmm @ Nd: ____________ % Gmm @ Nmax: ____________

Maximum Theoretical Specific Gravity: ____________ Retained Tensile Strength (percent): ____________

Sample obtained and tested by: ________________________________

Source: Hot-Mix Asphalt Paving Handbook 2000, 2nd Edition

Figure 3. Plant Report Example

2.5.2 Field Test Results

Field tests are conducted concurrent with the paving operations. See Chapter 11 on QA for details on this phase of testing. On projects that utilize a QA specification, both the contractor and the owner's representatives will be conducting testing and tracking the results. The key is to track all test results to evaluate how the contractor is performing against QA requirements. This allows the contractor to fine-tune their processes as needed to maximize the quality of the product and the owner to have confidence in what they are buying.

Information on what occurred at the paving site during mix placement and compaction operations should be recorded by both parties. The form of this information may differ between the agency's paving inspector and the contractor's superintendent, but essentially the same information should be reported by both. This consistency will allow for more meaningful discussions later if deficiencies should develop in the test results or in the performance of the mix under traffic.

Field compaction is widely held as the single most important construction property for the long-term performance of an asphalt pavement. A well-compacted dense-graded mixture will be impermeable to both water and air, resisting the aging effects of the environment. The mix is given the best opportunity to sustain the repeated loading from traffic when properly densified. See Chapter 8 for more information on compaction.

Data regarding field compaction should include the following: project number and location; type and number of tonnes (tons) of each mix placed and its exact location—layer number, thickness, lane, and station number; the location (both transversely and longitudinally—station number) of any tests taken; and the density results and method by which they were obtained.

Other project information that should be recorded includes weather conditions; type and make of compaction equipment used by the contractor; roller settings of amplitude, frequency, tire pressures, and ballast weight; type, amount, and location of any tack coat material placed; a running total of the tonnes (tons) of each mix placed on the project; and smoothness results obtained.

All samples taken must also be clearly identified on the form to reflect the location from which the material was gathered, the time and date of the sampling, the reason the sample was taken, the quantity of material the sample represents, and the name of the person who took the sample. Pictures and/or videos of the testing and the materials gathered are valuable. If a nuclear or non-nuclear gauge was used to determine the relative density of the mix, any calibration procedures used to check the reliability of the gauge should be referenced. Any failing test results should be highlighted. The "Remarks" area on the pavement report form should be used to report any unusual conditions or test results that occurred during the day. An explanation for any failing test results should be provided, if possible, and the steps taken to correct the problem should be noted, along with their results.

Field compaction is widely held as the single most important construction property for the long-term performance of an asphalt pavement. A well-compacted dense-graded mixture will be impermeable to both water and air, resisting the aging effects of the environment.

While the pavement's density is the most important factor in controlling its future performance, its smoothness and grade must also be achieved for the comfort and safety of the pavement users. Moreover, smooth pavements have been shown to last longer than rougher ones, and proper grading is needed to ensure drainage is achieved. Automated data-collecting vehicles are commonly used to determine the overall smoothness of a pavement, but the use of traditional 10-ft or longer straight edges still has its place. Namely, a long straight edge is needed to verify that transverse joints are smooth. Chapter 9 offers detail on the proper construction of joints, while Chapter 11 provides a discussion on smoothness.

2.5.3 Daily Diary

All project supervisors, both agency and contractor, should be required to keep a detailed daily diary for possible later reference. This document should be used to record all pertinent information about the conditions and production for each day's activities. Any changes that are made in the mode of operation of the asphalt plant or the laydown and compaction equipment should be documented along with why the change was made. The diary should have each day's weather conditions recorded, with updated weather information added periodically as needed throughout each day.

The daily diary should also document any non-routine events that occur on the job, including visitors to the project. It should also be used to record the reasons for any delays in paving (e.g., an equipment breakdown or poor weather conditions) and the duration of the delay.

The use of time-stamped and geolocated pictures and videos to further document a project is encouraged. Common items to consider documenting at the asphalt plant setup with pictures and video include aggregate stockpiles, paving site, traffic control, mixture delivery, paver operations, joint construction, and the compaction process. Handheld thermal cameras or smartphone attachments are inexpensive and can be invaluable tools for documentation.

For the information in a diary to be accurate and meaningful, it must be recorded as the events occur or shortly afterward. The diary should be one of the first activities of each workday, and it should be updated at least twice a day—once around midday and again at the end of the day. If job conditions and schedules preclude making the midday entry, the events of the day should always be recorded upon completion of each day's activities.

The information contained in the diary must be as detailed and complete as possible. If a conversation concerning project activity is held with other project personnel, whether agency personnel or contractor employees, the date and location of the conversation should be recorded. The names and titles of any people involved in the discussion should be noted, as well as the topics addressed. If changed work scope and/or costs are realized due to project discussions, it is essential to officially document any agreements reached and to produce a timely written and signed change order, usually before changes are carried out.

The importance of the information contained in the daily diary cannot be overemphasized. “Too much” documentation is not possible. A typical daily diary would be a bound notebook with printed consecutive page numbers. If one party to a dispute can present information written in a timely fashion in a diary, whereas the other can only rely on memory to reconstruct the events, the diary owner will usually have an advantage in the settlement of the disagreement. The information in the diary may also be useful for conducting follow-up research and for determining the reasons for premature pavement performance issues.

It is becoming more and more common to document diaries electronically using photos, electronic notes, voice memos/notes, etc. This electronic documentation should be carefully and regularly stored on an accessible server in a format that can be read by all.

2.6 SAFETY

Working around an asphalt plant can be hazardous. Machinery operation, high temperatures, noise, and moving delivery trucks and haul trucks all add to the possibility of an accident occurring. Common types of accidents at a plant include workers being burned by hot asphalt mix, getting sprayed with hot asphalt binder, crushing a hand in a piece of machinery, or being struck by a moving vehicle.

Working around an asphalt paving site can also be hazardous. Common types of accidents for those working around the paver include being struck by passing traffic, the paving equipment, haul trucks backing into or pulling away from the paver, and the compaction equipment. Burns from the hot mixture and equipment are also among the most common injuries.

Safety is everyone’s business on an asphalt paving project. Everyone working for the contractor—from the superintendent to the front-end loader operator at the asphalt plant, to the truck driver and the roller operator—must be continuously aware of the need to apply safe work habits. Likewise, everyone working as a representative of the agency—from the project engineer to the inspector at the paving site to a testing technician behind the paving operation—must all practice safe work habits. OSHA regulations must be known, understood, and followed by each person involved in the project.

Effective training and communication are key to a safe work environment. Every individual involved in the project should know what is expected and how to perform the assigned tasks. Proper training in the operation of a piece of equipment is essential for equipment operators. Retraining is necessary at frequent intervals.

Safety talks are a good way to start the day for both contractor and agency personnel. Several different organizations publish short, concise safety presentations that can be completed in 2 or 3 minutes. People need to be reminded that they are operating in a potentially dangerous environment at both the plant and the paving operation, and daily talks are one way of meeting this need. Further, if an unsafe work practice is noticed, corrective action should be taken immediately, even if the paving operation must be shut down until the unsafe practice has changed.

Individuals most likely to be hurt on an asphalt paving project are those who are new to this type of work. Without adequate training before they start on a paving project, these people do not fully understand the difference between following safe work practices and taking foolish chances. At times their enthusiasm to excel at a new job and to please others can overshadow their awareness of proper safety practices.

Needless injuries are also suffered by those who have been around the plant and the paving operations for many years and therefore may become overly comfortable and complacent with equipment and safety procedures. Safety should be as much a part of these individuals' day as it is for those new to the job.

Constant care and vigilance are needed to prevent accidents and injuries associated with asphalt operations. OSHA, NAPA, the Asphalt Institute, State departments of transportation (DOTs), and other organizations have publications and videos that address asphalt safety. These tools should be made available to relevant personnel and be part of regular safety training.

3. Asphalt Materials and Mix Design

3.1 INTRODUCTION

Asphalt mixtures have three primary ingredients: binder, aggregate, and air. The asphalt binder, also called asphalt cement or bitumen, is obtained from refining crude oil. Binders can be graded by several methods. Outside the United States and Canada, the most common method is the penetration grading system. In the early 1960s, the Asphalt Institute developed the viscosity grading system to use a more fundamental material property rather than the empirical penetration grading system. In the late 1990s, the United States and Canada adopted the performance-graded (PG) system developed under the Strategic Highway Research Program. The latest binder grading method uses the Multiple Stress Creep Recovery (MSCR) test and specification.

The aggregate used in asphalt mixtures is typically a combination of coarse and fine materials, with mineral filler added as needed. Locally available aggregates from a pit or a quarry are most often used to minimize haul costs.

The mix design process determines the correct proportion of binder and aggregate required to produce an asphalt mix with the properties and characteristics needed to withstand the effects of loading and the environment for many years.

Asphalt mixes require air voids to allow for thermal expansion of the binder without bleeding or flushing. Most asphalt mix designs are dense-graded and target air voids in the range of 3 to 4 percent. Open-graded asphalt mixtures are intentionally designed with high air voids (around 20 percent) to allow water to flow through the mix and drain to the side of the mat.

Mix design is performed in the laboratory, generally using one of two methods whose primary difference is the method of compaction. Until the late 1990s, the most common mix design method was the Marshall method, which was used by about 75 percent of State highway departments as well as by the DoD and the FAA. Now almost all State DOTs use the Superpave method of mix design. In this method, samples are compacted with a Superpave gyratory compactor and tested for volumetric properties. Additional tests are often performed to assess the asphalt mixture's moisture susceptibility and resistance to permanent deformation (rutting) and different types of cracking.

For an asphalt paving project, the mix design is most often developed by either the contractor or a private laboratory, although some government agencies still design their own mixes. Regardless of who

The mix design process determines the correct proportion of binder and aggregate required to produce an asphalt mix with the properties and characteristics needed to withstand the effects of loading and the environment for many years.

completes the laboratory mix design phase of the job, the result of the mix design process is a JMF. The JMF is the starting point for the contractor in producing the asphalt mix for the project. From the JMF, targets are established for acceptance quality characteristics. These targets are then used with tolerances and a quality measure for acceptance of airfield or roadway asphalt materials.

This chapter briefly reviews the properties of the materials used to produce an asphalt mix and the mix design process. Also discussed are some of the differences that can exist between laboratory- and plant-produced mixes and between JMF values and plant test results.

3.2 ASPHALT BINDER: GRADING SYSTEMS AND PROPERTIES

Binders must be tested to ensure that the product received and used meets the specifications. Early asphalt binder testing was either nonexistent or crude. Like the infamous "chew test," it sought only to distinguish between harder and softer binders. Inevitable progress brought about newer, more sophisticated methods of testing, which resulted in more comprehensive purchase specifications that directly relate to the intended performance expectations of the binder (e.g., stiffness and temperature profile, ductility, and flow) when incorporated into the asphalt mixture.

The Asphalt Institute maintains a database of U.S. State DOT and Canadian Province emulsion and binder purchase specifications.

3.2.1 Penetration Grading Systems

The penetration of an asphalt binder (AASHTO T 49, ASTM D946) is the penetration of a weighted needle into a binder sample measured in units of decimillimeters (0.1 mm) at 25 °C (77 °F). Asphalt mixtures with stiffer binders (i.e., with a lower penetration) will be stiffer at a given temperature than mixes with softer binders (i.e., with a higher penetration). For example, at a given temperature, a mix containing binder classified as 60–70 penetration grade will be stiffer and may require more compactive effort by the rollers to achieve the desired density than will a mix containing a 120–150 penetration grade asphalt binder. This empirical test is an indicator of stiffness at one temperature, but any relationship with overall mix performance can be significantly variable.

3.2.2 Viscosity Grading Systems

Grading of asphalt binders by viscosity (resistance to flow) is defined by a viscosity measurement at 60 °C (140 °F) on the material in its original (as received from the refinery) condition (termed AC, for asphalt cement) or on a binder considered to be comparable to the material after it has passed through the high temperatures of the plant production process (termed AR, for aged residue). In the AC grading system, a mix containing an AC-20 will be stiffer than a mix containing an AC-10. Similarly, in the AR grading system, a mix containing an AR-4000 will be stiffer than one containing an AR-2000 at the same temperature. The ASTM viscosity standard is D3381, while the AASHTO viscosity standard is M 226.

3.2.3 Superpave Performance-Graded System

Grading systems based on penetration and viscosity have worked reasonably well for many years and are still used in many countries because of the simplicity and portability of the testing equipment. However, these simpler grading systems can categorize binders within the same grade even though they may exhibit very different temperature and performance characteristics in the environment in which they are used.

The PG system was developed to provide an improved set of asphalt binder specifications (AASHTO M 320, ASTM D6373). This system endeavors to measure physical properties that can be related directly to field performance by engineering principles. The PG tests are performed at loading times, temperatures, and aging conditions that more realistically represent those encountered by in-service pavements. The PG specifications help in selecting a binder grade that will limit the contribution of the binder to low-temperature cracking, permanent deformation (rutting), and fatigue cracking of the asphalt pavement within the range of climate and traffic loading found at the project site.

An important difference between the PG specifications and those based on penetration or viscosity is the overall format of the requirements. For the PG binders, the performance criteria remain constant; however, the temperatures at which those properties must be achieved vary depending on the climate in which the binder is expected to serve. The binder is graded in 6 °C increments of pavement temperature. An example of a binder designation in this system is PG 64-22. For this example, the binder is selected to resist environmental conditions in which the average 7-day maximum pavement temperature is at least 64 °C (147 °F) but lower than 70 °C (158 °F). On the low-temperature side, the binder is selected to perform in pavement temperatures from −22 °C (−8 °F) down to just above the next grade at −28 °C (−18 °F).

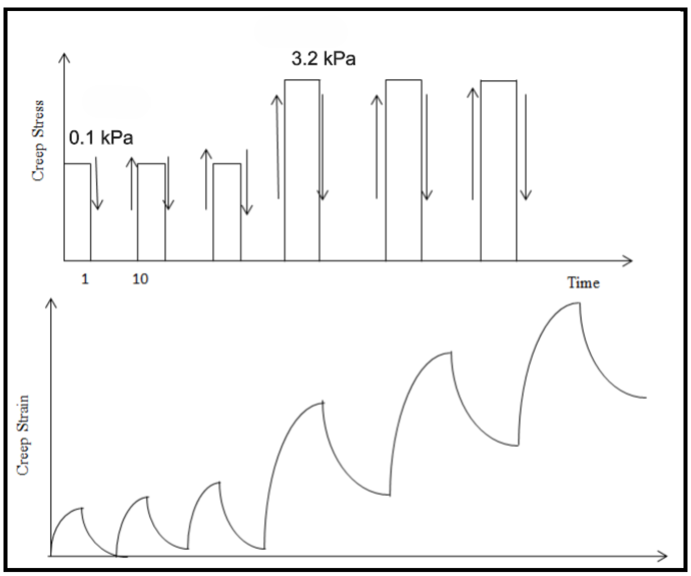
The PG specifications help in selecting a binder grade that will limit the contribution of the binder to low-temperature cracking, permanent deformation (rutting), and fatigue cracking of the asphalt pavement within the range of climate and traffic loading found at the project site.

While this concept worked well for conventional speed, moderate traffic-volume pavements and airfields, research indicated that it needed some refinement for pavements that had slow-speed loading and heavier loading. Rather than change criteria and/or test conditions to reflect a change in loading time and traffic volume, the architects of the PG system elected to simply adjust for traffic speed and volume by “grade bumping,” using stiffer grades than indicated by the climate alone. This was a simple way to ensure adequate support in high-volume and/or slow-loading conditions. Requirements for grade bumping can be found in the current AASHTO M 323 for roadways, and for airfields, the requirements can be found in the DoD UFGS 32 12 15.13 and FAA P-401/P-403 specifications.

3.2.4 Multiple Stress Creep Recovery Grading System

The MSCR specification (AASHTO M 332, ASTM D7405) endeavors to solve issues with the Superpave PG system, improving the way the high-temperature behavior of polymer-modified asphalts is addressed and removing the need to grade bump. It uses the creep and recovery test concept to evaluate the asphalt binder's potential for permanent deformation. Using the dynamic shear rheometer, a 1-s creep load is applied to the rolling thin-film oven-aged asphalt binder sample. After the 1-s load is removed, the sample is allowed to recover for 9 s. The test begins with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles, and then the stress is increased to 3.2 kPa and repeated for an additional 10 cycles.

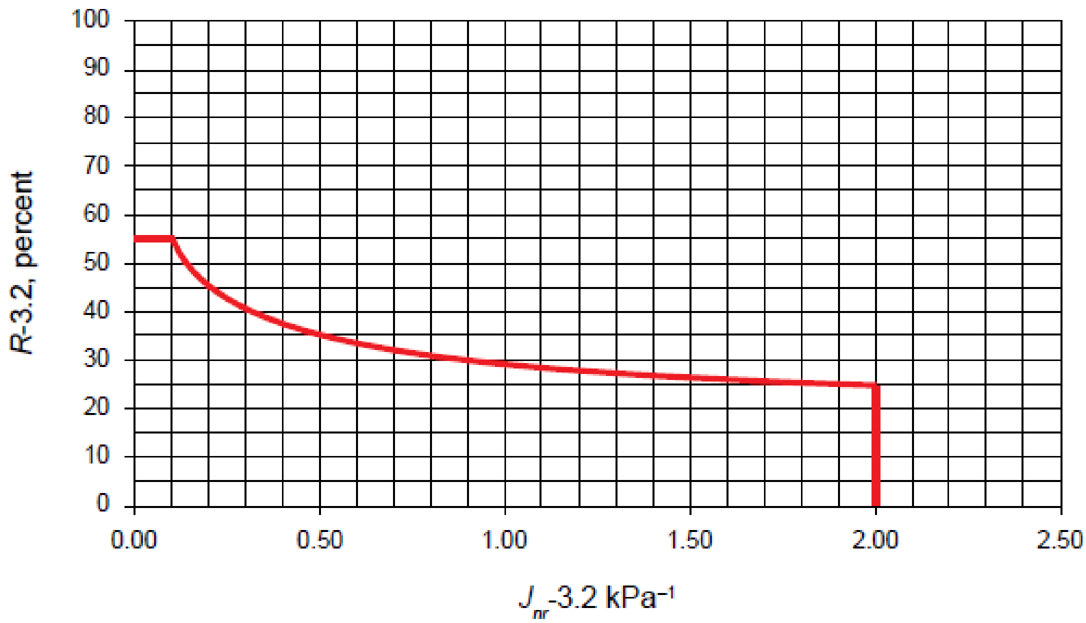
In the MSCR test, two separate parameters can be determined during each loading cycle: non-recoverable creep compliance (J_{nr}) and percentage of recovery (MSCR Recovery). Figure 4 shows a typical result from the MSCR test. The test specimens are creep loaded at 0.1 kPa and 3.2 kPa. After each 1-s creep load, the binder is allowed to recover for 9 s. J_{nr} is a measure of the residual strain left in the specimen after repeated creep loading and recovery, relative to the amount of stress applied. This parameter has been shown to be better correlated with rutting potential than the G*/sin δ parameter used in the Superpave system.



Source: U.S. Department of Transportation

Figure 4. MSCR Stress and Strain Responses

Figure 5 shows the acceptance criteria of AASHTO R 92 for MSCR Recovery. After the average amount of recovery is calculated, the results are used in combination with J_{nr} to indicate whether a binder has a significant elastic component.



Source: AASHTO (AASHTO R 92, Figure 1)

Figure 5. MSCR Recovery Acceptance Curve

Unlike the AASHTO M320 system, the test temperature used for the MSCR test is selected based on actual high pavement temperatures with no grade bumping. For example, if a binder grade would need to perform in an environment with average high pavement temperatures of 64 °C and low pavement temperatures reaching −22 °C, the MSCR test would be performed on the binder at a high temperature of 64 °C regardless of the traffic speed and loading. Higher loading is accounted for by increasing the stiffness (reducing the compliance) required for the asphalt binder at the grade temperature.

The designations shown in Table 1 are based on information found in AASHTO M 332.

Table 1. MSCR Designations

MSCR Designation	Traffic Situation
"S" (Standard)	Fewer than 10 million equivalent single axle loads (ESALs) and traffic speeds > 70 km/h
"H" (Heavy)	10 to 30 million ESALs or slow-moving traffic of 20 to 70 km/h
"V" (Very Heavy)	> 30 million ESALs or standing traffic of < 20 km/h
"E" (Extremely Heavy)	> 30 million ESALs and standing traffic of < 20 km/h

km/h = kilometers per hour Source: AASHTO

Note: Grade bumping is accomplished by using "H," "V," or "E" designations and not by increasing the PG high-temperature grade as recommended in AASHTO M 320.

For standard traffic loading, J_{nr} (determined at 3.2 kPa shear stress) is required to have a maximum value of 4.5 kPa^{-1}. Continuing the example, the subsequent grade would then be a PG 64S-22. As traffic increases to heavy and very heavy loading, the J_{nr} of the asphalt binder needs to be lower—allowing maximum values of 2.0 and 1.0 kPa^{-1}, resulting in binder grades of PG 64H-22 and PG 64V-22. For extremely heavy traffic loading, the J_{nr} of the asphalt binder could only have a maximum non-recoverable creep compliance of 0.5 kPa^{-1}, resulting in a PG 64E-22.

Unlike the AASHTO M320 system, the test temperature used for the MSCR test is selected based on actual high pavement temperatures with no grade bumping.

Although the MSCR grading system is specified by many State DOTs, at the time of this writing it is not specified for airfields, neither in the DoD UFGS 32 12 15.13 nor the FAA P-401/P-403 specifications.

3.2.5 Temperature-Viscosity Characteristics

The viscosity of an asphalt binder changes with temperature, with lower temperatures resulting in higher viscosity (higher "stiffness"). This temperature-viscosity relationship impacts several aspects of asphalt testing, production, placement, and compaction.

During lab testing of both asphalt binder and asphalt mixtures, the testing temperature is always specified and must be tightly controlled. Without this control, test results lose their meaning. For example, the test temperature for the Hamburg Wheel-Tracking Test might be 50±1°C for a particular agency. If the actual test temperature is lower, then the binder will be stiffer and the results will exhibit artificially low rutting. If the temperature is allowed to wander higher than the test temperature, the rutting results would falsely indicate that the mix is more rut-susceptible than it actually is.

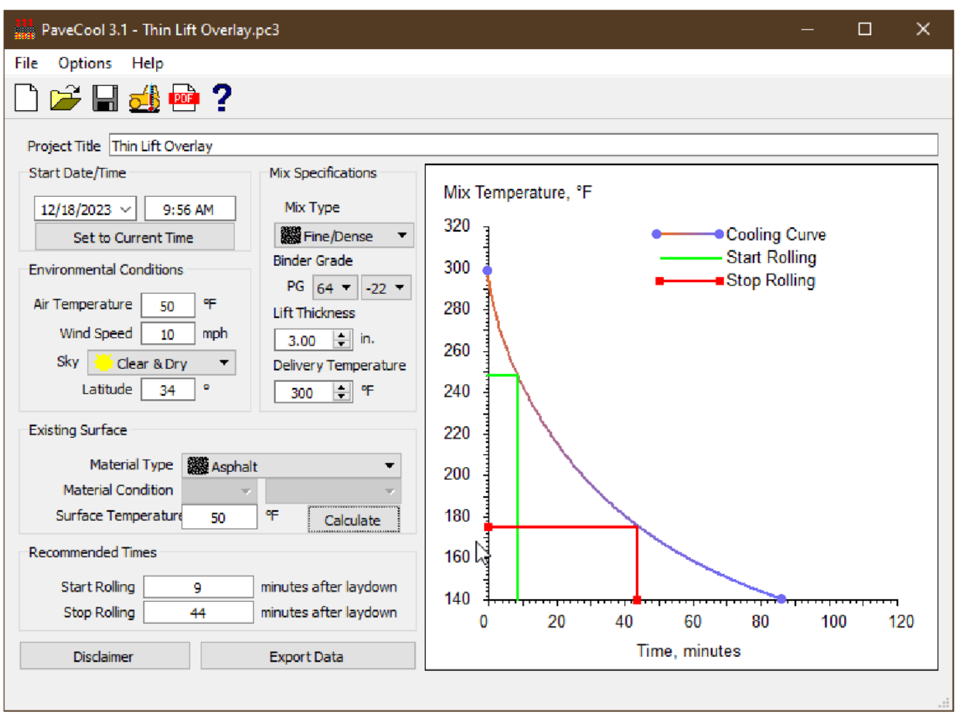
During production, the binder viscosity must be low enough that the binder can be pumped and handled in the facility. Both PG and MSCR specifications require that the binder viscosity be lower than 3 Pa·s at 135 °C.

During mix placement, viscosity has a large influence on the workability of the mixture. Hand work—when an asphalt crew laborer is placing the mixture with a shovel or an asphalt rake (lute)—becomes increasingly difficult as the viscosity of the binder increases. The mix flows through the paver more easily when the binder viscosity is lower.

The viscosity of an asphalt binder changes with temperature, with lower temperatures resulting in higher viscosity (higher "stiffness"). This temperature-viscosity relationship impacts several aspects of asphalt testing, production, placement, and compaction.

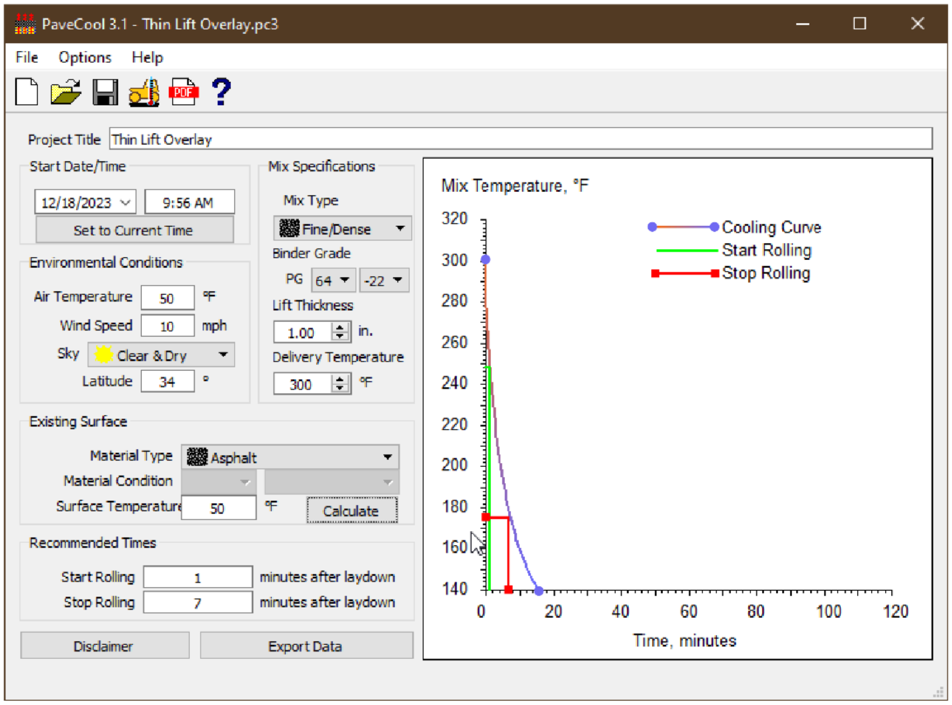
During compaction, the total time available to achieve proper mat density is influenced by the viscosity of the binder. As the binder becomes stiffer or more viscous as the mixture cools, a greater compactive effort is required to achieve a given density. The binder viscosity is not only affected by the inherent binder properties, but also the thickness of the compacted layer and environmental conditions during construction. Thinner layers will cool more quickly, significantly affecting the allowable time for compaction. Cooler, windier weather can drastically shorten the time available to achieve proper compaction or even make it impossible to achieve.

PaveCool and MultiCool are public domain applications that estimate the time available for compaction operations based on a variety of user-input variables. Figure 6 and Figure 7 demonstrate the effect of decreasing lift thickness on time for compaction, with all other variables held constant. Figure 6 estimates 44 min available for compaction for a 3-inch (76-mm) mat given several constants, including 50 °F (10 °C) air and existing surface temperatures and a fine/dense-graded mix with a PG 64-22 binder. Figure 7 shows that when using the same variables for a 1-inch (25-mm) mat, the time available for compaction drops to 7 min.



Source: Minnesota DOT

Figure 6. Available Compaction Time Example for a 3-inch Mat



Source: Minnesota DOT

Figure 7. Available Compaction Time Example for a 1-inch Mat

The rate of change in viscosity with change in the temperature of a binder is referred to as the binder's temperature susceptibility. A material that is highly temperature-susceptible is one that exhibits a large change in viscosity for a small change in temperature. Multiple binders that have the same penetration at 25°C (77 °F) may not necessarily have the same viscosity at 135 °C (275 °F) since their temperature susceptibility characteristics may vary. In the lab, reporting this temperature-versus-viscosity relationship is required for some mix design procedures since lab mixing and compaction temperatures are typically based on a prescribed viscosity level.

The rate of change in viscosity with change in the temperature of a binder is referred to as the binder's temperature susceptibility.

3.2.6 Polymer Modification

Polymer-modified asphalts (PMAs) work to flatten the temperature-viscosity relationship to make the binders less susceptible to changes in temperature. One way in which polymers are classified is based on their physical properties. Depending on their behavior when stretched with sufficient force, polymers are classified as plastomers (plastics) or elastomers (elastics). When stretched, plastomers will yield and remain in their stretched position when the load is released. Elastomers will yield under load (stretch) but will return to their original shape when the load is released. Most polyolefins behave as plastomers, while styrene-butadiene copolymers behave as elastomers.

When blended into asphalt, polymers tend to behave in two different ways. If the polymer forms discrete particles in the asphalt binder, then it functions primarily as a thickener or filler. This increases the viscosity of the asphalt binder while having no significant effect on low-temperature properties. If the polymer forms a continuous network in the asphalt binder, it functions as a homogeneous blend. This blend may impart some of the physical characteristics of the polymer to the binder, which may affect both the high- and low-temperature properties of the asphalt binder.

The task of the designer is to determine whether the extra cost of using PMA mixtures is worth the anticipated extra performance. For example, using a PMA mixture on a walking trail in a park may be an unnecessary extra expenditure. The use of a PMA mixture on a high-volume taxiway or roadway may easily be a better investment.

3.3 AGGREGATE CHARACTERISTICS AND PROPERTIES

Aggregates possess numerous characteristics that influence the performance of asphalt mixture. These characteristics not only influence the amount of binder required for satisfactory performance but also affect mix constructability and longevity. Selecting materials that meet certain quality characteristics is an important first step in the mix design process. The aggregate characteristics discussed in this section include particle size distribution (gradation), specific gravity, surface texture and shape, absorption, clay content, toughness, soundness, and deleterious materials.

The Superpave mix design process considers four characteristics particularly important: coarse aggregate angularity, fine aggregate angularity, clay content (sand equivalent), and flat and elongated particles. These are called “consensus properties,” and their criteria are set in AASHTO M 323 (see Table 2). Other important aggregate criteria are called “source properties,” and these are specified by the user agency on the basis of local experience with the materials and their availability. While all these properties have requirements in the FAA and DoD specifications, the airfield specifications do not use the terms “consensus properties” and “source properties.”

Selecting materials that meet certain quality characteristics is an important first step in the mix design process.

Table 2. AASHTO M 323 Aggregate Consensus Property Requirements

Design ESALs[a] (Million)	Fractured Faces, Coarse Aggregate,[b] % Minimum — Depth from Surface ≤100 mm	Fractured Faces, Coarse Aggregate,[b] % Minimum — Depth from Surface >100 mm	Uncompacted Void Content of Fine Aggregate,% Minimum — Depth from Surface ≤100 mm	Uncompacted Void Content of Fine Aggregate,% Minimum — Depth from Surface >100 mm	Sand Equivalent,% Minimum	Flat and Elongated,[b] % Maximum
<0.3	55/-	-/-	-[d]	-	40	-
0.3 to <3	75/-	50/-	40[e]	40	40	10
3 to <10	85/80[c]	60/-	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥30	100/100	100/100	45	45	50	10

Source: AASHTO

[a] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for a 20-year period.

[b] This criterion does not apply to 4.75-mm nominal maximum size mixtures.

[c] 85/80 denotes that 85 percent of the coarse aggregate has at least one fractured face and 80 percent has two or more fractured faces.

[d] For 4.75-mm nominal maximum size mixtures designed for traffic levels below 0.3 million ESALs, the minimum uncompacted void content is 40.

[e] For 4.75-mm nominal maximum size mixtures designed for traffic levels equal to or above 0.3 million ESALs, the minimum uncompacted void content is 45.

Note: If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to below 100 mm for mix design purposes.

3.3.1 Particle Size Distribution (Gradation)

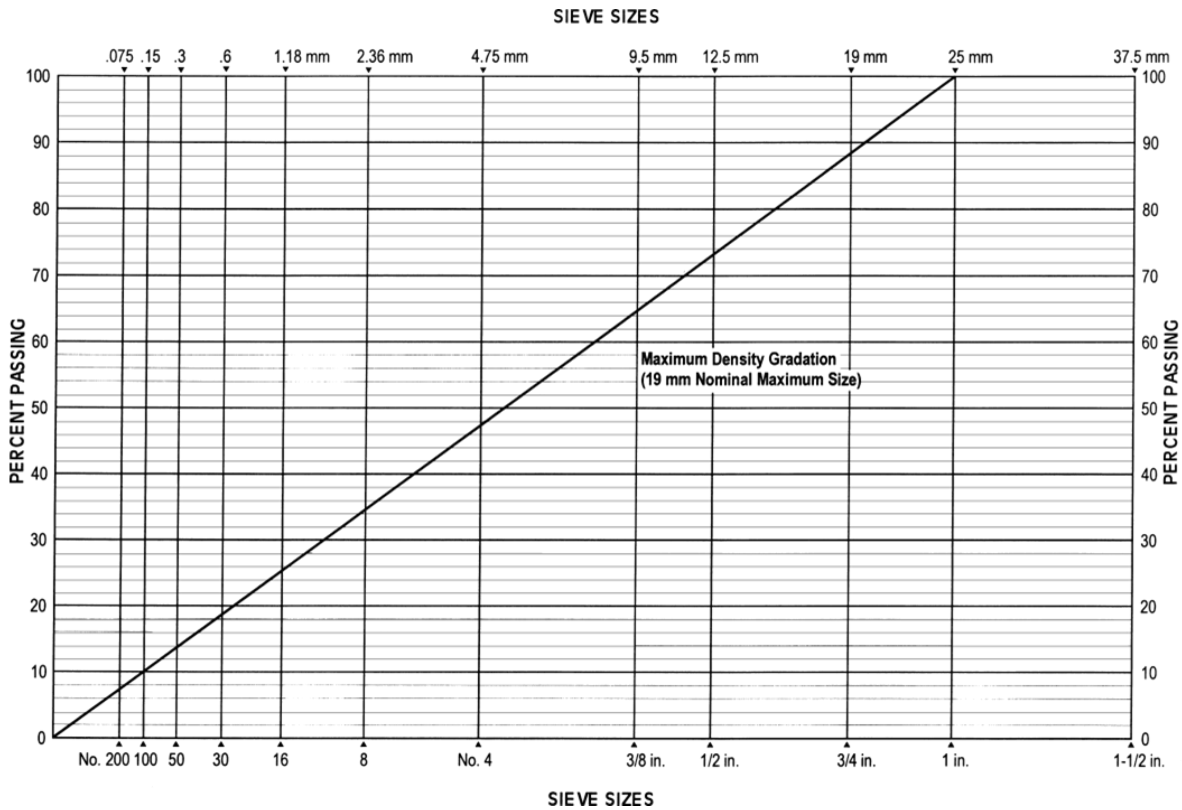
One of the important properties of aggregates for use in pavements is the distribution of particle sizes, or gradation. Gradation test methods are specified as either dry (ASTM C136/AASHTO T 27) or washed (ASTM C117/AASHTO T 11). For asphalt mix designs, the aggregate must always be washed to properly evaluate the percentage of fine particles.

Aggregate gradations having different maximum particle sizes will result in asphalt mixtures with different characteristics. Unfortunately, different specifications may have slightly different definitions for maximum particle size. The Superpave method uses the following aggregate size definitions:

- Maximum aggregate size—one sieve size larger than the nominal maximum size.
- Nominal maximum aggregate size (NMAS)—one sieve size larger than the first sieve to retain more than 10 percent by weight.

Gradation is generally controlled by specifications that define the distribution of particle sizes. AASHTO M 323 specifies Superpave aggregate gradation control points based on NMAS. Airfield asphalt mix gradation requirements are shown in FAA's P-401 and DoD's UFGS 32 12 15.13. They are grouped from coarsest to finest by Gradation 1, Gradation 2, and Gradation 3. The grading chart in Figure 8 represents a visual way of displaying aggregate gradations—the 0.45 power plot. The abscissa is particle size plotted to a 0.45

power scale, while the ordinate is usually the percent by weight passing a given size on an arithmetic scale.



Source: Asphalt Institute

Figure 8. Gradation Chart, Exponential Scale (0.45)

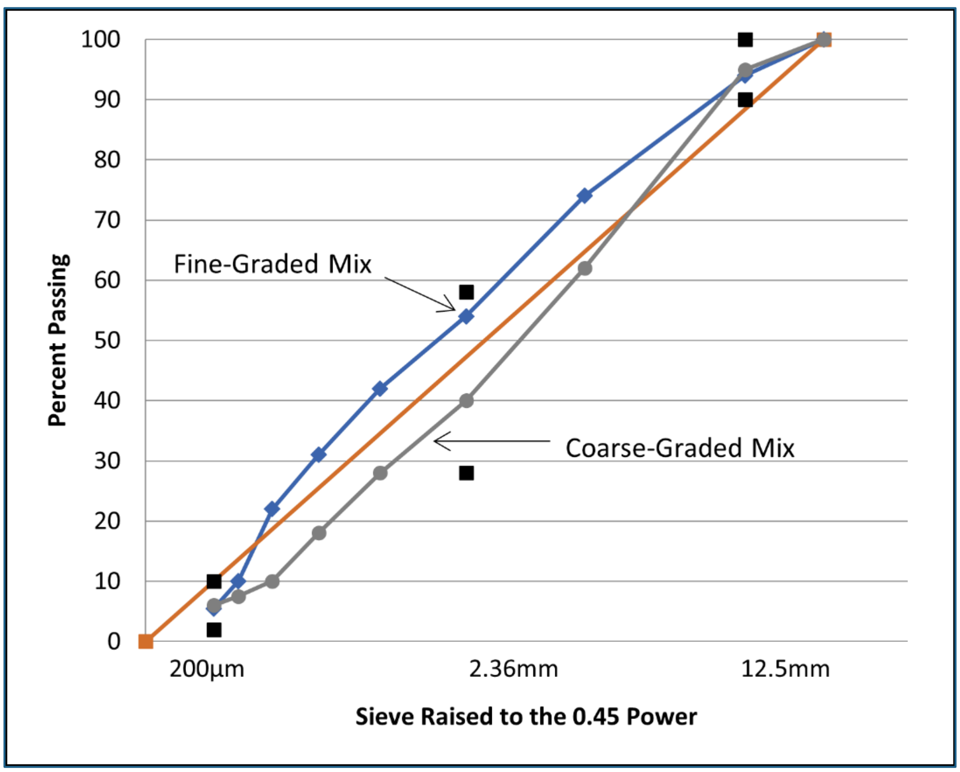
On this chart, the maximum density grading (i.e., the tightest possible particle packing) corresponds to a straight line drawn from the origin to the selected maximum particle size. This line on the .45 power chart is known as the MDL. The MDL shown in Figure 8 represents the maximum density gradation for an aggregate with a 1.0-inch (25.0-mm) maximum size. It must be noted that the MDL is approximate but can serve as a useful reference in proportioning aggregates. The actual gradation at which maximum density occurs, for any particular aggregate in a compacted asphalt mixture, is greatly influenced by the shape, strength, and surface texture of the aggregates, and it may not fall on the MDL.

The particle size distribution delineates the general type of aggregate structure in the asphalt mixture in two ways. First, the general mix type (dense-graded, open-graded, or gap-graded) is defined by the gradation. Second, the gradation also shows the NMAS of the mix. The NMAS of the mix to be used is usually related to its location in the pavement structure.

The most common type of asphalt mixture by far is the dense-graded mix. These mixes have an aggregate gradation somewhat evenly distributed throughout the entire range of sizes used. They can be used in new construction and in overlays; in base, intermediate, and surface layers; and on roadways and airfields. They can be coarse- or fine-graded, as shown in Figure 9. Fine-graded mixtures generally have gradations that plot above the MDL, while coarse-graded mixtures generally have gradations that plot below the MDL. Airfield mixes are typically fine-graded.

The most common type of asphalt mixture by far is the dense-graded mix. These mixes have an aggregate gradation somewhat evenly distributed throughout the entire range of sizes used.

The NMAS for surface mixes is generally 3/8 inch (9.5 mm) or 1/2 inch (12.5 mm), but it could be as fine as No. 4 (4.75 mm) or as coarse as 3/4 inch (19.0 mm). The choice of NMAS is often predicated on the desired surface texture, with a finer maximum size aggregate producing a smoother, tighter surface. Intermediate lifts typically use larger aggregate particles than surface mixes, while base mixes typically use 3/4-inch (19.0-mm) NMAS or larger. Dense-graded mixes should have a lift thickness of at least four times the NMAS when compacted. Lift thicknesses for fine-graded mixtures should be at least three times the NMAS.



Source: Asphalt Institute

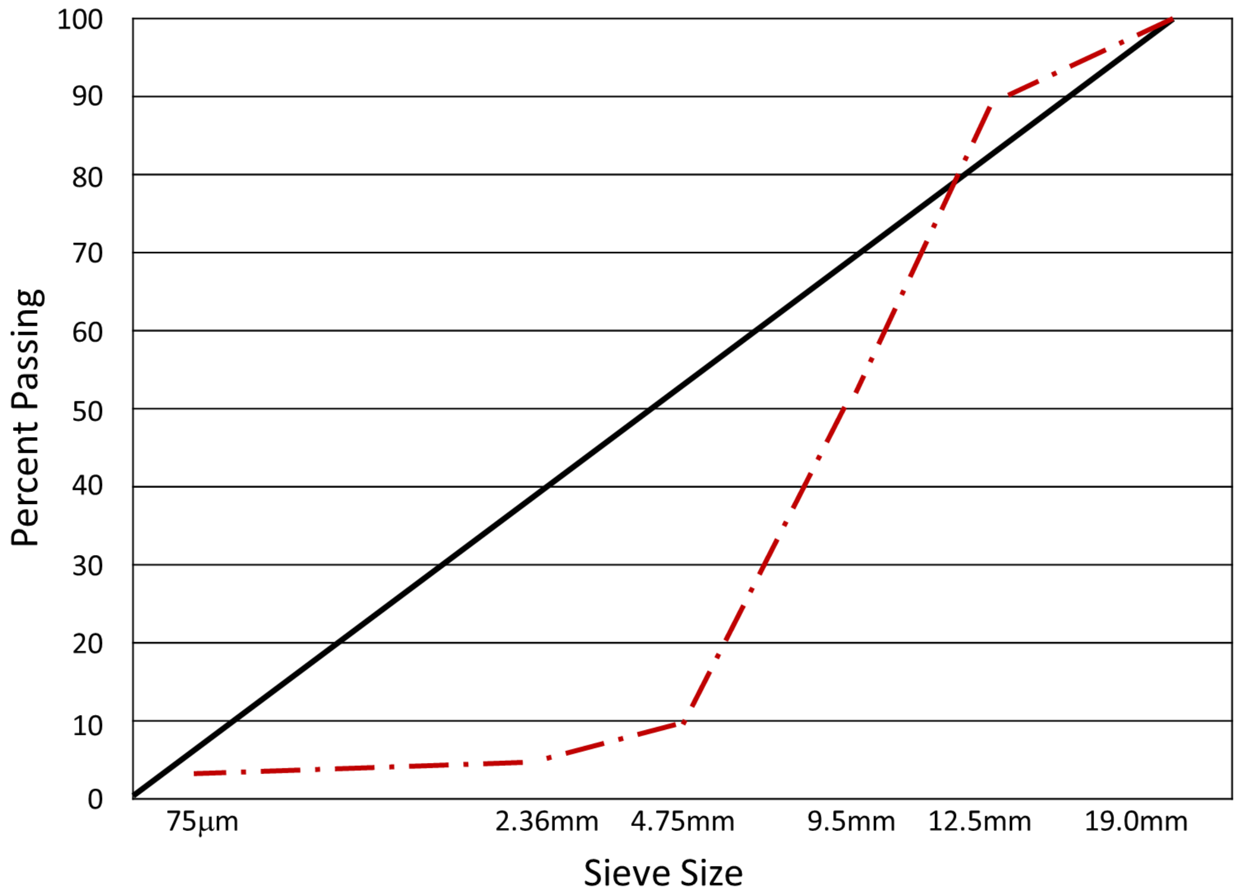
Figure 9. Dense-Graded Mixtures Plotted on a 0.45 Power Chart

Another basic type of asphalt mixture is an open-graded mix, graphed on a 0.45 power chart in Figure 10. These mixes are mainly used as a surface lift and primarily designed for safety. Their open aggregate structure is created by the predominance of uniformly sized aggregate particles, which creates air voids around 18 to 20 percent. Open-graded mixes allow rainwater to flow through the surface mix, then move laterally across the top of the layer below into the drainage system. This design greatly reduces the risk of hydroplaning, mitigates splash and spray from tires, reduces roadway glare, and dampens roadway noise. These mixes are not good candidates for airfield paving due to the increased risk of generating FOD. Open-graded surface mixes typically have a 3/8- to 1/2-inch (9.5- to 12.5-mm) NMAS and are specified in lift thicknesses two to three times the NMAS. The NMAS versus lift thickness guidance for dense-graded mixes does not apply to open-graded mixes because the mixes are merely bonded and securely seated to the underlying layer to preserve air void space. Overcompaction of these mixes would defeat their free-draining design purpose. Although traffic helps keep the mix from clogging, its permeability will continually reduce over time. Open-graded surfaces typically have a shorter lifespan than dense-graded mixtures.

Open-graded mixes can also be used as open-graded bases or as part of a permeable pavement. The concept of using an open-graded base (or asphalt treated permeable base, ATPB) along with a pavement edge drain system to move moisture out of the pavement structure has been around for decades. When using an open-graded base, a filter fabric must be placed on the existing subgrade or base to prevent fines migrating up and clogging the air voids in the open-graded asphalt layer. The edge drain system must be monitored to prevent crushing during construction and clogging due to rodent nesting or vegetation growth; otherwise, the pavement will hold water instead of drain water. These maintenance difficulties have resulted in fewer open-graded base systems being designed.

The concept behind porous pavements can also be applied to parking lots and low-volume residential streets for stormwater management. The typical design of this system consists of an open-graded surface mix that allows drainage through the pavement and into an underlying stone reservoir. A geotextile fabric is typically placed on the uncompacted subgrade to mitigate migration of fines up into the stone recharge bed.

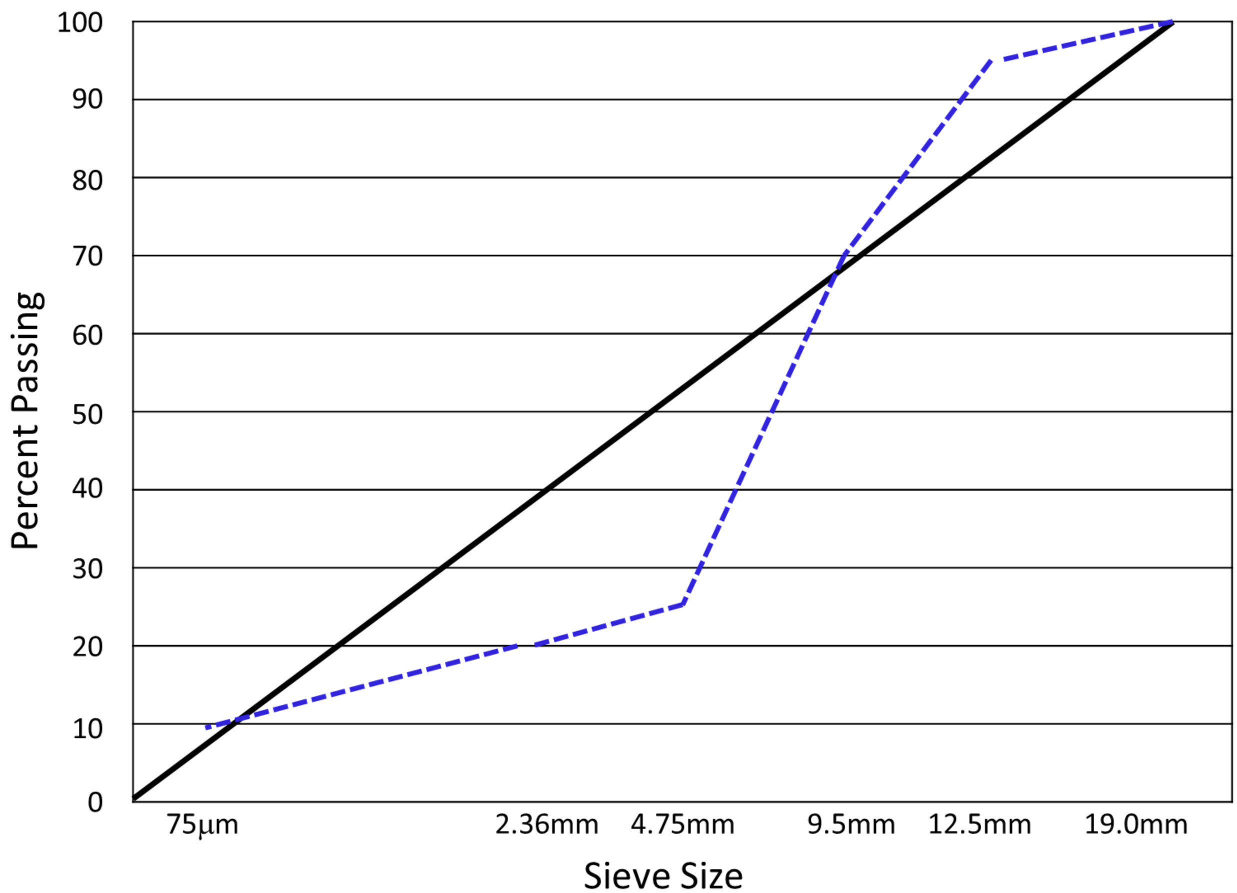
These porous pavement stormwater management systems are intended to allow quick penetration of precipitation through the pavement surface and slow infiltration through soil on which the stone reservoir is built. It is commonly thought of as being environmentally friendly due to reduced runoff and potentially cooler surfaces. Losing functionality due to clogging is still a concern. However, the porous surface can be milled and replaced to renew functionality. Permeable pavement systems are more expensive to install than traditional pavements, and as a design with a reservoir for stormwater management, they are typically not suitable for highways or airport pavements.



Source: Asphalt Institute

Figure 10. Open-Graded Mixture Plotted on a 0.45 Power Chart

Gap-graded mixtures have high percentages of coarse particles and fine particles, but few intermediate-sized particles, which is reflected in Figure 11. The target air void content is typically 4 percent. SMA is the most common example of a gap-graded asphalt mixture. It is a premium mix with high rut resistance due to coarse aggregate interlock and high durability due to the mastic created by the high binder content (typically polymerized) and mineral filler. Due to the higher binder content, and fibers which are often used to prevent draindown of the binder from the aggregate structure, SMA mixes are typically more expensive than dense-graded mixes. They are almost exclusively used as surface mixes. Their NMAS is typically 3/8 to 1/2 inches (9.5 to 12.5 mm), although some agencies specify different particle sizes. At the time of this writing, SMA mixes are used exclusively on roadways.



Source: Asphalt Institute

Figure 11. Gap-Graded Mixture Plotted on a 0.45 Power Chart

3.3.2 Specific Gravity

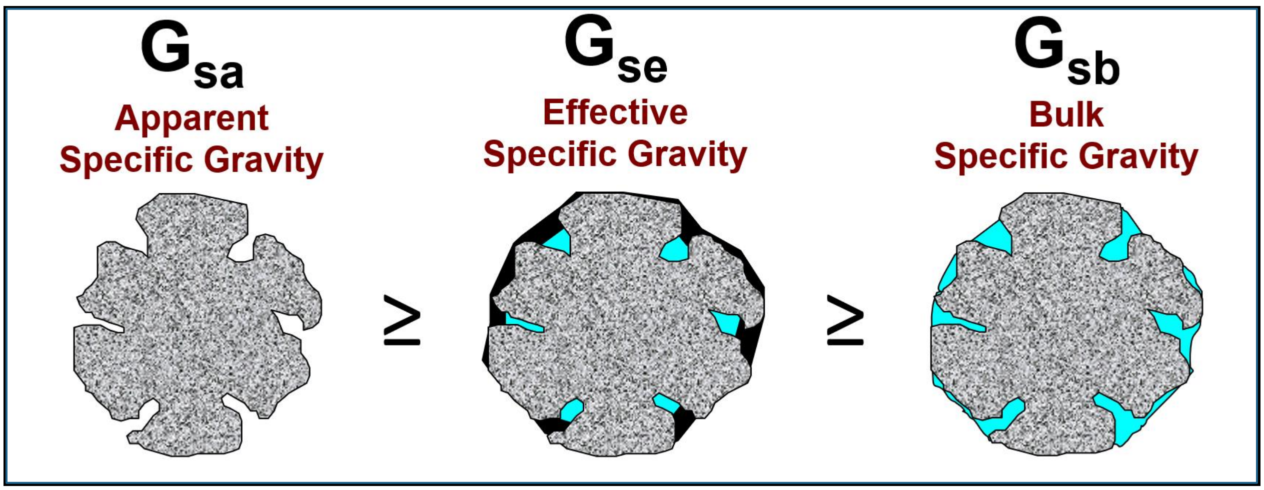
Aggregate specific gravity is an important property used to delineate the relative density of different aggregates. The ratio of the density (mass per unit volume) of each aggregate source to the density of water at 73.4 °F (23 °C) is the dimensionless property "specific gravity." A simple way to think of this property is "the number of times something weighs more than the equivalent volume of water." AASHTO T 84 (ASTM C128) and T 85 (ASTM D127) are used to determine fine and coarse aggregate specific gravity, respectively. In the asphalt industry, this property is shown to three decimal places (the nearest 0.001). These same tests are also used to determine aggregate absorption (to the nearest 0.1).

The following are the most commonly used aggregate specific gravities:

- Apparent specific gravity (G_{sa}).
- Bulk (dry) specific gravity (G_{sb}).
- Effective specific gravity (G_{se}).

Each aggregate specific gravity used in the asphalt industry uses the dry mass of the aggregate. As shown in Figure 12, the aggregate volumes used to calculate commonly used specific gravities are different. The volume used to calculate the apparent specific gravity is the smallest volume—the volume of the aggregate particle only. The volume used to calculate the bulk specific gravity is the largest volume—the volume of the aggregate particle plus the volume of the water-permeable voids in the aggregate particle. The volume used to calculate the effective specific gravity is in between—the volume of the aggregate particle plus the volume of the water-permeable voids in the aggregate particle, minus the asphalt-permeable voids. Therefore, G_{sa} is always a larger number than G_{se}, which is always a larger number than G_{sb}.

The ratio of the density (mass per unit volume) of each aggregate source to the density of water at 73.4 °F (23 °C) is the dimensionless property "specific gravity." A simple way to think of this property is "the number of times something weighs more than the equivalent volume of water."



Source: Asphalt Institute

Figure 12. Aggregate Specific Gravities

3.3.3 Surface Texture and Shape

The aggregate's surface texture is an important factor contributing to its frictional resistance. This characteristic also strongly influences the resistance of a mix to rutting. The rougher the texture of the aggregate, the better the rutting resistance of the mix will be.

The microtexture of fine and coarse aggregates has a significant effect on the skid resistance of asphalt pavements. Pavement microtexture and macrotexture, geology to resist erosion from acid rain, and aggregate polish resistance all contribute to skid resistance and are therefore important safety considerations. Most agency specifications require aggregates with one or more of these characteristics to be used in the surface lift.

The shape of the aggregate also influences the rutting resistance of a mix, with angular aggregate producing greater resistance than more rounded material. As with surface texture, the more angular the aggregate, the greater the compaction effort that will be required to produce a mix with a specified degree of density. When properly compacted, however, the resulting pavement will be more rut-resistant.

Three of the four Superpave consensus properties deal with particle shape: the coarse aggregate angularity test (ASTM D5821), the fine aggregate angularity test (AASHTO T 304, ASTM C1252), and the flat and elongated particles test (ASTM D4791). Generally, the acceptance criteria used for these parameters are more stringent as the amount of traffic increases and as the mix is placed closer to the pavement surface.

A particle is considered flat and elongated if the ratio of the longest dimension to the smallest dimension is greater than 5:1. Flat and elongated particles tend to break during mixing and handling, changing the properties of the aggregate skeleton. By placing a limit on the proportion of particles with these characteristics, the potential for aggregate fracture during production and construction is limited.

3.3.4 Absorption

The amount of binder that is absorbed by the aggregate can significantly affect the properties of the asphalt mixture. If the aggregate particles have high asphalt absorption, the asphalt content in the mix must be increased to compensate for binder material that is drawn into the pores of the aggregate and is therefore unavailable as part of the film thickness around those particles. This is accounted for in asphalt mix design through the use of AASHTO R 30, Mixture Conditioning of Asphalt Mixtures. In this procedure, the asphalt mixture is conditioned in the oven to allow for binder absorption before the mix is tested further.

The asphalt content in the mix must be increased to compensate for binder material that is drawn into the pores of the aggregate and is therefore unavailable as part of the film thickness around those particles.

If binder absorption is not accounted for, the resulting mix will have a lower effective binder content (the unabsorbed binder on the outside of the particles). This may not only cause the mix to be dry and stiff, but it may also facilitate raveling, which is the disintegration of a pavement surface due to the dislodgement of aggregates.

If absorptive aggregates with high moisture contents are used, challenges with drying during asphalt production may arise. If severe enough, these challenges can necessitate changes to production rate or other plant dryer settings. Not properly drying the aggregate can lead to compaction difficulties and long-term durability issues with the pavement.

3.3.5 Clay Content

Clay content, also known as sand equivalent (AASHTO T 176, ASTM D2419) is the fourth of the Superpave consensus properties. The presence of clay or plastic fines in the fine aggregate (material passing the 4.75-mm [No. 4] sieve) can have a detrimental effect on an asphalt mixture. For example, clay minerals coating aggregates can prevent asphalt binders from thoroughly bonding to the surface of aggregate particles, contributing to the loss of adhesion between the asphalt binder and aggregate and increasing the potential for water damage to the paving mixture. Higher fines will decrease the asphalt content needed to produce 4-percent air voids, resulting in lower film thickness and loss of mixture durability. Too many clay-like fines can cause check cracking in the mat and decrease mix stability.

Another measure of harmful clays and organic matter present in an aggregate is the methylene blue value (AASHTO T 330, ASTM C837). In this method, methylene blue solution is titrated in increments into distilled water containing sample material passing the 75-micron (µm) (No. 200) sieve. A small amount of water containing the sample material and titrated methylene blue is removed via a glass rod and dropped onto filter paper. When the clay fraction of the sample aggregate can no longer absorb more methylene blue, a blue ring forms on the filter paper. A high methylene blue value indicates a large amount of clay or organic material present in the sample.

3.3.6 Aggregate Toughness

Aggregate toughness would be considered a Superpave source property. The specific test procedures and critical values for source properties could not be agreed on by a national consensus. However, these properties can still be important in a given region.

Toughness tests are used to determine an aggregate's potential for degradation (production of fines and loss of angularity) during the handling, production, and placement of HMA. The two most common toughness tests are the Los Angeles abrasion (AASHTO T 96, ASTM C131) and Micro-Deval (AASHTO T 327, ASTM D6928) tests. The Los Angeles abrasion test evaluates the potential degradation of the aggregate in the dry condition. Some aggregates might degrade differently in a dry condition versus a wet condition, so the Micro-Deval test is used to assess degradation potential in the presence of water.

3.3.7 Aggregate Soundness

Other source property tests often include soundness tests. Soundness tests (AASHTO T 104, ASTM C88) estimate the resistance of aggregates to in-service weathering, typically in areas where freezing and thawing occur. These tests simulate the absorption, freezing, and thawing action of water into the aggregate particles by immersing the aggregates in a salty sodium or magnesium sulfate solution, then repeatedly dehydrating and rehydrating them. Upon rehydration, the salts that have been absorbed into the aggregate expand to simulate the expansion of freezing water. Magnesium sulfate is more aggressive, so loss limits are typically greater than those for sodium sulfate solutions.

3.3.8 Deleterious Materials

Another source property that is often specified is a maximum allowable percentage of deleterious materials. These materials are unsuitable because they are indeed deleterious—causing harm or damage to the asphalt mixture. They are typically defined as the percent by weight of undesirable contaminants such as clay lumps, soft shale, coal, wood, or mica. The most common deleterious materials test is the clay lumps and friable particles test (AASHTO T 112, ASTM C142). Different agencies specify a wide range of maximum allowable percentages, from as little as 0.2 percent to as high as 10 percent. It should be noted that many deleterious materials have a low specific gravity, so specifications in the higher range may allow much more deleterious material in the aggregate than the agency might want.

3.3.9 Recycled Materials

The asphalt industry has a history of recycling its pavements and of using materials from other nontraditional sources within pavements. While several materials have found their way into asphalt pavements, this Handbook will only address the two most common, reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS).

3.3.9.1 Reclaimed Asphalt Pavement

RAP has been used as a component of new asphalt mixes for many years. Most RAP is produced from milling existing asphalt pavements. RAP is also produced from any existing asphalt pavement by crushing and screening it to an appropriate size to be used as a component of a new asphalt mixture. RAP is generally not allowed in the surface of airfield pavements, except in shoulder areas, due to concerns about FOD.

Since RAP generally consists of the same components as a virgin mixture—aggregate and asphalt binder—it can readily be incorporated into a new mixture. Economically, there is a benefit to the judicious incorporation of RAP, thereby reducing the cost associated with purchasing new (virgin) materials.

The reuse of existing resources found in RAP provides significant environmental benefit by reducing the need to extract, haul, and refine new materials.

The source, stockpiling, and variability of RAP are critical considerations in both mix design and QC during production. To properly use RAP in an asphalt mixture, the producer should know the source of the RAP and, if practical, keep separate stockpiles of RAP from specific projects. A RAP obtained from a city street or parking lot may have substantially different binder properties, binder content, aggregate physical properties, and gradation than a RAP obtained from a highway or an airfield. Frequent sampling and testing of RAP stockpiles should be performed to determine actual material properties.

Since RAP generally consists of the same components as a virgin mixture—aggregate and asphalt binder—it can readily be incorporated into a new mixture.

It is important to remember that the binder portion of RAP materials has been aged during original plant production and further aged over many years of service in the environment. This aging makes the binder portion stiffer and less flexible. Hotter environments will tend to age the pavement more, resulting in an even stiffer RAP binder. A RAP binder's AASHTO M 320 grade might be three to four grades stiffer than the base environmental grade used in that location.

The aggregate portion of RAP requires less consideration. The RAP aggregate will have already absorbed binder into its pores and will not absorb additional binder from the new mixture. This fact is reflected in the AASHTO M 323 requirements for RAP aggregate testing. The three Superpave aggregate consensus properties that deal with particle shape—coarse aggregate angularity, fine aggregate angularity, and flat and elongated particles—must still be tested on the RAP aggregate after the RAP binder has been burned off or extracted. Because RAP aggregate retains at least part of the RAP binder after it has been burned off or extracted, the sand equivalent test results will be compromised and are therefore not required for the RAP aggregate. The main consideration for RAP aggregate is the percent passing the No. 200 sieve (P_{200}), which is typically high enough to limit the use of RAP for volumetric reasons.

3.3.9.2 Reclaimed Asphalt Shingles

The use of RAS as a component in asphalt mixtures can be attractive from an initial economic and environmental standpoint. RAS has a high percentage of asphalt binder—usually 20–30 percent—compared to RAP, which usually has an asphalt binder content of 4–8 percent. Since asphalt binder is generally the most expensive component of an asphalt mixture, using a reclaimed material with a high asphalt content can be very appealing to a contractor.

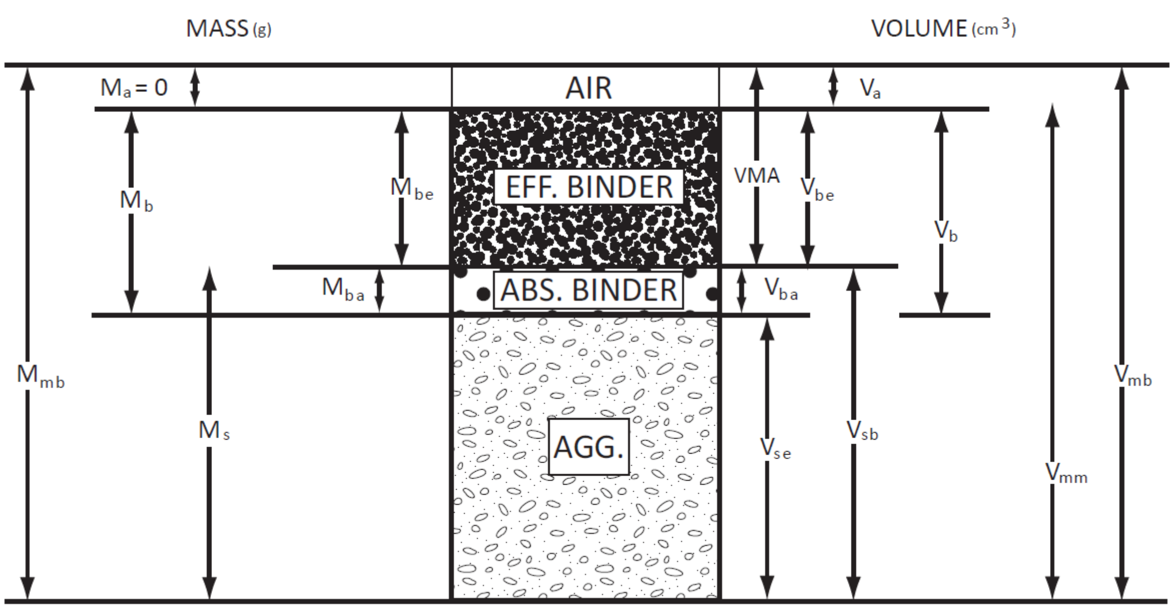
Unfortunately, the asphalt binder in RAS, which is manufactured differently than regular paving grade binders, is extremely stiff. Some research suggests that RAS binder may be a PG 142 or higher, with a softening point at more than 120 °C. It is difficult to reliably determine its physical properties using conventional binder testing equipment and procedures. One method that has been used with some success is to blend a known quantity of softer binder with the stiff RAS binder and extrapolate the test results to estimate the RAS binder properties. Regardless, this limits the ability to reliably predict asphalt binder performance in the field using the PG asphalt binder specification.

In addition to the question about characterizing the physical properties of the RAS binder, many asphalt technologists question the degree of blending (activation) that occurs in an asphalt mixture between a virgin (softer) asphalt binder and the asphalt binder contained in RAS. This is an even greater concern with asphalt mixtures produced at reduced temperatures utilizing warm-mix technologies.

Despite these issues, several agencies have experience using RAS in smaller percentages and have been satisfied with the subsequent pavement performance. From a sustainability viewpoint, the use of RAP and RAS in asphalt pavements can reduce the amount of new asphalt binder and aggregates required in mixtures, which can help stabilize the price of asphalt mixtures and save natural resources.

3.4 MIXTURE VOLUMETRICS

The volumetric properties of a compacted paving mixture are important criteria by which the quality of an asphalt mixture has historically been evaluated. The volumetric properties are determined using the mass and/or volume measurements of a mixture and its constituent components (binder, aggregate, and air), as shown in the phase diagram in Figure 13. They have generally provided a good indication of the mixture's probable performance during its service life.



Source: Asphalt Institute

Figure 13. Asphalt Mixture Phase Diagram

A volumetric mix design is often followed by one or more performance tests to assess how the mix responds to certain stresses in controlled conditions. The following subsections briefly discuss commonly specified volumetric parameters.

3.4.1 Asphalt Binder Content

Since only the binder on the outside of the aggregate particles is useful in binding them together, that portion of the total binder content is called the effective binder content. The remaining portion of the total binder content is the percent absorbed binder. Note that the absorption capacity of aggregate is finite, so adding more binder over and above the absorption capacity of the aggregate will not increase the percent absorbed binder.

3.4.2 Percent Air Voids

Air voids in a compacted asphalt mixture consist of the small air spaces between coated aggregate particles.

Technicians often use the terms “percent density” and “percent air voids” when discussing the same mix characteristic. When percent is expressed as a percentage of theoretical maximum specific gravity, the relationship between the two is shown in the following equations:

Percent density = 100 − percent air voids, or

Percent air voids = 100 − percent density

It is important not to confuse laboratory-molded air voids with mat core air voids. Laboratory specimens are compacted at specified rates using calibrated machine-loading in steel molds that provide consistent confinement. Mat specimens are cut from a mat that was compacted by rollers of varying types and sizes using a non-prescribed number of passes and relies on the surrounding asphalt mixture and tack coat for confinement. Laboratory air voids provide information about the quality of the asphalt mixture. Mat core air voids provide information about the quality of the compactive effort on the mat.

3.4.3 Voids in the Mineral Aggregate

The term voids in the mineral aggregate (VMA) is defined as the intergranular void space between the aggregate particles in a compacted paving mixture, expressed as a percent of the total volume. VMA represents the space that is available to accommodate the effective volume of binder (i.e., the binder not absorbed into the aggregate) plus the volume of air voids in the mix.

An asphalt mixture needs a minimum percentage of VMA to have enough volume to hold both the proper amount of air voids and the proper amount of binder. If the VMA gets too low, the mixture does not have enough void space to hold the proper amounts of effective binder and air voids.

If the mix has enough air voids but not enough binder, the asphalt film thickness is too thin and the pavement becomes less durable. If the mix has enough binder but not enough air voids, the mix becomes less stable.

3.4.4 Voids Filled with Asphalt

Voids filled with asphalt (VFA) is the percentage by volume of the VMA that is filled with the effective binder. VFA, like VMA, tends to increase as the mix becomes finer and the total aggregate surface area grows.

VFA is calculated to ensure that the effective asphalt portion of the VMA in a mix is in the proper range. If the VFA is too low, the mix is too dry and will exhibit poor durability. If the VFA is too high, the mix is too rich and may be plastic and unstable.

The acceptable range of VFA varies depending on the loading situation of the mat. Higher loading requires a lower VFA, because mixture strength and stability are more of a concern. Lower loading situations call for a mix with a higher VFA to increase asphalt pavement durability.

3.4.5 Dust Proportion

The dust-to-binder ratio of a paving mixture, sometimes referred to as the dust proportion, is the ratio of the percentage of aggregate passing the 0.075-mm sieve to the effective binder. The dust proportion property is usually calculated for dense-graded mixes only.

In general, this property addresses the workability of asphalt mixtures. A low dust proportion often results in a tender mix, which lacks cohesion and is difficult to properly compact in the field because it tends to readily deform and move laterally under the roller. A high dust proportion can lead to durability issues because of an increased aggregate surface area.

3.5 ASPHALT MIX PROPERTIES

An asphalt mixture can be designed to possess many specified properties. No single combination of aggregates and binder will maximize each of the desired properties discussed in the remainder of this section. The goal of mix design is to select a unique and economical blend of aggregate and binder that will achieve a good balance of the desired properties.

3.5.1 Stability

The internal friction provided by the aggregate particles and the cohesion provided by the asphalt binder provide stability to the asphalt mixture. Inter-particle friction among the aggregate particles is related to the shape and surface texture of both the fine and coarse aggregate and the characteristics of the aggregate gradation. Cohesion results from the bonding ability and the stiffness characteristics of the asphalt binder. A proper degree of both inter-particle friction and cohesion in a mix prevents it from movement in response to the forces exerted by traffic.

The goal of mix design is to select a unique and economical blend of aggregate and binder that will achieve a good balance of the desired properties.

Excessive amounts of rounded aggregates, such as natural sand or gravel, often lead to instability concerns such as rutting, shoving, and tenderness. Natural sands can also range significantly in fine aggregate angularity and are often restricted to a maximum of 15 percent to address these concerns. Stability increases with the use of more angular aggregate with rougher surface texture.

Using too much binder (relative to the optimum binder content determined during mix design) or too soft a binder grade (for the environmental and traffic conditions) can lead to rutting and shoving (shown in Figure 14). Stability will increase with the use of a stiffer binder and/or lowering the binder content back toward optimum.

Source: NCAT

Figure 14. Rutting Due to Unstable Surface Mix

3.5.2 Durability

The durability of an asphalt pavement is its ability to resist cracking and raveling (shown in Figure 15). Cracking and raveling are often due to aging of the binder, disintegration of the aggregate, and/or stripping of the asphalt film from the aggregate (see Figure 16). These factors are affected by in-place density, weather, traffic, and incompatibilities between the aggregate and binder.

Source: NAPA

Figure 15. Raveled Asphalt Pavement Surface

Source: Asphalt Institute

Figure 16. Stripping at the Lift Interface

Generally, during mix design the durability of a mixture is enhanced by the following:

- Sufficient binder (relative to the optimum asphalt content). Insufficient binder will lead to a dry mix that is prone to aging, premature cracking, and raveling. Binder content and total surface area of the aggregate dictate asphalt film thickness. Thick asphalt films do not age or harden as rapidly as thin ones do. It is important to note that creating room for sufficient binder content (i.e., thicker asphalt film) is a function of the VMA. As discussed in Section 3.4.3, this space is filled with air and binder. Adding more binder without increasing VMA simply replaces air void space with binder. Sufficient VMA allows room for both the proper air void content and the proper binder content.
- Sound, tough aggregate that resists disintegration under traffic loading.
- Compatible asphalt binder/aggregate combinations that help prevent moisture damage.
- Additives such as hydrated lime or liquid anti-stripping agents can be incorporated into the mix design to address stripping.
- Binder with an adequate low-temperature grade or MSCR grade, which will resist cracking as the pavement contracts in cold weather.

Figure 17 shows how a very durable fuel-resistant mix functions at an airfield. A V-22 Osprey is undergoing a “hot refuel” at Lynchburg Regional Airport in Virginia. The engines continue to run during the 35-min refueling procedure. The durability and fuel resistance of the mix mainly comes from a combination of factors working together: a modified asphalt binder (PG 82-28 or PG 88-22), high binder content with subsequent low laboratory air voids (1.5 to 3.5 percent), and a high mat density (minimum of 96 percent).

Source: Ron Corun

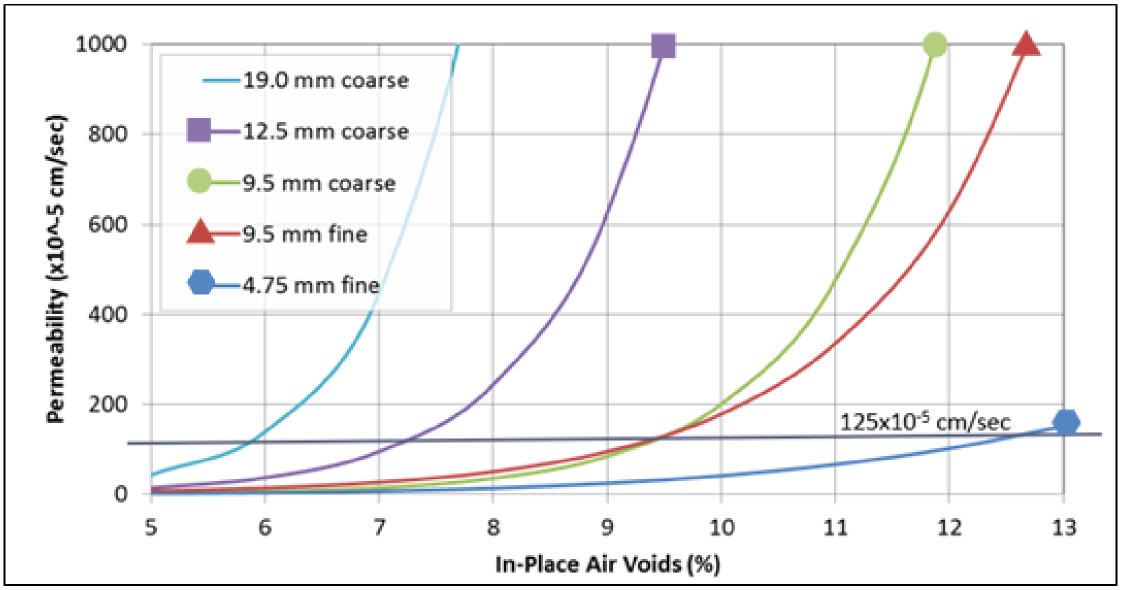
Figure 17. Fuel-Resistant Mix at Lynchburg Regional Airport

3.5.3 Impermeability

When an asphalt pavement is impermeable, the passage of air and water into or through the asphalt pavement is prevented or at least highly restricted. This characteristic is related to the air void content, the aggregate gradation, and the lift thickness of the compacted mixture.

Figure 18 uses data from National Center for Asphalt Technology (NCAT) Report 03-02, *An Evaluation of Factors Affecting Permeability of Superpave Designed Pavements.* For those agencies that specify a maximum permeability, a common upper limit of 125×10^{-5} cm/s^2 is shown in the graph. The NCAT report concluded the following:

- Air void content of dense-graded asphalt mixtures has a significant effect on the in-place permeability of the mat. As in-place air voids decrease, impermeability increases.
- The NMAS of dense-graded asphalt mixtures has a significant effect on the in-place permeability of the mat. As the NMAS of the mix decreases, the impermeability increases.
- Laboratory tests on specimens with different thicknesses showed that impermeability increases with an increase in mat thickness.



Source: NCAT (NCAT Report 03-02)

Figure 18. Permeability Versus In-Place Air Voids by NMAS

3.5.4 Workability/Compactability

Workability describes the ease with which an asphalt mixture can be placed and compacted. Mixtures with good workability are relatively easy to place and compact; those with poor workability are difficult to place and compact. Workability is especially important when hand placement and raking (luting) around manhole covers, sharp radii, and other obstacles are required.

Several factors impact the workability of HMA, including the following:

- **Temperature:** As the temperature of the asphalt mix increases, its viscosity decreases, making the mix more workable. However, excessive temperatures can lead to problems such as binder degradation and increased emissions.
- **Binder type:** The type of asphalt binder used can significantly affect workability. Polymer-modified binders, for example, can be less workable at certain temperatures due to their increased viscosity.

- **Aggregate properties:** The shape, size, and gradation of the aggregate can influence the mix's workability. Mixes with larger NMAS or with more angular aggregate shapes tend to be less workable.
- **Mix design:** The specific combination of binder, aggregate, and any additives in the mix design will influence workability. Certain mix designs, such as SMA or mixes with a high percentage of recycled materials, may present workability challenges.

Some factors that might make the mix less workable in the short term, such as polymer-modified binders and premium mix design types like SMA, typically improve long-term performance overall.

3.5.5 Fatigue Resistance

Fatigue resistance is the pavement's ability to perform under repeated wheel loads (traffic) without deteriorating. Research shows that air voids, binder content, and binder condition have a significant effect on a mixture's fatigue resistance. As the percentage of air voids in the pavement increases, either by design or inadequate compaction, fatigue resistance is drastically reduced. Likewise, a pavement containing asphalt binder that has aged significantly or has excessive amounts of RAP with no corresponding modification to the mix will have less resistance to fatigue. Specifying a polymer-modified asphalt binder can significantly improve the fatigue resistance of an asphalt mixture, as it can increase the effective binder content.

The most effective method to improve a pavement's fatigue resistance is not to specify a higher quality mix but to increase the overall structural thickness at the pavement design phase.

3.5.6 Skid Resistance

Skid resistance is the ability of an asphalt surface to provide adequate friction to the tires for safe braking and steering, particularly when the surface is wet. For good skid resistance, the tire tread must maintain contact with the aggregate particles and not ride on a film of water trapped between the pavement surface and tire (hydroplaning). FAA airfield runways are grooved, as shown in Figure 19, to avoid hydroplaning of the aircraft. A pavement with adequate surface microtexture and macrotexture will have greater skid resistance relative to a polished surface. Microtexture consists of wavelengths of 1 μm to 0.5 mm (0.0004 to 0.02 inches), and macrotexture consists of wavelengths of 0.5 to 50 mm (0.02 to 2 inches).

Skid resistance is improved using hard, durable, and angular (crushed) aggregate with a rough surface texture. The coarse aggregates must resist polishing (smoothing) under traffic. Calcareous aggregates (limestones) polish more easily than siliceous aggregates (quartz).

Mixtures that tend to rut or bleed present serious skid-resistance problems.

Source: Gonuc

Figure 19. Grooving an Airfield Runway

3.6 ADDITIVES

Additives are sometimes used in asphalt mixtures to enhance various properties and/or mitigate environmental impacts. Numerous products are on the market, but this section will discuss the most common additives.

3.6.1 Warm Mix Asphalt

WMA includes both additives and plant technologies that allow asphalt mixtures to be produced at lower-than-normal temperatures while maintaining mix workability, extending compaction windows and often acting as a compaction aid.

3.6.1.1 Foaming

Foaming is a common method of warm mix production that can reduce the required mixing temperature to as low as 250 °F (121 °C) in some instances. Foaming uses an injection of small amounts of water into the hot asphalt binder as it flows through special foaming injection nozzles. The rapid expansion of the steam creates microscopic bubbles in the binder that expand the volume of liquid and allow mixtures to be thoroughly coated at a reduced temperature.

Additives are sometimes used in asphalt mixtures to enhance various properties and/or mitigate environmental impacts.

3.6.1.2 Chemical Additives

A multitude of different chemical additives are available in the WMA market. These products are typically added by either premixing with the asphalt binder at the supplier's facility or by addition at the mix plant. The use of these products can reduce mixing temperatures significantly lower than the foaming process. Those products premixed at the asphalt binder terminal are handled and used without special equipment needs. Other products must be stored separately at the plant and accurately metered into the plant as directed by the WMA product supplier. Asphalt mix producers should refer to the additive manufacturer's recommendations when using these specialty products. Project specifications may dictate which additives can be used.

3.6.1.3 Organic Additives

Organic additives typically come in the form of paraffin wax and low molecular weight esterified wax with higher viscosity than asphalt binders below their melting point and lower viscosity at temperatures above their melting point. When mixed at temperatures above their melting point, they make the resulting mix more workable at lower temperatures. It is important that the melting point of the organic additive be higher than the expected in-service temperatures of the pavement to avoid potential issues related to rutting or deformation under load.

3.6.2 Liquid Anti-Stripping Additives

Chemicals known as liquid anti-stripping (LAS) additives have been used to treat moisture susceptibility in asphalt pavements. They function by reducing the surface tension between the asphalt binder and the aggregates, promoting better adhesion. Some of the chemical classes of amines that are used as LAS additives include fatty amines, amidoamines, and imidazolines. They all contain a hydrocarbon that has similar properties to asphalt and one or more amine groups. In addition to their chemistry, LAS additives can be characterized by properties such as heat stability and storage, concentration, viscosity, and odor. LAS additives are often added at the refinery or supplier's terminal if requested. The method and rate of incorporation during the mix design should conform to the recommendations of the binder and LAS suppliers. Regardless of the type of LAS, the actual dosage rate should be determined by testing. It is possible for an increased dosage to lower test results.

Compatibility issues often need to be resolved; certain aggregate geologies may perform better with certain LAS formulations. Most agencies maintain a qualified product list for LAS.

3.6.3 Hydrated Lime

Hydrated lime is sometimes used in asphalt mixtures, primarily to improve resistance to moisture damage by reacting with clay in or on aggregate particles. It can also be used to stiffen the binder for improved rut resistance and potentially reduce age hardening. USACE reports that hydrated lime is also used to reduce bacterial deterioration of asphalt in warm, wet climates.

The amount of hydrated lime needed to improve the moisture sensitivity of an asphalt mixture generally ranges from 0.5 to 1.5 percent by dry weight of aggregate. It is typically added either dry or mixed with water as a lime slurry.

The addition of hydrated lime has been known to impact volumetric properties in the mixture. It is recommended that the manner of introducing lime during the mix design process be similar in nature to the method used in the field during plant mix production. It is also recommended that the mix designer optimize the amount of lime to be added to the mix. The amount of lime required will depend on the binder and aggregate combination used in the mix.

For additional information on LAS additives and hydrated lime, see National Cooperative Highway Research Program (NCHRP) Synthesis 595, *Practices for Assessing and Mitigating the Moisture Susceptibility of Asphalt Pavements*.

3.6.4 Fibers

Fibers for asphalt mixtures can generally be grouped into two categories:

- Fibers intended to stop or mitigate draindown in SMA mixtures.
- Fibers intended to stabilize the mix and inhibit rutting, cracking, and shoving.

Fibers to mitigate draindown in SMA are typically either cellulose fibers or mineral fibers. Cellulose fibers are plant-based fibers made from woody plants, although some are finely shredded recycled newspaper. Cellulose fibers have high absorption, which helps them maintain high binder contents without draindown. Cellulose fibers can be provided in loose form or in pellets and are typically added at a rate of about 0.3 percent by weight of the total mix mass.

Mineral fibers (also called mineral wool or rock wool) are manufactured by melting minerals then physically forming fibers by spinning or extruding. Minerals used to create mineral fibers include slag or a mixture of slag and rock, basalt, brucite, and carbon. Mineral fibers are less common and can be provided in loose form or in pellets and are typically added at a rate of about 0.4 percent by weight of the total mix mass.

Fibers intended to stabilize the mix are typically polyester, polypropylene, aramid, or combinations of these. The fibers used for this purpose are strong, heat-resistant, and from 5 to 40 mm in length. Polyacrylonitrile fibers can have a softening point as low as 430 °F (220 °C), while aramid fibers have softening points more than 800 °F (425 °C). Although these fibers may not significantly increase the tensile strength of the asphalt mixture, research has shown them to significantly increase the fracture energy, thereby improving crack resistance and crack propagation. These fibers are most commonly added at a rate from 0.065 to 0.1 percent by weight of the total mix mass.

3.7 MIX DESIGN PROCEDURES

To produce an asphalt mix design, asphalt binder and aggregate are blended together in different proportions in the laboratory. The resulting mixes are evaluated using a standard set of criteria to permit selection of an optimum binder content (OBC). The type and grading of the aggregate and the type and amount of the asphalt binder influence the physical properties of the mix. The design (or optimum) binder content is selected to ensure a balance between the long-term durability of the mix and its resistance to rutting (stability).

3.7.1 Superpave Method

AASHTO M 323 Superpave Volumetric Mix Design and R 35 Superpave Volumetric Design for Asphalt Mixtures lay out the U.S. practices and specifications for the Superpave volumetric method of mix design. Many agencies supplement the volumetric method with additional testing to assess other properties such as the mix's rut and cracking resistance. The Superpave gyratory compactor (see Figure 20) is used to compact asphalt mix specimens.

Source: NAPA

Figure 20. Superpave® Gyratory Compactor

> *To produce an asphalt mix design, asphalt binder and aggregate are blended together in different proportions in the laboratory. The resulting mixes are evaluated using a standard set of criteria to permit selection of an optimum binder content (OBC).*

The volumetric mix design is accomplished in four steps: 1) selection of component materials, 2) selection of design aggregate structure, 3) selection of design asphalt content, and 4) evaluation of moisture susceptibility. Selection of the component materials includes selection of the appropriate binder and aggregate that meet requisite quality characteristic parameters provided in the project specifications.

After component materials that meet quality requirements have been selected, the design aggregate structure must be selected. The broad band aggregate gradation is specified either by the mix NMAS in AASHTO M 323 or by gradation number in airfield specifications (the FAA P-401 and DoD UFGS 32 12 15.13).

The aggregate structure can simply be preselected if the designer has sufficient history/knowledge of the local materials. If the designer needs to select and evaluate aggregates from multiple sources or sources with which they lack sufficient familiarity, trial blends are normally designed and evaluated. The designer estimates the optimum asphalt content of each trial blend, then mixes and compacts specimens. The subsequent volumetric properties for each trial blend are evaluated to see if they meet specifications. Typically, the most cost-effective blend of aggregates that will meet both lab and field specifications is selected as the design aggregate structure.

Asphalt binder is then added to the design aggregate structure, typically anywhere from three to five binder contents at 0.5-percent intervals bracketing the estimated OBC. Typically, two identical specimens are prepared and averaged at each binder content so variability can be minimized. The OBC is typically selected as the binder content at a preselected air void content. For AASHTO M 323 specifications, the target air void content is 4 percent. FAA specifies 3.5 percent air voids. It is important to check local specifications for the target air void content. The volumetric properties at the OBC are determined, and the designer ensures that the asphalt mixture meets all volumetric specifications at that binder content.

The final step in the Superpave method is to determine the mixture's moisture susceptibility. AASHTO M 323 specifically calls for AASHTO T 283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage, to pass with a tensile strength ratio of no less than 0.80. Other specifications may call for slightly different minimum tensile strength ratio values.

3.7.2 Marshall Method

The Marshall Method of mix design was historically the predominant method of mix design for dense-graded asphalt mixtures and is noted for the portability of its equipment. At the time of this writing, there is still one State DOT using the Marshall Method. It is an optional method for FAA and DoD mixtures, and it is still common outside the United States and Canada.

For a single selected aggregate gradation, specimens at five different asphalt contents are molded with manual or mechanical Marshall hammers and molds. FAA allows either hammer type in accordance with ASTM. DoD specifies the manual hammer or the mechanical hammer calibrated to the manual hammer. A given mass of asphalt mixture at a specified temperature is placed in the Marshall molds, and the hammer is used to deliver 35, 50, or 75 blows, depending on the specification. The mold is then flipped, and the same number of blows is delivered to the other side of the specimen. Typically, three identical specimens are prepared and averaged at each binder content so variability can be minimized.

The specimens are then tested for various volumetric criteria. In addition to mix volumetrics, the Marshall Method also applies mechanical testing in the form of stability and flow tests (AASHTO T 245, ASTM D6927), which are precursors to the balanced mix design (BMD) tests that are now coming into common practice. The specimens are loaded in indirect tension using a compression tester. The stability value is basically the maximum load that can be supported by a compacted Marshall sample, and the flow value is the deformation corresponding to the maximum load. In most cases, the OBC should be selected for which the compacted specimen has 3.5 percent air voids (FAA) or 4.0 percent air voids while meeting Marshall stability and flow criteria.

3.7.3 Balanced Mix Design Method

Advancements in performance testing brought the concept of BMD to augment or even replace volumetric design. BMD, as defined in Transportation Research Board (TRB) Circular E-C280, Glossary of Terms for Balanced Design of Asphalt Mixtures is "*an asphalt mixture design framework using mechanical tests correlated to field performance on appropriately conditioned specimens that address multiple modes of asphalt layer distress taking into consideration mixture aging, traffic, climate, and location within the pavement structure*." Although primary modes of distress considered by most practitioners of BMD are rutting and cracking, other distresses such as brittleness (evaluated by the Cantabro mass loss test) could also

Advancements in performance testing brought the concept of BMD to augment or even replace volumetric design.

be considered in a BMD process. *It is very important that any performance tests used are well-correlated to field performance.*

As of this writing, the following are the four primary approaches to BMD for mixture design:

3.7.3.1 Approach D

BMD Performance Design. This approach establishes and adjusts mixture components and proportions based on performance analysis with limited or no agency requirements for volumetric properties. The agency may set minimum requirements for asphalt binder quality and aggregate properties. Once the mechanical test results meet the BMD criteria, the mixture volumetric properties may be checked for use in production.

3.7.3.2 Approach C

BMD-Modified Volumetric Design. This approach begins with the volumetric mixture design method to establish preliminary component material properties, proportions, and asphalt binder content. The mechanical test results are then used to adjust either the preliminary asphalt binder content or the mixture component properties or proportions until the criteria are satisfied. For this approach, the final design is primarily focused on meeting BMD test criteria and may not have to meet all the mixture design volumetric criteria.

3.7.3.3 Approach B

Volumetric Design with BMD Optimization. This approach is an expanded version of Approach A. It also starts with the volumetric mixture design method for determining a preliminary OBC. Asphalt mixture mechanical tests are then conducted on the mix design at the preliminary OBC and two or more additional contents. The asphalt binder content that satisfies all the test criteria is identified as the final or target OBC. In cases where the BMD test criteria are not met at any of the binder contents, the entire mixture design process needs to be repeated using different mixture proportions or materials until all the BMD test criteria are satisfied.

3.7.3.4 Approach A

Volumetric Design with BMD Verification. This approach starts with the volumetric mixture design method for determining an OBC. The asphalt mixture at the OBC is then tested with the selected mechanical tests to assess its resistance to distresses of interest. If the mix design meets the test criteria, the JMF is established and production begins. If the mix design does not meet the test criteria, the entire mix design is repeated using different mixture proportions or materials until all the volumetric and BMD test criteria are satisfied.

A good reference for more details is NAPA publication IS-143 “Balanced Mix Design Resource Guide.” Table 3 summarizes each approach.

Table 3. Summary of BMD Approaches

BMD Approach	Volumetric Requirements	Mixture Mechanical Testing Requirements	Flexibility	Innovation Potential
A: Volumetric Design with BMD Verification	Full compliance	Full compliance	Most conservative	Lowest
B: Volumetric Design with BMD Optimization	Full compliance at preliminary OBC	BMD optimization through moderate changes in asphalt binder content	Slightly more flexible than Approach A	Limited
C: BMD-Modified Volumetric Design	Some requirements relaxed or eliminated	BMD optimization by adjusting preliminary asphalt binder content or mixture component properties or proportions	Less conservative than Approach A and Approach B	Medium degree
D: BMD Performance Design	Limited or no requirements	BMD optimization by adjusting mixture components and proportions	Least conservative	Highest degree

3.7.4 RAP Considerations

The mix design should be specific regarding the source of the RAP and whether it has been fractionated or not. Some contractors fractionate RAP by passing it over one or more screens to produce separate coarse and fine stockpiles for a more controlled gradation. Fractionating RAP can reduce the overall variability of the final mix when using higher percentages of RAP. Fractionating also helps mix designers because the coarse and fine RAP stockpiles have different properties, increasing the ways that the RAP can influence volumetric properties. The fine fraction of the fractionated RAP will have a higher binder content while the coarse fraction will have a lower binder content, relative to the same RAP if it were not fractionated.

Some agencies limit the amount of RAP in the mixture by specifying a maximum allowable percentage by weight. This is an acceptable approach when the percentage of asphalt binder in the RAP is relatively similar to the total asphalt binder content of the mixture. With the increased use of fractionated RAP, many agencies now recognize the need to specify the amount of RAP in terms of the RAP binder ratio—the ratio of the RAP binder in the mix divided by the mixture's total binder content. DoD and FAA airfield projects do not currently allow the use of RAP for surface mixes, except on shoulders.

Because the RAP binder has been significantly aged and stiffened, mixes with large percentages of RAP tend to be stiffer, less workable, and more difficult to compact during construction compared to mixes with a smaller percentage of RAP. If the impact of the aged RAP binder is not addressed in the mix design, the durability of a high RAP mix will suffer as well. High RAP mixtures should be engineered with a softer binder, more binder, or recycling additives to improve the durability of the mixture. The Asphalt Institute's MS-2 offers detailed guidance on binder grade adjustments due to the use of RAP, but in summary:

- Asphalt binder content and gradation must be determined for all RAP levels.
- At lower RAP levels, (less than 15 percent), the stiffer RAP binder has minimal effect on the total mix binder stiffness, so no grade adjustment is necessary.
- At moderate RAP levels (between 15 and 25 percent), select one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used in a virgin mix).
- At high RAP levels (greater than 25 percent), the physical properties of the extracted asphalt binder will need to be determined so that blending charts or equations can be used to select the appropriate grade of virgin binder. Assuming the RAP binder blends with the new binder at mixing temperatures, a softer new binder is blended with the stiffer RAP binder, resulting in a binder blend that meets the required grade for the project.

Once the appropriate virgin asphalt binder grade and percentage of each RAP source has been selected, the normal mixture design process can proceed. BMD testing can greatly assist in optimizing the mix design process using RAP. Refer to the NAPA BMD Resource Guide for more information.

3.8 LABORATORY VERSUS PLAN-PRODUCED MIXES

As noted earlier, differences will likely exist between the properties of an asphalt mix designed in the laboratory and the "same" JMF produced in a batch or drum-mix plant (typically air voids and VMA). It is important to examine those differences and understand how and why the test properties or characteristics of a mix produced in a plant may vary significantly from the results predicted by tests conducted on laboratory-produced material.

These revisions are usually required for several reasons, including:

- Aggregate samples obtained for the mix design will typically have less degradation from handling compared to the aggregate that passes through the production plant.
- The asphalt binder will likely be absorbed into the aggregate particles at a different rate during mixing and storage at the asphalt plant than in the laboratory.

- The mix design was performed with oven-dry aggregate, weighed out to the nearest 0.1 g, while the plant aggregate experiences ever-changing moisture conditions that cannot be perfectly accounted for on the continuously moving plant weigh belt.
- Unless the plant aggregate feed systems are perfectly calibrated 100 percent of the time, the blend percentages may be slightly different than the percentages precisely weighed out on a scale in the lab.
- The mix design may have been conducted and certified using aggregate material produced months or sometimes years before the project production takes place and not reflect the aggregate properties of mixture being produced.

Factors such as these make it almost inevitable that the blend percentages of the mix will need to be adjusted slightly in the field to produce a mix within specifications.

Asphalt contractors, producers, and inspectors should understand the owner's policies regarding allowable changes to the mix design.

The most common problem encountered in plant-produced mix is the failure to meet VMA and air void volumetric parameters. These properties are related, as a failing air voids test is usually the result of a changing VMA—assuming the binder content does not change. The change in VMA is most often explained by inconsistent mixture conditioning during testing or a change in the gradation and/or shape of the aggregate due to degradation during handling.

Proper mixture conditioning of samples is essential in providing accurate volumetric properties. The time and temperature of mixture conditioning can greatly affect the amount of asphalt absorbed in the aggregate, thus changing the maximum specific gravity of the mix (G_{mm}) and, to a lesser extent, the bulk specific gravity of the mix (G_{mb}). For example, G_{mm} samples taken at the plant and immediately tested may produce significantly lower G_{mm} values. This is because the mix has a higher volume due to the binder that has not had enough time to be absorbed into the aggregate. Artificially low G_{mm} values result in higher measured lab compacted density (lower air voids) and higher measured percent compaction on field cores.

If a sufficient conditioning time is allowed, binder will be absorbed into the mix at nearly the full absorption capacity of the aggregate, resulting in a lower mix volume because part of the binder has moved from the outside of the aggregate particles to the inside. Subsequently, the lower mix volume due to increased conditioning time will result in higher G_{mm} values and lower calculated densities.

For field-produced mixes to match laboratory design values, mix samples should be cured at similar temperatures for a similar length of time. Highly absorptive aggregates will magnify the importance of matching the curing time and temperature between the lab and the field.

Regarding gradation, it is important to remember that VMA is the result of the amount of aggregate packing that occurs in the mold when placed in the lab compactor. Anything that changes the void spacing in the specimen will affect the resulting VMA. A change in the percent passing on one aggregate sieve can alter the compaction characteristics of the mix and change the way the entire aggregate structure fits together.

Aggregate breakdown is common when going from mix design in the lab to plant production in the field. Each time the aggregate is handled at the quarry, loaded and unloaded into trucks, fed into cold bins, and traveled through the plant during drying and mixing, it tends to abrade the angular edges and create additional fines. This breakdown typically creates a higher percentage of minus No. 200 material (dust) relative to the aggregate samples used for the mix design, resulting in lower air voids and lower VMA (collapse) for plant-produced samples compared to the mix design, assuming the same binder content. Mix designers can take this into account when batching during the mix design process by adding more dust to minimize the difference between mix design gradation and the produced mix gradation.

When specifications only require the monitoring of air voids in the mix and not VMA, the VMA can unknowingly decrease. It is possible to simply reduce the amount of binder being added to the mix to restore the specified air voids level. Simply reducing the binder content may correct the air voids deviation but leave the mix dry with an insufficient amount of binder to provide durability. After evaluating sampling and testing procedures to ensure a standardization of curing parameters, options to restore the VMA in the mix should be explored. These may include the following, depending on the specific properties of the local aggregate:

- Make bin split/gradation changes that generate additional VMA.
- Increase the fracture content of the aggregate.
- Reduce natural sand components and increase use of washed screenings in place of regular screenings.
- Increase intermediate-sized chips (but too much will cause mix instability).
- Reduce the dust in the mixture by:
    - Washing some of the aggregates that contain high levels of dust.
    - Increasing the fine aggregates that contain smaller amounts of dust.
    - Using a dust collector surge bin to reduce the dust being returned to the mix.

3.9 SUMMARY

The objective of testing plant-produced asphalt mixtures is to favorably compare the test results with the laboratory JMF. This is often difficult to accomplish because of all the variables that exist at the plant—from the type of plant used to the specific plant operating conditions. There are often differences between laboratory and plant mixes—in the gradation of the aggregates, the rounding of the aggregates as they pass through the plant, the degree of hardening of the asphalt cement, incomplete drying in the drum, and the wasting of any fines through the emission-control system.

The JMF produced in the laboratory, therefore, should serve as a good starting point. The desired properties of the mix should be checked and verified on the plant-produced, laboratory-compacted asphalt mixture. Daily tests should be run to determine the characteristics of the mix being produced (mix verification). All mix test results should be within the range of the specification requirements.

Unless they contradict the project specifications, the following guidance may be helpful when testing plant-produced mixtures. If the test results on the plant-produced mix indicate compliance with the JMF requirements, the plant should continue to operate. If one or more of the mix properties are outside the desired range, an investigation should quickly be conducted to determine the cause and extent of the deficiency. In most cases, the plant should not be shut down nor drastic changes made to the mix design based on only one set of test results. A failing sample should be followed with immediate sampling and testing of additional material, rather than waiting on the next random sample time. If the second sample results confirm the first, immediate action should be taken to bring the mix back into compliance. It is typically more desirable for the plant-produced mix to meet volumetric requirements than it is for the field gradation to exactly match the mix design.

4. Mix Production

4.1 INTRODUCTION

The purpose of an asphalt mix plant is to blend aggregate and asphalt binder together at an elevated temperature to produce a homogeneous asphalt paving mixture.

Two basic types of HMA plants are currently in use: batch plants and continuous flow drum-mix plants.

Regardless of the type of production plant, the basic purpose is the same—to produce an asphalt mix within a specific temperature range containing the specified proportions of asphalt binder, aggregate, and any additional additives required. Both batch plants and drum-mix plants are designed to accomplish this purpose.

The following basic operations involved in producing asphalt mix are the same regardless of the plant type:

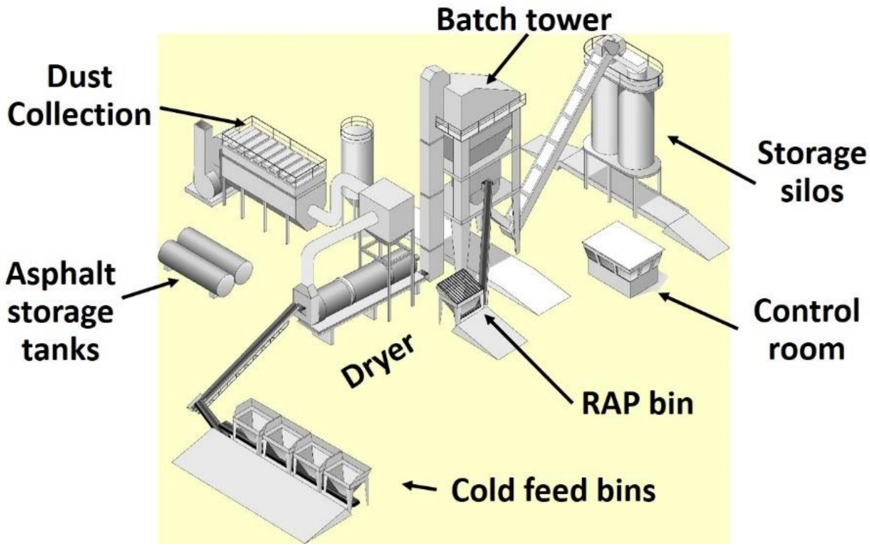
- Proper storage and handling of asphalt mixture components at the mixing facility.
- Accurate proportioning and feeding of the aggregate to the dryer.
- Effective drying and heating of the aggregate to the proper temperature.
- Efficient control and collection of the dust from the dryer.
- Proper proportioning, feeding, and mixing of asphalt binder and additives with heated aggregate.
- Correct storage, dispensing, weighing, and handling of finished mix.

The major difference between batch and drum-mix plants is in how they mix asphalt binder and aggregate after the aggregate has been proportioned, dried, and heated to the final mix temperature.

Batch plants screen and fractionate hot aggregate into separate bins after leaving the dryer. Asphalt binder and fractionated aggregate are then individually weighed into predetermined batches and mixed in a pugmill mixer, one batch at a time (see Figure 21).

***Batch plants** screen and fractionate hot aggregate into separate bins after leaving the dryer. Asphalt binder and fractionated aggregate are then individually weighed into predetermined batches and mixed in a pugmill mixer, one batch at a time.*

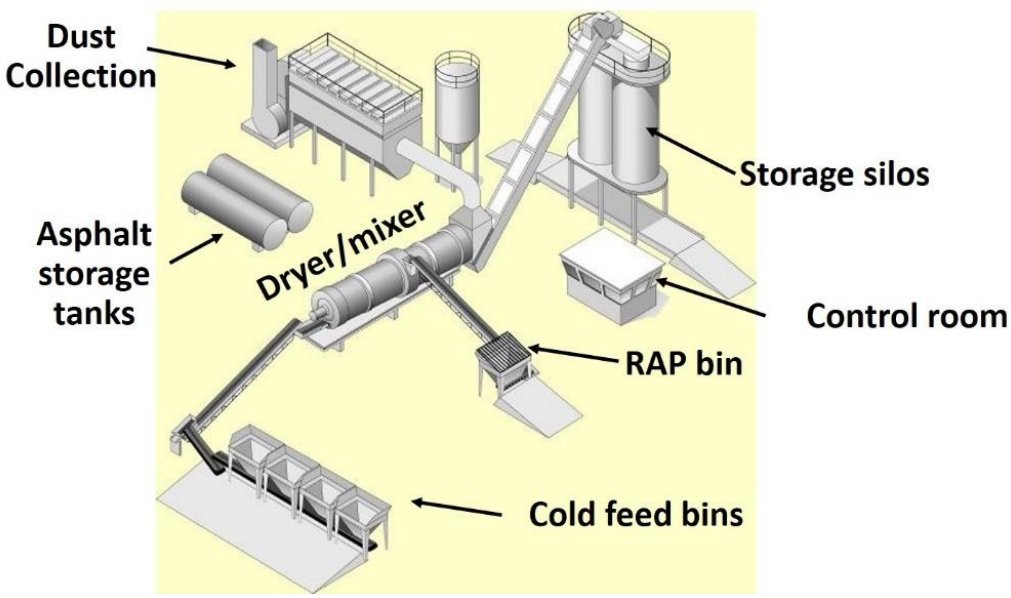
***Drum-mix plants** dry the aggregate and blend it with asphalt binder in a continuous process within the dryer drum*



Source: Asphalt Institute

Figure 21. Batch Plant Components

Drum-mix plants dry the aggregate and blend it with asphalt binder in a continuous process within the dryer drum; hence the name drum mixer (see Figure 22).



Source: Asphalt Institute

Figure 22. Drum Mix Plant Components

Uniform and continuous operations are critical to the production of quality asphalt mix. Uniformity helps ensure the mix is consistently produced to meet project specifications. This includes uniform delivery of raw materials, uniform material proportioning, and continuous, uniform operation of all plant functions.

4.2 MATERIAL STORAGE AND HANDLING

The quality of the asphalt mix produced is only as good as the material going into the plant. One of the necessities of ensuring quality production is that an adequate supply of suitable material be available prior to and during mixing operations. The following sections discuss the principles of handling and control of both asphalt binder and aggregate materials common to all asphalt mix plants.

4.2.1 Asphalt Binder

Asphalt binder is a black, thermoplastic, cementitious material whose consistency and viscosity changes based on temperature. When heated sufficiently it softens and becomes less viscous, allowing it to be pumped and to coat aggregate particles during asphalt mix production.

4.2.1.1 Binder Delivery

In most instances, asphalt binder comes from a pre-tested source and is accepted by certification. Records must be kept of all asphalt binder deliveries to the plant. The records should include the following information:

- Asphalt binder grade.
- Supplier's name and location or shipping point.
- Plant and project identification (if dedicated to a particular project).
- Date of delivery.
- Delivery invoice number.
- Grade certification and Material Safety Data Sheet.
- Identification of any additives incorporated at the binder terminal.
- The specific gravity or unit weight per gallon at 60 °F (liters at 15 °C).
- Asphalt binder quantity by weight.

Similar records should be kept on all other materials (such as mineral filler, hydrated lime, or other additives that are incorporated into the mix).

4.2.1.2 Binder Storage

The asphalt binder supply system consists of two major components. The first comprises one or more tanks used to store the asphalt binder until it is needed by the mixing plant. The second is a pump and meter system used to draw asphalt binder from the storage tank.

Asphalt binder storage tanks are insulated and heated to maintain the correct temperature to assure the binder can be pumped and mixed with hot aggregate. Temperatures are typically maintained by thermostatically controlled electric heat or a hot oil coil system, which circulates hot oil through a series of coils inside the storage tank. The system maintains the proper temperature of the asphalt binder, generally in the range of 300 °F (150 °C) to 350 °F (180 °C), depending on the type of asphalt binder.

Tanks that store modified binders are often equipped with agitators or stirring paddles to maintain constant circulation. For short periods of time, circulation using the asphalt plant's own pump(s) can be used for the same purpose. Some modified asphalt binders can have specific agitation requirements. Asphalt mix producers are encouraged to consult with the liquid binder supplier for proper temperature and storage requirements.

4.2.1.3 Binder Sampling

Asphalt binder samples are typically taken from a sampling valve in the delivery line between the binder storage tank and the plant after all inline binder additives have been added. When no inline binder additives are used, samples may be taken from a sampling device on a delivery vehicle, discharge line, or storage tank.

Following are a few important rules to follow when sampling asphalt binder:

- Enlist only a competent, well-trained technician to perform sampling.
- Wear personal protective equipment (such as gloves, face shield, and long-sleeved shirt) to protect from burn hazards.
- Ensure samples are representative of the entire shipment by taking them from the sampling valves provided for that purpose.
- Follow sampling methods described in ASTM D140 and AASHTO T 40.
- Use only new, clean, and dry metal sample containers.
- Allow at least 1 gal (4 L) of asphalt binder to flow from the sample valve prior to obtaining a representative sample.
- Seal filled sample containers immediately with clean, dry, tight-fitting lids. Any spilled material should be wiped from the container with a clean, dry cloth—**never** with a cloth dipped or soaked in solvent.
- Label clearly all sample containers for sample identification. Container lids should also be labeled because once a lid is removed, it will be necessary to match it to the appropriate container. Tags should be used only when there is no danger of their being lost in transit.

When asphalt binder is delivered from a transport vehicle into a storage tank, it is important to ensure that either the tank is clean or that it does not contain material that will contaminate the binder being pumped into the tank. If it is empty at the time the new material is being added, the tank should be checked to ensure that no water has accumulated on the bottom. If asphalt binder is loaded on top of an asphalt emulsion or on top of a layer of water in the tank, violent foaming of the asphalt binder may occur, creating a serious safety problem.

It is important to be aware that some asphalt binder can remain in the bottom of an "empty" tank. Therefore, placing asphalt binder of one type or grade into a tank that previously contained a different type or grade can cause an alteration of the properties of the asphalt binder to the point that it no longer meets specifications.

When asphalt binder is delivered from a transport vehicle into a storage tank, it is important to ensure that either the tank is clean or that it does not contain material that will contaminate the binder being pumped into the tank.

Maintaining a good line of communication with the liquid binder supplier is a critical step in assuring proper temperature, storage, and safety procedures are established.

4.2.1.4 Binder and Mixture Temperatures

Both asphalt binder and aggregate must be heated before they are mixed—the binder to make it fluid enough to pump and properly coat the aggregate, and the aggregate to make it dry and hot enough to accept the asphalt binder and produce a well-coated mix at the desired temperature and free of moisture.

The temperature of the aggregate controls the temperature of the mixture. Normally, a mixing temperature is specified based on the characteristics of the asphalt binder and on factors relating to mixing, placement, and compacting conditions.

Mixing should be done at the lowest temperature that provides for complete drying and coating of the aggregate particles and produces a mixture with satisfactory workability. Binder and additive supplier mixing temperature recommendations should be used if possible. Two asphalt binders with the same PG could have different optimum mixing temperatures, especially if they are produced by different methods. And they most certainly will have different mixing temperatures if one binder is modified and the other is not, or if warm-mix additives are involved.

Mixing should be done at the lowest temperature that provides for complete drying and coating of the aggregate particles and produces a mixture with satisfactory workability.

The following procedure is recommended for selecting the starting point for plant mixing temperatures:

1. Select plant mixing temperature based on recommendations from the binder supplier, previous experience with the same binder grade from this supplier, and project conditions (including weather and seasonal conditions, lift thickness, haul distance, and mixture considerations).

2. In the absence of supplier guidance, consult Table 4 for recommended plant mixing temperature for a given binder grade.
3. Generally, when using the table, use the middle of the range of temperatures as the starting point for the PG binder selected.
    - Typically, plant mixing temperatures will range from 265 to 300 °F (130 to 150 °C) for standard dense-graded mixtures using neat (unmodified) binders.
4. Do not allow plant mixing temperatures to exceed 350 °F (180 °C) to avoid excessive aging of the asphalt binder.
5. Use caution in raising plant mixing temperatures too high to improve field laydown and compaction. Excessive temperatures can have the following negative consequences:
    - The asphalt binder may be damaged.
    - Unnecessary fumes and odors may be generated.
    - Excessive asphalt binder draindown may occur in certain mix types.
    - The mixture may be tender and unstable under compaction equipment.
    - Unnecessary cost and emissions are added.

Table 4. Typical Plant Binder Storage and Mixing Temperatures

Typical Asphalt Binder Temperatures				
Binder Grade	HMA Plant Asphalt Tank Storage Temperature (°F)		HMA Plant Mixing Temperature (°F)	
	Range	Midpoint	Range	Midpoint
PG 46–28	260–290	275	240–295	264
PG 46–34	260–290	275	240–295	264
PG 46–40	260–290	275	240–295	264
PG 52–28	260–295	278	240–300	270
PG 52–34	260–295	278	240–300	270
PG 52–40	260–295	278	240–300	270
PG 52–46	260–295	278	240–300	270
PG 58–22	280–305	292	260–310	285
PG 58–28	280–305	292	260–310	285
PG 58–34	280–305	292	260–310	285
PG 64–22	285–315	300	265–320	292
PG 64–28	285–315	300	265–320	292
PG 64–34	285–315	300	265–320	292
PG 67–22	295–320	308	275–325	300
PG 70–22	300–325	312	280–330	305
PG 70–28	295–320	308	275–325	300
PG 76–22	315–330	322	285–335	310
PG 76–28	310–325	318	280–330	305
PG 82–22	315–335	325	290–340	315

Source: Asphalt Institute

4.2.2 Aggregate

Stockpiling and handling techniques for aggregate materials are the same regardless of the plant type used. It is important to understand that individual aggregate stockpile characteristics—including quality and gradation—can only be achieved during aggregate production, not at the asphalt mixing facility.

4.2.2.1 Testing and Certification

Aggregate property data should be recorded as aggregates are received at the plant site. If the material has not been tested or material changes have occurred due to handling, sufficient random samples should be obtained and tested to ensure compliance with all specifications after aggregate transport is complete. At a minimum, tests should be made available for gradation (washed sieve analysis) for all aggregate materials. It is recommended that all aggregate properties specified in the contract or plans be performed or verified during aggregate production and delivery, as discussed in Chapter 3.

4.2.2.2 Storage and Handling

Aggregate must be handled and stored in a manner that avoids contamination, minimizes degradation, and prevents segregation. The stockpile area should be clean and stable to prevent contamination. Materials should be stockpiled on a free-draining grade to prevent accumulation of moisture.

Site planning is important when building stockpiles at plant locations. Controlling drainage onsite is necessary to prevent contamination of aggregate by front-end loaders charging the plant and haul trucks delivering material. Plant sites and aggregate storage areas in low-lying areas may require the construction of a well-drained working platform or site to assure aggregate material can be handled without adulteration.

At permanent plant sites, paving the stockpile area will help prevent subgrade contamination and expedite moisture drainage from the stockpiles. Storing aggregate stockpiles, especially RAP, under a roof is an increasingly cost-effective option to minimize excess moisture. A consistently low moisture content lowers heating and drying costs and increases plant productivity and mixture uniformity.

To prevent intermingling and cross contamination of different aggregates, stockpile areas must have enough space for clear separation of stockpiles or make use of bulkheads (vertical dividers) to maintain separation of the materials. When bulkheads are used, do not allow the stockpiles to overflow into adjacent aggregate material.

4.2.2.3 Stockpiling and Segregation

One of the primary concerns with the handling and stockpiling of aggregate is segregation. The method used to control segregation depends on the nature of the material. Aggregates that are well-graded, from the NMAS to the finest particles, are the most prone to segregation. Sand, crushed fine aggregate, or any single-size aggregate material can generally be handled and stockpiled with little, if any, segregation.

When a well-graded aggregate containing both coarse and fine particles is placed in a stockpile with sloping sides (a cone shape), segregation is sure to occur as the larger particles will roll down the slope. Stockpile segregation can be nearly eliminated by making use of multiple fractionated material piles. Building a stockpile in layers can also help minimize this type of segregation. Pushing or casting aggregate over the side of a stockpile will result in segregation. Equipment operating on the stockpile, especially steel-tracked, should be minimized to prevent aggregate breakage, fines generation, and degradation.

The use of radial stacking conveyors allows more material to be stockpiled over a smaller area by raising the elevation of the stockpile. Proper use of a radial stacker includes raising the conveyor slowly after moving it horizontally to cause the stockpile to grow vertically. Segregation can occur if a stacker is allowed to drop aggregate from an elevated height.

Stockpile segregation can be nearly eliminated by making use of multiple fractionated material piles.

Figure 23 illustrates the capability of a telescoping radial stacking conveyor, which is very effective in eliminating stockpile segregation.

Source: Masaba, Inc.

Figure 23. Magnum Telescoping Conveyor Building a Stockpile in Windrows

4.2.3 Additives

Traditional asphalt mixtures consisting of only unmodified asphalt binder and virgin aggregate are becoming less common. Most modern asphalt mixtures contain modifiers or additives of some type. Recycled asphalt pavement and modified asphalt binder have been in use for many years and are regularly incorporated with minimal impact on plant processes. Many other additives that are used to improve mixture performance require special attention. Some additives, such as liquid antistrip and WMA additive, are often incorporated into the asphalt binder supply, either at the asphalt binder terminal or by injection at the plant. Additives added at the asphalt terminal are typically certified by the binder supplier and require no special accommodations at the asphalt plant.

Additives that are incorporated at the asphalt plant must be accurately metered and incorporated into the final product. Plant-incorporated additives may include LAS, hydrated lime, WMA, crumb rubber modifier, mineral filler, fibers, RAP, RAS, or many other possible products. All these materials will impact the performance of the asphalt mix produced and must be accurately metered into the plant to achieve the desired performance. Specifiers and additive suppliers should work together to ensure that the respective materials are received, stored, and incorporated into the mix as necessary to achieve the intended results. Asphalt mix producers are encouraged to refer to the additive manufacturer's recommendations when using any specialty product. See Chapter 3 for more discussion on additive materials.

4.3 AGGREGATE COLD FEED

The cold-feed systems on asphalt batch and drum-mix plants are similar. Each consists of cold-feed bins, feeder conveyors, a gathering conveyor, and a charging conveyor. The aggregate cold-feed system receives the aggregate material from the stockpiles, proportions the aggregate to achieve the gradation specified, and delivers the aggregate to the dryer. On most plants, a scalping screen is included in the system at some point.

If RAP is being fed into a plant, separate cold-feed bin(s), feeder belt and/or gathering conveyor, scalping screen, and charging conveyor are necessary to handle the extra material.

4.3.1 Cold-Feed Bins

The flow of aggregate through a plant begins at the cold-feed bins (see Figure 24). The plant is equipped with multiple bins to handle the different sizes of aggregate used in the mix. A bulkhead or divider should be used between each cold-feed bin to prevent overflow of the aggregate from one bin into another. If bins overflow, the commingled aggregate sizes can significantly alter the gradation of the mix and performance of the mixture produced.

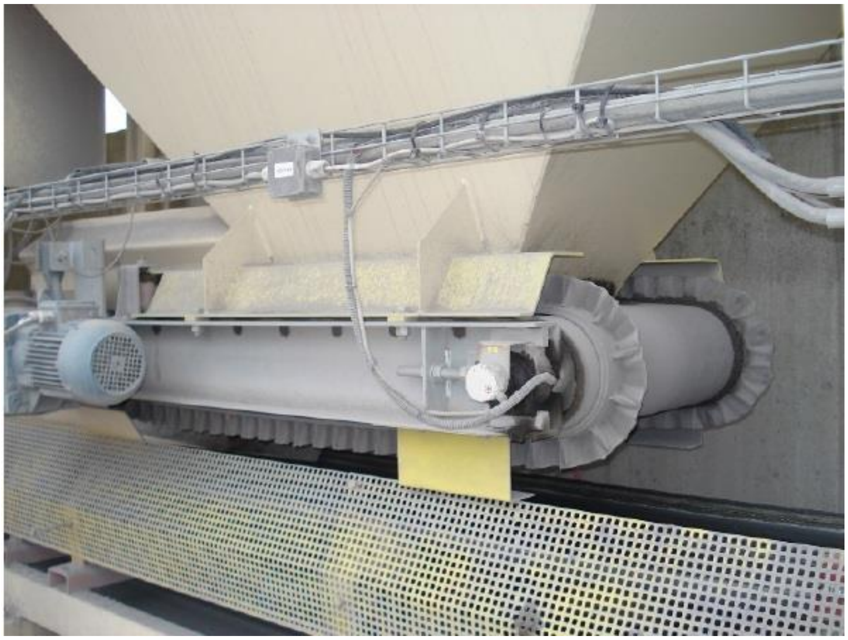
Uniform flow of properly sized aggregates is crucial to achieve consistent production. Once an aggregate material is introduced into the cold-feed bins, the plant cannot detect or correct inconsistencies in gradation or aggregate quality.

Source: Asphalt Institute

Figure 24. Loading Aggregate Cold-Feed Bins

4.3.2 Bin Feeders

Aggregates are delivered through calibrated feeder gates to belt feeders (short, variable-speed conveyor belts) located directly under each cold-feed bin (see Figure 25 and Figure 26). The rate of material from each bin is controlled by the feeder belt speed and feeder gate opening. This system provides a very consistent control of the aggregate flow from the individual bins onto the main conveyor that leads to the dryer.



Source: Asphalt Institute

Figure 25. Cold-Feed Bin Feeder Belt

Each cold-feed bin opening is typically equipped with a flow sensor (see Figure 26) placed directly in the material stream. If a bin runs empty or the discharge opening becomes clogged, a "no-flow condition" alert is sent to the plant computer.

Source: Asphalt Institute

Figure 26. Bin Feed Aggregate Sensor

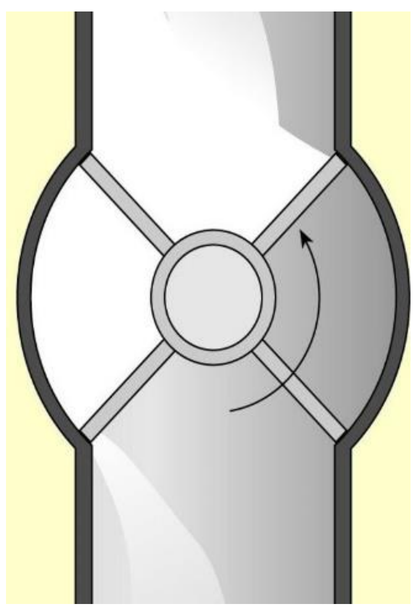
Because a uniform flow of properly sized aggregates is so important to consistent production, a check should be made before and during production to be certain that the feeder system is functioning properly. The following conditions are important for maintaining uniform flow and consistency:

- Correct sizes of aggregates in stockpiles and cold bins.
- No segregation of aggregate stockpiles.
- Accurately calibrated and secured feeder gates.
- No obstructions in feeder gates or in cold bins.
- No material clumping causing “bridging” that interrupts uniform flow.
- Correctly functioning bin vibrators, if equipped, to prevent bridging.
- Correct speed control settings.

4.3.3 Mineral Filler/Hydrated Lime Additive System

Extremely fine materials, generally referred to as the “dust” (minus 0.075-mm sieve) fraction of the aggregate gradation, are a critical component of any durable asphalt mix.

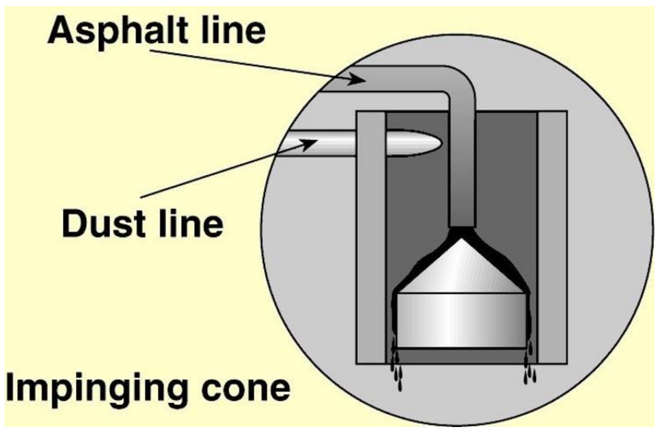
Mineral filler, such as hydrated lime, Portland cement, fly ash, limestone dust, or baghouse fines, should be stored in a silo or other appropriate container and delivered to the plant through a vane feeder system (see Figure 27) or small weigh hopper. The speed of the feeder is calibrated to the aggregate being delivered to the drum. The silo is normally equipped with an aerating system to keep mineral filler from packing into a tight mass and bridging the feeder opening. If the flow of filler is restricted, the vane feeder will still rotate, but no material will be sent to the plant.



Source: Asphalt Institute

Figure 27. Vane Feeder Schematic

Once metered, a pneumatic system or auger is used to move the material to the required location. In a drum mixer, it is typically located near the binder supply line in the drum. This proximity allows the liquid binder to capture the extremely fine material, preventing it from being diverted back to the dust collection system. Terminating both supply lines under a hood or impinging shroud (see Figure 28) will add extra protection by separating the fine material from the high-velocity airstream flowing through the dryer.



Source: Asphalt Institute

Figure 28. Drum Mixer Impinging Hood or Cone

To continuously meter the dust, storage silos typically make use of a weigh hopper or pod to accurately meter the rate of material flowing from storage into the mixing process. If this method is not available, frequent checks on the calibration of the feeding and weighing mechanisms should be performed.

Some agencies require the use of hydrated lime as an anti-stripping agent. There are many methods in use that successfully incorporate hydrated lime into a mix. A common method is to add hydrated lime directly to moist aggregate or combine it with water to make a slurry and then mix it with the aggregate in a separate pugmill. Generally, the lime-aggregate mixture is fed directly into the plant after mixing. However, an aggregate treated with a lime slurry mixture may be stockpiled to allow for additional marinating and drying before introduction into the plant for mixing. For more information on the use of hydrated lime as an anti-stripping agent, refer to Section 3.6.3.

4.3.4 Reclaimed Asphalt Pavement

The cold-feed system for handling RAP is essentially the same as the conventional cold-feed system for new aggregate. On most plants, as shown previously in Figure 21 and Figure 22, a separate cold-feed bin is used. The bin (or bins) is like the cold-feed bins used for aggregate except that all four sides of the RAP feed bins are usually much steeper. The steeper sides reduce the tendency of the reclaimed material to bridge the opening at the bottom of the bin. The RAP should be passed through a scalping screen to remove any oversized pieces of asphalt mixture or deleterious material.

It is an important point to keep in mind that RAP sources must be properly and randomly tested for consistency prior to producing the mixture. If RAP consistency is variable, using a higher percentage will increase the probability that the final product will be out of specification. This is one reason why some specifying agencies frequently ask for RAP sources to be stockpiled separately and why RAP percentages are often limited in the final product.

RAP sources must be properly and randomly tested for consistency prior to producing the mixture.

One way to reduce RAP variability is to fractionate it into two sizes—a fine material and a coarse material. The splitting screen size may range from 9.5 to 19 mm (3/8 to 5/8 of an inch). The material is then proportioned into the mix as if it were two sources of material. Additional information concerning recycled material is available in Section 3.3.9.

4.4 AGGREGATE DRYING AND HEATING

From the cold-feed bins, aggregates are delivered to the dryer drum. The dryer accomplishes two things: it dries the aggregate and heats the aggregate to the required temperature.

4.4.1 Aggregate Dryer

The dryer is a sloped, rotating cylinder ranging from about 5 to 10 ft (1.5 to 3 m) in diameter and 20 to 40 ft (6 to 12 m) in length (see Figure 29). It has an oil or gas burner with a blower fan to provide the primary air for combustion of the fuel. The exhaust fan is a critical element that pulls the heated gases through the dryer and assists in the complete combustion of burner fuel. The exhaust fan is located beyond the dryer, at the end of the dust control equipment (discussed further in Section 4.7).

Source: NAPA

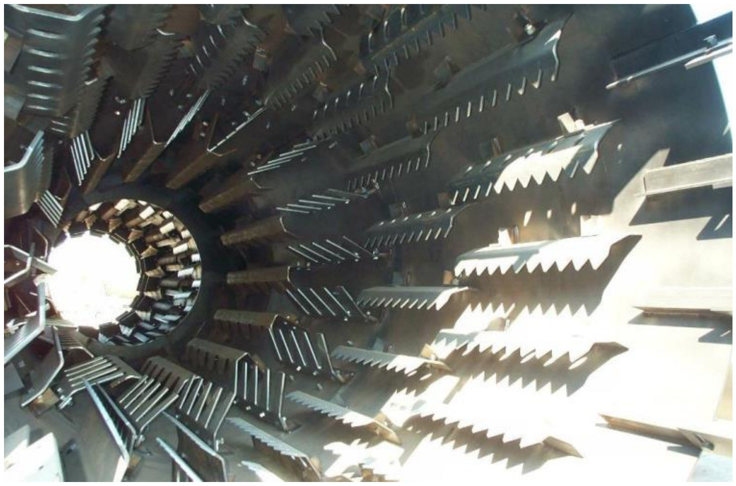
Figure 29. Typical Batch Plant Dryer

The inside shell of the drum has bolted-on or welded-on longitudinal troughs and channels, called flights, which lift the aggregate and drop it in a continuous shower or "veil" through the heated gases flowing through the dryer (see Figure 30). The slope of the dryer; its rotation speed, diameter, and length; and the arrangement and number of flights all combine to determine the time the aggregate will spend in the dryer.

Source: Asphalt Institute

Figure 30. Uniform Veil of Aggregate in Dryer

Near the open flame area of the burner, also known as the combustion zone, special flighting traps the aggregate near the wall of the dryer and carries it over the top of the flame. This prevents individual particles from passing through the flame and interfering with complete fuel combustion. Maintenance of the flights in the drum to produce a uniform veil of aggregates (see Figure 31) across the drum is necessary to efficiently produce a consistent mix.



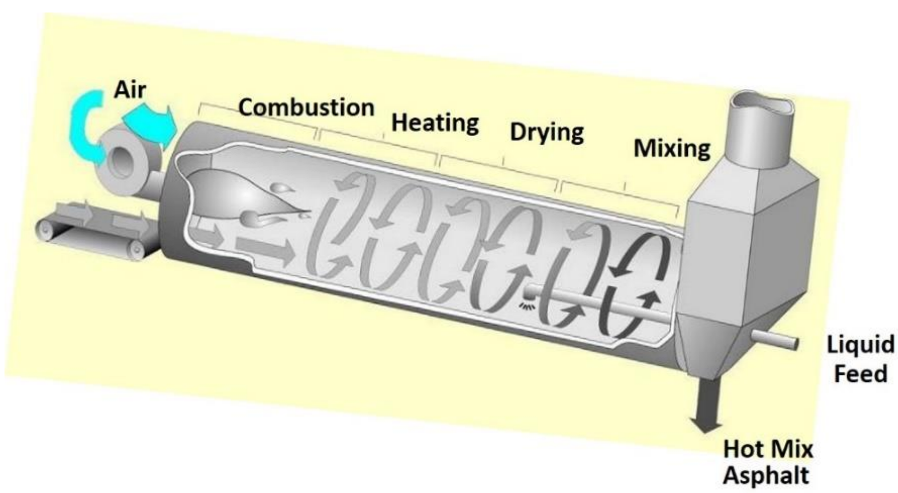
Source: Stansteel/Hotmix Parts & Supply

Figure 31. Different Types of Dryer Flights

4.4.1.1 Aggregate Dryer Types

There are two basic types of dryers: parallel-flow and counterflow. They are named for the relationship between the flow of the aggregate and the flow of the hot gases within the dryer. Regardless of the dryer style, the principles of drying aggregate are the same.

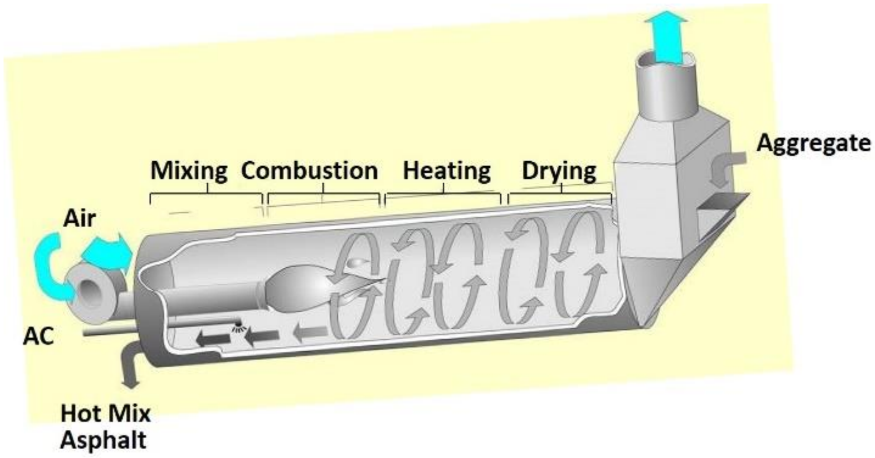
In parallel-flow dryers (see Figure 32), the aggregate and the air flow in the same direction. Cold aggregate is introduced into the dryer at the same end as the burner (the higher end of the drum), and the materials flow toward the lower end of the dryer parallel to the airflow.



Source: IIT Kharagpur

Figure 32. Parallel-Flow Dryer

In counterflow dryers (see Figure 33), the aggregate and air flow in opposite directions, counter to each other. The burner is in the lower end of the drum and the aggregate is carried down through the drum against the airflow. Counterflow dryers are more common because they provide more efficient heat transfer than parallel-flow dryers.



Source: IIT Kharagpur

Figure 33. Counterflow Dryer

4.4.1.2 Aggregate Dryer Capacity

The drying process controls the overall production rate of the entire facility. Asphalt mix cannot be produced faster than the aggregate can be dried and heated. Dryer capacities are rated for heating and drying aggregate at a specific moisture content (typically 5 percent). If the aggregate moisture content is higher, the quantity of aggregate being fed to the dryer must be reduced to dry the aggregate properly. Consequently, there is a drop in the dryer's production. Dryer slope, flighting, product temperature, aggregate type, atmospheric conditions, and elevation will also impact dryer performance.

If the aggregate moisture content is higher, the quantity of aggregate being fed to the dryer must be reduced to dry the aggregate properly.

Aggregate moisture content should be determined at least twice a day and more often if moisture conditions change, such as after rainfall. The average moisture content of the aggregate coming into the plant dryer or drum mixer is needed by the plant control system to permit proper setting of the burner controls, calculation of the dry weight of the incoming aggregate, and determination of the binder supply for drum-mix plants.

4.5 BATCH PLANTS

Batch plants (shown in Figure 34) get their name from the fact that during operation they produce asphalt mixture in batches, one batch at a time, one after the other. The size of a batch varies according to the capacity of the plant's pugmill (the mixing chamber where aggregate and asphalt binder are blended). Batch sizes can vary from 2,000 to 10,000 lbs (900 to 4,500 kg).

Source: Gencor Industries

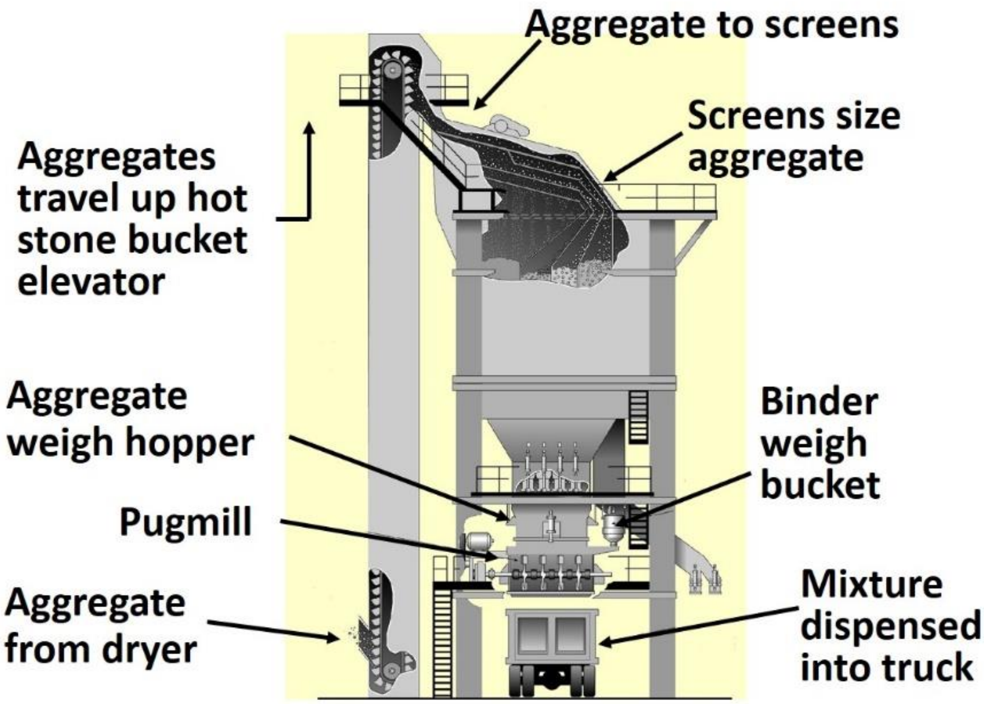
Figure 34. Asphalt Batch Plant

4.5.1 Operations

As discussed earlier, the basic operations of both batch and drum-mix plants are similar except for the aggregate and asphalt mixing procedures. Material storage and handling, aggregate cold feeds, and aggregate heating and drying, as well as emissions control, are all quite similar for batch and drum-mix plants. This section will focus on the mixing operations that are unique to a batch plant.

4.5.2 Screening and Storage of Hot Aggregate

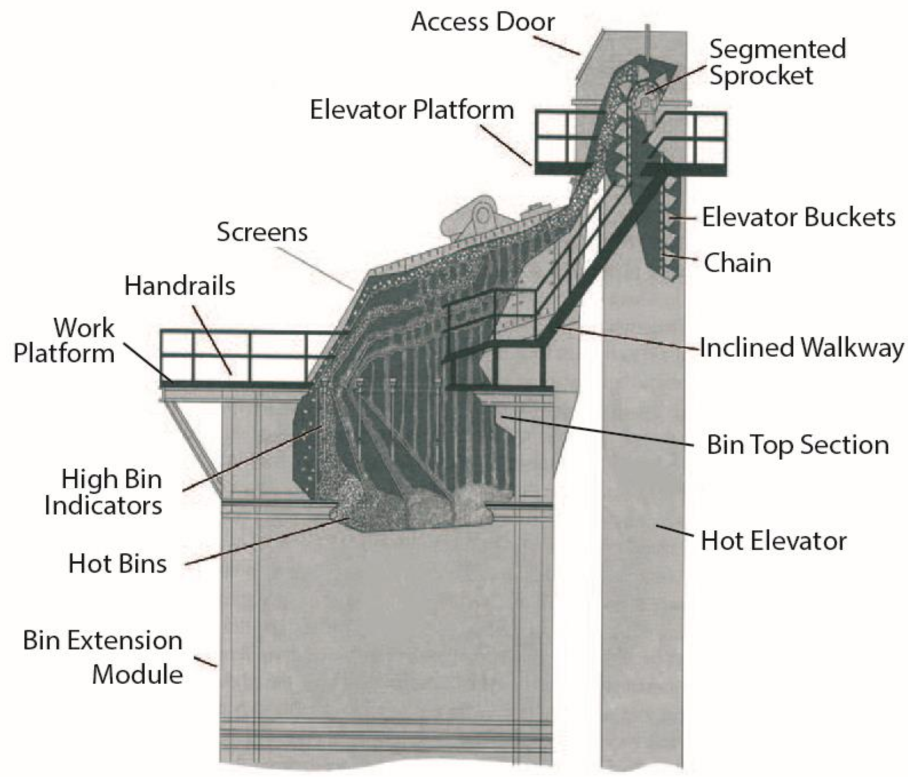
After the aggregate has been heated and dried, it exits the dryer into a hot elevator. The hot elevator is a nearly vertical, enclosed bucket conveyor that carries the aggregate to the top of the "batching tower" (see Figure 35). The aggregate is discharged from the elevator into a screening unit. The hot aggregate passes over a screening unit that separates it into various-size fractions and deposits those fractions in hot bins.



Source: Asphalt Institute

Figure 35. Batching Tower

The screening unit includes a set of several different-size vibrating screens inside a large housing. The screens separate the aggregate into specific sizes. The first screen is a scalping screen that removes oversized aggregate. This is followed by two to four screens, decreasing in size from top to bottom. The sizes of the screens used will depend on the plant and the gradation of the aggregate for the mix being produced (see Figure 36). The screens are designed to allow the finest particles to drop completely through to the first hot bin, and larger particles move along the screens to be deposited into the subsequent bins.



Source: Asphalt Institute

Figure 36. Screening Decks and Hot Bins

4.5.3 Hot Bins

Hot bins are located directly below the screening unit and used to store the heated and screened aggregates. Hot bins have indicators that tell when the aggregates fall below a certain level. These indicators may be either electronic or mechanical. Each bin should also be equipped with an overflow pipe or a high bin indicator to prevent excessive amounts of aggregate from spilling into the other bins. When a bin severely overfills, the screen above it rides on the overloaded aggregate, resulting in a heavy carryover and possible damage to the screen.

Hot bins are referred to by their total capacity. This can be as low as 20 tons for a small, portable batch plant to as large as 300 tons for a large, stationary plant. A very common capacity is in the range of 40 to 80 tons (36 to 72 tonnes).

Not all aggregate passes through the screening deck and hot bins. Mineral filler and dust returning from the baghouse are fed directly into the weigh hopper and weighed as a separate component.

4.5.4 Hot-Bin Sampling

Batch plants are equipped with devices for sampling hot aggregate from the bins. Most plants utilize a sample container mounted at the end of a control rod. When placed under the hot-bin feeder or gate, the containers catch a complete cross-section of the aggregate flow as it drops out of the bin. Some plants have a device to divert the flow of aggregate from the hot bin to a sample container. It is essential that such containers be properly located when taking the sample so that they collect a representative sample of the material.

During production, as the aggregate flows over the plant screens, the finest particles fall first into one side of each bin, and coarser particles travel along the screen to the other side of each bin. When material is drawn from the bin, the aggregate stream consists predominantly of finer material on one side and coarser material on the other. Therefore, the position of the sampling device in the stream of material discharged from a bin determines whether the sample will be composed of a finer portion, a coarser portion, or an accurate representation of the material in the bin. This condition is especially critical in the first or Number 1 (finest aggregate) bin since the material in this bin strongly influences the amount of asphalt binder required in the mix.

4.5.5 Calibration

Normally it is the contractor's responsibility to calibrate the asphalt plant; however, agency inspectors are often required to observe and be aware of the procedures used to arrive at an aggregate combination that meets the JMF.

It is important to understand that the hot-bin percentages used to calculate batch weights are different than the cold-feed bin percentages. For the plant to produce the desired JMF specified in the mix design, the content of each hot bin must be analyzed. Once the plant is started and allowed to reach proper operating condition, a sample of aggregate is taken from each hot bin and analyzed. Once the gradation of material in each hot bin is determined, the exact percentage by weight from each hot bin to meet the design mix can be determined.

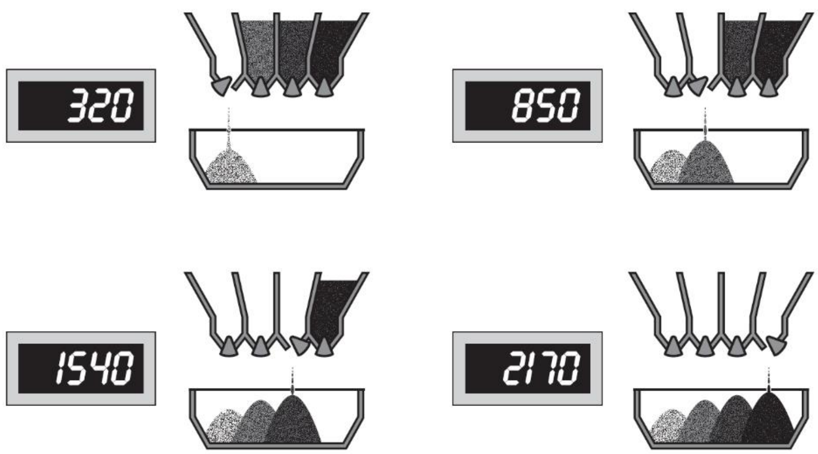
The hot-bin percentages used to calculate batch weights are different than the cold-feed bin percentages

It is possible for a batch plant to change mixture types from truckload to truckload. However, if the aggregate being supplied by the cold feed is not balanced with the aggregate discharge from the hot bins, the system can become unbalanced and result in one bin overflowing and another being starved of material. The smaller the hot bin size, the more easily it becomes unbalanced. The plant operator can only change the amount of hot-bin material being discharged into the mixer. This can be altered for a load or two (depending on the size of the hot bins), but when the plant becomes severely unbalanced, production will need to cease, and the plant cleared of excess aggregate in the bins to reestablish a balanced condition. Continual use of overflow chutes from the hot bins indicates the mixture being produced is not in sync with the gradation of the material being proportioned by the cold-feed system.

4.5.6 Drawing Material from the Hot Bins

The aggregate is drawn from each hot bin, one bin at a time, into a weigh hopper positioned above the actual mixing chamber or pugmill. The weigh hopper is continuously weighed, and the contribution of each hot bin is accurately determined for each batch of mix produced.

Usually, the coarsest aggregate is drawn (or pulled) first, the intermediate size aggregates next, and the finest aggregate last. This system allows the most efficient utilization of the available volume in the weigh hopper since the finer aggregates will partially penetrate the voids in the coarser aggregates. This information is normally entered into a computer that controls the opening and closing of the bins to obtain the correct amount of aggregate from each hot bin. Figure 37 illustrates how the cumulative scale settings are used to control the weight of aggregate drawn from each bin.

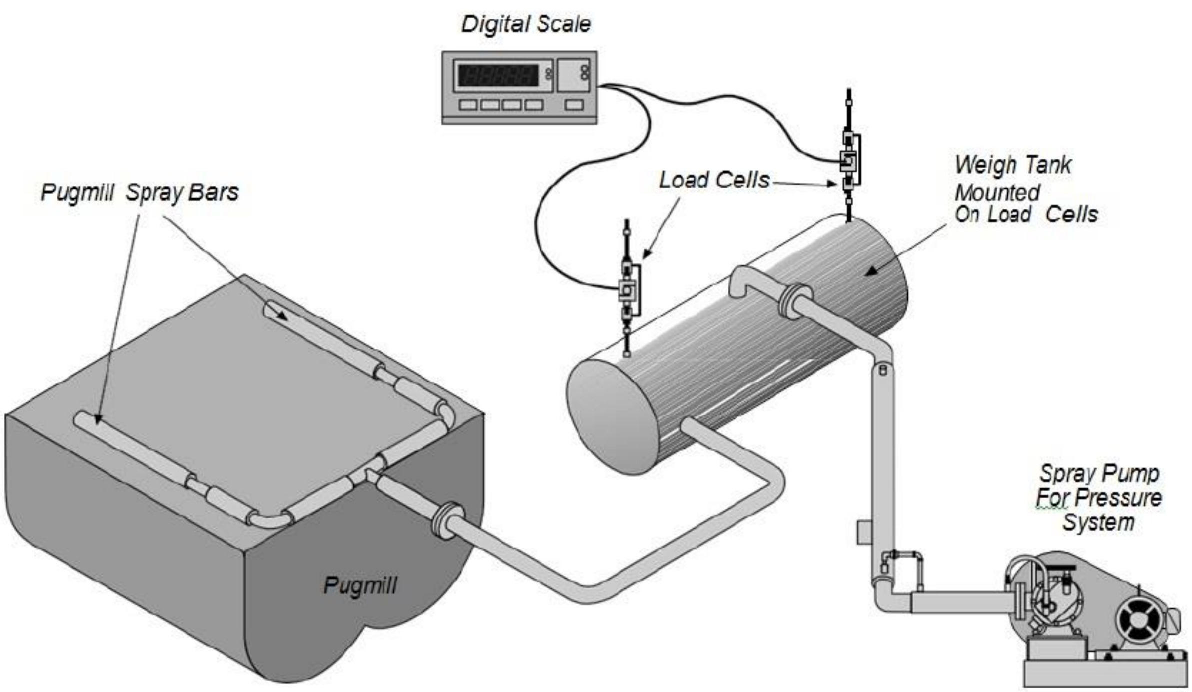


Source: Asphalt Institute

Figure 37. Cumulative Hot-Bin Batching

4.5.7 Introducing the Asphalt Binder

From the weigh hopper, the aggregate is deposited into the plant's pugmill (mixing chamber), where it is blended with the proper proportion of asphalt binder. In a typical plant system, the binder is weighed separately in weigh buckets—which are enclosed, heated, and sealed units—before being introduced into the pugmill. When the weight of asphalt binder in the bucket reaches a predetermined level, a valve in the delivery line closes to prevent the excess binder from being discharged into the bucket. The binder is then pumped through spray bars into the pugmill (see Figure 38).



Asphalt cement is weighted separately in a load cell-mounted weigh tank.

Source: Asphalt Institute

Figure 38. Batch Plant Binder Supply System

4.5.8 Pugmill Mixing

Once the batching of aggregate and asphalt binder is completed, the aggregate is transferred to a mixing chamber, called a pugmill (shown in Figure 39), which is located immediately below the weigh hopper.

Typical batch plants use a twin-shaft pugmill, which consists of a mixing chamber with two horizontal shafts, on which several cross arms are mounted. Pugmills are lined with sacrificial steel wear plates to absorb the scouring effect of mixing hard, angular aggregate particles.

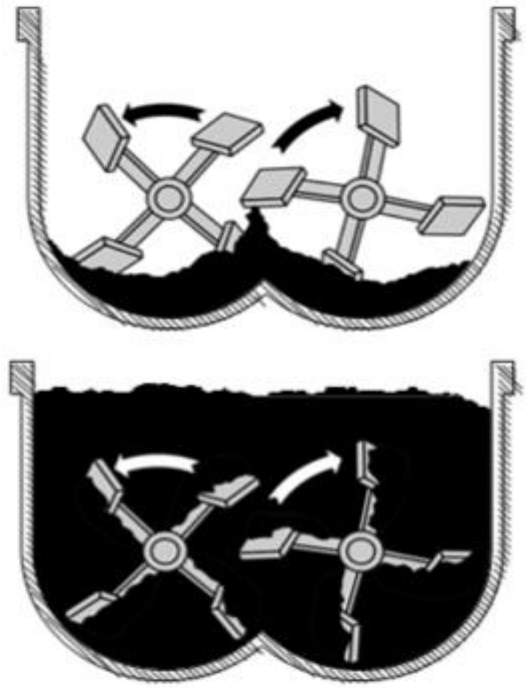
Source:Asphalt Institute

Figure 39. Batch Plant Pugmill

At the end of each cross arm is a metal plate, commonly called a mixing paddle. These paddles must be adjusted to avoid dead zones in the pugmill. Dead zones are areas where the materials are not properly agitated. To avoid this situation, the paddles should be adjusted so that the clearance between the paddle tips and the mixer liner is less than one-half the maximum size aggregate used in the mix. Worn or broken paddles should be replaced as soon as possible.

If the pugmill is overfilled or underfilled, nonuniform mixing will occur (see Figure 40). With too little material in the pugmill, the paddles are not able to adequately mix the material. If the pugmill is overloaded, part of the material will tend to float on the top of the batch and not be thoroughly mixed. These situations can be avoided by following the manufacturer's rated batch size. Normally the manufacturer's rating is based on a percentage of the pugmill live zone. This live zone is the net volume of the inside of the pugmill below a line extending across the top arc of the mixing paddles. The volume of the shafts, cross arms, paddles, and liner is not included in this volume. In most cases, the maximum operating efficiency of a pugmill is achieved when the paddle tips are barely visible at the surface of the material during mixing.

If the pugmill is overfilled or underfilled, nonuniform mixing will occur.



Source: Asphalt Institute

Figure 40. Incorrect Pugmill Operation

The complete mixing cycle is the blending of asphalt binder, aggregates, and mineral filler to produce mix. The length of time between the opening of the weigh-box gate and the opening of the pugmill discharge gate is referred to as the batch mixing time. The batch time typically consists of two stages: a dry mixing stage and a wet mixing stage. The dry mixing stage is a short portion of the batch time used (10 seconds or less) to mix the aggregates before introducing the binder. The wet mixing stage is the mixing time after the binder has been introduced into the mix. The total batch mixing time must be long enough to produce a homogenous mixture of evenly distributed and uniformly coated aggregate particles. To monitor batch mixing time, most job specifications require the use of some type of timing device.

The total batch mixing time must be long enough to produce a homogenous mixture of evenly distributed and uniformly coated aggregate particles.

Mixing time may be set within specification limits for each mix in any given plant by the procedure described in AASHTO T 195 or ASTM D2489, Determining Degree of Particle Coating of Bituminous-Aggregate Mixtures. This system bases the degree of mixing on the percentage of coarse particles that are 100 percent coated with asphalt binder and correlates it with mixing time. Only coarse particles are used in this procedure because they are the last to be coated in the mixing process.

4.5.9 Batch Plant Automation

A batch plant control room (shown in Figure 41) typically has the following plant control areas:

- A master motor control console with start/stop switches for all plant motors, which are interlocked for safety and plant protection.
- A computer system that controls the motor starts and stops in a pre-planned and programmed sequence so they cannot be started unless previous conditions are met, i.e., the main conveyor belt cannot be started unless the dryer drum is turning, or the burner cannot fire up unless the exhaust fan is running.
- A burner control console with start/stop switches, increase/decrease switches, and the safety circuits required for the burner.
- A cold-feed control console with start/stop switches and increase/decrease switches to control the feed from individual cold bins to the dryer. Many cold-feed control consoles have manual/automatic selector switches that allow the operator to control the feed from each bin manually or to recall a cold-feed mix formula from memory, select the desired production rate, and automatically feed the dryer to match the batch cycle requirements. A separate computer is sometimes found dedicated to this type of cold feed automation.
- A computerized batch automation that resides in a batch control console.
- A draft control and air emission-control console that houses controls for the exhaust fan, dryer draft, and air emission-control equipment.
- Mineral filler, baghouse fines return, hydrated lime control, or other additive control panels, if that equipment is required for the project.

Source: NAPA

Figure 41. Batch Plant Control Room

4.5.10 Recycling with a Batch Plant

All recycling methods in batch plants utilize conductive heat transfer instead of convective heat transfer. Conductive heat transfer is accomplished by mixing cold recycled material with hot aggregate. Convective heat transfer is accomplished by exposing cold aggregate to hot gases. In batch plants, regardless of the recycling method used, superheated hot virgin aggregate is used to heat the cold, moist RAP. A brief discussion of common batch plant recycling and heat transfer methods is described below.

4.5.10.1 Weigh-Box Recycling Technique

With the weigh-box method of recycling, cold (unheated), moist RAP is added to the weigh hopper, where the batch controller weighs it as an additional aggregate material. The feed bin for the RAP and the elevated conveyor that is required to reach the weigh hopper typically have large motors and pneumatic clutches with brakes so they can be started and stopped instantly. This facilitates feeding just the right amount of RAP into the weigh box.

The RAP is then mixed with the superheated virgin aggregates in the weigh hopper. Conductive heat transfer occurs in the weigh hopper and the pugmill throughout the dry mixing stage. During the heat transfer process, the moisture in the RAP generates a significant amount of steam. The pugmill and weigh hopper area must be enclosed and vented to the emission-control system to control this instantaneously large volume of steam and dust.

While recycled mixes with up to 50 percent RAP content can theoretically be produced with this method, in day-to-day practical field conditions, it is rare to see RAP percentages higher than 25 percent with the weigh-box heat transfer method. This is because RAP moisture contents typically run in the 3- to 5-percent range, and elevating the aggregate temperature beyond 600 °F (315 °C) is difficult due to dryer limitations. Also, dryer exit gas temperatures can impose a practical limit if baghouses are used in the plant. The filter fabric used in the bags of the baghouse has temperature limitations, and a massive increase in fuel consumption is required to obtain the required aggregate temperature.

4.5.10.2 Pugmill Recycling Technique with Separate RAP Weigh Hopper

This method of recycling uses a separate weigh hopper for RAP, which empties its batch component into the pugmill. Typically, a high-speed slinger conveyor is used to convey RAP from the RAP weigh hopper to the pugmill, although a chute or high-speed screw conveyor can also be used. The same heat transfer, steam release, and practical limits apply to this approach as apply to the weigh-box method of batch plant recycling. By adding an additional weigh hopper to the batch facility, the RAP is conveyed into and weighed in its own hopper while the virgin asphalt binder and virgin aggregates are being weighed separately, which slightly reduces the batching time.

4.5.10.3 Bucket Elevator Recycling Technique

This approach to batch plant recycling eliminates the steam release typical of the mixer and pugmill heat transfer methods. In the bucket elevator recycling method, cold, moist RAP is mixed with the superheated virgin aggregate as the aggregate exits the dryer and enters the bucket elevator.

The continuous steam release resulting from conductive heat transfer occurs in the buckets as the virgin aggregate/RAP mixture makes its way to the screen deck. The steam released from the RAP is carried away by the fugitive dust ductwork already fitted to the bucket elevator and screen deck.

Because the RAP is being continually blended with the virgin aggregate, belt scales are used on both the conveyor feeding virgin aggregate into the dryer and the conveyor feeding RAP into the bucket elevator. The scales ensure the maintenance of a proper ratio of RAP to virgin aggregate.

Gradation control for mix production is accomplished in one of two ways, and both are different from that in a batching facility producing completely virgin mixes. In the first method, the RAP and virgin aggregate are both screened together over the screen deck, and the composite mixture is separated into the different hot bins in the tower. Each hot bin is sampled for asphalt binder content and gradation. The binder content of the material must be determined in each hot bin. Gradations of the hot-bin samples must then be evaluated, and individual hot-bin percentages calculated based on the recovered gradations from each supply bin. The asphalt binder content reclaimed from the RAP is then determined based on the extraction results, and the new liquid binder requirement for each batch is established. It must be assumed that the RAP is consistent not only in the recovered stone gradation but also in the asphalt binder content and particle size of the RAP itself.

This approach to mix production is more difficult than with a weigh-box or pugmill injection method; therefore, a second method, which utilizes a screen bypass, is frequently used. With this method, the only gradation control is at the cold-feed bins feeding the dryer, same as with drum-mix style plants. The virgin aggregate/RAP mixture is stored in a single hot bin in the tower and then weighed up as one pre-blended mixture in the aggregate weigh hopper. The mixture is diverted into one bin, typically the Number 1 bin, using a chute from the hot elevator to bypass the screen deck.

Many agencies allow this type of approach but usually also require belt feeders with variable-speed drives, speed displays, and total and proportional control over each feed bin. This is the same generic requirement used for feeder gradation control on drum mixer-style plants. Because the trip up the elevator is relatively short in duration, and because the RAP must be dry before it passes over the screens (or is stored in the combined RAP/aggregate bin), RAP percentages rarely run over 20 percent with this approach.

4.5.10.4 Introducing RAP into Heat Transfer Chamber or Dryer

This approach is essentially the same as the standard bucket elevator method, but RAP is added to the combustion area of the dryer and is shielded from the flame by a shroud or by extending the burner tube. Another difference is that steam release also begins in the dryer shell. An advantage of this process is that the virgin aggregate and RAP are already combined as they exit the dryer and enter the elevator.

Higher percentages of RAP can be achieved (25 to 35 percent is typical) than with standard bucket elevator methods because the RAP has a longer period for heat transfer to be completed. All other aspects of the standard bucket elevator method apply to this recycling approach.

4.6 DRUM AND CONTINUOUS PLANTS

Drum mixing simplifies the process of producing asphalt mixtures by eliminating the need for several major mechanical components when compared to batch plants. Operationally, the major difference between drum-mix plants and batch plants is that in drum-mix plants, the aggregate is not only dried and heated within the drum but also continuously mixed with the asphalt binder.

4.6.1 Operations

The mixing drum, or drum mixer, is where this type of plant gets its name. Because there are no gradation screens, hot bins, weigh hoppers, or pugmills in a drum-mix plant, aggregate gradation is totally controlled by the aggregate, RAP, and mineral filler cold-feed systems.

4.6.2 Drum-Mix Plant Operations and Components

The components of the drum-mix plant are shown in Figure 42.

Source: Astec Industries

Figure 42. Typical Drum Mixer Layout

Individual aggregates are deposited in the cold-feed bins, from which they are fed individually in designed proportions onto a cold-feed conveyor. An automatic aggregate weighing system monitors the amount of aggregate flowing into the drum mixer. The weighing system is interlocked with the controls on the asphalt binder storage pump and a continuous metering system, which draws binder from a storage tank and introduces it into the drum. The asphalt binder and aggregate are thoroughly blended while rotating in the drum. A dust collection system captures excess dust escaping from the drum and mixing chamber. From the drum, the mix is elevated by a metal slat conveyor to the top of a surge bin or storage silo where it stays until loaded in a truck, as described in Section 4.9.

4.6.3 Aggregate Feed

In a drum-mix plant, mix gradation and uniformity depend mostly on the cold-feed system. Hence, it is essential the aggregate be correctly proportioned prior to its entry into the dryer/mixing drum. The most efficient way to accomplish this is with a multiple-bin cold-feed system equipped with precision belt feeders for the control of each aggregate.

Under each bin is a variable-speed belt feeder, which drops the metered aggregate onto a main collection belt that runs under all the cold-feed bins. The collection belt then transports the proportioned aggregate material to the main cold-feed conveyor belt, which carries the aggregate to the drum mixer.

Most cold-feed conveyor belts are equipped with provisions to conveniently obtain representative samples of the full flow of material for gradation determination or for calibration. Such devices are usually installed at the end of the belt just prior to entry into the drum mixer. Devices are available that can be installed on the main belt to divert or collect accurate samples without stopping the belt (see Figure 43).

Source: Asphalt Institute

Figure 43. Conveyor Belt Sampling Device

Drum-mix plants require a continuous weighing system on the main cold-feed conveyor belt. As aggregate passes over the scale, they are continuously weighed and monitored by the hot-plant control system. No material should be diverted from or added to the conveyor belt after it passes the belt scale.

It is important to understand that the aggregate is weighed on the belt before drying. The total moisture content of the material entering the plant must be known so the asphalt pump can meter in the correct quantity of asphalt binder.

The moisture content of the cold-feed aggregate should be checked before beginning each day's operation and again around mid-day. If the moisture content is believed to vary during the day, it should be checked more frequently. Some plants have moisture sensing devices that can sense changes in moisture content, coupled with the control system that compensates for moisture changes automatically.

4.6.4 Asphalt Binder Control with a Drum Mixer

Asphalt binder control in a drum mixer operation is done continuously. The asphalt binder is measured through a calibrated meter relative to aggregate flow after it has been corrected for moisture content and then combined with the aggregate in the mixing area of the drum.

The asphalt binder content is interlocked to the aggregate flow. The monitoring system notes changes in the weight of aggregate over the belt scale and adjusts the asphalt binder flow to compensate for these changes.

The binder supply line runs continuously to keep pace with the aggregate weighbridge to deliver the proper ratio of binder in the mixing chamber. To confirm the metering system output is correct requires frequent verification of calibration or recalibration.

The asphalt binder is measured through a calibrated meter relative to aggregate flow after it has been corrected for moisture content and then combined with the aggregate in the mixing area of the drum.

Taking a drum-mix plant offline to perform a calibration test can be very costly and time-consuming. Inline calibration tanks (see Figure 44) are an efficient way to calibrate asphalt metering systems without the downtime and risk associated with using the conventional tanker truck method.

Source: ALmix Industries

Figure 44. Stationary Asphalt Binder Calibration Tank

4.6.5 Aggregate Flow

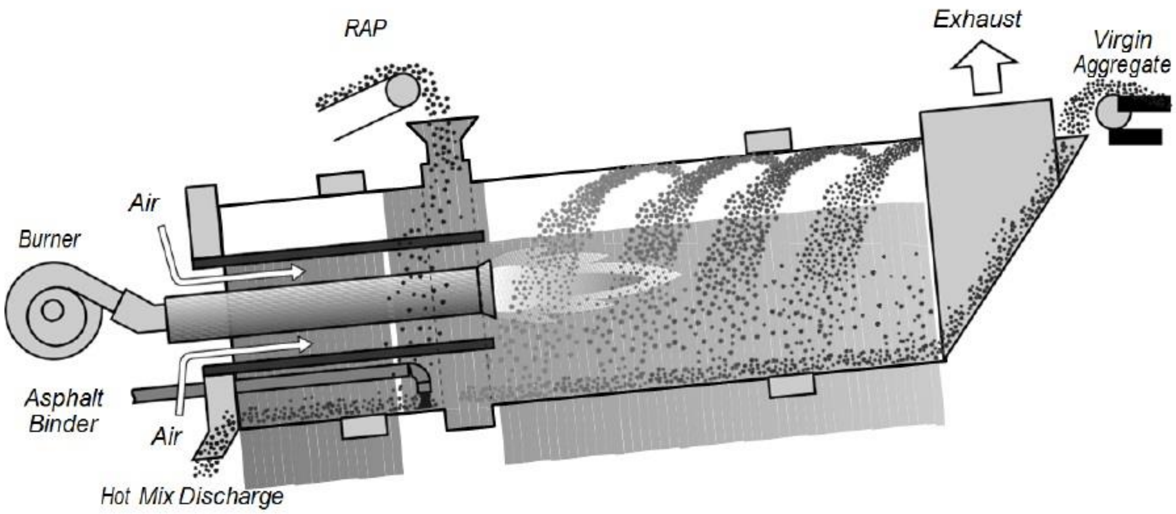
Aggregate enters the primary zone of the drum, where the burner dries and heats it. The aggregate then moves to a secondary zone, where asphalt binder is added and the two are thoroughly blended. The mixture of hot asphalt binder and the moisture released from the aggregate produces a foaming mass that traps much of the fine material (dust) and coats the larger particles. It is important that the aggregate in the drum not only rotate with the revolving motion of the drum but also spread out sufficiently to make heating and drying of all particles quick and efficient. Drum mixers are equipped with specially designed flights to create a "veil" or curtain of aggregate at appropriate parts of the drum for obtaining maximum drying and minimizing exhaust gas temperatures.

4.6.6 Binder Flow

Asphalt binder is pumped from the binder storage tank and enters the mixing drum at the appropriate point in accordance with the plant design. When the asphalt binder is added into the drum, it is pumped into the drum's lower end at about the same location that the mineral filler and/or baghouse fines are introduced. Adding asphalt binder and dust in close proximity allows the binder to trap a good portion of the fines and coat them before they are picked up by the high-velocity exhaust gas stream. The exhaust gases are passed through a dust collection system where any of the remaining dust is trapped and removed to meet emission requirements, as discussed in Section 4.7.

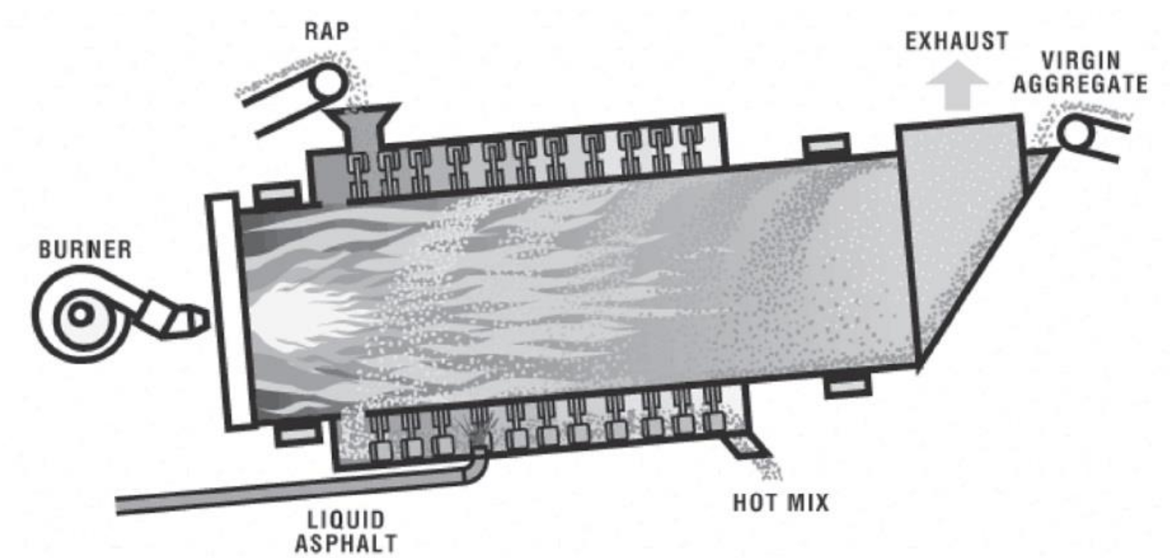
4.6.7 Recycling with a Drum-Mix Plant

The introduction of RAP into a drum-mixing operation is quite different from the methods used in a batch plant. To minimize RAP binder damage and emission-control problems, it is necessary to add RAP via a split-feed system. In a split-feed system, new aggregate enters the drum in one location, and the RAP enters the system downstream, where it is not in direct contact with the burner flame. Figure 45, Figure 46, and Figure 47 illustrate typical RAP entry points for several types of drum-mix plants.



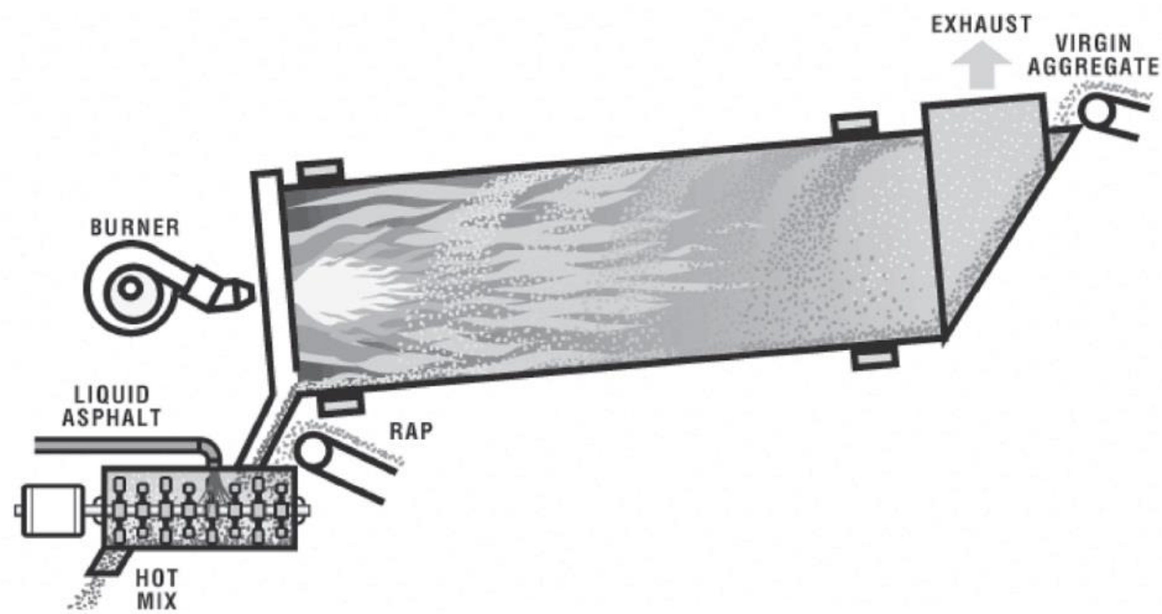
Source: Asphalt Institute

Figure 45. Counterflow Drum-Mix Plant



Source: Asphalt Institute

Figure 46. Unitized (Double-Barrel) Drum-Mix Plant



Source: Asphalt Institute

Figure 47. Counterflow Dryer with Separate Continuous Mixer

As mentioned in Section 4.5.10 regarding RAP in batch plants, a drum mixer also requires superheated virgin aggregate to transfer heat into the RAP and remove any moisture present. These conditions can present significant obstacles that can limit the maximum rate and amount of RAP mix that can be produced.

Normally, if 20 percent or less RAP is incorporated into a recycled mix and a split-feed system is used, minimal emission-control issues arise. As the percentage of RAP rises and the moisture content of the RAP increases, there is a greater potential for heat transfer and emission problems. A typical drum-mix plant requires carefully controlled production conditions to incorporate over 50 percent RAP in a recycled mix without major emissions and heat transfer issues.

4.7 EMISSION-CONTROL SYSTEM

The high-speed air flowing through the dryer that carries away exhaust gases also removes small, dust-sized particles (smaller than 0.075 mm) from the aggregate blend. Because this dust is part of the mixture design, it must be captured and returned to the mix being produced. Removing the dust from the exhaust stream with high-efficiency emission-control equipment prevents plant-produced dust emissions from exceeding local, State, and Federal air quality limits.

4.7.1 Basics of Dust Collection

The amount of airborne dust is a function of the material being dried, the velocity of the air in the dryer, and the location of the binder injection point that captures the smaller particles.

The emission-control system on most asphalt plant facilities generally consists of primary and secondary dust collectors. The dust collectors are situated downstream of the dryer and filter the air that exits the drum.

4.7.2 Primary Collectors

The purpose of the primary collector is to collect and remove the larger dust particles contained in the exhaust gas stream. The typical primary collectors are called the knockout box or the cyclone collector.

The knockout box is the simplest type of primary collector (see Figure 48). The exhaust gas flows through an expanded chamber, causing the airspeed to decrease. The chamber also contains plates to cause a change in the direction of airflow. The speed reduction and direction changes cause the larger dust particles to drop out of the airstream to the bottom of the box, where they are reintroduced in the dryer.

Source: Gencor Industries

Figure 48. Knockout Box Returning Coarse Fines to the Dryer

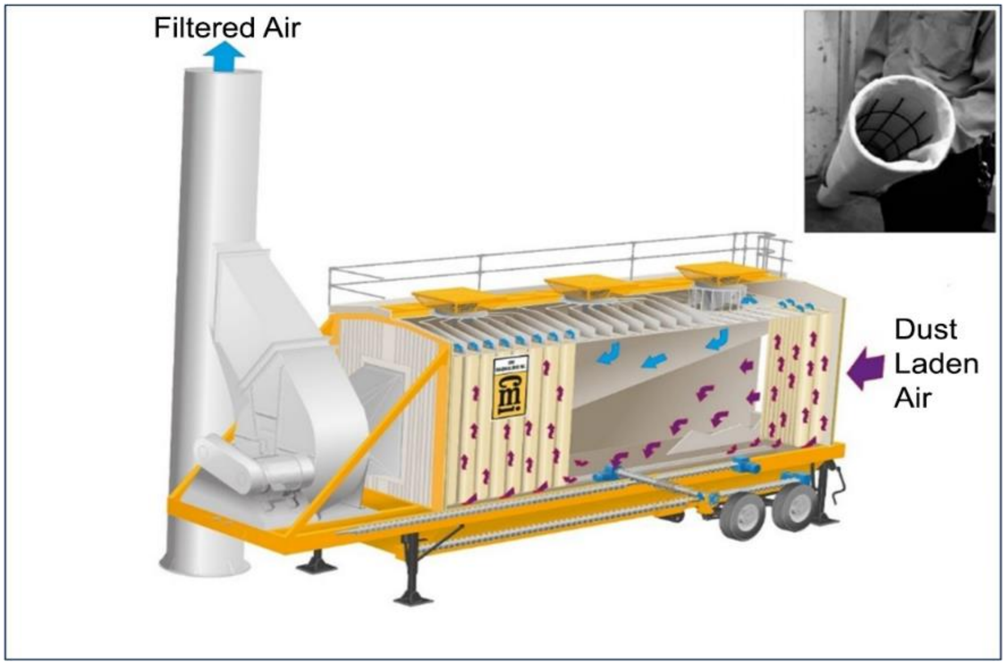
Cyclone collectors are more efficient than knockout boxes and operate on the principle of centrifugal separation. The exhaust stream circulates inside the collector (shown in Figure 49), and particles hit the outside wall and drop to the bottom of the cyclone. Speed and directional changes also assist as the exhaust is discharged through the top of the collector. The fines collected at the bottom of the cyclone are picked up by a dust-return auger and may be returned to the plant or removed.

Source: Asphalt Institute

Figure 49. Cyclone Collector Returning Coarse Fines to the Dryer

4.7.3 Secondary Collectors

The purpose of the secondary collector is to filter out the finest dust particles. The most common type of secondary collector is referred to as a baghouse. A baghouse (see Figure 50) is a large metal housing containing hundreds of heat-resistant fabric filter bags. A typical unit may contain as many as 800 bags. It operates on a principle similar to a vacuum cleaner. The dust-laden exhaust gases are pulled through the filter bags supported on long wire cages to prevent collapse. The dust is trapped on the outside of the bag as the air passes through the filter cloth to the clean air side, effectively cleaning all the dust from the exhaust stream. When properly operated, baghouses can be very efficient, removing over 99 percent of the dust from the dryer exhaust.



Source: CMI Roadbuilding, Inc.

Figure 50. Baghouse Dust Collector

Dust continuously collects on the outside of the fabric filter while the dryer is in operation. Periodically, a pulse of air is passed through the bag in the opposite direction, causing the bag to flex in reverse. The collected dust drops off the bag and falls to the bottom hopper of the baghouse. This collected dust can either be returned to the mix production process or removed. When dust is returned to the plant process, certain operational practices are important to keep the dust return uniform and consistent. Non-uniform introduction of baghouse fines back to the plant can cause erratic volumetric test results. Refer to Section 4.3.3.

4.8 TEMPORARY MIXTURE STORAGE

To prevent plant shutdowns due to interruptions in paving operations or shortages of haul trucks, most asphalt plants are equipped with either one or more storage silo(s) or a surge bin for temporary storage of asphalt mix. As the fresh mix exits the plant, it is deposited onto an enclosed drag-slat type of conveyor that takes it to the top of the storage silo or bin, where it enters the bin and is held until discharged into trucks from the bottom.

Insulated storage silos (shown in Figure 51), with capacities as high as several hundred tons, can store mixture for several hours. Extended storage times will impact the volumetric properties of the mix and may prematurely age the binder. For this reason, most agencies have specifications that limit the length of time a mix can be held in storage.

Source: Duval Asphalt

Figure 51. Insulated Storage Silos

Portable drum-mix plants equipped with self-erecting storage structures are most frequently used at remote or temporary plant sites. These non-insulated surge bins (shown in Figure 52 and Figure 53) are smaller and can store mix only for relatively short periods of time.

Source: Asphalt Institute

Figure 52. Portable Surge Bin

Source: Asphalt Institute

Figure 53. Portable Storage Silo

Silos work well if certain precautions are followed, but they can be a major source of segregation if the mix is not introduced into the silo properly. Mix should never be allowed to flow continuously into a storage silo; particle size differences and momentum will cause the mix to segregate. Typically, a small batcher (or holding bin) is placed under the drag-slat conveyor with its opening directly aligned on the centerline of the silo. Once a pre-set amount is accumulated, gates in the bottom of the batcher automatically cycle fully open and fully closed, releasing the mix in a single mass (see Figure 54). During continuous operation, the batcher should never completely cycle empty, and the mix level in the storage silo should be maintained between one-third and two-thirds of the silo capacity to minimize segregation.

Source: NAPA

Figure 54. Silo Batcher

4.9 WEIGHING AND LOADOUT

From the temporary storage silo, asphalt mix is deposited into trucks ready to be hauled to paving sites. (See Chapter 6 for truck loading procedures.) The quantity of mixture delivered from plant to paving site can be determined by any of three methods:

- Using a batch plant's automatic recording system.
    - The system records the accumulated weight of individual batches dropped directly into a truck from the pugmill. The internal plant scales should be calibrated and certified to use this method successfully.
- Using load cells attached to the support legs of a storage bin.
    - The load cells collectively accumulate the subtraction of weight from the bin as a truck is loaded.
    - Load cells are calibrated and certified as accurate.
- Weighing loaded trucks on scales.
    - The scales directly indicate the tare weight of the truck and net weight of the mix.
    - The scales should be level, horizontal, and of sufficient length to weigh all truck axles at one time. The most common type of truck scale used is the beam scale (see Figure 55).

Source: NAPA

Figure 55. Truck Scale Under Storage Bins

The accuracy of any truck scale or weigh system should be checked periodically. Random truckloads selected throughout production and weighed on an alternative, certified scale provide for a good check on the accuracy and calibration of the weigh system being used.

> *The accuracy of any truck scale or weigh system should be checked periodically.*

4.10 SAFETY

Personnel working at an asphalt plant must always be safety-conscious and on the alert for potential dangers to personnel and property. Safety considerations cannot be overemphasized.

Safety considerations at an asphalt plant include the following:

- Dust is not only a threat to lungs and eyes, but it may contribute to poor visibility, especially when trucks, front-end loaders, or other equipment are in use around the stockpiles or cold bins. Reduced visibility in work traffic is a prime cause of accidents.
- Noise can be a significant hazard. It is harmful to hearing and can distract workers' awareness of moving equipment or other dangers.
- Moving belts should be a constant concern, as should belts to motors and sprockets and chain drives. All pulleys, belts, and drive mechanisms should be

covered or otherwise protected. Loose clothing that can get caught in machinery should never be worn at an asphalt plant.

- Good housekeeping is essential for plant safety. The plant and yard should be kept free of debris, pipes, hoses, or other obstacles that can cause a trip and fall hazard.
- High-voltage lines are required to distribute electrical power to all the major plant components. Power lines should be properly mounted or buried and protected. Any loose connections, frayed insulation, or improperly grounded equipment should be repaired immediately.
- Plant workers should not work on or near stockpiles or cold-feed bins while the plant is in operation. With limited sightlines, loader operators who are focused on stockpile management and keeping cold-feed bins properly charged can easily overlook a person on the ground. Equipment training regarding blind spots is encouraged.
- Burner flames and high temperatures around plant dryers are obvious hazards. Installing control valves that can be operated from a safe distance on all fuel lines helps reduce the danger. Flame safety devices also should be installed on all fuel lines. Smoking should not be permitted near asphalt or fuel storage tanks. Frequent checks should be made for leaks in oil heating lines and jacketing on the asphalt distribution lines. Safety valves should be installed and be in good working order on all lines. Screens, barrier guards, and shields should be installed as protection from steam, hot asphalt, hot surfaces, and similar dangers.
- For workers around hot liquid asphalt binder, all shirts should be long-sleeved, completely buttoned, worn tucked in, and cuffs buttoned at the wrist. Gloves with gauntlets that extend up onto the arm should fit loosely so that they can be flipped off easily if accidentally covered with hot asphalt. Pants without cuffs should extend over boot tops.
- Workers should use extreme care when moving around plant components, observing the screens and hot bins, and collecting samples. There should be covered or protected ladders or stairways to provide safe access to all parts of the plant. All stairs and platforms should be provided with secure handrails. All workers around the plant site should always wear a hardhat.
- Traffic patterns should be planned with both safety and convenience in mind. Trucks entering the plant to pick up a load of hot mix should not have to cross the path of loaded trucks leaving the plant. In addition, trucks should not have to back up.

4.11 TROUBLESHOOTING AND CHECKLISTS

A daily summary report of all plant activities should be kept. This should include the results of all tests performed during the day and a tabulation of the amounts of material received and used during production.

The following checklists can be used as needed by plant operation and QC personnel to determine plant readiness for production:

PLANT CHECKLISTS

Checklist for material handling and storage

- ❑ Do the aggregates meet specifications?
- ❑ Are the proper sizes being produced?
- ❑ Is the aggregate storage satisfactory?
- ❑ Are the stockpiles separated properly?
- ❑ Are the stockpiles constructed properly?
- ❑ Is the stockpiled aggregate handled correctly?
- ❑ Is segregation being controlled?
- ❑ Is the mineral filler or hydrated lime being kept dry?

Checklist for cold feed

- ❑ Does the cold-feed setup comply with specifications?
- ❑ Do the cold-feed bins contain properly sized aggregates?
- ❑ Are the cold-feed bins charged properly?
- ❑ Are the cold-feed bins flowing (without bridging) properly?
- ❑ Do the cold aggregate feeders perform satisfactorily?
- ❑ Are the cold aggregate feeder gates set correctly?
- ❑ Are all cold aggregates being fed uniformly?
- ❑ Are the cold aggregate feeders calibrated?

Checklist for asphalt heating, circulating, and temperature of mixture

- ❑ Is the asphalt uniformly heated to the temperature specified?
- ❑ Have all the lines been checked for leaks?
- ❑ Are mix production temperatures within specifications?
- ❑ Has the binder feed been calibrated?

Checklist for drum-mix plant

- ❑ Have the aggregate feeds been calibrated?
- ❑ Has the liquid binder feed been calibrated?
- ❑ Are the aggregate and binder feeds interlocked?
- ❑ Are the plant components in good condition and adjusted?
- ❑ Is the binder at the proper temperature when introduced into the drum?
- ❑ Does the mix appear to be uniformly coated?
- ❑ Is water dripping from the bottom of the storage silo?
- ❑ Do the scales comply with specifications?
- ❑ Have the scales been calibrated?
- ❑ Have the scales been checked for tolerance?

Checklist for batch plant

- ❑ Do the scales comply with specifications?
- ❑ Have the scales been calibrated?
- ❑ Have the scales been checked for tolerance?
- ❑ Does the binder bucket tare properly?
- ❑ Does the weigh box hang free?
- ❑ Are the mixer parts in good condition and adjustment?
- ❑ Is the proper size batch being mixed?
- ❑ Are the bin draws in proper sequence?
- ❑ Is binder distributed uniformly along the length and width of the pugmill?
- ❑ Are the aggregates and binder at proper temperatures?
- ❑ Do any valves or gates leak?
- ❑ Is the mixing time adequate?
- ❑ Are the weight points set properly for batch weights?

- ❑ Are the mixer shafts revolving at proper speed?
- ❑ Are the screen capacities sufficient to handle the feed from the dryer?
- ❑ Are the screens clean?
- ❑ Are the screens worn or broken?
- ❑ Is the screen carryover irregular or excessive?
- ❑ Are the hot-bin partitions solid without signs of excessive wear?
- ❑ Are the overflow chutes free-flowing?
- ❑ Is the amount of needed material in each bin being maintained?
- ❑ Is the access for sampling adequate?

Checklist for dryer and dust collector

- ❑ Does the dryer and dust collector comply with specifications?
- ❑ Is the aggregate properly dried?
- ❑ Are the aggregates at the proper temperature?
- ❑ Are the dryer components in balance?
- ❑ Is the dryer production in balance with other plant components?
- ❑ Are temperature-measuring devices installed correctly and calibrated?
- ❑ Are the collected fines wasted, or are they fed back to the mixing chamber?
- ❑ Is the dust-return system in balance with the dryer?

Checklist for storage silos

- ❑ Does the silo contain a batcher?
- ❑ Are the baffles or other devices to prevent segregation working properly?
- ❑ Is the silo discharge opening properly configured to prevent segregation?
- ❑ Does the discharge gate open and close efficiently?

Checklist for sampling and testing

- ❑ Are sufficient samples being taken to comply with the sampling plan?

- ❑ Are the samples representative of the material?
- ❑ Are all the tests being conducted properly?
- ❑ Are the test results available soon enough to be effective?
- ❑ Are the records complete and up-to-date?

Checklist for miscellaneous responsibilities

- ❑ Have the truck beds been inspected?
- ❑ Are the truck beds drained after release agent application?
- ❑ Is the release agent on the agency's Approved Product List (APL)?
- ❑ Do the trucks meet specification requirements?
- ❑ Are the trucks equipped with tarpaulins or covers?
- ❑ Does the mix have a uniform appearance?
- ❑ Does the mix satisfy the placing requirements?
- ❑ Have all personnel been properly instructed?
- ❑ Are safety measures being observed?

5. Surface Preparation

5.1 INTRODUCTION

The performance of an asphalt mixture under traffic is directly related to the condition of the surface on which the pavement layers are placed. For a full-depth asphalt pavement, if the condition of the subgrade soil is poor (particularly if it is wet and rutted under the haul trucks), the ultimate life of the roadway may be significantly reduced. For asphalt layers placed on top of a new, untreated granular base course, that base material should be stable, the surface should be dry, and the base should not be distorted by the trucks carrying mix to the paver. For mix laid on top of existing asphalt layers, that surface should be properly prepared, with all distresses and defects repaired and the surface cleaned. A tack coat should also be used to ensure a bond between the existing pavement surface and the new asphalt overlay. When asphalt mix is placed over a Portland cement concrete (PCC) pavement, the PCC surface should be properly prepared and a tack coat applied.

The performance of an asphalt mixture under traffic is directly related to the condition of the surface on which the pavement layers are placed.

5.2 BASE PREPARATION FOR NEW ASPHALT PAVEMENTS

5.2.1 Subgrade Soil

If the asphalt pavement is to be placed directly on the subgrade soil, that subgrade material should meet all applicable requirements for moisture content, density, structural support, grade, elevation, and smoothness. After the subgrade soil is determined to be ready for paving, and before paving is allowed to commence, the subgrade should be proof rolled to ensure it will be able to support the weight of the haul traffic. Proof rolling is a process where compacted soil is checked for soft areas in order to supply a balanced support system for the structure of the pavement. The subgrade must provide a firm foundation before the application of the prime coat or the asphalt paving begins. If distortion of the subgrade soil occurs during the paving operation, placement of the mix should be stopped until the condition of the soil can be corrected.

5.2.2 Granular Base Course

If the asphalt layer is to be constructed directly on a new or existing untreated granular base layer, that base material should be placed to grade and profile and meet all the requirements for moisture content, density, structural strength, and smoothness. Proof rolling should be done, however, on top of the granular base material, and the amount of deflection of the base and the amount of indentation of the truck wheels in the granular base course material should be noted. If the base material is stable and dry and does not deflect and indent significantly under the wheels of a loaded tandem axle truck, placement of the prime coat or the new asphalt mix should be permitted to start. If the condition of the granular material is not satisfactory, the base course should be reworked or stabilized until it is in the proper condition for overlaying. Check with the owner agency for any specific requirements they may have for proof rolling.

5.2.3 Prime Coat

The prime coat acts as a temporary waterproofing layer that protects the subgrade soil as well as the base course. A prime coat helps maintain the prepared moisture content of the subgrade and base materials by preventing moisture from escaping while also helping to prevent these layers from absorbing excess moisture during rainfall before paving. Prime coats allow these layers to be used for light traffic on roadways, bind together any dust on the surface of these material layers, promote the bond, and prevent slippage between these layers and the new asphalt overlay. However, the main purpose of a prime coat is to protect the underlying materials from wet weather. If the underlying materials can be covered prior to the rainfall, then a prime coat may not be needed.

There is generally no need to place a prime coat of asphalt emulsion or cutback asphalt on the subgrade soil. This is especially true when the soil is a silty clay or clay material because the prime coat material cannot be absorbed into that subgrade material. The use of a prime coat on sandy subgrade soils is also questionable. If the sandy material displaces excessively under the wheels of the haul trucks, it should be stabilized with some type of binder material before paving to achieve the required load-bearing properties. In such cases, the application of a prime coat will generally not be enough to hold the sandy soil in place during paving operations. A prime coat should not be used as a substitute for proper preparation of the subgrade soil. When a prime coat is used, the prime coat material should be applied to the base course with a pressure distributor at least 48 hours before paving is to begin.

Historically, cutbacks have been the preferred prime coat material because of their superior penetrative qualities into the base. However, increased environmental restrictions on the use of cutback materials have led to their decreased availability and use. Industry has responded with the development of EAPs (emulsified asphalt primes) that improve an emulsion's ability to mimic cutbacks in terms of penetration and are more environmentally friendly than cutbacks.

An EAP penetrates more slowly and is applied at a lower rate. Unlike a cutback prime, EAPs are most successful when mixed into the base material by a motor grader or rotary-mixer type equipment. This mixing can be done at the time of final grading and rolling of the base material. Prime applications are done under the same general weather conditions as paving; however, for cutbacks to properly cure, 24 to 72 hours of favorable weather are required. Curing times depend greatly on the material and weather conditions.

The ideal prime rate is the amount of material that the aggregate base will absorb in a 24-hour period. Typical application rates for prime coats vary with the type of prime coat material used. When a medium-curing cutback—either an MC-30 or MC-70 as specified in AASHTO M 82—is used, the application rate ranges from 0.2 to 0.5 gal/yd^2 (0.9 to 2.3 L/m^2). When an EAP is used, application rates vary from 0.1 to 0.3 gal/yd^2/inch of scarification depth (0.5 to 1.4 L/m^2 per 25 mm of depth). Exact application rates are determined by the project engineer under the prevailing conditions at the time the work is done. If all the prime coat material is not completely absorbed, the excess should be blotted with sand or removed.

5.3 ASPHALT SURFACE PREPARATION FOR ASPHALT OVERLAYS

The degree of preparation needed for an existing asphalt pavement depends on the condition of that surface. At a minimum, failed areas should be removed and replaced, potholes properly patched, cracks cleaned out and sealed, and ruts filled in or, preferably, removed by cold milling.

5.3.1 Pavement Replacement and Patching

It is inadvisable to attempt to cover failed areas of an existing pavement with new overlay material. Removal and replacement should be carried out on all existing pavement areas where severe load-related distress has occurred. All asphalt mixtures and granular base materials that have failed should be excavated or cold milled and then either recycled or wasted. Subgrade distortion should be repaired by undercutting and replacement with suitable backfill material. Proper subsurface drainage should be installed as necessary. New granular base course material, a stabilized base course, or asphalt mix should be placed to bring the strength of the pavement structure in each failed area to the same level as the surrounding good pavement layers. If asphalt mix is used to patch a large area, it should be placed with a paver and compacted with one or more large rollers. Localized failed areas should be patched properly. Each area should be cut back to sound pavement and squared up, with the sides as vertical as possible, the loose material and water in the hole removed, a tack coat applied to the sides and bottom of the hole, the mix placed in the hole, and the new material adequately compacted, preferably with a roller (see Figure 56, Figure 57, and Figure 58). If the pothole is deeper than 4 inches (100 mm), the mix should be placed in more than one layer and each layer compacted properly. If the number of localized patches required is excessive, consideration should be given to full lane replacement, considering all economic and operational impacts.

It is inadvisable to attempt to cover failed areas of an existing pavement with new overlay material. Removal and replacement should be carried out on all existing pavement areas where severe load-related distress has occurred.

Source: Asphalt Institute

Figure 56. Existing Material Removed Prior to Patching

Source: Asphalt Institute

Figure 57. Material Placed in Localized Patch

Source: Asphalt Institute

Figure 58. Compaction of Patch

5.3.2 Crack Filling

Badly cracked pavement sections, especially those with pattern cracking (e.g., map or alligator), must be patched or replaced. The benefits of filling other cracks in the existing surface depend, in part, on the width of the cracks. If the cracks are narrow (less than 3/8 inches [10 mm] in width), it is doubtful that the crack-sealing material will enter the crack instead of pooling on the pavement surface. Such cracks should be widened, if desired, with a mechanical router before sealing is attempted. If wider cracks are present, they should be blown out with air and cleaned of debris. The crack-sealing material should be inserted when the cracks are clean and dry. The level of the filling material for the crack should be slightly lower than that of the surrounding pavement surface and should not spill over the top of the crack, where it could create a bump in the new pavement layer during the rolling process (see Figure 59). Previously overbanded cracks may require the aged sealant material to be heated and scrapped from the surface of the pavement prior to placing an overlay to prevent the same bump creation. If cracks are wider than 1 inch (25 mm), or if the pavement on either side of the crack is slumping, then a mastic sealing process is encouraged prior to overlay to promote a smoother finished surface.

Depending on the cause of the cracking, the amount of reflective cracking that occurs in an overlay can sometimes be reduced using a surface treatment (seal coat) on the existing pavement. If that pavement structure contains a great number of cracks, consideration may be given to applying a surface treatment instead of filling individual cracks. The cracks should be cleaned, if feasible, by being blown out with air. The surface treatment should be applied when the pavement surface is clean and dry and should consist of a single application of asphalt binder material (asphalt binder, cutback asphalt, or asphalt emulsion) and cover aggregate. While not too common, a slurry seal consisting of an asphalt emulsion, fine aggregate, and water may alternatively be used.

Source: U.S. Army Corps of Engineers

Figure 59. Bump Caused by Excessive Use of Crack Sealant

5.3.3 Leveling Courses

Common practice in the past has been to place a leveling course on the existing pavement surface to improve the rideability of the pavement structure. This leveling course, sometimes called a wedge and level course or a scratch course, is designed to fill in the low spots on the pavement surface. The leveling action is accomplished using the floating screed on the paver, with more asphalt mix being placed in the low spots than on the high spots in the existing pavement surface. The areas with thicker mix, however, typically compact more than areas with thinner mix. This problem, termed differential compaction, requires that multiple courses be constructed over a pavement surface that is badly out of shape before a smooth surface can be obtained.

As the mix passes from under the paver screed, it is in a relatively loose condition, being just slightly compacted by the vibratory screed. Compaction by the rollers reduces the thickness of the newly placed layer. The rule of thumb is that conventional mixes will compact approximately 1/4 inch per 1 inch (6 mm per 25 mm) of compacted thickness. Thus, to achieve a compacted course 1 inch (25 mm) thick, about 1-1/4 inches (31 mm) of mix would have to be placed by the paver. Similarly, approximately 3-3/4 inches (95 mm) of mix would need to pass from under the paver screed to construct a layer with a compacted thickness of 3 inches (75 mm). Also, better results for leveling courses have been noted when the gradation is on the fine side of the MDL. The asphalt mixture shall be placed at a compacted lift thickness no less than 3 times its NMAS for fine-graded mixes and no less than 4 times its NMAS for coarse-graded mixes. Moreover, a smaller NMAS gradation is advisable, as larger-sized gradations are more prone to their largest stones dragging and marring the surface created in high spots of the leveled surface.

When a leveling course is placed, the asphalt mixture laid in the low areas (in the wheelpaths if the pavement is rutted) will be thicker than the mix placed over the high points in the surface (between the wheelpaths). The thicker mix will compact more under the rollers, particularly if a pneumatic tire roller is used, than will the mix that is thinner. Thus, low spots will still exist in the wheelpaths where the mix has been compacted to a different degree (and thus a different air void content) than the mix between the wheelpaths. Because of the problem of differential compaction, multiple layers of mix are usually needed to eliminate the roughness in the existing pavement surface. A rule of thumb is that one layer after compaction will remove approximately 80 percent of a low spot. Two layers, each being compacted separately, will remove approximately 95 percent of a low spot.

5.3.4 Milling

Milling, also called cold planing, is a process that removes a portion of the existing pavement layer to provide the desired surface elevation and texture for asphalt or concrete overlays. In general, the milling is categorized into full or partial depth depending on the amount of material removed, which is often dictated by the existing pavement condition. Full-depth milling refers to the removal of the entire asphalt layer down to the base and applies to the severely deteriorated pavement structure. Partial-depth milling removes only an upper portion of the asphalt layer that is distressed (rutted and/or cracked), and the remaining asphalt layer continues serving as a structural layer after rehabilitation. Determining the milling depth is a primary concern of partial-depth rehabilitation since the milling depth affects the quality, productivity, and project cost. The goal is to mill to a depth below the distresses so as not to inhibit the desired performance of the new asphalt layer.

Milling can be accomplished in any width necessary, from 6 inches (150 mm) to more than 13 ft (4 m). Figure 60 shows a typical milling machine. If equipped with automatic grade and slope controls like those used on an asphalt paver, the milling machine can produce a level surface in one pass over the existing surface. The RAP produced by the milling process can be hauled back to the asphalt plant for future recycling. In addition, if the milled surface is properly cleaned, its texture can enhance the bond between the new and old layers and may reduce the possibility of slippage of the overlay over the existing surface.

Source: Roadtec

Figure 60. Typical Milling Machine

When the milling depth is variable or slightly thinner than the existing asphalt lift thickness, a "scab" may form. A scab refers to a thin layer of an existing layer that was not completely removed in the milling process (see Figure 61). The scab often results in variations in surface texture and elevation. In addition, the bond between the scab and the remaining existing asphalt may also weaken during the milling and paving process. Scabbing is likely to contribute to lower ride quality and density issues due to differential compaction between the scabbed and non-scabbed areas. Scabbing is also likely to cause premature pavement distresses, including cracking and delamination, that eventually shorten pavement surface life. To prevent scabbing, the contractor should closely monitor milling depth, especially when milling over concrete pavement. If scabbing occurs during the milling operation, the contractor should lower the milling head to fully remove the scabbing or drop back and perform another pass to fully remove the scabbing. The contractor and owner should agree on any adjustments to the milling depth as this will likely result in more asphalt mix to be placed, resulting in a contract overrun. Slowing the forward speed of the milling machine may also help mitigate the occurrence of scabbing.

Source: Asphalt Institute

Figure 61. Scabbing

A pavement surface that has been milled is typically very dusty and dirty. Once the pavement has dried, multiple sweepings with a mechanical broom are usually needed to remove all the residual grit from the milled surface. In some cases, it may be necessary to dampen the milled surface before sweeping or to air-blow or flush the milled surface with water to remove dust and very fine material completely. While this cannot be done on airfields, opening the milled surface to traffic will help remove the dust and very fine material. Any dust and dirt left on the milled surface will greatly affect the bond between that course and the new asphalt overlay.

Any dust and dirt left on the milled surface will greatly affect the bond between that course and the new asphalt overlay.

Because of the increased surface area of the milled pavement (from the grooves left by the cutting teeth on the milling machine), an additional quantity of tack coat material may be required to ensure an adequate bond between the old and new layers (see Figure 62). That increased quantity is a function of the type, number, condition, and spacing of the teeth on the cutting mandrel of the milling machine but is typically in the range of 20 to 30 percent more than for an unmilled surface.

Source: Asphalt Institute

Figure 62. Tack Coat on a Milled Surface

5.4 PCC SURFACE PREPARATION FOR ASPHALT OVERLAYS

When asphalt mix is placed over a PCC pavement, the PCC surface should likewise be properly prepared. Any severely distressed areas in the concrete slabs should be cut out, removed, and replaced with either a PCC or asphalt mixture using full-depth slab repair techniques. Corrective work should also be completed on the underlying subbase or subgrade material, if necessary. Any severely spalled areas at joints should be repaired using partial-depth slab replacement methods. PCC should be used for partial-depth repairs. Rocking slabs should be stabilized. Depending on the condition of the PCC pavement, procedures such as crack and seat, break and seat, or rubblizing of the existing pavement can be used before the overlay is placed, particularly if the slabs are rocking under traffic loading. Consideration can also be given to the use of a crack-relief layer between the existing PCC pavement and the new overlay.

For joints that are poorly sealed, the old seal material should be removed and the joints cleaned. When dry, the joints should be resealed with appropriate joint-sealing material. Care should be taken not to overfill the joints, particularly in cool weather when they are open wide. In all cases, as with crack sealant, the final level of the joint-sealing material should be below the top of the surrounding pavement surface. Once the patching and resealing have been accomplished, the surface of the PCC pavement should be cleaned completely using mechanical brooms and air blowing or water flushing, or both, where needed.

5.5 TACK COAT

The purpose of a tack coat is to ensure a bond between all asphalt layers. The tack coat should not be used in lieu of cleaning the existing surface—removing accumulated dust and dirt by mechanical brooming or by flushing with air or water. If a good bond is not formed between the existing surface and the new overlay, slippage may occur. The new overlay may be shoved in a longitudinal direction by traffic, particularly at locations where the traffic accelerates or where vehicle brakes are applied. More importantly, poor bonding will significantly reduce a pavement's fatigue resistance, taking years off its life. Thus, the pavement surface must be clean before the tack coat is applied.

5.5.1 Tack Coat Materials

The tack coat material is normally asphalt emulsion but can also be asphalt binder or cutback asphalt. A survey completed in NCHRP Synthesis 516, *Tack Coat Specifications, Materials, and Construction Practices*, indicated that emulsions are the most common tack coat materials, with SS-1, SS-1h, CSS-1, and CSS-1h being the most widely utilized emulsion grades for tack coat in North America. Many other emulsified products are also used, such as quick set (QS), anionic rapid sets (RS-1 and RS-1h), and cationic rapid sets (CRS-1 and CRS-1h). Specifications for these emulsions can be found in AASHTO M 140 (anionic emulsions) and AASHTO M 208 (cationic emulsions). Many new proprietary products classified as reduced-tracking tack materials are also growing in use. Reduced-tracking tacks are designed to improve pavement performance by avoiding the tracking problems associated with traditional tacks. These materials are typically manufactured to harden quickly and adhere minimally to construction vehicle tires.

Tack coat materials should be applied by a pressure distributor, as shown in Figure 63. All nozzles on the distributor should be appropriately sized, fully open and functioning, and should be turned at the same angle to the spray bar (approximately 30 degrees). In addition, the spray bar should be at the proper height above the pavement surface to provide for a double or triple lap of the liquid asphalt material. The result will be the proper amount of overlap between the nozzles and a uniform application of the tack coat to the road surface. The tack coat material should be heated to the proper temperature so that it is fluid enough to be sprayed uniformly from the nozzles instead of coming out in strings.

Source: Asphalt Institute

Figure 63. Distributor Applying Tack Coat

5.5.2 Tack Coat Application Rate Versus Residual Rate

Uniformity of application and a proper application rate are key to achieving a successful tack coat. Figure 64 and Figure 65 illustrate a tack coat application that is uneven due to improper equipment operation, with too much tack coat in some areas and not enough in others. Proper tack coat application, shown in Figure 66, will leave a residual asphalt binder content of approximately 0.040 to 0.070 gal/yd^2 (0.181 to 0.317 L/m^2) on the roadway. The amount of residual tack coat needed will depend on the condition of the pavement surface. An open-textured surface requires more tack coat than a surface that is tight or dense, and a dry, aged surface requires more tack coat than a

Uniformity of application and a proper application rate are key to achieving a successful tack coat.

surface that is "fat" or flushed. In addition, more tack coat may be needed on a milled surface because of the increased surface area, as discussed earlier. A residual rate of as much as 0.080 gal/yd^2 (0.362 L/m^2) of asphalt binder may be needed to ensure a proper bond. Recommended residual application rates for various surface types can be seen in Table 5 and Table 6.

Source: Asphalt Institute

Figure 64. Non-Uniform Application of Tack Coat

Source: Dr. Imad Al-Qadi

Figure 65. Non-Uniform Application of Tack Coat

Source: Asphalt Institute

Figure 66. Uniform Application of Tack Coat

Table 5. Recommended Tack Coat Application Rates—U.S. Customary Units

Surface Type	Residual Application Rate gal/yd^2	Undiluted Application Rate* gal/yd^2	Diluted 1:1 Application Rate* gal/yd^2
New Asphalt	0.020–0.045	0.030–0.065	0.060–0.130
Existing Asphalt	0.040–0.070	0.060–0.105	0.120–0.210
Milled Surface	0.040–0.080	0.060–0.120	0.120–0.240
PCC	0.030–0.050	0.045–0.075	0.090–0.150

*Assumes emulsion is 33% water and 67% asphalt. Source: Asphalt Institute

Table 6. Recommended Tack Coat Application Rates—Metric Units

Surface Type	Residual Application Rate L/m^2	Undiluted Application Rate* L/m^2	Diluted 1:1 Application Rate* L/m^2
New Asphalt	0.091–0.204	0.137–0.306	0.274–0.612
Existing Asphalt	0.181–0.317	0.272–0.476	0.544–0.952
Milled Surface	0.181–0.362	0.272–0.543	0.544–1.086
PCC	0.136–0.226	0.204–0.339	0.408–0.678

*Assumes emulsion is 33% water and 67% asphalt. Source: Asphalt Institute

It is essential to differentiate between the residual tack coat rate (the amount of asphalt binder remaining on the pavement surface after the water has evaporated) and the application rate (the amount of emulsion sprayed from the distributor). Most asphalt

It is essential to differentiate between the residual tack coat rate (the amount of asphalt binder remaining on the pavement surface after the water has evaporated) and the application rate (the amount of emulsion sprayed from the distributor).

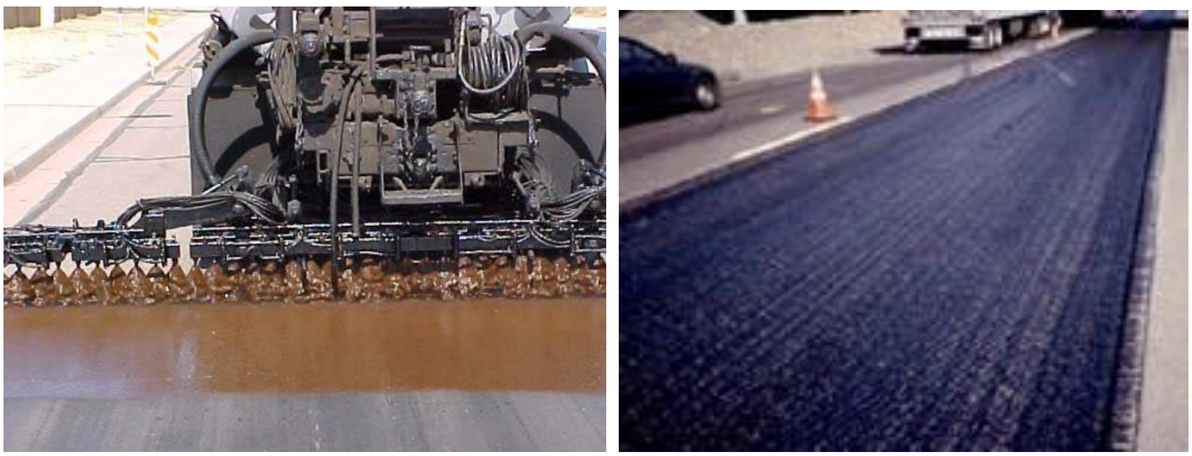
emulsions contain 60 to 65 percent residual asphalt binder and 35 to 40 percent water, plus a small amount of emulsifying agent. For ease of calculation, it can be assumed that an asphalt emulsion is approximately two-thirds asphalt cement and one-third water. The amount of asphalt binder left on the pavement surface after the water has evaporated from the emulsion is the most important factor in obtaining a bond between the existing pavement surface and the new overlay. If the project only specifies the residual application rate and not the undiluted application rate, the undiluted rate can be determined by starting with the amount of residual asphalt cement required on the pavement surface and working backward to determine the rate of emulsion to spray from the distributor.

As an example, suppose that the present pavement surface is relatively tight and dense. It is determined that the residual amount of asphalt binder on the pavement surface needs to be 0.040 gal/yd^2 (0.181 L/m^2). If an undiluted SS-1 asphalt emulsion is used for the tack coat, the application rate for that material should be approximately 0.060 gal/yd^2 (0.271 L/m^2), calculated as (0.040)÷(2/3) = 0.060 gal/yd^2 [(0.181)÷(2/3) = 0.271 L/m^2]. If the SS-1 asphalt emulsion has been diluted with equal parts water, the application rate needed to obtain the same amount of residual asphalt on the pavement surface will be different. Using a 1:1 dilution rate, the application rate for a residual amount of 0.040 gal/yd^2 (0.181 L/m^2) will be 0.120 gal/yd^2 (0.543 L/m^2). Thus, with the use of a 1:1 diluted emulsion, twice as much emulsion must be applied to the pavement surface from the distributor to have the same amount of residual asphalt when all the water has evaporated. Whether the specifications allow tack coat dilution should be verified—this is not allowed on military airfield projects.

If the amount of water in an asphalt emulsion is not considered when determining the application rate from the distributor, the correct degree of adhesion may not be achieved. Too little tack coat will not provide sufficient bond between the old and new pavement layers. On the other hand, too much tack coat may contribute to slippage of the overlay on the existing pavement surface and possible bleeding of the tack coat material through a thin overlay. If asphalt cement is used as the tack coat material instead of an asphalt emulsion, the residual amount of asphalt on the pavement surface should be the same as the applied amount. Thus, if 0.040 gal/yd^2 (0.181 L/m^2) of residual binder material is desired, the application rate from the distributor should also be 0.040 gal/yd^2 (0.181 L/m^2).

5.5.3 Tack Coat Breaking and Setting

When an asphalt emulsion is applied as a tack coat, it is brown in color because it contains both asphalt cement and water. After a short period of time, the emulsion will “break” (change color from brown to black) and the water will begin to evaporate (see Figure 67). The rate of evaporation will depend on the type and grade of the emulsion used, the application rate, the temperature of the existing pavement surface, and the environmental conditions. Once all the water is gone, the emulsion is said to have “set.” The rate of set depends on the same conditions that control the rate of break of the emulsion. Under most circumstances, an emulsion will set in 1 to 2 hours.



Source: Asphalt Institute

Figure 67. Emulsion Tack Coat Applied—Unbroken Tack *(left)*, Broken Tack *(right)*

There is debate about whether asphalt mixtures can be placed on top of the emulsion tack coat before it has set or even broken. Tack coat material before breaking can be very slippery and prone to tracking off the applied surface by sticking to vehicle tires. When using conventional pavers, it is important to keep all traffic off the emulsion tack coat until it has broken and, if practical, until it has set. With a spray paver (see Figure 68), the tack is sprayed just ahead of the screed. Some agencies require a specialized formulation of tack to use with spray pavers (see the survey in NCHRP Synthesis 516), but others use the same material that would normally be used. The tack does not have time to break with the spray paver, and the emulsion will break immediately upon contact with the new asphalt mixture. The water, 0.080 gal/yd^2 (0.362 L/m^2), typically will evaporate and escape as steam through the loose hot mix. There is not enough water to lower the mat temperature significantly.

When using conventional pavers, it is important to keep all traffic off the emulsion tack coat until it has broken and, if practical, until it has set.

Source: Integral dx

Figure 68. Spray Paver

It is important that the tack coat material remains on the pavement surface to create the bond between the layers. If the tack coat material is picked up by the truck tires and tracked down the roadway, adjustments must be made. Either the tack coat should be allowed to set before haul truck traffic is permitted to run over it, or a material transfer vehicle (MTV), offset from the lane being placed, can be used. Many agencies are also specifying the use of reduced-tracking tack coats (trackless) to help mitigate tack coat pickup.

If asphalt cement is used as the tack coat material, it will cool to ambient temperature very quickly. Further, because there is no carrier material (water) to evaporate, paving may immediately follow the asphalt cement tack coat application.

If the overlay is to be constructed under traffic, the tack coat is normally placed only a short distance in front of the paver—within the lane closure and far enough ahead for the tack to set properly before the asphalt mixture is laid on top of it. Traffic should be kept off the tack coat. If the roadway being paved is closed to traffic, the tack coat can be placed as much as 24 hours ahead of the laydown operation, provided there will be no issues with wind depositing dust or organic materials on the freshly tacked surface. Doing so will ensure that the tack coat is completely set before the mix is placed on top of it. It is never good practice to place the tack coat one day, permit traffic to run over the tack coat for a period, and then place the overlay later.

If equipment problems (plant or paver breakdowns) prevent tack coat material that has been applied by the distributor from being paved over before traffic must use the roadway,

> *It is important that the tack coat material remains on the pavement surface to create the bond between the layers. If the tack coat material is picked up by the truck tires and tracked down the roadway, adjustments must be made.*

it is suggested that posted speed limits on that section of roadway be significantly reduced until the overlay operation can take place. Depending on the amount of residual asphalt cement on the pavement surface and environmental conditions, the level of friction available for traffic at the pavement surface may be greatly reduced by the presence of the tack coat material, especially in wet weather. The excess tack may also end up on vehicles, creating a major public relations problem. In addition to lowering the posted speed limits, it is highly advisable to apply a light layer of sand on top of the tack coat to prevent its pickup by traffic and to improve the skid resistance of that section of roadway until the overlay can be placed. The application rate of the sand should be in the range of 4 to 8 lb/yd^2 (2.2 to 4.4 kg/m^2), depending on the application rate of the tack coat material and the gradation of the sand. Excess sand should be broomed from the pavement surface with an additional application of tack coat applied before the overlay is placed to ensure a proper bond between the overlay and the existing surface.

The application of tack coat material is essential when an overlay is being constructed on an old existing pavement surface—either asphalt, PCC, or surface treatment. It is sometimes assumed that tack coat is not needed when a layer of new mix is being placed over another layer of asphalt pavement that has been laid within a few days if the underlying new layer has not become dirty under traffic or from windblown dust. However, the potential cost to the agency if there is insufficient bond between the two layers greatly exceeds the cost of applying the tack coat. Tack coat should be used on a recently placed asphalt mix layer, but the residual asphalt content should be minimal—approximately 0.020 gal/yd^2 (0.091 L/m^2), or half of what is needed for most old, tight, existing surfaces. Thus, the application rate for an undiluted SS-1 emulsion should be only approximately 0.030 gal/yd^2 (0.136 L/m^2).

5.5.4 Asphalt Distributors

Asphalt distributors (see Figure 69 and Figure 70) are designed specifically to apply asphalt products uniformly. They consist of a truck- or trailer-mounted insulated tank ranging in capacity from 800 to 5,500 gal (3,000 to 20,800 L). Most distributors are equipped with a heating system that will maintain the material at the proper application temperature. They are also equipped with a power-driven pump that circulates the tack coat material from the distributor to the spray bar and creates pressure in the spray bar. Although the methods of maintaining pressure may vary, all distributors use pumps to deliver asphalt material to the spray bar. The circulating system, which consists of an engine- or hydraulic-driven pump, does the following:

- Fills the distributor tank.
- Circulates material through the bar and tank.
- Sprays material through the bar or hand wand.
- Draws material back to the tank from the bar or hand wand.
- Pumps material from the tank to outside storage.
- Transfers material from one storage tank to another.

The circulation system on a distributor is capable of handling products at a range of viscosities, temperatures, and application rates. Heavy, stiff asphalt binders require heating to higher spraying temperatures and may require a heavy-duty pump and heater system. A system of spray bars with nozzles applies the asphalt to the road's surface. The nozzle type should match the material volume and viscosity. Spray bars cover widths of up to 30 ft (9.1 m) in one pass.

Source: NAPA

Figure 69. Asphalt Distributor

Source: Asphalt Institute

Figure 70. Tack Coat Application

The correct pump speed and pressure control the spray fan. Too low of a pressure may result in streaking from a nonuniform discharge of material from the individual nozzles. Too high of a pressure, besides atomizing the asphalt, may distort the spray fan. Manufacturers supply charts and data for proper pump speed or pressure for determining the volume-per-minute of discharge for each nozzle size.

A tachometer is used as an aid in maintaining uniform distributor speed. Newer distributors have interlocks between the asphalt pump and the forward speed of the distributor. As the distributor changes speed, the pump speed is automatically adjusted to compensate for the change in speed of the distributor, thus maintaining a constant application rate. Due to all these variables, it is important to ensure a proper and uniform application of tack coat through routine verification or calibration checks of each individual distributor, with recalibrations as needed. At a minimum, it is recommended that distributors be calibrated annually. A standard that is helpful when calibrating is ASTM D-2995, "Standard Practice for Estimating Application Rate and Residual Application Rate of Bituminous Distributors."

5.5.4.1 Loading the Distributor: Safety Considerations

Caution is required by distributor operators and those responsible for loading the various materials into the distributor to avoid dangerous scenarios. Table 7 offers a guide for loading products in a safe manner.

Table 7. Product Loading Guidance

Last Product in Tank	Product to be Loaded			
	Asphalt Cement	Cutback Asphalt	Cationic Emulsion	Anionic Emulsion
Asphalt Cement	OK to Load	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cutback Asphalt	Empty*	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cationic Emulsion	Empty*	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity
Anionic Emulsion	Empty*	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load
Crude Oil or Residual Fuel Oils	Empty*	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Any Product Not Listed	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned

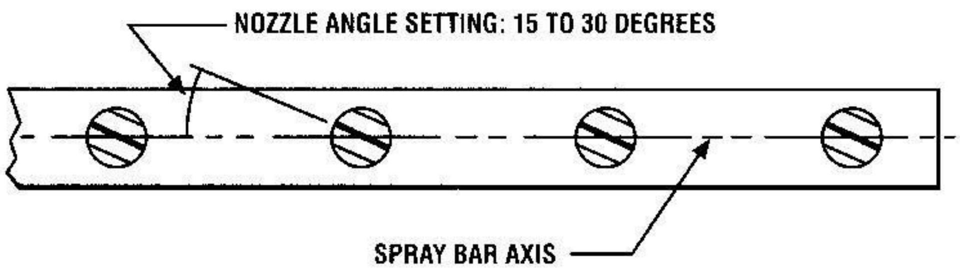
*Any remaining material will be dangerous. Source: Asphalt Institute

5.5.4.2 Setting up the Distributor

One of the most important parts of the distributor is the spray bar. The spray bar is mounted on the back of the distributor and is composed of a series of spray nozzles evenly spaced (i.e., every 4 inches [100 mm]) along the bar. It is essential that the spray bar has constant pressure and temperature along the entire width for equal output from all nozzles. To accomplish this, the spray bar is equipped with a return line for continuous circulation of heated and pressurized material. Most models are equipped with shutoff valves on each nozzle, or groups of nozzles, to optimize a spray pattern or for spraying irregular areas.

The distributor must be properly set up to apply the desired application rate uniformly for the entire length and width of the area to be tacked. Proper setup includes ensuring correct nozzle size, spacing, and orientation on the spray bar; spray bar height; and distributor speed. Proper nozzle selection is imperative for consistent and uniform application of the materials. Users are encouraged to consult with their equipment manufacturer for guidance on nozzle selection.

Before use, nozzles should be checked for damage and proper setting. The angle of the long axis of the nozzle openings (see Figure 71) must be adjusted so that the spray fans do not interfere with each other. The nozzle angle varies according to the make of the distributor but is typically between 15 and 30 degrees. It is important that all nozzles be set at the same angle.



Source: Asphalt Institute

Figure 71. Proper Nozzle Alignment

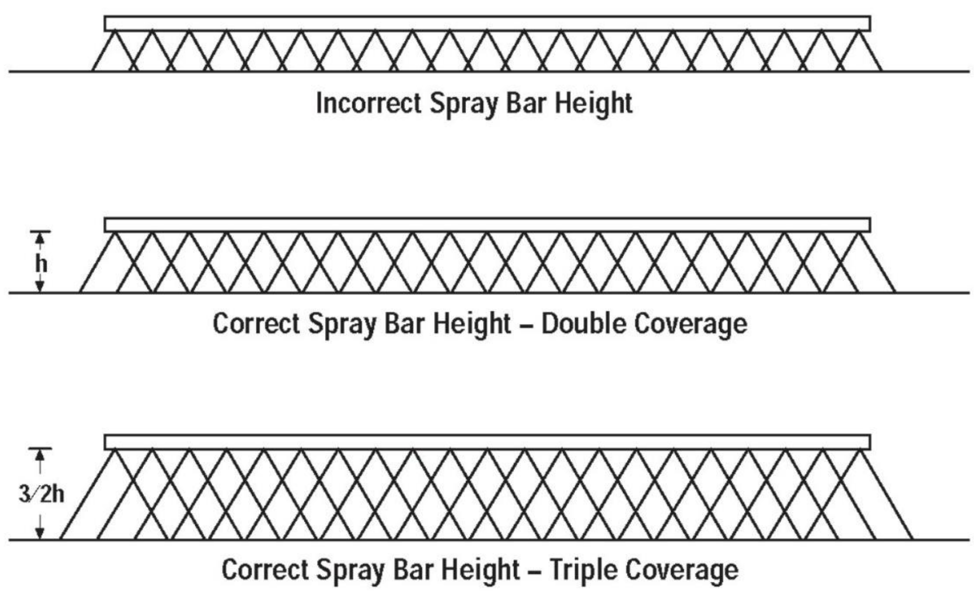
Some operators will set end nozzles at a different angle (from 60 to 90 degrees with respect to the spray bar) to try to obtain a good, straight edge. This practice should **not** be permitted as it will produce a fat streak on the edge and rob the adjacent spray fan of the overlap from this nozzle. Using a special end nozzle set at the same angle as all the other nozzles will provide more uniform coverage and make a better edge.

Adjusting the height of the spray bar to obtain uniform coverage of the tack coat material is a critical step in distributor setup. The spray bar should be set to obtain triple or, at minimum, double overlap (coverage). Choosing which of these coverages is best for a given scenario is based on many factors. Regardless of which option is used, the spray bar height must be precisely set to avoid any streaking in the tack application that can cause uneven tack coverage (see Figure 72). Spray bars set too high can result in wind distortion. A best practice is to set the spray bar height to get triple lap coverage. With the nozzles at 4-inch (100-mm) centers, a bar height of 12 inches (300 mm) off the ground is required to achieve triple overlap.

The distributor must be properly set up to apply the desired application rate uniformly for the entire length and width of the area to be tacked. Proper setup includes ensuring correct nozzle size, spacing, and orientation on the spray bar; spray bar height; and distributor speed.

However, tack is a very light application that may require smaller-orifice nozzles to develop nice, full spray fans, especially when triple overlap is used. In addition, higher forward ground speeds are typically needed to apply the desired application rate. Smaller-orifice nozzles tend to clog easier, and faster forward ground speeds are not always desirable in a construction zone. Double overlap or single coverage using larger nozzles and slower speeds is sometimes necessary. While not preferred, most inspectors seem to accept variations such as shooting out of every other or every third nozzle, along with bar height and nozzle angle adjustments, provided the result is uniform coverage and the application rate is maintained.

For best results, the height of the spray bar above the road surface should not vary more than 1/2 inch (12.5 mm) during application. Additional steps must be taken to ensure this maximum permissible height variance is not violated as the load lightens on the suspension of the distributor truck. Most distributors now have automated mechanical controls to maintain the proper height.



Source: Asphalt Institute

Figure 72. Spray Fan Overlap

5.5.4.3 Determining Emulsion Application Temperature

Recommendations for spraying temperatures for asphalt emulsions are generally in the 120–180 °F (50–80 °C) range. For tack coats specifically, being in the upper portions of this range reduces the break time for the emulsion, which speeds the construction process. Review of local specifications and the material supplier's recommendations for individual situations is encouraged.

5.5.4.4 Verifying Application Rates

It is important to verify the final application rate of tack coat applied to compare against the specified rate (see recommended rates in Section 5.5.2). This section covers calculating the residual tack coat rate of the emulsion applied. Application rates are most often expressed as a volume per area, such as gallons/square yard or liters/square meter, but they can also be expressed in terms of mass as pounds/square yard or kilograms/square meter. Specifiers should designate whether the volume to be placed is a residual binder rate, emulsion rate, or a specific diluted rate.

> *It is important to verify the final application rate of tack coat applied to compare against the specified rate.*

5.5.4.5 Calculating Application Rate by Volume

The calculations to determine tack coat applications are rather straightforward. All asphaltic materials' volumes change with temperature; therefore, a standard temperature is required to determine the appropriate volumes used. The volume of asphalt emulsions is reported at 60 °F (15.5 °C), therefore, the specified application rates shown in Table 5 and Table 6 use volumes at 60 °F (15.5 °C). Table 8 provides the necessary temperature-volume corrections needed to convert volumes at other temperatures to the standard 60 °F (15.5 °C) volume.

Residual asphalt application rate calculations need to account for not only the temperature but also the water that is present in an undiluted emulsion and any water added during dilution. The following steps can be useful when calculating the tack coat application rate by volume in gallons/square yard:

> ***Step 1:*** *Determine the distance traveled.*
> ***Step 2:*** *Calculate the area covered = distance traveled X width sprayed. (convert from square feet to square yard if needed).*
> ***Step 3:*** *Calculate the gallons of material applied = beginning volume—ending volume. The volumes may be determined by using a dipstick calibrated to the truck's tank (much preferred), or onboard meters.*
> ***Step 4:*** *Correct for temperature back to 60 °F by applying correction factor.*
> ***Step 5:*** *Account for any dilution.*

> ***Step 6:*** *Calculate residual asphalt by accounting for the water in the original emulsion.*
> ***Step 7:*** *Calculate residual asphalt application rate which is the gallons of residual asphalt applied divided by the area of application.*

The same steps can be used to calculate the tack coat rate by volume in L/sq m.

5.5.4.6 Calculating Application Rate by Mass

Application rates may also be calculated using the mass of the applied product. Most emulsion manufacturers will show the weight per gallon at 60 °F on the bill of lading that accompanies the shipment. When weigh scales are available, the mass of the distributor can be determined before and after application to determine the amount of material sprayed. Note that a temperature correction is not needed when calculating by mass as temperature changes do not affect the mass of the materials. The calculation process is very similar to the steps shown above.

The application rate (shot rate) calculations by mass are as follows:

> ***Step 1:*** *Determine distance traveled.*
> ***Step 2:*** *Calculate the area covered, multiply the distance traveled by the width sprayed. (Convert from sq. ft. to sq. yd. if needed).*
> ***Step 3:*** *Calculate mass of diluted emulsion applied.*
> ***Step 4:*** *Calculate undiluted emulsion mass. This calculation assumes unit weight of the diluted emulsion is equivalent to unit weight of the undiluted emulsion.*
> ***Step 5:*** *Calculate the gallons of emulsion used.*
> ***Step 6:*** *Calculate residual asphalt application.*

The same steps can be used to calculate the tack coat rate by volume in L/sq m.

Table 8. Temperature-Volume Corrections to 60 °F (15.6 °C) for Emulsified Asphalt

°C	°F	Multiplier	°C	°F	Multiplier	°C	°F	Multiplier
10.0	50	1.00250	37.8	100	0.99000	65.6	150	0.97750
10.6	51	1.00225	38.3	101	0.98975	66.1	151	0.97725
11.1	52	1.00200	38.9	102	0.98950	66.7	152	0.97700
11.7	53	1.00175	39.4	103	0.98925	67.2	153	0.97675
12.2	54	1.00150	40.0	104	0.98900	67.8	154	0.97650
12.8	55	1.00125	40.6	105	0.98875	68.3	155	0.97625
13.3	56	1.00100	41.1	106	0.98850	68.9	156	0.97600
13.9	57	1.00075	41.7	107	0.98825	69.4	157	0.97575
14.4	58	1.00050	42.2	108	0.98800	70.0	158	0.97550
15.0	59	1.00025	42.8	109	0.98775	70.6	159	0.97525
15.6	60	1.00000	43.3	110	0.98750	71.1	160	0.97500
16.1	61	0.99975	43.9	111	0.98725	71.7	161	0.97475
16.7	62	0.99950	44.4	112	0.98700	72.2	162	0.97450
17.2	63	0.99925	45.0	113	0.98675	72.8	163	0.97425

°C	°F	Multiplier	°C	°F	Multiplier	°C	°F	Multiplier
17.8	64	0.99900	45.6	114	0.98650	73.3	164	0.97400
18.3	65	0.99875	46.1	115	0.98625	73.9	165	0.97375
18.9	66	0.99850	46.7	116	0.98600	74.4	166	0.97350
19.4	67	0.99825	47.2	117	0.98575	75.0	167	0.97325
20.0	68	0.99800	47.8	118	0.98550	75.6	168	0.97300
20.6	69	0.99775	48.3	119	0.98525	76.1	169	0.97275
21.1	70	0.99750	48.9	120	0.98500	76.7	170	0.97250
21.7	71	0.99725	49.4	121	0.98475	77.2	171	0.97225
22.2	72	0.99700	50.0	122	0.98450	77.8	172	0.97200
22.8	73	0.99675	50.6	123	0.98425	78.3	173	0.97175
23.3	74	0.99650	51.1	124	0.98400	78.9	174	0.97150
23.9	75	0.99625	51.7	125	0.98375	79.4	175	0.97125
24.4	76	0.99600	52.2	126	0.98350	80.0	176	0.97100
25.0	77	0.99575	52.8	127	0.98325	80.6	177	0.97075
25.6	78	0.99550	53.3	128	0.98300	81.1	178	0.97050
26.1	79	0.99525	53.9	129	0.98275	81.7	179	0.97025
26.7	80	0.99500	54.4	130	0.98250	82.2	180	0.97000
27.2	81	0.99475	55.0	131	0.98225	82.8	181	0.96975
27.8	82	0.99450	55.6	132	0.98200	83.3	182	0.96950
28.3	83	0.99425	56.1	133	0.98175	83.9	183	0.96925

Source: Asphalt Institute

5.6 SUMMARY

The following key factors should be considered when monitoring surface preparation operations:

- A prime coat is generally not needed on subgrade soil unless the prepared subgrade at the proper moisture content will not be paved for several weeks. There is a difference of opinion on the benefits of using a prime coat on a granular base course, but in many cases a prime coat can be eliminated without detrimental effect on the performance of the pavement structure, especially when the pavement structure to be placed on the base course is relatively thick—maybe 6–8 inches (150–200 mm). With thinner pavements, the prime coat becomes more important.
- Before paving an existing surface, any failures in the surface of the existing pavement must be removed and replaced or repaired by patching.
- If cracks are present in an existing asphalt pavement surface, they generally should be sealed individually, or some type of surface treatment may be applied to the whole roadway area. Removing the distressed surface by milling prior to overlaying is also a very common approach. Joints in PCC pavement that are poorly sealed should be routed out and sealed. Rocking PCC slabs should be stabilized.

- A rough, uneven asphalt surface should be leveled with asphalt mix (using a paver to place the mix) to fill in the low spots on the surface, or it should be milled to create an even surface while removing surface distresses.
- Once the needed repairs have been completed, the pavement surface should be cleaned of all dust, dirt, and other debris. This should be accomplished using multiple passes of a mechanical broom. If brooming does not remove all accumulated dirt, flushing with air or water may be required.
- The application of a tack coat must be accomplished before an overlay is constructed on an existing asphalt or PCC surface.
- Proper distributor setup is critical to the successful application of tack coat. The distributor used should be checked to ensure that all the nozzles are open and set at the correct angle and that the spray bar is at the proper height above the pavement surface.
- The application rate for the tack coat should be based on the desired residual amount of asphalt cement on the road surface, which should be between 0.040 and 0.070 gal/yd^2 (0.181 and 0.317 L/m^2) for normal surfaces. The application rate should also be based on the actual amount of asphalt cement in the emulsion—whether the emulsion is diluted or not before it is applied. For example, an undiluted SS-1 emulsion should be applied from the distributor at a rate of 0.060 gal/yd^2 (0.271 L/m^2) to obtain 0.040 gal/yd^2 (0.181 L/m^2) of residual asphalt on the pavement surface.
- Milled pavements may need a greater amount of residual tack coat. Too little tack coat will not provide the needed bond between the old and new layers. On the other hand, too much tack coat may promote slippage of the new overlay on the old pavement or bleeding of the tack material through a thin overlay.
- Asphalt mixture should be placed on top of an emulsion tack coat that has broken—changed color from brown to black. The tack coat should not be picked up and tracked by the haul trucks, however.
- Tack coat should not be left exposed to traffic. If doing so is necessary, proper precautions, such as reducing the posted speed limit on the roadway and sanding the surface with excess sand being broomed from the surface, should be taken.
- A tack coat should be placed between layers of new asphalt. The amount of residual asphalt on the new roadway surface should be approximately half that appropriate for an old, tight, existing pavement surface.

6. Mixture Delivery

6.1 INTRODUCTION

Following the production of asphalt mixtures at the asphalt plant, these materials are loaded into haul vehicles and trailers, either directly or after they have been stored for a short time in a silo or surge bin. The goal of this stage of the paving process is to provide a steady, regularly spaced, uninterrupted supply of consistent, homogeneous materials. Accomplishing this goal helps to ensure that the paver can proceed at a constant speed for the entirety of the paving day. Experience has shown that a paver operating at a constant speed without stops produces the smoothest and longest-lasting pavement.

6.2 PLANNING

The planning process for a paving job includes determining the number of trucks needed and ensuring the truck drivers are properly trained. The size and types of available trucks, the time to make one trip from the plant to the paver and back (known as cycle time), the planned hourly plant production rate, the length of the paving shift, and any mixture stored at the start of the workday are all details that should be considered by the paving contractor to properly plan their trucking needs. Also, drivers should be trained in their proper role in loading at the plant, hauling, and unloading at the paver to minimize segregation, ensure safety, and promote continuous paving.

The cycle time includes all steps that are a part of a complete cycle. This may include time to load and ticket the truck, tarp the load, haul it to the paving site, wait onsite to unload, dump and clean, and return to the plant.

If a shift begins with paving material stored in a silo, that material effectively adds production capacity for the contractor. The amount of added capacity is determined by the amount stored and the shift length. For example, if a 10-hr shift begins with 250 tons of mixture in a silo, this equates to 25 tons/hr (250 tons/10 hr) of additional production capacity. Thus, the true production will be the tons/hour produced by the plant plus the added tons/hour supplied from the silo.

Determination of the required minimum number of trucks is an important aspect of planning for an asphalt paving project. The items stated above are needed to properly estimate this requirement. The minimum number of trucks needed can be calculated by the following equation:

$$\boldsymbol{Haul\ Units\ (Trucks)} = \frac{\boldsymbol{Plant\ Production\ \left({}^{T}\!/_{hr}\right)}}{\boldsymbol{Average\ Load\ \left({}^{T}\!/_{Truck}\right)}} \times \boldsymbol{Cycle\ Time\ (min)} \times \frac{\boldsymbol{hr}}{\boldsymbol{60\ min}}$$

Where:

T = tons
hr = hours
min = minutes

The answer is always rounded up. For example, if the equation yields 13.1 trucks, a minimum of 14 trucks will be needed.

EXAMPLE

Determine the minimum number of trucks for a job with the following information:

Plant Production =	*250 T/hr (227 tonnes/hr)*
Silo Charge at Start of Day =	*200 T (180 tonnes)*
Shift Length =	*10 hr*
Truck Capacity =	*20 T (18 tonnes)*
Load Time and Ticketing =	*4 min*
Tarping Time =	*2 min*
Haul to Jobsite =	*35 min*
Time on Site =	*4 min*
Dump and Clean =	*4 min*
Return Haul =	*35 min*

Step 1: Determine True Plant Production Rate

This will be the added production rate from the use of the materials stored in the silo at the beginning of a shift plus the plant production rate. In this example, 200 tons are stored that will be used over a 10-hour workday.

$$\frac{200\,T}{10\,hr} + 250\frac{T}{hr} = 270\ \frac{T}{hr}$$

Step 2: Determine the Total Cycle Time

The total cycle time will be the sum of each of the steps encountered from the loading to the return of a single truck: 84 min in total.

Step 3: Calculate the Total Trucks Needed:

$$Haul\ Units\ (Trucks) = \frac{270\left({}^{T}/_{hr}\right)}{20\left({}^{T}/_{Truck}\right)} \times 84\ (min) \times \frac{hr}{60\ min} = 18.9\ Trucks$$

This number should always be rounded up. Therefore, 19 trucks will be needed to maintain a proper flow of mix to the jobsite.

The time interval between each delivery should be consistent, and the trucks should not be allowed to bunch up at the paver or at the plant. If a break in the delivery of material occurs, the paver contractor should stop the paver using a rapid stop technique and then use a rapid start when enough trucks are on the jobsite. This method will promote continuous paving. Starting and stopping the paver for each truck as it arrives on the project will reduce the smoothness and quality of the finished pavement and negatively affect the density of the mat.

Starting and stopping the paver for each truck as it arrives on the project will reduce the smoothness and quality of the finished pavement and negatively affect the density of the mat.

6.3 TRUCK TYPES

Three primary types of trucks are used for asphalt paving jobs: the end-dump, the bottom-dump or belly-dump, and the live-bottom or flow-boy.

Regardless of the truck or trailer type, the floor of the hauling unit should be smooth and free of dimples that might cause release agents to puddle. The side walls of the box should also be true to prevent material hanging up during discharge. Overall, the truck bed should be clean, well-maintained, in good condition, and capable of safely and legally transporting material to the jobsite. The lifting device on dump beds should be maintained so that the bed can be lifted to continuously move the material from the truck bed to the paver hopper. All hauling units should be continually monitored for signs of mechanical problems or leaking fluids (except air conditioning condensate) that can potentially damage the asphalt. If problems are found, the hauling unit should be immediately removed from the lineup until repairs can be made.

6.3.1 End-Dump Trucks

The end-dump truck delivers mix directly to the hopper of the paver or an MTV (see Figure 73). These trucks may have three to six axles and a capacity of 12 to 20 tons (11 to 18 tonnes). More axles mean more capacity. The advantage of the end-dump truck is its short wheelbase, which makes it easy to maneuver. The end-dump truck can also be a semitrailer truck, which is essentially a large, articulated dump truck, with a capacity of 20 to 25 tons (18 to 23 tonnes). The two disadvantages of this type of truck are that it requires improved operator skill and its large dump bed can cause problems with overhead obstructions (wires, bridges, and trees). Because of this truck's size, special care should be exercised when loading it due to the increased potential for aggregate segregation. Especially for the larger end-dumps, care should be exercised to avoid having the truck bed pressing against the paver. This is most likely to happen when the bed is at its highest point.

Source: Asphalt Institute

Figure 73. End-Dump Truck

6.3.2 Bottom-Dump Trucks

Bottom-dump trailers (often referred to as belly-dump trucks) are used when windrow paving is utilized (see Figure 74). Windrow paving is a process where asphalt mixture is placed directly on the roadway in front of the paver, which is equipped with a pickup machine (also known as a windrow elevator) that collects the windrowed material and feeds it into the paver hopper. This windrow elevator may be a standalone unit or may be connected directly to the paver.

Bottom- or belly-dump trucks generally require that a dump operator be stationed on the grade to open the gates and control the spread rate of the asphalt material onto the grade in front of the paver. The dump operator is responsible for maintaining the proper amount of material to keep the paver hopper uniformly charged. The windrow should be consistently sized from truck to truck. During paving, if the quantity on the grade is found to not match the paving width or depth, material should be added or removed—without stopping the paver. The dump operator needs to be trained to also monitor the depth of material in the hopper to ensure that a proper volume of material is being supplied. They should adjust the discharge volume if necessary to properly balance the needs of the paving project.

Source: Asphalt Institute

Figure 74. Bottom-Dump Truck

6.3.3 Live-Bottom Trucks

Live-bottom trucks (also known as flow-boy or horizontal-discharge trucks) have a conveyor system that moves the material from the hauling unit directly into the paver hopper without the need to raise the truck bed (see Figure 75). This system has a safety advantage because the bed does not need to be raised, so it is not prone to interacting with overhead hazards such as utility lines. Segregation is minimized as the material is moved in mass on the conveyor system or live-bottom system as it is discharged into the paver hopper. Moreover, this style of truck does not press on the paver hopper as can happen with end-dumps.

Proper cleaning of the conveyor or discharge plates ensures that cold chunks are not left in the truck bed. Daily checks between loads ensure that the system is operational and that no loose or damaged components will break during the workday.

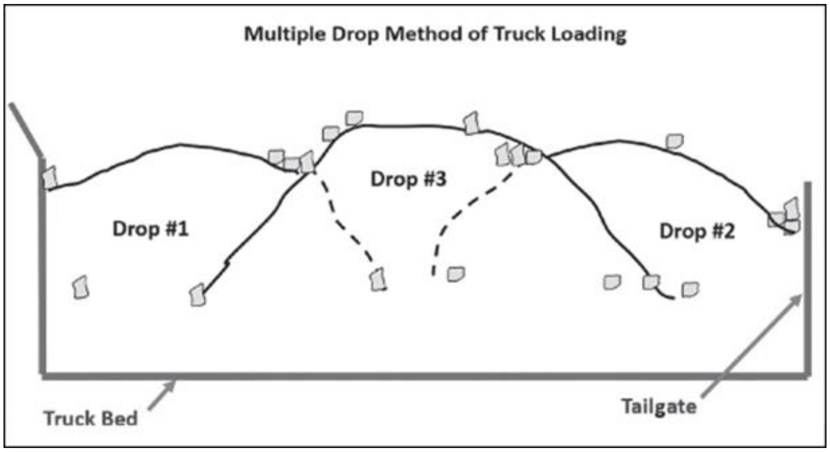
Source: Asphalt Institute
Figure 75. Live-Bottom Truck

6.4 PROPER TRUCK LOADING

Segregation (both physical and thermal) is very difficult to deal with at the paver, as pavers are not designed to remix materials. Consequently, the procedures used to transfer the asphalt mixture into the haul vehicle are critical in minimizing segregation.

The use of best practices during loading can dramatically reduce the chance of segregation. Reducing the free fall distance, when possible, will help prevent segregation. Discharging the mix should always be in mass and dropped straight vertically into the truck. Trucks are loaded from a discharge gate at the bottom of storage silos on a drum or batch plant or, on some batch plants, directly from the discharge gate.

The number of tons loaded and the number of drops will vary depending on the size and capacity of the truck. It is a best practice to avoid loading with a single drop, which will cause segregation of the material and result in the larger aggregate rolling to the front and back of the truck bed. As illustrated in Figure 76, a minimum of three drops is recommended. It is a good practice to load the truck with multiple drops of approximately the same amount of material. The truck is moved forward and backward so that the loads are placed in a specified sequence with the first drop at the front of the truck bed, the second drop at the tailgate, and subsequent drops in the middle of the bed.



Source: Asphalt Institute

Figure 76. Example Truck Loading

For standard end-dump trucks, three drops are usually sufficient. Longer truck boxes will require more drops to prevent segregation (typically an odd number of drops). To facilitate loading, stations can be marked at the side of the loading area so the plant operator can direct the truck where to stop. Loading the truck using multiple drops to reduce the length of the face of the pile, and thus reduce the rolling distance for aggregate, will minimize physical segregation.

6.5 HAULING PROCEDURES

After the haul vehicles are loaded at the plant, they must proceed directly to the paving location. It is important that truck drivers be thoroughly trained so they are aware of what is expected during loading, hauling, and unloading to maintain a steady flow of asphalt mixture to the paver. Haul trucks should not arrive simultaneously with other haul trucks (clustering or platooning). A notable exception is military airfield paving work, where platooned-deliveries may be required for ingress and egress from the facility being paved for security reasons. Driver training should focus on safe and timely deliveries as key elements in the construction of a quality asphalt pavement.

All haul truck beds should be smooth and clean. Truck beds should be inspected for cleanliness prior to loading them with fresh mix. The bed of the haul truck should be free of all deleterious materials before the mix is placed in it. Any debris in the bed from previous use of the truck should be removed. The bed should also be reasonably smooth and free of any major indentations or depressions where the truck bed release agent and mix could accumulate. The dumping lip should be cleaned between loads, and tailgate-latching devices should be lubricated so they release on command.

6.5.1 Release Agents

Once the haul truck bed is clean, it should be coated with a release agent to prevent the asphalt mixture from sticking to the bed. Nonpetroleum-based materials should be used for this purpose. While diesel fuel was once the most used release agent, it is no longer allowed and should not be used as it damages the mixture. Modern release agents are proprietary chemical packages that are supplied in concentrated form and diluted with water to application strength. Most agencies will have an “approved products list” for release agents. Manufacturers’ dilution and application rates must be observed to ensure good performance.

The release agent should be sprayed uniformly over the sides and bottom of the truck bed, using the minimum quantity necessary to cover the surface area of the bed without runoff. Any excess agent should be drained from the bed before the truck is loaded with mix. It is important to monitor the effectiveness of the release agent with the type of binder and mix being used. If trucks require excessive cleaning after each delivery, a different release agent may be appropriate.

6.5.2 Tarps and Insulated Beds

Maintaining the temperature of the plant mix during its journey from the plant to the paving site is imperative. If mixture temperature differentials of 25 °F (14 °C) or more occur, the mixture is considered thermally segregated. Cooler days and/or longer hauls increase the probability of this occurring. Ideally, all trucks should have insulated beds and an insulating waterproof cover (also known as a tarp) that overlaps both the sides and back of the bed to keep airflow and rainwater off the asphalt mixture (see Figure 77). The overlap should be at least 1 ft (0.3 m). The insulation should be both on the sides and the bottoms of the beds. These features assist in combating thermal segregation. Some agencies require the use of tarps regardless of weather conditions.

Source: Tim Murphy

Figure 77. Tarped Truck Bed

6.5.3 Truck Spacing

The goal of trucking is to provide a steady, regularly spaced, uninterrupted supply of consistent, homogeneous material. A factor in accomplishing this is to determine the ideal spacing between trucks. This ideal spacing can be determined based on the inputs for calculating the minimum truck numbers (see Section 6.2). Namely, the total cycle time divided by the actual number of haul trucks used should indicate appropriate truck spacing. Admittedly, a lot of external factors that are beyond the control of the contractor can come into play once a truck is on the road and alter this gap in real time.

The goal of trucking is to provide a steady, regularly spaced, uninterrupted supply of consistent, homogeneous material.

Maintaining the calculated interval and avoiding clusters of trucks at the asphalt plant at the paver can be a significant challenge. This is especially true on urban paving projects. Training is the key. Namely, training the truck drivers, plant operator, dump person, and paver operator on why this uniformity is desired and what to do when it is violated. When trucks return to the plant in a group, the plant operator should be trained to maintain the proper loading interval to reestablish the correct truck spacing. Similarly, when a group of trucks arrives at the paving site, the dump person and the paver operator should maintain their pace to reestablish the proper interval as well. Consistency builds a better road and airfield pavement.

6.6 UNLOADING THE MIX

When the loaded haul trucks arrive at the paving location, the next step is to unload the trucks by transferring the asphalt mixture to the paver. The use of best practices to transfer the load of asphalt mixture from the haul truck to the paver is necessary to ensure that paver operation is continuous and that the mix is not segregated during the unloading process.

The onsite individual designated as the dump person controls the unloading of the trucks and has a major influence on both the smoothness of the mat and the potential for segregation. The paver operator must concentrate on the laydown process and is not available to address communication problems directly to a driver without stopping the paver. For this reason, a trained dump person is recommended.

The unloading procedure will naturally vary depending on the type of truck being unloaded. Thus, the following sections address unloading directly into the paver's hopper, windrow paving, and the use of an MTV.

6.6.1 Direct Feed into the Paver

If an end-dump truck is used, the bed of the truck should be raised a short distance to break the load to the rear and allow the mix in the bed to shift and slide back against the tailgate before it is opened. This practice will cause any segregated coarse aggregate material to be incorporated back into the mass of mix rather than being delivered first into the paver hopper. Once the tailgate is opened, this procedure will also allow the mix to be discharged from the truck in a mass and to flood the hopper of the paver, further reducing the possibility of segregation behind the paver screed. In addition, raising the bed before the truck backs into the paver reduces the time required to unload the truck and makes the truck exchange more efficient. The use of tailgate chains to control the tailgate opening to reduce mix flow is seriously discouraged. Reducing the mix flow to a slow-moving stream could result in a major source of segregation.

The same procedure should be employed, if possible, when a live-bottom truck is used to transport the mix. On some such trucks, it may be possible to start the belt or slat conveyor for a few seconds before the end gate on the truck is opened. Doing so will create a mass of material that can be delivered to the hopper, instead of allowing any coarse aggregate particles that have rolled to the end gate to exit into the hopper first.

For both end-dump and live-bottom trucks, it is imperative that the trucks do not back all the way to the paver, bumping against it. Bumping the paver will create an indentation or bump in the mat that rolling cannot remove. Rather, these trucks should back to within 12–18 inches (300–450 mm) of the paver, as directed by the dump person or paver operator. At this point, the truck stops, releases the brakes, and waits for the paver to make contact.

After the paver contacts the hauling unit, push rollers mounted on the front of the paver facilitate moving the truck forward without interfering with the rotation of the truck tires. If a wheel-locking device is being used, it locks the hauling unit to the paver to prevent separation and spillage on the grade and simplifies the operation on rolling terrain. Once the wheel-locking device is engaged, the driver should be instructed to raise the dump bed and release the tailgate as quickly as possible to surge the paver hopper.

When a wheel-locking device is not used, the experienced truck driver will anticipate the sudden rush of material into the paver hopper and briefly apply additional brake pressure to prevent the hauling unit from being forced out from the hopper and spilling material onto the pavement directly ahead of the paver. Without a wheel-locking device, it may be necessary for the driver to continually maintain a slight pressure on the brakes to

For both end-dump and live-bottom trucks, it is imperative that the trucks do not back all the way to the paver, bumping against it. Bumping the paver will create an indentation or bump in the mat that rolling cannot remove.

keep the truck from rolling away from the paver as the load is emptying. This is especially true when paving steep grades. Additional training for truck drivers is encouraged to minimize issues.

6.6.2 Windrow Paving

Windrow paving places the mix in a longitudinal windrow on the grade directly in front of the paver to facilitate a nonstop paving operation. A pickup machine operated in front of the paver picks up the material and places it in the hopper. Windrow paving operations are usually confined to warm, dry climates, where the chance of a surprise rainstorm cooling the material in the exposed windrow is minimal.

The dump operator plays a vital role in maintaining a quality paving operation. Proper windrow management will maintain continuous paving speed while minimizing segregation and heat loss. The quantity of mix on the grade is controlled by a dump operator as the hauling unit is unloaded and the size of the windrow is adjusted according to the level of material in the hopper. A well-trained crew can successfully pave for hours, producing a high-quality mix pavement without stopping.

The windrow-building process can allow the mixture to segregate, with the larger aggregate accumulating along the bottom outside edges of the windrow. Therefore, steps must be taken to ensure that the windrow pickup device picks up the entire windrow cleanly and that any segregated material is directed back toward the center of the material flow as it is moved through the windrow pickup device and into the paver. Adding plates to force the material into a smaller stream and keeping the volume of material in the hopper at a high level helps reduce mix segregation.

A uniform unloading process calibrated to the plant production and paver speed will assist in maintaining proper truck spacing and continuous paving. Once a windrow is started, each successive truck should back over and straddle the full cross-section end of the previously placed material to eliminate load-to-load segregation and maintain uniform windrow size. No more than one load of mix should be allowed to be exposed at any time.

6.6.3 Material Transfer Vehicle

The MTV (see Figure 78) is primarily used to transfer the material from the haul truck to the paver hopper. The use of an MTV has several benefits but adds additional cost to the paving operation. An MTV has been shown to improve smoothness and reduce segregation. For these reasons they are specified to be used on airfields and are required on many highway projects.

When used properly, an MTV makes it easier to have a nonstop paving operation. The material holding bin or belt on an MTV acts as a surge hopper and can hold up to 25 tons (23 tonnes) of mix. A special insert in the paver hopper holds an additional 15 tons (14 tonnes). With the equivalent of two to three extra truckloads of material immediately in front of the paver, this onsite material storage is valuable because it allows for continuous paving even when there is a delay in truck deliveries from the plant.

Source: NAPA

Figure 78. Material Transfer Vehicle

When an MTV runs out of material, the paver must stop, and a continuous paving operation is not possible. Keeping a constant stream of trucks in front of the MTV is therefore necessary if a continuous paving operation is to be achieved. If a gap occurs, the MTV should be stopped without being completely emptied when waiting for trucks so that a consistent minimum amount of mix is retained on the augers to mix with the new material delivered from the next haul truck. In addition, the paver should be stopped with its hopper half full so that the amount of mix in front of the paver screed remains constant and the proper smoothness of the mat is achieved.

Loading materials into an MTV is like loading into a paver. Direct feed with an end-dump or live-bottom truck or a windrow operation can be employed.

Offsetting an MTV from the lane being paved can have noted advantages too. Namely, this practice can keep all the construction vehicles out of the paving lane. This protects the tack coat from contamination or tracking, improving its performance. Operating an MTV in this manner is generally required on airfield paving projects.

The mass of an MTV is quite large. Therefore, an assessment of the existing material's ability to handle this loading without being damaged is important. Especially on low-volume roadways, caution is advised.

6.7 TRACKING QUANTITIES

During truck loading, the quantity (normally expressed in tons) is typically measured and stored electronically as part of the permanent project record. Each load is issued an individual and sequentially numbered load ticket that typically includes the type, quantity, and temperature of the delivered mix, the time of loadout, the accumulated total, and the identity of the truck. Also, any required Safety Data Sheet information can be preprinted on the back of the delivery ticket.

The quantity of mixture delivered from plant to paving site can be determined by one of the following three methods:

- Use a batch plant's calibrated and certified plant scales. Use the accumulated weight of individual batches dropped directly into a truck from the pugmill or from a surge bin.
- Weigh loaded trucks on scales that can measure the tare weight of the truck and net weight of the mix. The scale must be level, horizontal, and of sufficient length to weigh all the truck's axles at once.
- Use calibrated and certified load cells attached to the support legs of a portable surge bin to accumulate the subtraction of weight as the truck is loaded.

Paperless tracking of quantities is gaining favor with DOTs and contractors. This practice is known as e-ticketing. FHWA defines e-ticketing as "a paperless process for tracking, documenting, and archiving materials information, accessible in real time via mobile devices." Moreover, FHWA has promoted the use of e-ticketing via the inclusion of e-construction technologies in rounds 3, 4, and 6 of its Every Day Counts program. The NCHRP published a synthesis of the current state of the practice in 2020 with Synthesis 545, *Electronic Ticketing of Materials for Construction Management*. The COVID-19 outbreak has been credited with the expansion in the use of e-ticketing. The elimination of paper that is handled by multiple people was seen as a means to deter the spreading of the disease.

E-ticketing streamlines the management of information by automating the collection, handling, and verification of mix production data. This allows for the real-time capture of construction data, which can then be mined as needed either during or after a project is completed. The data is recorded and archived automatically, streamlining the process. The information captured on an e-ticket is the same as on the traditional paper tickets.

7. Mix Placement

7.1 INTRODUCTION

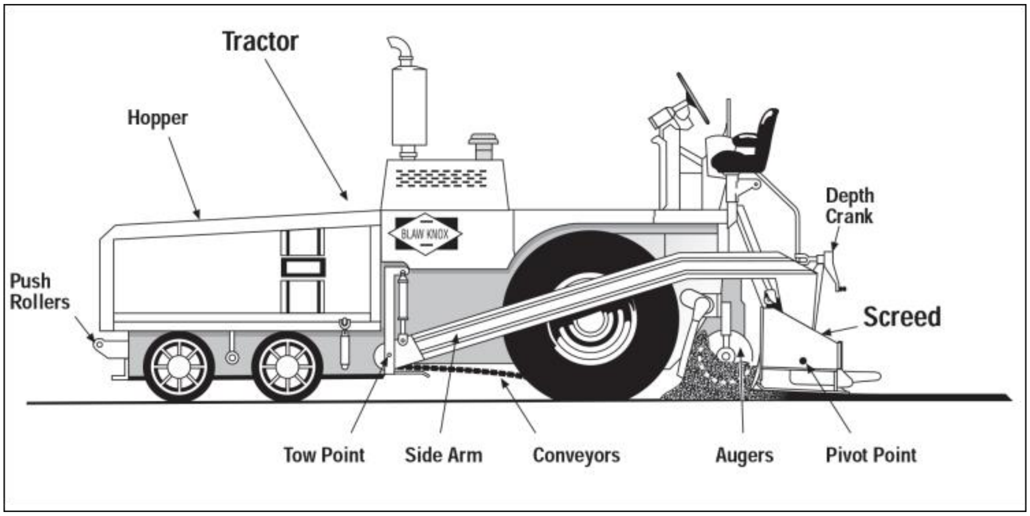
The placement operation (also known as laydown or paving) is a critical part of the construction of a quality, long-lasting asphalt pavement. It is important to understand the proper operation of the paving equipment and paving best practices to obtain a durable, smooth-riding pavement that meets the standards of quality construction. Some agencies require the contractor to submit a plan that outlines the practices and procedures that will be used during the laydown process. This is a great opportunity for both the contractor and agency to understand all aspects of the process to meet the agency's specifications.

A paver is used to place asphalt mixture to the desired width, grade, cross slope, and thickness with a uniform mat texture, thus improving the rideability and smoothness of the roadway. There are two types of pavers—track (crawler) and rubber-tire (pneumatic)—which perform similar functions in a paving operation.

The track paver, on which the tracks may be all steel, steel equipped with rubber pads, or an endless rubber track, offers a high degree of flotation and traction. A rubber-tire paver has a much higher travel speed and is more maneuverable than a tracked paver. When set up and operated properly, both types can place a smooth, uniform mat to meet the required project tolerances.

7.2 TRACTOR UNIT

A paver has two primary components: the tractor unit and the screed unit. The tractor unit provides all electrical, hydraulic, and propulsion energy required to complete placement operations in the field. The tractor unit performs the functions necessary to receive asphalt mix from haul trucks or MTVs or to pick up mix with a windrow elevator, carry it through the machine back to the augers, and uniformly distribute the mix across the width of the screed. The tractor unit tows a self-leveling screed unit through the mix as it is placed. The screed provides the initial texture and compaction to the mat as it passes out from under the screed. Figure 79 shows key elements of the tractor and screed units.



Source: Asphalt Institute

Figure 79. Schematic of Asphalt Paver

7.2.1 Push Rollers

The push rollers, located on the front of the paver hopper, are used to maintain contact with the tires of the haul truck and to push it ahead of the paver. The rollers must be clean and rotate freely to allow smooth forward travel of the paver. If the push rollers are not cleaned periodically and do not rotate freely, the truck tires will slide on the rollers and increase the load on the paver. Moreover, if one roller rotates freely and the other does not, the paver may be more difficult to steer.

Many pavers are equipped with a truck hitch located underneath or incorporated into the push rollers on the front of the paver, as shown in Figure 80. The purpose of the hitch is to keep the truck in contact with the paver and thereby prevent the truck from becoming disconnected and inadvertently dumping mix on the pavement in front of the paver. The hitch, which is controlled by the paver operator, has forward-extending arms with rollers attached. The rollers are retracted into the truck tire rim and against the tire itself, preventing the truck from losing contact with the paver during the unloading process. Once the truck bed has been emptied of mix, the truck hitch is withdrawn, and the truck is able to pull away from the paver.

Source: Asphalt Institute

Figure 80. Truck Hitch on Front of Paver

7.2.2 Material Handling System

The material feed system on the tractor unit plays a very important part in producing a consistent, high-quality mat behind the paver. The material feed system typically consists of a paver hopper, slat conveyors, material flow gates, and a pair of augers.

7.2.2.1 Paver Hopper

The paver hopper, shown in Figure 81, receives delivered mix and serves as a temporary storage area for material delivered from the haul vehicle, the windrow elevator, or the MTV. The hopper capacity allows the paver to maintain a constant forward motion between loads of mixture being delivered. Mixture delivery methods are detailed in Chapter 6.

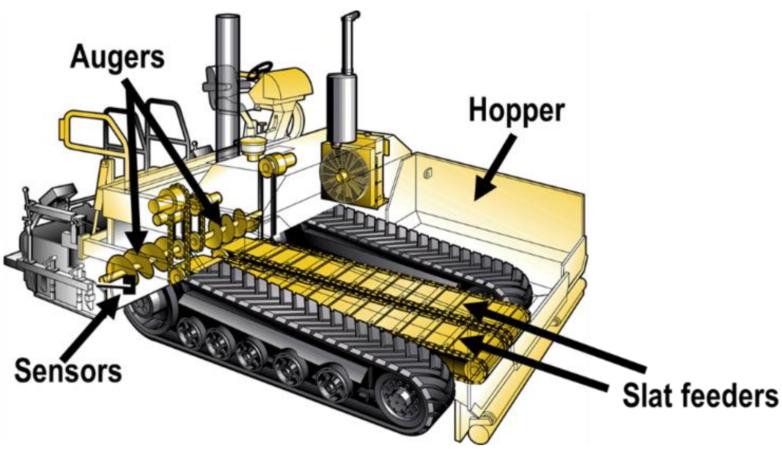
Source: Asphalt Institute

Figure 81. Paver Hopper Between Loads

7.2.2.2 Slat Conveyors

At the bottom of the paver hopper there is typically a set of slat conveyors consisting of heavy chains and flight bars (see Figure 82). The slat conveyors are a continuous system, with the slats being rotated back to the bottom of the hopper underneath the paver itself. These devices are used to carry the asphalt mix from the hopper through the tunnels on the paver and back to the augers. The slat conveyor on one side of the paver operates independently from the one on the other side. The conveyor system operates independently of the speed of the paver and, on most pavers, independent of the speed of the augers. Thus, the amount of mix being carried back through the paver on one side may differ from that being delivered on the other side, and the paver operator can change the feed rate to either side of the paver to pave shoulders, ramps, turnouts, etc.

On some pavers, the slat conveyor system has been replaced by a screw conveyor system. The purpose of this latter system is to remix the mix in the paver hopper and reduce segregation behind the screed.



Source: Asphalt Institute

Figure 82. Material Feed System

7.2.2.3 Flow Gates

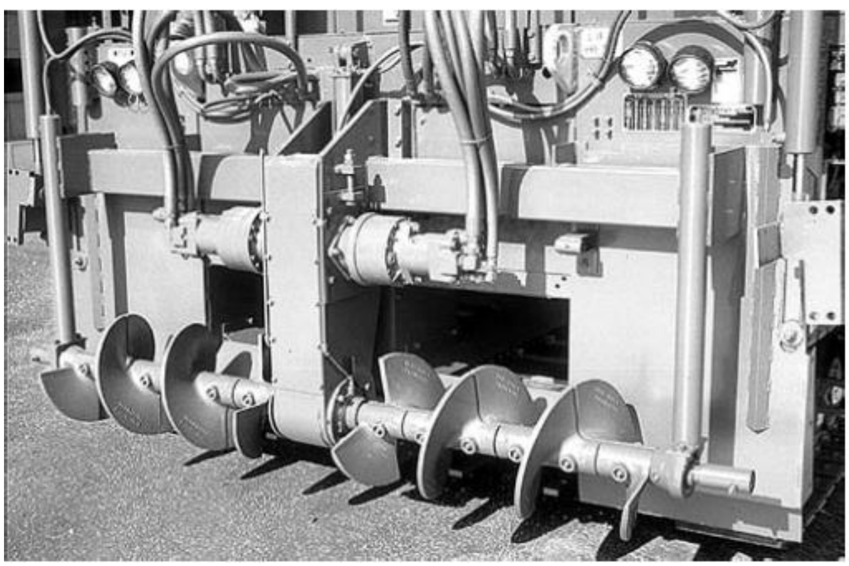
At the back of the paver hopper on many pavers is a set of flow gates. These gates, one over each of the two slat conveyors, are used to regulate the amount of mix that can be delivered by each conveyor. The flow gates should be adjusted to provide a uniform head of material (at a level at or just above the center of the auger shaft) in front of the screed. Flow gates are not required when the conveyor and respective auger are independently driven. If more mix is required on one side of the machine than on the other, the speed of the conveyor on that side is increased by the paver operator or by the automatic flow control system to deliver more material back to the augers, thus keeping the head of material in front of the screed consistent. The level of mix in the hopper should always be maintained above the level of the flow gates or tunnel openings at the back of the hopper.

7.2.2.4 Augers

The mix carried to the back of the tractor unit by the slat conveyors is deposited in front of the augers (see Figure 82). Like the two slat conveyors, the augers on each side of the paver are operated independently of one another. The auger on one side of the paver is run in conjunction with the slat conveyor on that same side of the paver. In addition, the paver operator has the option of running the left or right conveyor and auger system in either manual or automatic mode. In automatic mode, a feed control sensor on that side of the machine controls the level of material at the outside edge of the auger. It is extremely important that the augers carry a consistent amount of mix across the front of the screed so that the head of material in front of the screed remains as constant as possible.

It is extremely important that the augers carry a consistent amount of mix across the front of the screed so that the head of material in front of the screed remains as constant as possible.

At the junction of the two augers in the center of the paver, adjacent to each side of the auger gearbox, there typically is a differently shaped auger (reverse auger) or a paddle used to tuck mix under the gearbox and ensure that the mix placement at this location is the same as that across the rest of the width of the mix being laid. A paver equipped with a pair of reverse paddles is shown in Figure 83 with the screed removed.



Source: Asphalt Institute

Figure 83. Paver Auger with Reversing Center Flights

If sufficient mix is not placed under the center of the screed and tucked under the gearbox, a longitudinal streak may be seen behind the paver at the center of the screed. This streak can be a form of segregation when gravity allows the mix from the two conveyors to flow under the gearbox. The surface texture of the mat at that location can be more open than that of the adjacent mix and is generally darker in color. This, however, is not always a segregation problem. Rather, the rougher texture and darker color can be caused by a lack of mix placed under the gearbox. When carefully measured, the elevation of the mix in the streak may be slightly below that of the surrounding mix—the streak is actually a low spot in the mat surface. If a gearbox streak is visible at the center of the main paver screed, installation of a reverse auger or paddle system on the paver must be verified. If the reverse augers or paddles are present, adjustments should be made to tuck more mix under the gearbox; worn augers or paddles should be replaced as necessary.

The area around the auger is often referred to as the auger chamber. The auger chamber, shown in Figure 84, is bounded by the front of the screed, the base upon which the mixture is being placed, and the rear of the tractor unit. Modern pavers are equipped with variable height augers that can be changed as needed.

Source: University of Idaho Visual Productions

Figure 84. Auger Chamber

The horizontal distance from the auger to the screed front and the rear of the tractor unit should be equal if possible. A good rule of thumb is to maintain these distances at three times the maximum aggregate size of the mix.

The height of the auger from the base layer is normally set in accordance with the paving depth. A good rule of thumb is to set the distance from the base layer to the bottom of the augers equal to the loose lift thickness plus 2 to 2.5 times the maximum aggregate size in the mix being placed. When auger height is too low, imperfections in the mat texture can appear. The elevation of the bottom of the auger should never be even with or lower than the top of the mix being placed. If centerline segregation is noticeable, raise the augers an additional inch to allow more room for the mix to fill in the center of the auger box.

The amount of mix carried in the auger chamber should be as constant as possible. The proper depth of material on the augers is at the center of the auger shaft. The level of material carried in front of the screed should not be so low as to expose the lower portion of the auger flights. Further, the level of mix delivered to the screed should never be so high as to cover the upper portion of the auger. This constant level of material in front of the screed must continue all the way past the end of the auger. When paving wider than the basic screed, auger extensions and material confining plates (tunnel extensions) uniformly carry the mixture the full width of the screed. Ideally, the auger and tunnel extensions should be within 12–18 inches (0.3–0.5 m) from the end plate of the screed to minimize segregation and maintain a constant head of material in front of the screed, as shown in Figure 85.

Source: Reway

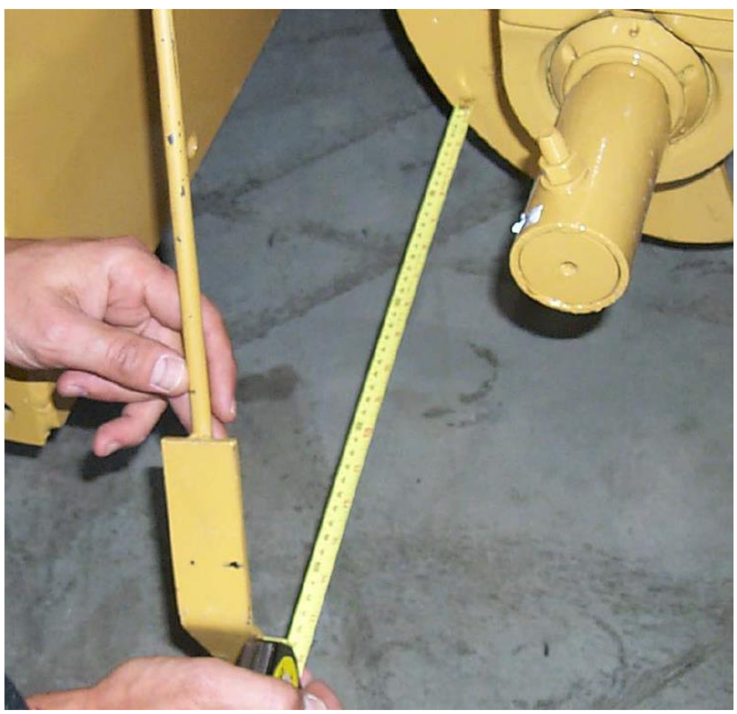
Figure 85. Uniform Head of Material at Axle Height

If the feed system is set and operating properly, the slat conveyors and augers on each side of the paver will rarely shut off; they will operate in a slow, continuous manner (20–40 revolutions per min). This continuous action of the conveyors and augers is accomplished by setting the proper position for the hopper flow gates (if any) and determining the correct speed setting for the conveyors and augers. The key to placement of a smooth pavement layer is the use of the material feed system to maintain a constant head (level) of material in front of the screed, primarily by keeping the slat conveyors and augers running as close to 100 percent of the time as possible. Intermittent operation of the slat conveyor and auger systems may cause roughness in the mat, as well as auger shadows and ripples in the mat behind the screed.

Material-control sensors precisely control the volume of material (head of material) in front of the screed. The auger/conveyor combinations on both the right and left sides of the paver work independently of each other, requiring separate material-control sensors. The sensors control the movement of material by starting, stopping, or running at variable speeds to furnish the correct volume of material to match the material demand based on the paving width, depth, and speed.

To operate properly, the sensors must monitor the live (constantly moving) head of material to provide a uniform flow of material in front of the screed. Original equipment manufacturers and aftermarket suppliers use different types of sensors and mount them in different positions to monitor and control the flow of material.

Two common types of material sensors are contact sensors and ultrasonic sensors. Contact sensors use a switching device, such as an on-off switch or potentiometer, that is activated by a paddle arm physically touching the flow of material. As the paddle arm, shown in Figure 86, approaches a near-vertical position, the auger drives start to deliver more mix until the arm reaches a preset angle and shuts off.



Source: University of Idaho Visual Productions

Figure 86. Paddle Switch

Ultrasonic sensors, shown in Figure 87, are non-contact devices that use sound waves to continuously monitor the face of material being carried in front of the screed. As mix is consumed, the distance being measured by the sensor increases and the auger systems are activated to replenish the volume of mix in front of the screed. To ensure an accurate reading, the sonic beam should be aimed perpendicular (approximately 90 degrees) to the active flow on the face of the mixture. The controller then varies the speed of the conveyors and augers on each side of the machine to maintain a constant level of mix across the front of the screed.

Source: Caterpillar, Inc.

Figure 87. Non-Contact Sensor

As the level of mix in front of the screed rises and falls, the speed of the feed system increases or decreases to maintain a constant level and uniform flow across the width of the screed. For the automatic feed control system to function properly, the feed sensors should be located as close to the outside ends of the augers as possible. If rigid paver screed extensions are used, the control arm should be mounted beyond the ends of the augers, just inside the end gate on the paver screed. If a hydraulically extendable screed is used, the location of the feed sensor control arm should be such that the amount of mix carried in front of the extensions is minimized. In most cases, this means the sensor should be mounted on the end gate of the paver screed and the sensor paddle or wand hung only a short distance in front of the end of the extendable screed.

7.2.3 Hopper Management

The amount of mix in the paver hopper should always be kept at a level above the top of the flow gates or tunnel openings at the back of the hopper. Doing so permits the paver operator to keep the conveyors on the paver full and thus maintain a constant head of material in front of the paver screed. This practice is particularly important between truckloads of mix to reduce segregation problems.

As shown in Figure 88, the sides, or wings, of the hopper are movable. It is considered a best practice to not fold (dump) the wings. However, some paver operators fold the wings of the paver between every load of mix. To prevent spillage of the mix out of the front of the hopper when the wings are folded, the operator often pulls down the amount of mix left in the hopper by continuing to run the slat conveyors, which results in the slat conveyor running empty. This can allow mix to segregate as it trickles down to the conveyor, as illustrated in Figure 89. The material in the outer edge of the wings can become segregated when discharged from the truck. In addition, the mix in the stagnant area of the hopper will begin to cool. This cooling can become significant, especially in cooler weather. This is a perfect formula for the truckload-to-truckload segregation discussed in Chapter 10.

Source: Asphalt Institute

Figure 88. Folding Hopper Wings

Source: Asphalt Institute

Figure 89. Poorly Managed Paver Hopper

To prevent asphalt mix from collecting in the corners of the paver hopper, a fillet can be placed in each corner of the hopper. A triangular piece of sheet steel bolted to the sides of the hopper will prevent mix from being carried in the corners of the hopper. It is also possible to simply not empty the wings of the paver during the paving day. The mix will cool and build up a natural angle of repose. At the end of the day, the cold material is removed from each wing area and transported back to the asphalt plant for recycling.

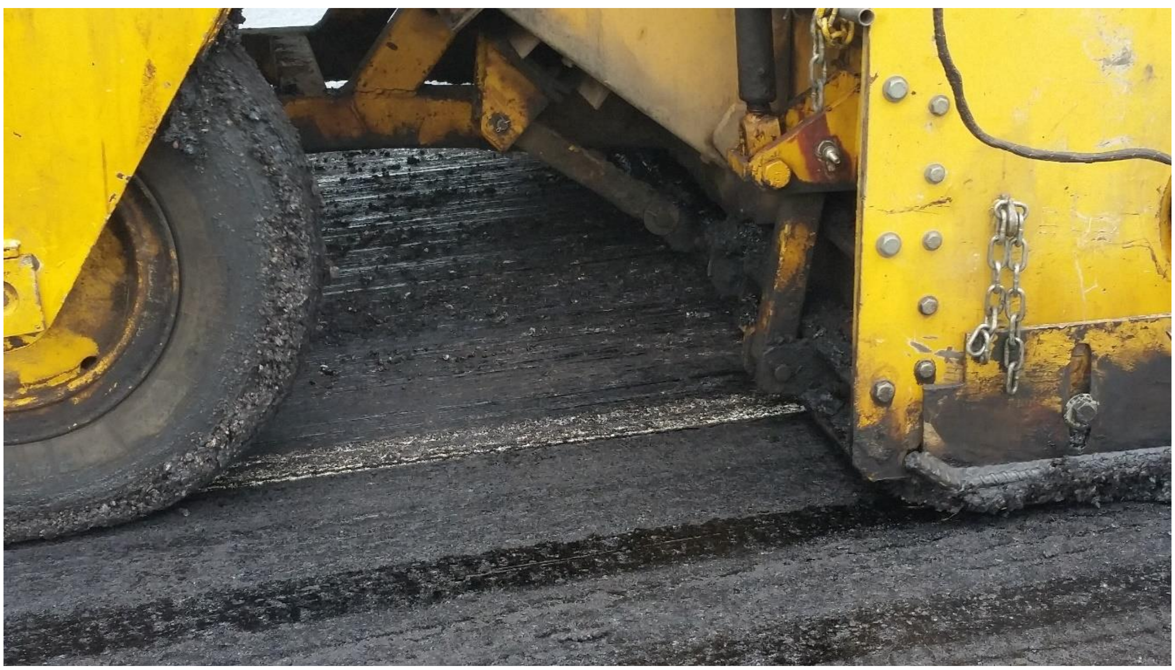
The best practice is to avoid asphalt mix from collecting or cooling in the wings by using a hopper insert as described in Chapter 6 and using an MTV or window elevator to feed the paver. The steep sides of a hopper insert provide for constant live action focused directly over the slat conveyors and eliminate segregation caused by the paver hopper. This also disconnects the transport vehicles from the paver, reducing dump time and inadvertent contact with the paver. Keeping the hopper full between truckloads of mix helps maintain a constant head of asphalt mix in front of the paver screed and reduces mixture and equipment heat loss. In addition, a paver hopper insert adds material storage, which helps maintain continuous paving.

When it is necessary to fold the wings, the wings should be emptied before the mix that collects in the corners of the hopper has cooled. The sides of the hopper should be slowly raised as soon as the haul truck has been emptied and has pulled away from the paver. A steady forward paving speed of the laydown machine should be maintained as the hopper sides continue to rise. The wings should be fully elevated before the amount of mix remaining in the hopper is lower than the top of the flow gates or the openings at the back of the hopper. The slat conveyors should never be visible at the time the wings are raised—or at any other time during the paving operation. The paver should be stopped before the tunnel openings or flow gates are visible, and the sides of the hopper then lowered.

When using a windrow elevator (shown in Figure 90 and Figure 91), the blades on the slat conveyor must be set at the right level to pick up as much of the mix that has been placed on the existing pavement as possible. Essentially, no mix should be left in the windrow, except a minimal amount in the low spots on the pavement surface when a leveling course is being placed. Any thin layer of material remaining will cool quickly and may result in difficulties in compacting the mix. In addition, longitudinal streaks may occur in the mat behind the paver at the same location as the outside edges of the windrow.

Source: Asphalt Institute

Figure 90. Windrow Elevator



Source: Asphalt Institute

Figure 91. Windrow Elevator Picking Up the Entire Windrow

7.3 SCREED UNIT

The screed unit, which is towed by the tractor unit, establishes the thickness of the asphalt layer and provides the initial texture to the new surface. In addition, through its weight and vibratory action, the screed imparts the initial density into the material being placed.

The concept of the free-floating paver screed was developed in the early 1930s. The design allows the paver screed to average out changes in grade or elevation experienced by the wheelbase (rubber tires or crawler tracks) of the tractor unit. The floating screed concept is employed on all modern asphalt pavers in use today.

Screeds are classified into two basic types: fixed-width and hydraulically extendable. A fixed-width screed consists of one screed frame that is typically 8 or 10 ft wide. Fixed, bolt-on extensions, shown in Figure 92, must be attached to increase the paving width. Fixed-width screeds are less complex and more rigid, which makes it easier to create uniform layer density from edge to edge when paving wide widths.

Source: Asphalt Institute

Figure 92. Fixed-Width Screed with Vibratory Bolt-On Extensions

Hydraulically extendable screeds are the most common screed type in use today. Continuously variable widths up to twice the width of the main screed provide increased versatility. Hydraulic screed extensions, shown in Figure 93, are able to pave variable-width pavement sections while the paver is in motion. Lane bump-outs, tapered lanes, and radius sections are just a few examples.

All screed extensions, either fixed or hydraulically extended, must be properly adjusted to place an asphalt mat to the desired thickness, providing a uniform surface across the top of the mat.

Source: NAPA

Figure 93. Extendable Screed Paver

Hydraulic screed extensions are mounted in one of two ways, either in front of or behind the main screed. Front-mounted extensions move in and out in front of the main screed. Front-mounted screeds can be retracted more easily than rear-mounted extensions. This is because the front-mounted screeds can displace the head of the mix into the main auger chamber as they are retracted. Rear-mounted screeds must deal with the compression of the paving mix against the end of the main screed as they are retracted. Hence, front-mounted screeds are more often seen on urban-type projects, and rear-mounted screeds are preferred by crews that pave mainline highways and airfield projects that require less frequent width changes.

7.3.1 Tow Points

The screed unit is attached to the tractor unit at only one point on each side of the paver. This point, shown in Figure 94, is called the tow (or pull) point. The tow points are pin-type connections that allow the leveling arms (also called side arms, pull arms, or tow arms) of the screed to freely rotate or pivot around those points. The tow points are mounted to the end of a hydraulic cylinder that is fixed to the tractor frame. The height of the tow points can be manually adjusted or controlled automatically by the paver. Automatic screeds are thoroughly discussed in Section 7.4.

7.3.2 Line of Pull

The line of pull refers to the angle at which the screed is pulled forward. A smoother pavement surface is generally placed when the towing force is applied parallel to the final surface that is being placed. Thus, the elevation of the tow points should be set in relation to the thickness of the mat being constructed. Generally, thin lifts of HMA require a lower initial tow point setting, while thick lifts of mix require a higher initial setting.

Source: University of Idaho Visual Productions

Figure 94. Tow Point and Line of Pull

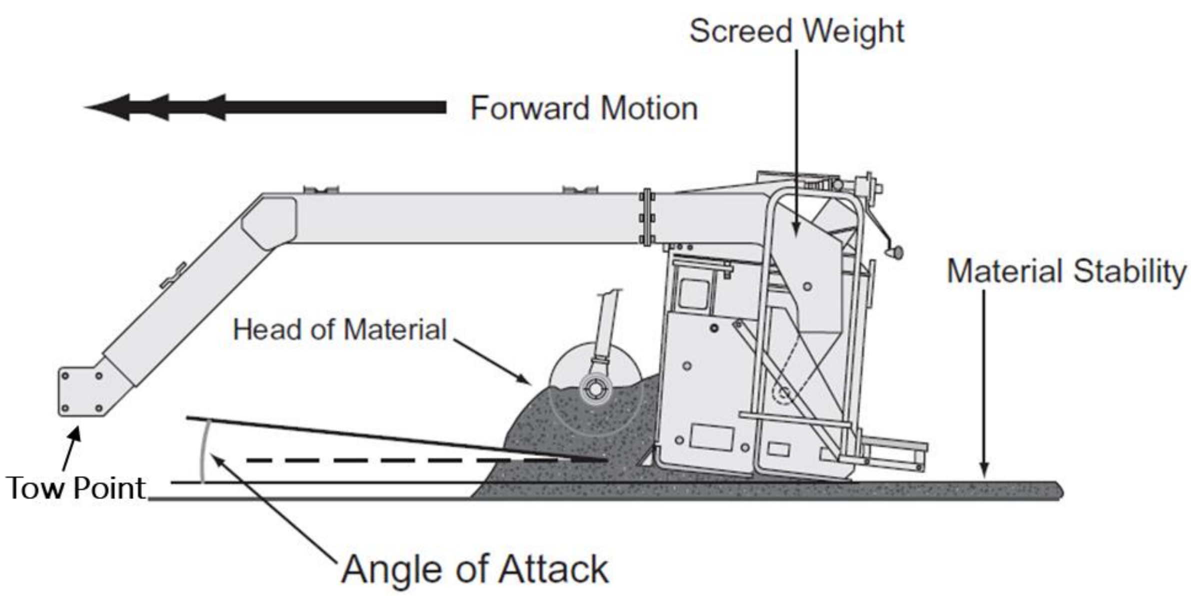
For a relatively thin mat, if the tow point setting is extremely high, the towing forces are applied at an upward angle that increases the lift forces acting on the screed. To maintain a given thickness of material, the angle of attack of the screed must then be decreased to compensate for the increased lift. In this condition, the screed runs at a slightly nose-down angle of attack. Only the front portion of the screed is then compacting and finishing the HMA being placed; the result is poor mat texture and extreme wear on the front portion of the screed plate. In addition, when the paver stops, the screed can have a tendency to rock or teeter as the tractor relaxes the tension on the screed. This may increase the amount of settling of the screed and introduce bumps into the mat.

For a relatively thick mat, if the tow point setting is extremely low, the towing forces are applied at a downward angle that decreases the lift forces applied to the screed. To maintain a given thickness of HMA, the angle of attack of the screed must then be increased to compensate for the decreased lift. In this condition, the screed runs with the rear portion of the screed bearing the majority of the compacting and finishing pressure. This causes poor mat texture and extreme wear on the rear portion of the bottom of the screed plate. Increased control of the forces applied to the screed is gained by setting the tow points in relation to the thickness of the mat being placed.

The floating screed principle is able to operate under manual control. When operated under manual control, it is important that the tow points on both sides of the tractor are at the same level above the base layer. The position of the tow points can be altered by raising or lowering the tow point mounts. For most asphalt mixtures, the tow points are positioned near the middle of the tow point range of movement. For some asphalt mixtures, such as those that are very stiff or very tender, it may be advantageous to raise or lower the elevation of the tow points to improve the texture of the mat being placed.

7.3.3 Forces Acting on the Screed

The ability of a free-floating screed to function is the result of the delicate balancing of forces that react on the screed (see Figure 95). The forces on the screed must be in equilibrium (the sum of all forces equal to zero) for the free-floating screed to remain suspended in the mix as it is towed by the tractor unit. The forces exerted on the front of the screed and below the screed are counteracted by the weight of the screed and the angle of attack. When a change in any one force occurs, the screed will rise or fall until it reaches a new equilibrium, and the thickness of the mat being placed will change accordingly.



Source: Asphalt Institute

Figure 95. Elements That Impact Screed Forces

Many forces impact the screed. It is important to understand those forces that are most easily managed in the field: the angle of attack, paver speed, head of material, and mixture properties (temperature).

> *The forces on the screed must be in equilibrium (the sum of all forces equal to zero) for the free-floating screed to remain suspended in the mix as it is towed by the tractor unit.*

7.3.3.1 Angle of Attack

The forward end of the screed tow arms attaches to pivot points at the tow point on the paver. The tow point pivot is always free to rotate as the screed is towed through the mix. There is another pivot at the rear of the tow arms where it attaches to the screed. This screed pivot is locked into position by the thickness control device (screw) located on the screed. The position of this locking screw establishes the angle of attack.

The pitch of the angle of attack contributes significantly to the upward force on the screed and allows the free-floating screed to function. If no other force acting on the screed changes, an increase in the angle of attack will increase the upward component of force acting on the screed. Decreasing the pitch reduces the upward force on the screed. The screed elevation will respond to changes of force until the forces exerted on the screed return to equilibrium.

The tow point elevation and the angle of attack should be adjusted so that there is uniform pressure on the bottom of the screed plate (from front to back) while paving at the desired thickness. If the angle of attack is too low, there will be excessive pressure and wear on the nose of the screed; if too high, that pressure and wear will be on the tail of the screed. Both conditions can result in nonuniform texture problems and roughness in the finished mat surface.

7.3.3.2 Paver Speed

The upward force exerted on the screed changes as the speed of the paver increases and decreases. As the speed of the paver increases, the upward force created by the material passing under the screed is reduced. When this force is reduced, the weight of the screed causes it to fall. If the tow point remains unchanged, the falling screed rotates about the tow point pivot and increases the angle of attack until equilibrium is reached at a new elevation (thinner mat). Conversely, when the paver speed decreases, the friction is increased, creating more force against the screed. The screed rises until the decreasing angle of attack and weight of the screed reach equilibrium with the increased force of the mix. Because the speed of the paver has a major effect on the angle of attack of the paver screed, it is good paving practice to keep the speed as consistent as possible during laydown operations.

Ideally, the speed of the paver should be matched to the production rate of the asphalt plant. Assuming the paving day length is the same as the plant production day, the ideal paving speed is when the paver consumes the mix at the same rate it is produced by the plant.

As an example, if an asphalt plant is producing 300 tons per hr for 10 hrs, it would produce 3,000 tons per day. If the pavement being placed requires 1,000 tons per mi, the plant will produce a 3-mi (15,840 ft) length of pavement. If that length is to be paved in 10 hrs (600 min), the theoretical paving speed would be 15,840 ft divided by 600 min, which equals 26.4 ft per min.

Should the pavement being placed require 1,500 tons per mi, the length would be 2 mi per 10-hr day. In this case, the paving speed is 10,560 ft divided by 600 min, which equals 17.6

ft per min. Every project will be different, but consistent, nonstop paving should be the goal. Section 7.5 provides an in-depth discussion on calculating yield.

When the paver needs to be stopped, it should be stopped as quickly and smoothly as possible before the level of mix in the hopper is drawn down below the top of the flow gates or the tunnel openings.

As noted previously, to achieve the smoothest possible mat behind the paver screed, it is essential to keep the paver always moving at a constant speed. Running the paver faster than necessary to place all the delivered mix and then stopping to wait for the next haul truck to arrive at the paving site will diminish the quality of the mat.

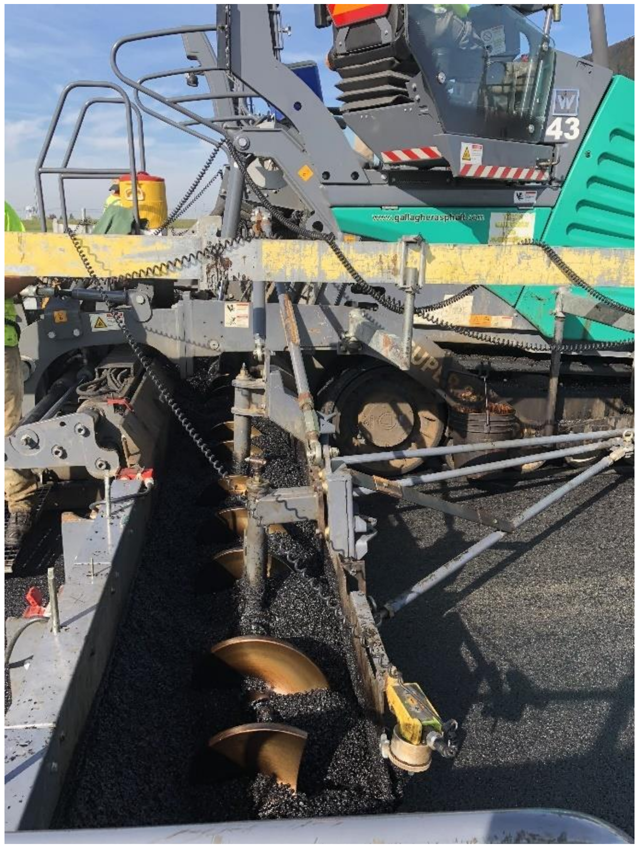
When the paver needs to be stopped, it should be stopped as quickly and smoothly as possible before the level of mix in the hopper is drawn down below the top of the flow gates or the tunnel openings. This will keep the head of material in front of the screed constant while the effect of the change in the paver speed on the angle of attack of the screed is minimized because of the rapid speed change. The paver operator should return the laydown machine to the desired paving speed as quickly as possible to minimize the effect of the change in paver speed on the angle of attack. It has been found that the "rapid stop, rapid start" procedure for stopping the paver provides for good mat smoothness and consistent mat thickness.

It is good paving practice for the paver to remain in one position, with the hopper as full as possible and the head of material constant, until additional mix arrives. If a long delay is expected, consideration should be given to constructing a transverse joint.

7.3.3.3 Head of Material

The head of material is the amount of asphalt mix in the auger chamber that exerts force against the screed. When the head of material changes, the net force acting on the screed also changes. As the forces acting on the screed change, the screed must come to a new angle of attack to compensate for the change in force acting on it.

The head of material in the auger chamber is directly affected by the operation of the slat conveyors and augers on each side of the paver. When the slat conveyors and augers are operating, the mix is pulled from the paver hopper, through the tunnel, and is distributed across the front of the screed by the augers. If the flow of material and paver speed is relatively constant, the head of material pushing against the screed remains relatively constant as well, and the mat being placed has a smooth and consistent texture (see Figure 96).



Source: Asphalt Institute

Figure 96. Paving Wide with a Uniform Head of Material

If the head of material is allowed to vary, the screed moves up and down in reaction to the forces acting on it. When the amount of mix being carried by the augers is decreased because the slat conveyor and auger systems are running low or shut off, the screed moves downward, thus reducing the thickness of the mat behind the screed. As the slat conveyor and auger systems come on, more mix is carried back to the augers and across the front of the screed. This increases the force on the screed and causes it to rise to a new elevation, resulting in a thicker mat. Thus, it is very important to regulate the amount of mix in front of the screed since a consistent head of material in front of the screed is associated with a consistently smooth mat behind the paver.

7.3.3.4 Mixture Stiffness

Another factor that affects the balance of forces on the screed is the temperature or consistency of the mix. If a cold load of material is deposited in the paver hopper, the stiffer mix increases the force acting on the screed and causes the screed to rise, increasing the thickness of the layer placed. If, on the other hand, a hot load of mix is delivered to the paver, the decrease in viscosity of the binder material reduces the stiffness of the mix and reduces the force exerted on the screed. This situation causes the screed to fall and reduces the layer thickness. The mixture type can also play a role in the amount of force exerted by the head of material against the screed. For example, a coarse mix with a highly modified asphalt binder is stiffer than a sandy mixture with an unmodified binder.

7.3.4 Thickness Controls

As noted earlier, the screed is attached to the leveling or tow arms on each side of the paver through pivot points. The thickness control mechanism, usually either a crank or a handle, allows the screed to be moved or rotated around a pivot point. The key to the leveling action of the screed is the attachment to the tractor unit at tow points that pivot. This allows the screed to react to the forces exerted on it and remain in an equilibrium position. As the mix passes under the screed plate, the screed floats through the mix, establishing the mat thickness and the texture of the surface while providing the initial compaction of the mat.

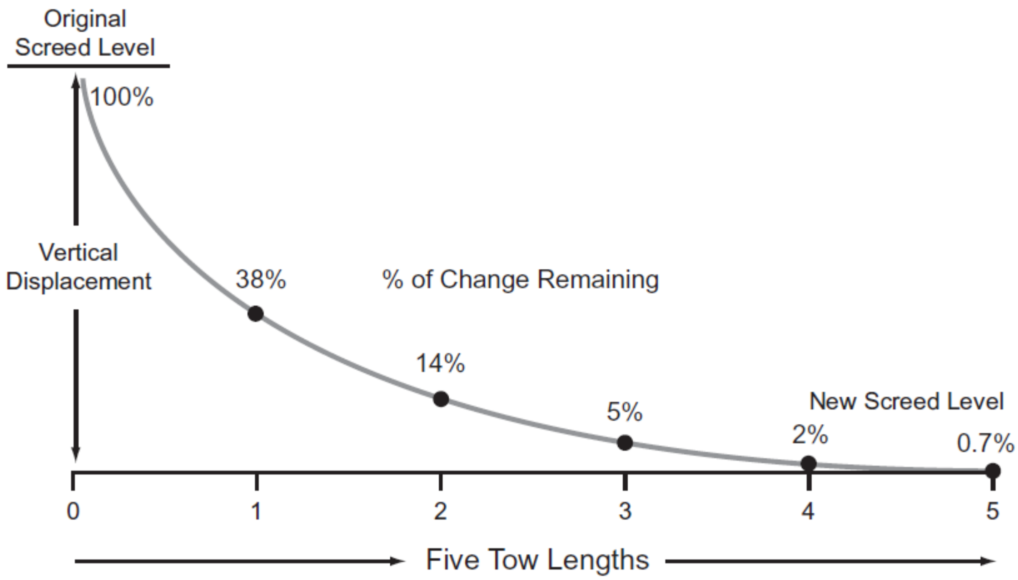
The key to the leveling action of the screed is the attachment to the tractor unit at tow points that pivot. This allows the screed to react to the forces exerted on it and remain in an equilibrium position.

7.3.4.1 Changing the Thickness Control Screws

For a constant position of the tow points (the tractor unit running on a level surface and without automatic screed controls), altering the setting of the thickness control screws changes the angle of attack of the screed and the forces acting on the screed. This in turn causes the screed to move up or down to a new elevation as the paver moves forward, thus altering the thickness of the mat being placed. The reaction of the screed to changes in the angle of attack is not instantaneous. There is a lag in the reaction that allows the screed to average out variations in the input forces acting on it.

Figure 97 shows the reaction time of the screed when a change is made to the angle of attack, either at the screed or at the tow points. It takes approximately five times the length of the tow arms for the screed to complete 99 percent of the change, up or down, to the desired new elevation. This means that if the length of the tow arms is 10 ft (3 m), the paver must move forward at least 50 ft (15 m) before a thickness-control screw change is completely carried out by the paver screed. The same applies if the angle of attack of the screed is changed by the automatic screed controls changing the height of the tow points.

Reaction of the Screed over Five Tow Lengths



Source: Asphalt Institute

Figure 97. Distance Required for the Screed to Reach Equilibrium

It is essential for the screed operator to be aware of this lag in the reaction time of the screed. If a second change in the setting of the thickness control crank is made before the first change has been accomplished, the first change will never be completed, and it will still take an additional five times the length of the leveling arm for the second thickness change to be carried out. For this reason, continual changes in the setting of the thickness control devices are likely to be highly detrimental to the pavement smoothness.

Because of the delayed reaction time of the screed, a single mat-depth measurement should not be used to justify a change in the angle of attack of the screed. Indeed, even two or three measurements should not be averaged to determine whether a change in the setting of the thickness control cranks is needed. If the uncompacted thickness of the mat is to be checked using a depth gauge, the mat thickness behind the screed should be measured at least five times at 6-ft (2-m) intervals longitudinally. A better way to periodically check yield is to determine the distance 10 truckloads of mix should cover, based on the width and uncompacted thickness being laid. This distance is then compared with the length of pavement the paver has actually placed using the same number of tons of mix. If the distance covered is significantly different than it should have been, the setting of the thickness control cranks should be changed to slightly adjust the angle of attack of the screed to achieve the desired result.

Continual changes in the setting of the thickness control devices are likely to be highly detrimental to the pavement smoothness.

7.3.4.2 Changing the Tow Point Elevation

The above discussion also applies when there is a change in the height of the tow points on the tractor unit. If the height of the tow points moves, the change in their elevation translates to a change in the angle of attack of the paver screed. The paver must still move forward for approximately five times the length of the leveling arm on the machine for the screed to react to the change in the location of the tow points and move up or down to the new elevation. As a roadway is being paved without the use of automatic grade and slope controls, the tractor unit moves upward and downward in response to the grade of the underlying pavement. The vertical movement of the tractor translates into vertical movement of the tow points on the sides of the paver. Each time the tractor goes over a hump or into a dip in the existing pavement surface, the elevation of the tow points changes. This in turn alters the angle of attack of the screed, causing the amount of material flowing under the screed to be decreased or increased. The fact that it takes five times the length of the leveling arm before the screed reacts completely to a change in the location of the tow points allows the screed to reduce the thickness of the asphalt mix being placed over the high places in the existing surface and to place more mix in the low spots of the roadway. It is this averaging or leveling action that forms the basis for the floating screed principle discussed earlier.

The use of automatic paver controls, discussed in the next section, allows the paver to construct a smoother pavement by keeping the location of the screed tow points constant, relative to a predetermined reference, as the tractor unit moves up and down vertically in response to small changes in the grade of the underlying pavement surface. By maintaining the tow points at a constant relationship to the predetermined reference while the tractor moves vertically, the force on the screed remains constant, and the angle of attack of the screed is consistent in comparison with the reference. This allows the screed to carry out the leveling action needed over a longer reference length to reduce the roughness of the existing surface through the application of the new asphalt layer.

7.3.5 Screed Strike-Offs

The screed on some pavers is equipped with a plate on its front edge called a strike-off (or sometimes a pre-strike-off). The purpose of this device is to control the amount of mix allowed to pass under the nose of the screed, thereby affecting the screed's angle of attack. The strike-off is also used to reduce the wear on the leading edge of the screed.

When a strike-off is present, its position is important. If the strike-off is set too high, extra material is fed under the screed, causing the screed to rise. The resulting increase in the mat thickness must be overcome by manually reducing the angle of attack of the screed using the thickness-control cranks. This in turn causes the screed to pivot around its pivot points and ride with a lower angle of attack. Rapid wear of the screed nose plate results because the front portion of the screed is doing most of the compacting and finishing. This often leads to inconsistent mat texture. In addition, the screed settles more when the paver is stopped between truckloads of mix because the screed's weight is carried only on its front.

When the strike-off is set too low, the thickness of the lift is reduced because not enough mix is allowed to pass under the screed. To maintain the proper mat thickness, the angle of attack of the screed must be altered, causing the screed to ride on its tail in a slight nose-up attitude. This increases the wear on the back edge of the screed and reduces the compactive effort applied by the screed. It also causes the screed to settle more whenever the paver is stopped because of the concentration of the screed's weight on a smaller surface area.

The exact location of the strike-off depends on the make and model of paver being used and the thickness being placed. For relatively thin layers of pavement (1 inch [25 mm] thick or less), the strike-off is usually placed lower than when thicker lifts of mix are being placed. Similarly, for thick lifts of asphalt pavement (greater than 2 inches [50 mm]), the strike-off assembly is usually raised slightly above the normal position. In general, the strike-off is located in the range of 3/16 to 1/2 inch (5 to 13 mm) above the bottom plane of the main screed plate. No compaction of the mix occurs under the strike-off.

7.3.6 Vibratory Screeds

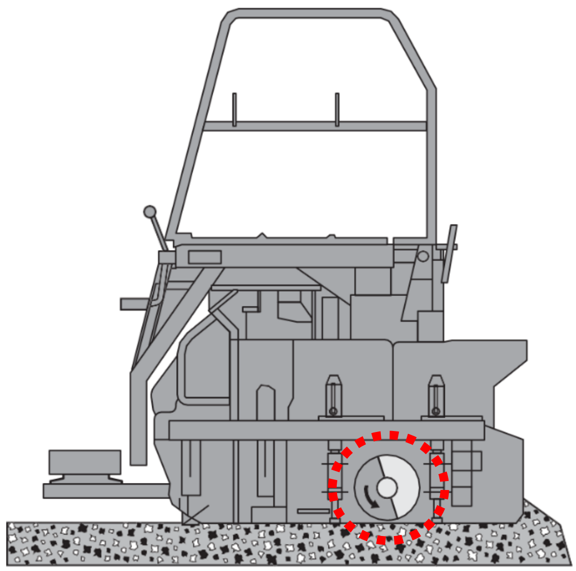
The amount of compaction imparted to the asphalt mix by the screed is a function of many variables. The properties of the mix itself are important—its stiffness, its temperature, and the amount of asphalt binder and moisture it contains all affect the ability of the screed to densify the mix. The degree of compaction achieved is also affected by the amount of bearing pressure applied to the mix by the screed, as well as the thickness of the mat passing under the screed.

Screed vibration is achieved using a rotating shaft and counterweight. Two elements of the vibrating screed (see Figure 98) contribute to the degree of compaction achieved: the frequency of vibration (number of vibrations per minute) and the amplitude (amount of force) imparted by the screed. Increasing the revolutions per minute of the shaft will increase the frequency of the vibration and the compactive effort. Typically, the vibrators should be used at the highest frequency setting to obtain the maximum compactive effort.

Vibrators should be used at the highest frequency setting to obtain the maximum compactive effort.

The applied amplitude is determined by the location of the eccentric weights on the shaft. The position of the eccentric weights can be altered to increase or decrease the amount of compactive effort applied. Typically, the amplitude setting selected is related to the thickness of the mat being placed—lower amplitude for thinner lifts and higher amplitude for thicker lifts.

The density achieved by the paver screed is also a function of the speed of the paver. As the paver moves faster, the screed dwells for less time over any given point in the new mat, and the amount of compactive effort applied by the screed decreases. It can be expected that approximately 70 to 90 percent of the theoretical maximum density (TMD) of the HMA will be obtained when the mix passes out from under the paver screed.



Source: Asphalt Institute

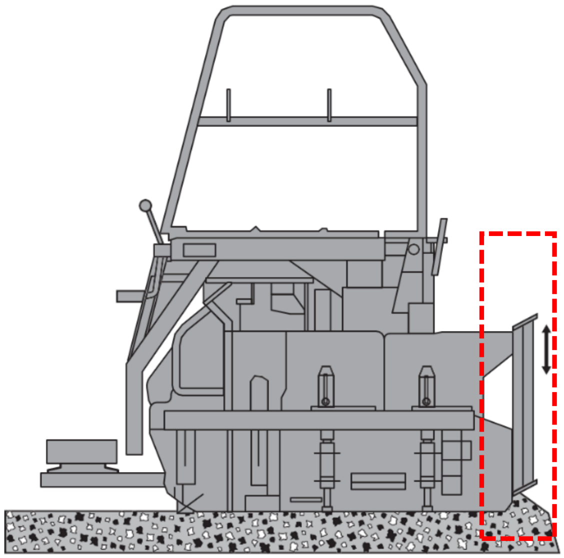
Figure 98. Vibrating Screed

7.3.7 Tamper Bars

Some screeds have vertical tamper bars at their leading edge (see Figure 99) that serve a dual purpose: they strike off the mixture and direct the mix under the screed. This can often produce a greater initial density than a vibratory screed.

At higher paving speeds, the tamper-bar system does not have enough time to tuck the material under the screed. The speed at which this becomes an issue varies depending on mix properties and lift thickness. This can result in a surface texture where the surface aggregates appear to be dragging along behind the screed or even a torn asphalt pavement surface. Some pavers have screeds with dual tamper bars—a second line of tamper bars behind the first. While a second tamper bar may add additional initial density and allow for faster paving speeds, it makes the screed mechanically more complicated and harder to maintain.

To operate properly, tamping bars must be adjusted and maintained according to the manufacturer's recommendations. Tamper bars typically protrude below the leading edge of the screed just enough to catch a fingernail on it, or 1/64–1/32 inch (0.4–0.8 mm). An agency-approved release agent should be applied at the end of each shift to keep bars from seizing up at the start of the next paving cycle.



Source: Asphalt Institute

Figure 99. Tamping Bar Screed

7.3.8 Screed Heaters

The screed is equipped with two or more heaters, or burners, depending on the age and model of the paver. The purpose of the heaters is to preheat the plate on the bottom of the screed to the temperature of the mix being laid. The screed should be heated before paving operations begin and at any time the screed has been raised out of the mix for an extended period. The screed should be at nearly the same temperature as the asphalt material passing under it to ensure that the mix does not stick to the screed plate and tear, imparting a rough texture to the mat. A properly heated screed provides for a more uniform mat surface texture and a more consistent mat thickness. To preheat the screed, the heaters are normally operated for a period of 10 to 20 min before the laydown operation begins. Care should be taken to avoid overheating, which can cause permanent warping of the screed plate. Electric screed heaters tend to provide more uniform heating of the screed. Usually within 10 minutes after paving has begun, the temperature of the screed plate has increased to the point at which it can generally be maintained by the temperature of the mix passing under it. Thus, the heaters are not needed and are shut off. A major misconception is that the heaters can be used to heat up cold material as it passes under the screed. This is simply not true. Only the very top surface of the mix is warmed up slightly, while the bottom of the screed may be superheated to the point of warping. For the same reasons, the

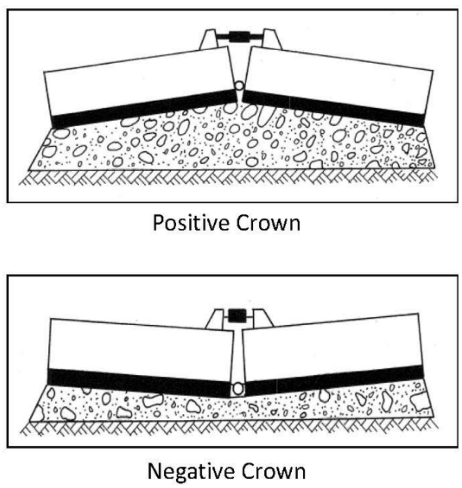
A major misconception is that the heaters can be used to heat up cold material as it passes under the screed.

screed heaters should not be used to increase the temperature of the mix sitting under the screed for a period of time while awaiting the arrival of the next haul truck.

7.3.9 Screed Crown

When paving crown into the pavement cross section (such as the centerline of the pavement), the screed can be angled at its center to provide the correct slope (see Figure 100). The amount of crown that can be introduced into the screed varies with the width of the screed and with the make and model of the equipment.

The crown is typically adjusted using a turnbuckle device to flex the bottom of the screed and impart the desired degree of crown. When rigid extensions are used, the cross-sectional profile of the mat can be altered at any of the points where the extensions are joined (such as when paving a different shoulder slope). If a hydraulically extendable screed is being used with the paver, the crown can be introduced not only in the center of the screed, but also at the points between the screed and the hydraulic extensions.



Source: Asphalt Institute

Figure 100. Screed Crown

When paving flat sections (one lane at a time), some paver manufacturers recommend that the screed be warped slightly, from front to back in its center, to facilitate the passage of mix under the screed and to obtain a more uniform texture on the asphalt mat. This process involves setting the lead crown on the screed slightly above the tail crown on the screed. In general, there should be more lead than tail crown, but the amount of difference depends on the make of paver and the type of screed. Normally the lead crown setting is 1/32 to 3/16 inches (1 to 5 mm) greater than the tail crown setting, with 1/8 inches (3 mm) being the average difference between the crown settings. For hydraulically extendable screeds, some paver manufacturers do not recommend setting any amount of lead crown into the front edge of the screed.

Because of different recommendations for different makes and models of pavers, it is suggested that the manufacturer's operation manual be consulted before the crown is set into the screed.

7.4 GRADE CONTROL

The goal of the grade control system is to maintain the screed tow points on a smooth line of pull as the paver travels forward. The self-leveling action of the screed takes place continuously as the tractor unit travels over the roadway. The thickness of the asphalt mat being placed is determined by the reaction of the screed to the location of the tow points, the speed of the tractor, and the head of material in the auger chamber. The entire operation occurs without the thickness-control cranks on the screed ever being changed.

7.4.1 Manual Grade Control

It is easy to visualize that if a paver were a single axle unit with the tow points fixed to the axle, the tow point elevation would directly follow the existing surface, with minimal improvement to the final surface smoothness. Because pavers have multiple axles, with the tow points being roughly in the middle of the paver's wheelbase, the length of the paver wheelbase becomes the reference. Thus, based on the combination of the tow point movement being the average of the wheelbase and the delayed screed reaction, under manual screed control the screed will average out deviations in the roughness by placing more mix over the low points and less mix over the high points of the existing surface.

7.4.2 Automatic Grade Control

Automatic grade controls enable the tow point to refer to a reference system that is not directly tied to the movement of the tractor unit but to a reference line established by a mobile ski, preset stringline, or remote (three-dimensional [3-D]) control. Automatic grade controls adjust the tow points up or down to maintain a constant height difference between the tow point and the reference line. Keeping the elevation of the tow points constant in direct relationship to the reference permits the screed to maintain a more consistent angle of attack, which in turn provides for a smoother mat behind the screed.

Many factors affect the smoothness of the mix placed by the paver. The use of automatic screed controls by itself does not ensure that the mat constructed will be smooth. Proper attention to the operation of the paver, as discussed in Section 7.3, is extremely important to obtaining a smooth-riding pavement layer. In addition, it is important to remember that because the free-floating screed places more mix in low spots and less mix on high spots, differential

It is important to remember that because the free-floating screed places more mix in low spots and less mix on high spots, differential compaction of the asphalt mix will result in a compacted surface that is rougher than the surface placed.

compaction of the asphalt mix will result in a compacted surface that is rougher than the surface placed.

7.4.2.1 Mobile References

There are several types of mobile references (sometimes referred to as a “ski”). The purpose of a mobile reference system is to average the effects of grade changes in an existing surface over a greater distance than that obtained from just the wheelbase of the paver.

7.4.2.2 Floating-Beam Grade Reference

A floating-beam mobile reference is the most common grade reference system (see Figure 101). It consists of a rigid beam with a series of spring-loaded feet attached to the bottom of the beam. One or more of the feet can move over a single high or low point on the pavement surface without altering the overall slope of the beam along its length. The hinged “feet” can “walk” over small undulations or loose rock on the roadway without altering the slope of the beam. The floating-beam reference system will average the variation of the existing grade over 30–40 ft (9–12 m).

Source: Caterpillar Inc.

Figure 101. Floating-Beam Grade Reference

7.4.2.3 Sonic-Tracker Grade Reference

A sonic-tracker mobile reference system attaches a rigid beam to the side of the paver that holds multiple sonic sensors along its length (see Figure 102). The sensors direct sonic waves downward that echo off the surface. The echo is timed to establish the height of the sensor above the reference surface. The multiple height readings are continuously averaged together to provide a reference line.

Source: Caterpillar Inc.

Figure 102. Sonic-Tracker Grade Reference

7.4.2.4 Combination Grade References

The longer the grade reference used, the better the paver will average out variations in the existing pavement surface. Consequently, the smoothest pavements are built using a combination over-the-screed mobile reference system that senses off the existing grade in front of the paver and reaches over-the-screed to sense off the new mat being placed behind the screed (see Figure 103). Since the new mat is significantly smoother than the existing pavement surface, the majority of the variations detected are limited to those measured by the front sensor(s). Combination systems can be made up of individual floating beams connected by either a rigid framework or spring-loaded wire stretched over the screed. This type of system can reach between 40 and 60 ft (12 to 18 m) in length.

Source: Brian K. Wood

Figure 103. Over-the-Screed Grade Sensor and Cross-Slope Checking

7.4.2.5 Fixed-Grade References

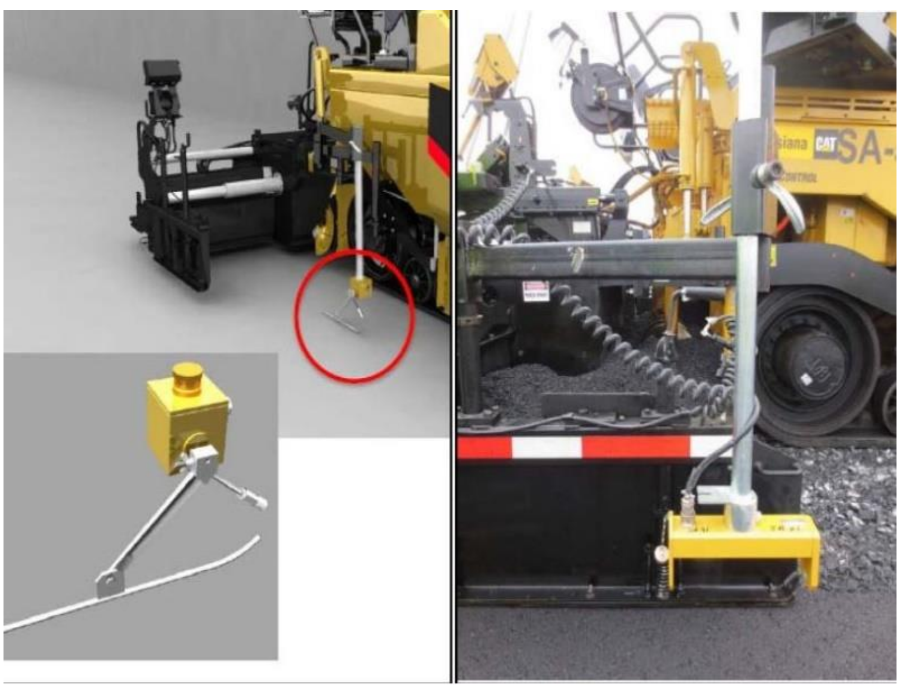
A fixed-grade reference refers to a method of grade reference that duplicates an existing surface or profile—primarily a single point reference (matching shoe or non-contact sensor) or a fixed stringline reference. The purpose is to duplicate or mirror the respective reference.

7.4.2.6 Single-Point Reference (Matching Shoe)

The purpose of the single-point grade reference is to duplicate the grade of an adjacent surface, such as an adjoining lane, curb and gutter, or a lower surface layer. A single-point reference device may be a matching shoe or a single non-contact grade sensor.

Fixed-grade references using a single device should be used with caution because anomalies, such as mix spillage and pebbles or drainage inlets in curb and gutter, can create an irregular profile that will be directly reflected in the adjacent paving surface.

The location where the single-point sensor is placed on the paver will impact the response of the paver to grade changes. It is important to remember that the sensor is calibrated to detect a specified reference or measure a distance. As a wand or matching shoe traverses a reference, the tow point will maintain a constant distance to within a very small tolerance. A non-contact sensor is constantly measuring a distance, and the tow point moves to stay within a very close tolerance to a predetermined distance. Both types of sensors, shown in Figure 104, will continuously call for the tow points to change until the offset with the sensor returns to its “comfort range.”



Source: Caterpillar, Inc.

Figure 104. Single Point Grade Referencing

> *Fixed-grade references using a single device should be used with caution because anomalies, such as mix spillage and pebbles or drainage inlets in curb and gutter, can create an irregular profile that will be directly reflected in the adjacent paving surface.*

Placement near the tow point locks in the distance between the grade reference and the tow point elevation. The sensor and tow point really do not care what the screed does as it trails one tow arm length behind the tow point. The fact that it takes the screed one tow arm length to get 65 percent of the angle of attack change reconciled will put the screed very close to where it should be as paving progresses. Placement of the single-point sensor at the tow point will result in smaller movements of the tow point and smoother pavement, but it may not always match the grade reference exactly.

When the sensor is placed at the rear of the tow arm, near the auger, the tow point reaction is quite different. When the sensor is mounted near the auger or screed, the sensor more closely follows the position of the screed. When the sensor gets out of its comfort range, it calls for an adjustment to the tow point elevation. But since the screed is slow to react to the tow point change, the sensor continues to call for more movement of the tow point; hence the tow point continues to move until the sensor is satisfied. These movements of the tow point height are larger and more rapid when compared to the tow point reaction with the sensor located at the tow point. The result is that the screed quickly reaches the new elevation called for by the sensor. Placement of a single point sensor near the auger will obtain the closest continuous match to the grade reference, but smoothness may be reduced.

When placing the second lane of a base course or a binder course layer, it may be better to use a longer mobile reference ski instead of a joint-matching shoe. The mobile reference will provide better input for constructing a smooth pavement surface than a single-point sensor. If sufficient smoothness has been achieved in lower layers, a single-point matching device would be an appropriate choice to match adjacent surfaces or specific elevation for the final lift.

7.4.2.7 Fixed Stringline

The use of an erected stringline, shown in Figure 105, provides the opportunity for the placement of the smoothest possible asphalt mat behind the paver screed. The stringline can be made of wire or nylon cord. This method of supplying elevation input provides the most consistent reference for the paver tow points, enabling a predetermined grade to be matched very accurately if the controls are used properly.

Source: Applied Research Associates, Inc. (ARA)

Figure 105. Stringline on an Airfield Project

Unfortunately, there are several obstacles to successful implementation of fixed stringline control. The most notable are that it is very expensive and time-consuming to install and maintain. In addition, the line must be kept very taut and undisturbed by personnel and equipment over long sections of the project. Thus, for the vast majority of highway paving projects, an erected stringline is not used.

However, fixed stringlines can be very helpful where longitudinal and transverse profiles along with final elevation points are important, such as airfields. Special projects such as racetracks or other applications with critical superelevated curves may be good candidates for fixed stringline grade references.

It is important to note that establishing a smooth paving platform contributes significantly to a uniform and balanced laydown operation. Using automatic controls on milling machines improves mixture yield, smoothness, and in-place density.

7.4.3 Slope Control

Paving that is done with automatic screed controls as described in Section 7.4.2 is often accomplished with a combination of grade control on one side of the paver and slope control to determine the grade on the other side of the machine. The slope control operates through a slope sensor that is located on a cross beam between the two side arms of the screed. The cross slope is regulated by a pendulum device that is part of the slope control system. The required degree of cross slope is simply dialed in to the slope controller, shown in Figure 106.

Source: Asphalt Institute

Figure 106. A Modern Cross Slope Controller

One side of the screed is controlled by the grade sensor(s), while the other is controlled by the slope controller. In almost every case, the inside or centerline edge of the finished mat is controlled by grade and the outside edge by slope. It is very difficult to match the centerline joint if slope control is used to control the inside edge of a paved lane. It is extremely difficult, if not impossible, on multiple-lane sections.

When slope control is used, the thickness of the mat on the side of the machine that is controlled by the slope sensor may be variable in depth, depending on the condition of the existing surface. Without regard to the condition of the existing surface, the slope controller maintains a constant cross slope of the finished mat exiting the paver, regardless of the resulting thickness of the asphalt layer placed. If there is a high point in the present pavement surface, the slope controller causes the screed to place less material over that location; if there is a low point in the existing pavement, the slope controller causes the screed to deposit more mix in that location. It is good practice to check the slope of the lane routinely with a carpenter level or other method.

When properly operated, a slope controller will very accurately place a lift with a surface at the exact slope. However, if the sublayer is irregular, differential compaction will result, and the final surface will not be uniform across the section after rolldown. A properly prepared or corrected base layer that conforms to the longitudinal and transverse profile will greatly enhance a uniform and balanced paving operation. For a wide pavement, such as an airport runway, it is good practice to continually check the elevation of the outside edge of the mix being placed. While the use of one or more stringlines across a wide pavement can help provide the proper cross slope, dual mobile reference skis (controlling both sides of the paver) are often utilized.

7.4.4 Remote Grade and Slope Control (3-D Paving)

Traditional grade and slope control is often referred to as two-dimensional (2-D) paving. Three-dimensional (3-D) paving allows a laydown operation to achieve a specific elevation while maintaining longitudinal grade and slope. Achieving an exact result requires control of the lower layers of the pavement section. Since the placement of nonuniform mat thickness results in differential rolldown, a successful project begins with a precise base layer placement or milling operation.

3-D paving is a process where the tow points of the paver are automatically controlled by an electronic file that contains all the grade, slope, and elevation data. This data can be from the original project design file or captured and recorded during project construction, for example, during subgrade preparation, base layer placement, or milling operations.

3-D paving begins with one or two prisms located on the screed, shown in Figure 107. These prisms are mounted at a fixed and measured height above the screed. The prisms are constantly tracked by an onsite universal total station.

Source: SITECH Construction Systems

Figure 107. Dual Receivers on a Paver

Depending on the project site, there may be multiple total stations because they must maintain line of sight with the paver and are limited in range to 500–1000 ft (150–300 m), depending on the system provider. Total stations (shown in Figure 108) constantly measure the location of the paver prism and transmit position data to a receiver and controller unit on the paver. The controller processes the position data received and controls the tow point height to maintain the screed at the final elevations in the data file.

Some systems, often called 3-D grade control, may use only one prism to control the grade line (replacing the ski) on one side of the screed, with the other end of the screed controlled by the slope controller or matching shoe. Other systems use two prisms, one on each side of the screed, to provide full 3-D control.

Total stations are located at control points throughout the project, with known coordinates and elevations pre-determined for each. 3-D paving is typically used on strategic projects with a limited footprint due to the limited range of the total stations. Excellent results can be expected on all types of projects but may become difficult to execute on long, high-tonnage overlay projects, whereas airfield projects are excellent candidates for 3-D paving.

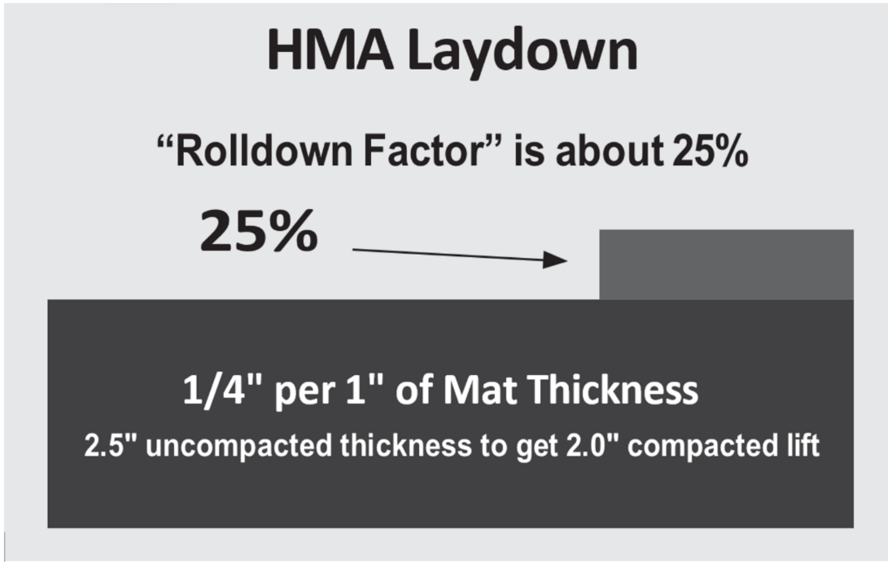
Source: JP Excavating, Inc.

Figure 108. Universal Total Station Tracking Paver

7.5 LAYER THICKNESS

After asphalt material is spread and struck off by the screed, it is in a "loose" state even though it has received some initial compaction from the tamper bar or vibratory screed. It is critical that the thickness of the loose mixture after it has been placed is sufficient to allow for consolidation through the compaction process so that the final thickness meets the thickness specified in the project plans.

To accomplish this, a rolldown factor for each material must be considered. This factor varies depending on mixture type, with a common rolldown factor (for a typical dense-graded mix) being approximately 25 percent (see Figure 109). For instance, assuming a 25-percent rolldown factor on a 2-inch compacted lift thickness, the thickness placed by the paver must be 25 percent thicker or 2.5 inches thick. When gap and open-graded materials are being placed, a rolldown factor of about 15 percent is probably more accurate. During paving operations, it is a best practice for the screed operator to regularly measure the thickness of the loose mat directly behind the paver. When necessary, adjustments to mat thickness should be made to ensure that the proper amounts are being placed. A more in-depth discussion regarding the construction of transverse joints at startup is discussed in Chapter 9, Section 9.2.2.



Source: Asphalt Institute

Figure 109. Rule of Thumb Rolldown Factor for Dense-Graded Mixtures

Spread rate is a useful calculation that onsite inspectors and paving foremen can use to confirm the paver is set up properly and placing the proper amount of material. It is based on the unit weight information from the lab and is expressed in terms of pounds per square yard of material for every inch of compacted thickness. These units are typically expressed as lbs/yd^2-inch.

The formula for spread rate is as follows:

$$Spread\ Rate = Unit\ Weight\ \left(\frac{lbs}{ft^3}\right) x\ \frac{1\ ft}{12\ in}\ x\ \frac{9\ ft^2}{1\ yd^2} = \frac{lbs}{yd^2\ in}$$

With this factor, quantities can be readily calculated as follows in any number of terms based on the width, feet, and the depth and compacted inches for a given distance:

Tons/linear foot (T/LF), which is useful determining tonnage to move a paver a certain distance.
Tons/project station (T/sta) to compare quantities with the project plan sheets.
Tons/mile (T/MI) to compare with overall contract quantities.

7.6 ESTABLISHING PAVER SPEED

Planning is necessary for constructing a high-quality asphalt pavement, and it begins by coordinating the amount of material needed, the number of trucks needed, and the amount of compaction needed before the mix temperature falls below compactible levels. Uniform paver speed is essential to keep the paving plan intact. The paver operator must be trained to monitor the arrival rate of the material, the flow of material through the paver, and the pace of the compaction train and try to keep all three operations in balance. The paver operator's main goal should be to maintain a pace consistent with the pace of the compaction train and not worry about surges of delivery trucks arriving in front of the paver. By releasing trucks from the paver in an orderly manner, the paver operator can help maintain spacing of trucks returning to the plant.

To balance a paving operation that provides continuous forward motion and uniform pavement placement, calculations must be made to estimate the following:

The number of trucks needed to deliver mix.
The paving speed.
The production capacity of the compaction train.

A perfectly balanced mainline highway paving operation will run continuously, without interruption, at the same rate of production as the asphalt plant. The number of trucks required is covered in Section 6.2 and is assumed to be sufficient for continuous operation for the following example.

Calculating Paver Speed

Assumptions:

Plant production = 350 T/hr
Compacted unit weight = 150.2 lbs/ft^3
Compacted lift thickness = 2.0 inches
Paving width = 14 ft

Determine the spread rate:

$$150.2\left(\frac{lbs}{ft^3}\right) x \left(\frac{1\,ft}{12\,in}\right) x \left(\frac{9\,ft^2}{yd^2}\right) = 112.65\frac{lbs}{yd^2\,in}$$

Or directly calculate tons per linear foot of mix:

$$(1\,ft\,)\,x\,(14\,ft)\,x\left(\frac{2\,in}{12\,\frac{in}{ft}}\right) x\,150.2\frac{lbs}{ft^3}\,x\,\frac{1\,T}{2000\,lbs} = 0.17523\,\frac{T}{ft}$$

1 ton of mix will cover:

$$\frac{1\,T}{0.17523\,\frac{T}{ft}} \approx 5.71\,ft$$

The distance paved in 1 hour equals:

$$350\,\frac{T}{hr}\,x\,5.71\,\frac{ft}{T} = 1{,}998.5\,\frac{ft}{hr}$$

Calculate paving speed in feet per minute:

$$\frac{1{,}998.5\ ft}{60\ min} = 33.3\ \frac{ft}{min}$$

This calculation is a theoretical number that assumes continuous operations with no paver stops. If paver stops are anticipated, then they should be factored in via an efficiency factor. Maintaining the same production rate per hour will require the paver to move faster. If it is anticipated that the paver will be moving 90 percent of the time, this should be accounted for with an efficiency factor of 0.90, as shown below:

$$\frac{33.3\ \frac{ft}{min}}{0.90} = 37.0\ \frac{ft}{min}$$

One can see that even if the paver is down 10 percent of the time, it does not take a large increase in ground speed to make up the lost time. If the compaction production rate (covered in Section 8.5.2) is not able to keep up with a calculated paving speed, the paver speed and plant production will need to be reduced or additional rollers added to maintain production and achieve the specified density.

7.7 RELATED PAVING OPERATIONS

While asphalt pavers will place most of the mixture on a project, there will always be small, inaccessible areas where it is not practical or where pavers cannot maneuver to place the needed mixture.

7.7.1 Hand-Spreading Operations

Small repairs and patching, small drainage swales, variable-width areas such as narrow tapers, radii, fillets, etc., are examples of areas that require hand-spreading and finishing.

Attention to the process is required when placing and spreading by hand. The mixture should be delivered uniformly in small piles to avoid mix segregation, placing the supply piles in a manner where shovelers and rakers must move the bulk of material the least distance. Sufficient space should be available so that workers are not required to stand in the fresh mix. Broadcasting or throwing mixture from shovels should never be allowed because segregation will result. The small piles should be spread using shovels and rakes/lutes, discarding any clumps of mixture that have formed into lumps and do not break down easily when struck with a shovel edge. After uniformly placing the mix, and before rolling starts, the surface should be checked with a straightedge and all irregularities corrected. On cool days, careful attention should be paid to the mix temperature. Hand placement of mix accelerates the cooling of the material, and compaction needs to begin as soon as possible to ensure adequate time for compaction.

It is important to understand that hand-spread mix has not been pre-consolidated by a vibrating screed or tamping bar, and the rolldown factor of the mixture may be significantly greater than mix placed by a paver. Thirty to 50 percent rolldown is not uncommon with hand-placed material.

7.7.2 Supplemental Operations and Appurtenances

Items considered supplemental paving operations include roadway widening, shoulders, and superelevated curves. In some cases, such as widening and shoulder construction, specially designed pieces of paving equipment and attachments are available to perform the work easily and efficiently. Certain other roadway appurtenances, such as asphalt curbs, dikes, ditches, spillways, and slopes, are increasingly becoming part of paving contracts. For these jobs, special equipment or special asphalt mixtures (or both) may be required.

7.7.3 Roadway Widening and Shoulders

Typical two-lane pavements are 24–28 ft (7.3–7.9 m) wide. Many thousands of miles of primary routes are inadequate in width and thickness to meet today's standards. For details on geometric standards, refer to "A Policy on Geometric Design of Highways and Streets, 7th Edition, 2018," commonly referred to as the "Green Book," from AASHTO for more information.

For safety reasons, evaluating and planning can greatly improve the original alignment of substandard roadways that need widening before strengthening them with overlays. Widening may range from a few feet (greater than 1 m) on one side of a pavement to the addition of full-width traffic lanes on both sides. For safety reasons, proper traffic control must be maintained throughout construction. Work should never take place on both sides of the pavement at the same time and should avoid excessive lengths of open trench. Widening requires trenching to adequate width and depth, typically by templates or attachments to a motor grader so that the walls and base are neat and true to line and grade. For wider excavations, a continuous excavator or a milling machine that loads trucks while cutting the trench to appropriate line and grade can expedite the process. Contractors should roll the subgrade with adequate compaction equipment until it is firm and free of loose material and compaction exceeds the minimum requirements. Typical compaction references are a Modified Proctor Test or a California Bearing Ratio Test to confirm compliance with the required density. Workers should trim and clean the existing pavement edges nearly vertically and remove all dirt and foreign material, then spray the edge with an ample amount of tack coat to adhere the new mixture to the existing pavement. They should then place the asphalt pavement base in layers and compact it to the required density. Appropriate compaction equipment will need to be selected—vibrating plates for narrow trenches, special trench rollers available in different widths, or full-size rollers for wider sections.

When adding shoulders to an existing roadway, contractors should observe the same procedures and precautions used for roadway widening. For safety reasons, it is important that enough mix is placed to assure that after rolldown, the new shoulder height matches the existing pavement edge to avoid drop-offs or ponding water.

When paved shoulders are part of the initial construction, contractors should use the procedures for mainline paving. Variable-width screeds should be considered to pave shoulders at the same time as the mainline and eliminate the longitudinal edge joint.

7.7.4 Superelevation

On new construction, paving curve sections with superelevated cross slopes is generally not a problem. The prepared base and/or foundation material is usually superelevated or sloped the same as the new pavement. This allows placing the same uniform thickness on the curved or superelevated sections as on the tangent or straight sections. As the paver proceeds through the transition to the superelevated section and out again, the paver and the screed tilt accordingly on the prepared foundation, and little, if any, adjustment in the screed controls is required.

When building a superelevated pavement on a flat or crowned base or subgrade, use variable thickness layers to build the pavement. Pavers equipped with automatic slope controls allow the transverse cross slope to be “dialed in” as the paver moves through the superelevated curve. Sensors riding on an erected or traveling stringline maintain grade control for the screed nearest the sensor. The depth at the other side depends on the transverse cross-slope setting.

When the paver reaches the point where the slope begins to change and transitions into a superelevated section, stakes or other markers on adjacent lanes indicate the required cross slopes for the screed operator to dial in/out continuously as the paver proceeds through the transition. The change in cross slope is gradual, and small errors in dialing will not affect the riding quality of the pavement. Once the paver enters full superelevated cross slope, the slope setting will remain the same throughout. Then, as the paver exits the fully superelevated section, the cross slope is gradually dialed out using the same procedure, but in reverse.

7.8 BEST PRACTICES CHECKLISTS

The following list includes important points to keep in mind for the paving foreman, superintendent, or inspector.

7.8.1 General Guidelines

- Never run the hopper empty between loads. (The level of material in the hopper should not be allowed to fall below the top of the tunnel opening.)

- Establish and maintain a continuous paving speed. (Establish the speed by balancing the delivery of material with the compaction process.)
- Control the head of material in the auger area to within ±1 inch (±25 mm).
- Do not allow trucks to bump into the paver.
- Do not spill material on the grade in front of the paver (when dumping directly into the paver hopper or cleaning truck tailgates).
- Do not fold the hopper wings between loads. It is best to only fold the wings when cleaning out the hopper, either at the end of a shift or due to an extended work stoppage.
- Practice good paver starting and stopping techniques.
- Eliminate overcorrecting of the depth screws.
- Make sure the end gates are adjusted properly and in contact with the existing pavement.
- Use best practices for compaction of the in-place asphalt pavement and ensure that all roller marks are smoothed out (see Chapter 9).

7.8.2 Establishing and Maintaining Proper Head of Material

- Set the flow gates and/or slat conveyors to maintain a continuous auger speed.
- Make sure the material feed sensors are operating properly.
- Install tunnel extensions so they are within 12 to 18 inches of the endplate.
- Lower the auger to a position approximately 2 to 4 inches above the screed plate.
- Position, heat, and null out the screed properly on the starting blocks.
- Charge the auger chamber with material, allowing the augers to turn until the auger chamber is filled to the height of the auger shaft, out to the end gate. They stop automatically. (Use a shovel if necessary to fill any void at the outside near the endplate.)
- Begin paving, making head of material adjustments to match the paving width, depth, and paving speed while maintaining a consistent head of material at the augers.

7.8.3 Reducing Segregation in the Paver Hopper

- Observe arriving haul units to verify proper loading procedures are being followed.
- Minimize spillage in front of the paver.
- Do not allow the level of material in the hopper to fall below the top of the tunnel opening.
- Properly fold in the hopper wings only when necessary.
- After paving stops:
    - Move paver to a designated cleanout area.
    - Fold hopper wings to facilitate cleaning hopper.

    - Transport cold or segregated mixture from hopper wings back to the plant for recycling.

7.8.4 Reducing Mat Texture Imperfections

- Maintain equipment in good condition and make all needed repairs in a timely manner.
- Set augers at the proper height settings for the mix and lift thickness being placed.
- Adjust bolt-on and hydraulic screed extensions in a uniform plane.
- Check and adjust the lead and tail screed crown to ensure it meets the equipment manufacturer's requirements.
- Ensure tunnel and screed extensions are in place and within 12 to 18 inches of the end plate.
- Establish and maintain a balanced paving speed and constant head of material.

8. Compaction

8.1 INTRODUCTION

The final step in the construction of asphalt pavement is the compaction process. Compaction is the process by which the freshly placed asphalt mat is compressed (or densified) to reduce the in-place air voids in the mat. Compaction is accomplished while the mat is still at elevated temperature directly behind the paver. The initial compaction forces are applied by the paver screed during placement, and the final compaction is achieved by rollers of various types. During the compaction process, aggregate particles in the mat are reoriented closer and closer together and locked into place to provide a strong skeleton for the asphalt mixture.

Compaction is the most important factor in the performance of a flexible pavement. Adequate compaction of the mix increases fatigue life, decreases permanent deformation (rutting), reduces oxidation or aging, decreases moisture damage, increases strength and stability, and decreases low-temperature cracking. Research and experience have consistently shown that asphalt mixtures that are constructed with marginal materials but well compacted have a good opportunity to perform acceptably. However, mixtures that use top-quality materials and have great volumetric designs but are poorly compacted are more prone to poor performance. Therefore, it is important for an agency to include a density requirement in their specifications that results in a consistent, optimum air void content after compaction.

Compaction is the most important factor in the performance of a flexible pavement.

8.2 DEFINITIONS

It is important to understand the terminology associated with asphalt pavements. The following definitions are offered.

Compaction—the process that reduces the volume of an asphalt mixture, shrinking its air voids and reorienting its aggregate closer and closer together, inducing aggregate interlock. This forms what is known as the aggregate skeleton of a mixture, which is its main source of strength.

Density—the mass of a material per unit volume. In the asphalt pavement community, the term density is usually inferred to mean relative density.

Laboratory density—a calculated value that multiplies the measured bulk specific gravity (G_{mb}) by the density of water (62.4 lb/ft^3 or 1,000 g/L) at the design air voids, most commonly following AASHTO T 166 or ASTM D 2726.

Theoretical maximum density (TMD)—a calculated value based on the laboratory testing procedure that follows AASHTO T 209. In this test, a sample of an asphalt mixture's specific gravity with zero air voids is determined; the symbol G_{mm} is used for this value. To get its density, this value is multiplied by the density of water (62.4 lb/ft^3 or 1,000 g/L). This value is often referred to as Rice specific gravity or Rice density if multiplied by the density of water. The test is named after Jim Rice, who was the developer of the testing procedure.

Relative density—the percentage of a reference density. Almost universally, the reference density for asphalt pavements is the TMD.

8.3 ROLLERS

While the first implement to induce densification is the screed on the paver, it is the rollers that typically do most of the compaction. By far the most common screed types are the vibratory screeds. These will typically be adjustable to maximize their effectiveness. The screed operator should always follow the procedure outlined by the manufacturer of their screed to accomplish this. The density range that can be expected behind a vibratory screed will be around 70 to 90 percent for most mixtures constructed to the proper thicknesses.

There are screeds more commonly found in Europe that are known as high-density screeds. These use tamping bars to achieve higher densities compared to vibratory screeds. However, to get this higher density and to produce the desired smoothness, the paver must move forward at notably slower speeds than are more common with vibratory screed-equipped pavers.

As previously stated, rollers are the tool that does most of the compaction. Rollers come in different configurations. Traditionally, paving crews have used four common types: static steel, pneumatic, vibratory steel, and combination rollers. While these are still common, additional types now include oscillatory rollers and vibratory pneumatic rollers. Additionally, rollers may be equipped with intelligent compaction technology (see Section 8.3.7).

8.3.1 Static Steel-wheeled Rollers

Static steel-wheeled (or static) rollers have steel drums in two different configurations. Double-drum rollers are more common, but a three-wheeled configuration is also available (see Figure 110). One characteristic of the three-wheel and split-drum configuration is that the drum's rotation speed can change from one side versus the other when steering to reduce tearing or cracking.

Source: Dynapac

Figure 110. Static Steel Roller

The contact pressure from the roller is the main source of compactive energy with steel rollers. Contact pressure is affected by the weight of the roller, typically 3–14 tons (2.7–12.7 t), and their drum width, typically 40–54 inches (102–137 cm). Static rollers usually can be ballasted to increase their mass. Water is commonly used for this purpose. Use of an appropriate antifreeze should be included if freezing is possible.

The weight of the roller is transmitted to the mixture through the contact pressure that is exerted under the drums. Therefore, the contact pressure under the drums should not exceed the supporting capability of the mixture being compacted. Harsher, more stable mixtures used on high-volume highways or airfields may require heavier rollers. Less stable mixtures used for driveways, parking lots, and other low-volume situations may require smaller, lighter rollers. In most cases, the asphalt mat is stable enough to allow the use of rollers with a high contact force.

Because steel-wheel rollers vary in width and weight, a simple calculation can be used to quantify the compactive effort applied by static rollers. By dividing the weight of the roller by the width of all drums, the overall static linear load can be determined, expressed in pounds per linear inch (PLI) or kilograms per centimeter (kg/cm) of roller. For example, an 8-ton roller with two 50-inch drum widths would calculate out to 160 PLI. The PLI can be used to match rollers of different sizes and manufacturers when establishing a rolling pattern. Static, steel double-drum rollers typically provide a minimum of 250 PLI (44.6 kg/cm), and large, three-wheel static rollers typically provide a minimum of 350 PLI (62.5 kg/cm), making them effective breakdown or intermediate rollers.

The two ways to adjust the compactive force of a steel-wheel roller are to adjust the ballast (weight) of the roller and the speed. Adding weight, or ballast, will apply greater force on the uncompacted mixture with each pass. Adjusting the speed affects the dwell time at each location on the mat. Slower rolling speeds raise the dwell time and increase the density increase from each pass of the roller.

All steel-wheel rollers (static and vibratory) used for rolling include a water-spray system and scrapers to moisten the drums to help prevent mix from sticking to the drums. Each drum should be checked for wear on the surface with a metal straightedge and should not be used if grooves or pits have worn into the rolling drum. Also, scrapers should be routinely inspected and replaced if they are excessively worn.

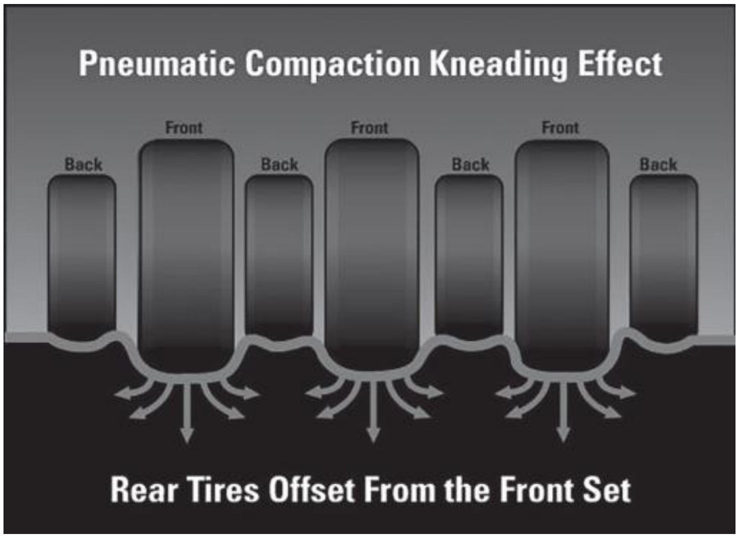
8.3.2 Pneumatic Tire Rollers

Pneumatic rollers (see Figure 111), commonly referred to as rubber-tire rollers, are equipped with rubber tires instead of steel drums. Typically, rubber-tire rollers are equipped with three to five tires on the front axle and four to six tires on the rear axle. The wheels can move up and down semi-independently of each other. Unlike a steel-wheel roller, the surface of a rubber-tire roller adjusts to the shape of the underlying surface. The intermediate position is the most common phase where pneumatic rollers are used.

Source: Volvo

Figure 111. Pneumatic Roller

The oscillating wheels and conforming rubber tires result in a constant pressure being exerted across all points of the new mat and a kneading action that manipulates and compacts the mixture differently than a steel-wheel roller. Figure 112 illustrates the kneading action of a rubber-tire roller. The arrows illustrate typical lines of force in the mat.



Source: Asphalt Institute

Figure 112. Forces of Pneumatic (Rubber) Tire Roller

Rubber-tire rollers work well on uneven surfaces, such as leveling courses, as the tires exert a constant pressure and do not bridge over low spots as do the steel-drum rollers. Their kneading action tends to tighten and densify the surface more than steel-drum rollers, thus decreasing permeability. Pneumatic rollers can provide increased density. They tend to be more effective in compacting tender mixes. On tender mixes, their tire air pressure may have to be reduced.

Rubber-tire rollers may be equipped with 15-, 17-, 20-, or 24-inch (380-, 430-, 510-, or 610-mm) diameter wheels and should have smooth tires for asphalt compaction. All the tires should have the same ply rating and the same inflation pressure, preferably the same model from the same manufacturer.

The contact pressure of the tires is calculated as the wheel load divided by the contact area of the tire with the pavement surface. The ply rating of the tire determines the maximum and minimum inflation pressures. Inflation pressure directly affects the contact area and resulting contact pressure. Running the tires at the mid to lower end of the inflation pressure range will help improve the surface texture by sealing the surface. Running the tire inflation pressure higher increases the compactive effort of the roller. Some pneumatic rollers have the capability to change tire pressure and automatically maintain a preset tire pressure while in operation.

There are several ways to adjust the compactive force of a rubber-tire roller. The first is to add or remove ballast. The second is to adjust the tire pressure. The third is to adjust the speed, which affects the dwell time just as in steel-wheel rollers. As was true for static steel rollers, slower speeds increase the compactive effort of each pass.

Pneumatic rollers can be used in the breakdown phase of compaction, but it is the intermediate phase where they see the most usage. Nonuniform subgrade strength can be more evident when rubber-tire rollers are used for breakdown, as the individual wheels can exert high stress on small areas of subgrade weakness that wide, rigid steel drums tend to bridge.

When a rubber-tire roller is used for breakdown rolling, very little horizontal movement of the mixture should occur in the direction of travel. This is because each tire flattens slightly as it drives over the mixture, permitting almost all the compactive force to be exerted vertically on the mat. Excessive horizontal movement of the mix in the direction of travel occurs when the tire diameter is too small, tires are overinflated, or the mix is not stable enough to use a rubber-tire roller for breakdown.

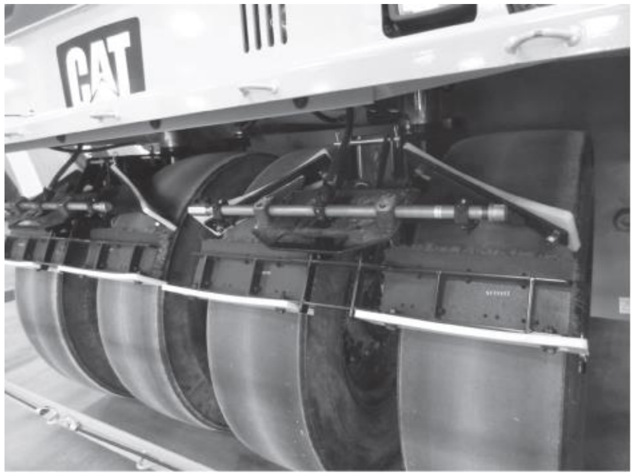
There is some lateral horizontal movement of the mix under a rubber-tire roller, at right angles to the direction of travel. This may cause small bumps or tire marks on the surface that can be rolled out with subsequent passes. Reducing the tire pressure will reduce this lateral displacement. The surface may look irregular, but this appearance is mostly cosmetic.

Desirable rubber-tire roller requirements for breakdown and intermediate compaction are as follows:

- Weight per wheel of 3,000 to 4,500 lbs (1,360 to 2,141 kg).
- A 20-inch (510-mm) minimum wheel diameter.
- Tire inflation pressure of 70 to 75 psi (483 to 517 kPa) when cold and 90 psi (620 kPa) when hot for most mixtures, but the pressure can be reduced if necessary for lower stability or tender mixtures.

Mixture pickup by pneumatic rollers needs to be addressed. Modified mixtures are the most prone to pickup. Preventing or at least reducing the amount of mix pickup by the rubber-tire roller is important. Keeping the tires clean and hot, near mat temperature, is the best way to avoid pickup.

Newer rubber-tire rollers are equipped with a water-spray system that can be used during initial warmup to mitigate mix pickup. Typically, each tire is equipped with a wetting mat that helps distribute the spray water over the tire surface. If pickup occurs, adding small doses of non-foaming detergent or approved water-soluble release agent to the roller water tank may help. All rubber-tire rollers are also equipped with scrapers to remove any materials from tires. Figure 113 illustrates such a system.



Source: Caterpillar, Inc.

Figure 113. Water-Spray System and Wetting Mats on Pneumatic Tires

The operator should strive to get the tires hot and keep them that way before initiating compaction. After ensuring that the wheels are clean, they should run the roller back and forth on a previously placed mat for at least 10 min to warm the tires. Using skirts that surround the tires is encouraged as this will help with both the warming process and keeping the tires warm. If an extended pause in paving occurs, the operator should keep the tires warm by keeping the roller moving as was done during the warmup time.

8.3.3 Vibratory Rollers

Vibratory rollers are the most versatile and common type of rollers used on asphalt. They come in a large variety of configurations. The rollers compact by a combination of weight and vibration of their steel drums. The vibration is produced by a rotating eccentric weight located inside the drum (or drums) and can be adjusted for both amplitude and frequency. These adjustments help to tailor the roller to the mix being paved and its thickness.

Source: Dynapac

Figure 114. Double-Drum Vibratory Roller

Vibratory rollers are the most versatile and common type of rollers used on asphalt.

There are two basic models of vibratory rollers: the single drum and the double drum. Typically, single-drum vibratory rollers are used to compact soil or aggregate bases, while double-drum vibratory rollers (shown in Figure 114) are used to compact asphalt. Both drums usually provide propulsion and vary from 3 to 5 ft (0.9 to 1.5 m) in diameter and from 4 to 7 ft (1.2 to 2.1 m) in width.

Static weight, as the term implies, is merely the overall weight of a vibratory roller operating in a static or non-vibratory mode. Vibratory rollers vary in static weight from 2.5 to 18 tons (2.3 to 16.4 t). Widths vary from 40 to 84 inches (102 to 214 cm). Their static weight in terms of drum width is generally from 160 to 180 PLI (29 to 32 kg/cm).

Frequency is the rate at which the vibration impacts generated by rotating eccentric weights occur. Frequency is expressed in vibrations per minute (VPM) or hertz (Hz). Typical frequencies of rollers used for asphalt compaction range from 2,500 to over 4,000 VPM (42 to 67 Hz). The high-frequency drum movement puts the aggregate particles in the mixture in motion, allowing them to slide past one another more easily under the compactive force of the drum. The general rule of thumb is to use the highest frequency setting available. High frequency allows the roller to be operated at a greater efficiency for any forward speed compared to lower frequencies.

Most vibratory rollers are equipped with a VPM indicator or gauge on the control panel that is visible to the operator. With wear and the extreme environment, these gauges can very quickly become out of calibration and inaccurate. A digital or vibratory handheld reed tachometer is a good QC tool that can be placed on the asphalt mat adjacent to the vibratory roller to accurately measure the VPM.

Amplitude is the up-and-down motion of the drum that is caused as the eccentric weight spins inside it. The positioning of weights is adjustable and can be spaced uniformly around the axle or entirely on one side. When the weights are uniformly spaced, they are essentially in balance and impart very little centrifugal force to the drum. Repositioning and locking the weights on one side of the axle unbalances the centrifugal force applied to the drum. This unbalanced condition imparts an up-and-down force to the drum that creates an impact force. The higher the amplitude, the greater the vertical force and the greater the impact force exerted on the mix.

While some vibratory rollers may have high and low amplitude settings, newer rollers provide the operator with a range of amplitude settings. Generally, the thickness of the mat, mix aggregate properties, and compactibility of the mixture are all factors to be considered when selecting the proper amplitude setting for a project. It is usually recommended to start with a high frequency and low amplitude and adjust from these settings as needed. As lifts get thicker, around 2.5 inches (65 mm) or more, or with more robust mixtures, then higher amplitude may be warranted at startup. Thin-lift applications that are less than 1 inch (25 mm) in compacted thickness are generally compacted with static rollers or vibratory rollers in static mode.

The number of impacts per foot or meter should be established as a target before compaction begins. This target should never be less than 10 impacts per foot (IPF) (31 impacts per meter). Corrugations or washboarding will result from fewer impacts than this minimum. The typical target range is 10–14 IPF (31–47 impacts per meter).

Modern rollers provide real-time feedback to the operator on amplitude, frequency, and IPF. If a roller does not have this feature, then the desired IPF can be used to calculate the appropriate forward speed manually to achieve the target. For example, if the minimum desired IPF is 12, and the roller's frequency is 3,600 VPM, the maximum speed of the roller in terms of miles per hour (mph) is calculated as follows:

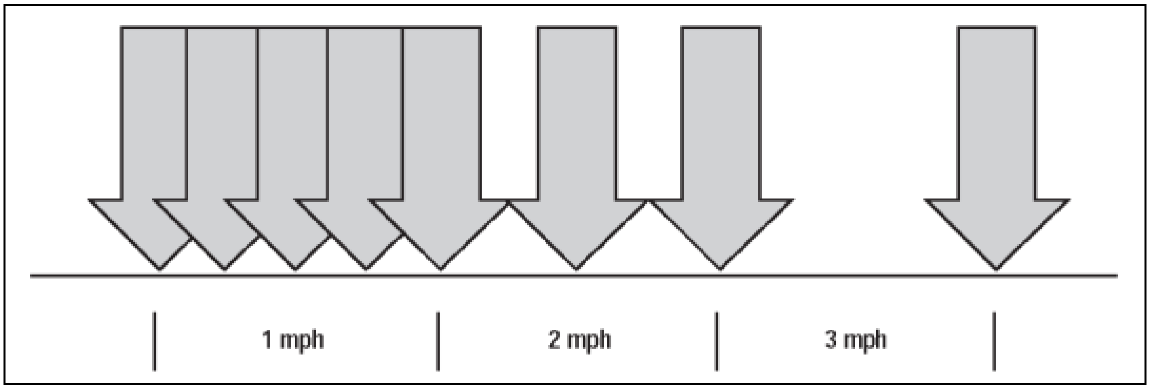
3,600 VPM / minimum 12 IPF = maximum 300 ft per min, or maximum 3.4 mph

Building a chart such as shown in Table 9 allows an operator to easily see what speed they need to target to achieve the appropriate impact rate. Caution is encouraged when speeds increase even on high-frequency rollers. Their higher frequency advantages are maximized when traditional speeds are targeted.

Table 9. Maximum Roller Speed Versus Drum Frequency (for range of 10 to 14 IPF)

Hertz	VPM	Maximum Roller Speed (mph)				
		Impacts per Linear Foot				
		10	11	12	13	14
40	2400	2.7	2.5	2.3	2.1	1.9
42	2520	2.9	2.6	2.4	2.2	2.0
44	2640	3.0	2.7	2.5	2.3	2.1
46	2760	3.1	2.9	2.6	2.4	2.2
48	2880	3.3	3.0	2.7	2.5	2.3
50	3000	3.4	3.1	2.8	2.6	2.4
52	3120	3.5	3.2	3.0	2.7	2.5
54	3240	3.7	3.3	3.1	2.8	2.6
56	3360	3.8	3.5	3.2	2.9	2.7
58	3480	4.0	3.6	3.3	3.0	2.8
60	3600	4.1	3.7	3.4	3.1	2.9
62	3720	4.2	3.8	3.5	3.3	3.0
64	3840	4.4	4.0	3.6	3.4	3.1
66	3960	4.5	4.1	3.8	3.5	3.2
68	4080	4.6	4.2	3.9	3.6	3.3
70	4200	4.8	4.3	4.0	3.7	3.4

In summary, impact spacing, vibration, amplitude, and roller speed can be used to adjust the compactive effort of a vibratory roller. Slowing the forward speed of the roller decreases the impact spacing, causing the number of IPF to increase. As the speed of the roller increases for a given vibration frequency, the spacing of the impacts grows. The relationship between speed and frequency to obtain a target IPF is illustrated in Figure 115. For asphalt mix compaction, rollers are generally operated at the highest frequency setting available for that roller, with the speed of the roller adjusted to meet the desired impact spacing.



Source: Asphalt Institute

Figure 115. Relationship Between Speed and Vibration Frequency

Vibratory rollers can be operated with both drums, either the front or the back drum, or neither drum vibrating. Each of these options has a situation where it may be preferred. With both drums vibrating, the maximum compactive effort per pass is occurring. This may be used on a stable mixture that requires the most energy to achieve the desired density. Having only the front drum vibrating has the front drum achieving density and the rear drum creating a smoother finish. Switching it up and having the trailing drum vibrating may be a wise choice for a mixture with less stability or more tenderness. Operating in static mode for both drums is usually for thin lifts or when in finishing mode.

Paying attention to the feedback that a mixture provides during compaction can assist in the densification of the pavement, especially with vibratory rollers. For example, a tender mix may respond well to a pass or two in static mode followed by vibrations being initiated to achieve the desired density. However, if conditions change and the mix starts to cool more quickly, the excessive energy used may crush aggregate or de-compact the mixture.

Special attention may be necessary when using a vibratory roller on steep grades. Especially on the initial passes, care should be taken when the roller is traveling downhill to not vibrate and shove the mix down the slope.

8.3.4 Oscillatory Rollers

Oscillatory rollers (see Figure 116) have a longer history in Europe, where they were developed, but they are now common tools in the Western Hemisphere too. They are double-drum steel rollers that look very similar to vibratory rollers. An oscillatory roller will typically have an oscillatory and a vibratory drum; some have oscillation on both drums. They are usually used effectively in either the breakdown or intermediate phase. Instead of a mostly vertical compactive force as generated by vibratory rollers, oscillatory rollers are equipped with two vibrating units that operate in synchronization to create a rocking motion in the drum. This rocking motion provides both horizontal and vertical compactive forces that are transmitted tangentially into the asphalt mat.

Source: Wirtgen

Figure 116. Double Drum Oscillatory Roller

Oscillatory rollers exert lower vertical impact forces than vibratory rollers, which may be desirable where there are concerns of damaging nearby infrastructure. Some examples are bridge decks or where underground utilities, especially older ones, are not very deep. Using an oscillatory roller to compact a longitudinal joint can also be very effective. The less aggressive kneading action from an oscillatory roller has been shown to achieve high-density readings with less potential for any tearing of the mat. Moreover, when a mixture is struggling to respond favorably to vibratory rollers, or at lower mixture temperatures, an oscillatory roller may be effective.

8.3.5 Combination Roller

Combination rollers have two different roller types (static steel-wheeled or vibratory steel-wheeled and pneumatic [rubber-tired]) on the same roller (see Figure 117). The most common type of combination roller is equipped with a vibratory drum on the front and pneumatic rubber-tired rollers on the back. This configuration combines the benefits of a vibratory steel drum with the kneading action of pneumatic tires. They are generally used on smaller paving projects such as parking lots, projects with uneven surfaces (manholes, catch basins, etc.), and projects with steep grades. Some contractors also find them to be useful for the compaction of approaches where their maneuverability can be advantageous.

Source: Bomag

Figure 117. Combination Roller

8.3.6 Vibratory Pneumatic Roller

Vibratory rubber-tired rollers, as shown in Figure 118, are pneumatic rollers that have the capability to vibrate the front tires. As is the case with steel-drum vibratory rollers, vibrations are generated by a rotating eccentric weight on shafts along the front axle. Both the frequency and amplitude of the vibrations are controlled independently of roller travel and engine speed. This type of roller provides the benefits of both the kneading action from the rubber tires with the dynamic forces from vibratory compaction. This roller configuration is especially beneficial for intermediate rolling and compacting along confined joints.

Source: Sakai America, Inc.

Figure 118. Vibratory Pneumatic Rubber-Tired Roller

8.3.7 Intelligent Compaction

Intelligent compaction (IC) is a compaction process that utilizes advanced technology to produce a more consistently densified product. An example of an IC system is shown in

Figure 119. An IC roller is a vibratory roller with technology designed to provide better QC during the compaction process. IC rollers incorporate an integrated system to measure stiffness, Global Positioning System (GPS)-based real-time mapping, infrared temperature sensors (front and back), and onboard computers. The computer monitor displays color-coded maps in real time to track roller location, number of passes, surface temperatures, and relative stiffness of compacted materials. The GPS provides extremely accurate roller location data during the compaction process that can be paired with mat temperature and accelerometer data. Roller drums are equipped with accelerometers to measure drum movement during compaction and translate this into an Intelligent Compaction Measurement Value (ICMV). ICMV is a generic term coined by FHWA. It is a real-time measurement of the mixture's relative stiffness. Five levels of ICMV are currently envisioned, from a relatively basic empirical solution to a mechanistic solution based on dynamic methods and artificial intelligence.

Source: Ammann Group

Figure 119. Roller Equipped with IC Technology

The computer monitor showing a color-coded project map is mounted so the operator can see the ICMV, the mat temperature, and the number of roller passes made during the compaction process. Research and field experience have shown that IC technology will improve the consistency of roller passes and uniformity of compaction simply by providing this critical information in real time to the operator and other project personnel. Figure 120 shows a conventional double-drum vibratory roller equipped with IC technology.

Source: Sakai America, Inc.

Figure 120. Double-Drum Vibratory Roller Equipped with IC Technology

8.4 FACTORS AFFECTING COMPACTION

Many factors have a significant effect on the ability to effectively and efficiently compact asphalt pavements, including the materials used, the mix design, mixture temperature, field operations, and the quality of the materials on which the asphalt is laid. Compaction equipment and the compaction operation itself also have a major effect and will be covered later in this chapter.

The following factors influence the compactibility of an asphalt mixture and will be discussed in the following sections:

- Mixture properties.
- Environmental conditions.
- Layer (lift) thickness.
- Subgrade and bases.

8.4.1 Mixture Properties

The physical characteristics of an asphalt mixture play a significant role in its compactibility. Understanding how these properties affect mix compactibility is important for achieving proper mat density. The specific material properties that are of interest include the following:

- Aggregate properties and gradation.
- Asphalt binder properties.
- Mixture temperature.

8.4.1.1 Aggregate Properties and Gradation

Aggregate gradation, surface texture, and angularity are the primary aggregate characteristics that affect the compactibility of the mixture.

Open-graded mixes are very easy to compact, only seated with a couple of passes; they should not be compacted, or the high void content would close up. The high mastic content of SMA helps compaction, plus the amount of rolldown is less (15 percent compared to 25 percent for dense-graded mixes). While small amounts of natural sand around the No. 30 (0.60 mm) sieve can improve compactibility, excessive sand will increase mixture tenderness and may be difficult to compact. Also, as the maximum aggregate size increases or the amount of coarse aggregate increases, without a corresponding increase in lift thickness, the mixture will be more resistant to compaction.

An increase in surface texture and angularity also makes a mix harder to compact, but it provides for vital vehicle/pavement friction. Crushed, rough-surfaced, cubical aggregate provides more particle-to-particle friction versus round, smooth, natural aggregate, improving long-term performance.

The dust content, or material passing the No. 200 (0.075 mm) sieve, can also affect the compaction process. If the dust content falls below the target percentage from the mix design, the mix can also become tender and hard to compact. If the target value for dust is exceeded, the mix will generally become prone to check cracking during compaction (see Chapter 12.9).

8.4.1.2 Asphalt Binder Properties

The grade of asphalt binder affects a mixture's compactibility. Stiffer binder grades require more compactive effort relative to softer grades. Modified binders provide more rut resistance and increase the durability of a mix. Stiffer and modified binders typically require higher compaction temperatures than softer, unmodified binders.

The use of WMA technology can play a role in the compaction process. There are many different WMA additives and techniques on the market. While the purpose of WMA started out to be primarily lowering production and construction temperatures, field studies and practical applications have shown that WMA can also be an effective compaction aid. The effectiveness of WMA as a compaction aid varies with the type of WMA technology used.

8.4.1.3 Mixture Temperature

Since asphalt binder is a thermoplastic material, its viscosity increases as the temperature drops. When the asphalt is fluid (hot), it acts as a lubricant that facilitates compaction of the mixture. As the binder cools, it becomes stiffer and binds the aggregates to the point where the asphalt mat is not compactible.

The temperature of a mixture is key in obtaining density. Asphalt mixtures are most efficiently compacted when they are at or near optimum high temperatures for that mix. Typical starting compaction temperatures are usually in the range of 275 to 310 °F (135 to 155 °C) for both unmodified and modified binders. Due to the wide range of asphalt grades and modifiers, the contractor is encouraged to discuss the appropriate mixing and compaction range with the binder supplier.

In addition, compaction should be completed before the internal mix temperature falls below what is referred to as cessation temperature, typically around 175 to 180 °F (80 to 82 °C). Continuing to compact below these temperatures will typically not significantly increase density and can damage the mat by fracturing the aggregate. This is why most specifications say compaction operations should cease once the mix cools to a certain minimum temperature.

The optimum high and cessation temperatures (see the rolling zone discussion in Section 8.5.3) of a mix will vary from project to project. Therefore, it is important to establish target starting and cessation temperatures at the beginning of each project. The goal of the contractor is to complete the compaction operation and obtain optimum density in that temperature range.

During adverse weather conditions such as cold ambient temperature and/or high winds, the mat will cool more rapidly. In those scenarios, it is sometimes acceptable to raise the starting mix compaction temperature to increase the amount of time to densify the mixture before it cools. However, the increase in temperature should be moderate and never exceed the recommended maximum mixing temperature provided by the binder supplier.

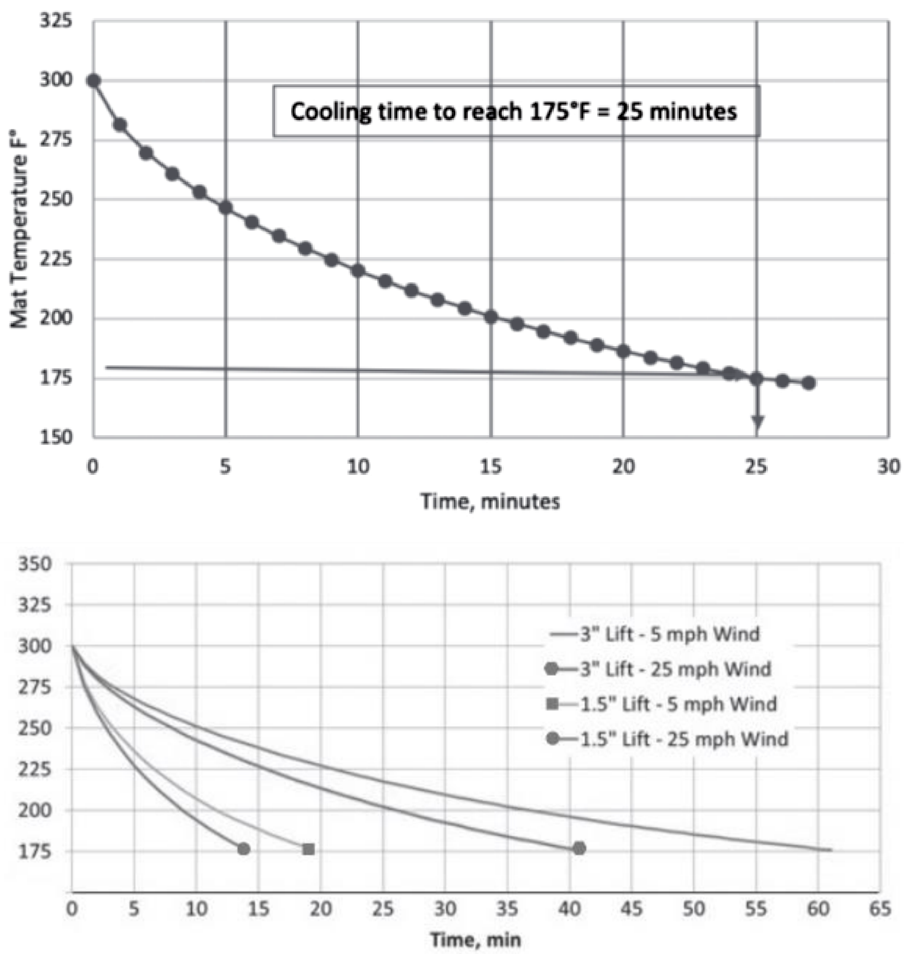
8.4.2 Environmental Conditions

After an asphalt mixture is produced, it is constantly losing temperature. Temperature loss is very slow when it is in a large, bulky state such as a storage silo, an insulated and tarped truck, or perhaps in an MTV. When it is in a windrow, or behind the paver, it is less bulky and losing heat much more quickly. Contractors are forced to work within a specified temperature window to achieve the needed compaction to promote a long-lasting pavement.

It is critical for contractors to understand how environmental factors will affect this window of opportunity. Important factors that come into play include air, surface, and mixture temperatures; wind conditions; overcast versus clear skies; and lift thickness.

Traditionally, standardized nomographs showed an estimation of time available for compaction. Now, online calculators, software, and mobile device applications provide better job-specific estimations. These more advanced tools consider the binder grade, mixture temperatures, and the mat's compacted thickness, plus site-specific factors such as latitude, base temperature, and other environmental conditions. Not only are the software tools more accurate, but they also allow for real-time updates as conditions change in the field.

Free software programs such as PaveCool or MultiCool are available online and as mobile apps that predict asphalt pavement cooling during construction. These user-friendly programs estimate how site-specific conditions affect the cooling of a freshly placed mat. The results help contractors plan their rolling operations to achieve target density more efficiently. Actions such as increasing plant mix temperature, covering hauling units, minimizing haul length, shortening windrows in front of pickup machines, etc. can all lessen the rate of cooling. Figure 121 shows typical plots from MultiCool. The lower graph illustrates how 3-inch lifts cool slower relative to 1.5-inch lifts, and how 25 mph winds accelerate cooling relative to 5 mph winds.



Source: MultiCool

Figure 121. Estimating Cooling Rate of Asphalt Mat During Compaction

8.4.2 Layer Thickness

Compacted lift thickness must be considered when planning a paving project. It impacts both the compactibility of the asphalt mat and how rapidly the mat will cool. When the compacted lift is too thin in relation to the NMAS of the mixture, it will be difficult to achieve the required density. The aggregate particles tend to break, especially during vibratory compaction, because there is insufficient room for particle reorientation. Too thin a lift and thus fractured aggregate is a far too common problem.

The recommendation for minimum thickness of a single lift of dense-graded asphalt mixtures is four times the NMAS for coarse-graded mixtures. For fine-graded mixtures, a minimum of three times the NMAS is advised. Fine-graded mixes have a gradation that lies above the MDL, while coarse-graded mixes have a gradation falling below the MDL. Historical pavement thickness guidelines of two times the "top size" are inappropriate for NMAS-defined gradations and are susceptible to poor pavement performance.

The following is an example for a coarse-graded mix with an NMAS of 0.5 inches (12.5 mm):

Minimum acceptable lift thickness = 4×0.5 inches = 2 inches (50 mm) compacted thickness.

Similarly, the following is an example for a fine-graded mix with an NMAS of 0.5 inches (12.5 mm):

Minimum acceptable lift thickness = 3×0.5 inches = 1.5 inches (37.5 mm) compacted thickness.

The time available for a contractor to achieve density is also affected by the lift thickness. Thick lifts, which may be defined as greater than 3 inches (75 mm), have less material exposed to the air and subsurface in relation to their volume and therefore cool slower. Therefore, the contractor will have more time to compact a thicker lift than a thinner option. Also, it is generally easier to achieve the required density of thicker lifts than of thinner ones. Thicker lifts can be utilized when placing highly stable mixtures that are difficult to compact or when paving in adverse weather conditions causes rapid cooling. Thicker layers can permit mixtures to be placed at lower temperatures because of the reduced rate of cooling. Running simulations on PaveCool or MultiCool will provide a clear picture of thickness' effect on cooling during construction, as was seen in Figure 121.

8.4.3 Underlying Conditions

The subgrade or base (or other underlying material) must be firm and non-yielding under the haul trucks and other construction equipment to provide a solid platform for compaction of subsequent asphalt layers. Subgrades or bases that show movement under trucks or construction equipment will need additional compaction or some type of remedial work to overcome this deficiency before paving. Therefore, it is good practice to conduct proof rolling of the subgrade or aggregate base prior to paving to identify any areas that require corrective action. The remedial work could be one of the many stabilization processes that are available or complete removal and replacement with a more suitable material. Haul trucks may also be limited in size and weight or rerouted where possible to prevent pumping action of subgrade and base materials.

A uniform grade is highly advantageous regardless of the material on which the asphalt is being placed. A nonuniform grade will lead to variable thickness in the asphalt layer. Moreover, high spots from the irregular surface tend to bridge steel-wheel rollers over ruts and other low spots. This will lead to variable densities and uneven grades in those layers. Over time, the nonuniformity that was paved upon will reflect to the surface, compromising its performance.

A best practice is to correct nonuniformity prior to paving. Some of the more common options include properly grading the base or subgrade, milling the existing surface, or placing a leveling lift of asphalt if milling is not an option. All of these options are intended to bring the surface to a uniform grade.

8.5 COMPACTION VARIABLES UNDER THE OPERATOR'S CONTROL

A number of the primary compaction variables can be controlled during the rolling process by the operator, including roller speed, number of roller passes, rolling zone, and rolling pattern. For vibratory and oscillatory rollers, direction of travel and mode of operation are also under the operator's control. Each of these factors affects the level of density achieved under the compactive effort applied to the mix.

8.5.1 Roller Passes and Coverages

Each point on a freshly laid mat needs the rollers to pass over it a certain number of times. A pass is defined as a single movement of a roller over any point. Thus, a roller moving in the forward direction over a point (one pass) and then coming back over that point when the roller reverses (second pass) will have made two passes.

Coverages are the number of tracks from one side of an asphalt mat to the other needed to cover the mat once. This is calculated by first determining the effective roller width:

$$Effective\ Roller\ Width = Roller\ Width - Overlap$$

Overlap is the amount of the drum that overhangs previous tracks. This is typically about 4 to 6 inches.

Thus, the equation for the number of tracks for proper coverage will be:

$$Coverage = \frac{Paving\ Width}{Effective\ Roller\ Width}$$

Unless the coverage equation happens to produce a whole number, the answer will always be rounded up to the next whole number.

8.5.2 Roller Speed

Establishing and maintaining roller speeds is critical to getting consistent compaction. The more quickly a roller passes over a particular point, the less time the weight of the roller "dwells" on that point. This in turn means that less compactive effort is applied to the mixture. As roller speed increases, the amount of density gained with each roller pass decreases. The roller speed selected depends on a combination of factors: paver speed, layer thickness, and position of the equipment in the roller train. Target roller speed should always be the lowest pace that will achieve density and allow the paver to maintain a continuous and constant operating speed. In general, roller speeds will be no more than walking speed to accomplish these goals.

As roller speed increases, the amount of density gained with each roller pass decreases.

Once established, the roller speed should not change unless density requirements are not being met. If this happens, the roller will either have to slow down, or additional passes will need to be added. Reviewing the target paver speed should occur if a change in the roller speed or pass count is made. The paver and the rollers always need to be coordinated and balanced with each other.

Having selected a roller speed that balances with the paver speed, the roller should resist speeding up if the paver pulls away. Speeding up may catch the paver, but critical density will be lost due to the faster roller speed.

When using vibratory rollers, impact spacing is determined by the frequency, VPM or hertz, and the roller's speed, in feet or meters per minute. Recommended impact spacing is 10–14 IPF (31–47 impacts per meter). Falling below this range will produce a washboarding effect, harming the ride quality. When the impact spacing is greater than this, ride quality can also be affected by the formation of ridges in the fresh mat.

The determination of IPF or meter is accompanied by taking the forward speed in either feet or meters per minute and dividing by the frequency. Paving crews are encouraged to predetermine the number of IPF they are seeking and to then calculate the forward speed that will produce this level by using the following equation:

$$\frac{Frequency\ of\ Vibration\ \left(\frac{Vibrations}{Minute}\right)}{Desired\ Impacts\ per\ Length} = Roller\ Speed\left(\frac{Length}{Minute}\right)$$

For example, a target of 12 IPF is sought with a roller whose frequency is set at 4,200 VPM. The appropriate roller speed would be:

$$\frac{4200\left(\frac{Vibrations}{Minute}\right)}{12\ Impacts\ per\ Foot} = 350\left(\frac{Feet}{Minute}\right) \Longrightarrow 4.0\ mph$$

Similarly, if the target was 36 impacts per meter with the same roller setting, the speed would be:

$$\frac{4200\left(\frac{Vibrations}{Minute}\right)}{36\ Impacts\ per\ Meter} = 117\left(\frac{Meters}{Minute}\right) \Longrightarrow 7.0\ km/hr$$

Note that rollers do not only travel forward, but they also need to reverse their directions. They may occasionally need to refill their water reservoirs for the spray system that minimizes the pickup of the fresh asphalt by the drum during a work shift as well. These factors must be accounted for. An "efficiency factor" will have to be applied for these reasons. The typical range for an efficiency factor is 75 to 85 percent (0.75 to 0.85). If the refilling of the water is not needed, then it may be as high as 90 percent (0.90). The equation to do this calculation is:

$$Roller\ Speed\ \times Efficiency\ Factor = Effective\ Roller\ Speed$$

The effective roller compaction speed is calculated for this roller thusly. The roller is 84 inches wide and the overlap between tracks is 6 inches. The paving width is 14 ft, and the roller efficiency factor is 80 percent.

Apply the roller efficiency factor as follows to determine effective roller speed:

$$Roller\ Speed\ \ X\ Efficiency\ Factor = Effective\ Roller\ Speed$$

$$350\left(\frac{ft}{min}\right)\ X\ 0.80 = 280\ \left(\frac{ft}{min}\right) = 3.2\ mph$$

$$117\left(\frac{meters}{min}\right)\ X\ 0.80 = 93.6\ \left(\frac{meters}{min}\right) = 5.6\ km/hr$$

Determine number of roller passes for coverage of the width being pulled:

$$\frac{Paving\ Width\ (ft)}{Effective\ Roller\ Width\ (ft)} = Number\ of\ Tracks\ for\ Coverage$$

$$Effective\ Roller\ Width\ (ft) = Roller\ Width\ (ft) - Overlap\ (ft)$$

$$7\ (ft)\ -0.5\ (ft)\ = 6.5\ (ft)$$

$$\frac{14\ (ft)}{6.5\ (ft)} = 2.15\ Tracks\ for\ Coverage$$

The answer is always rounded up, so in this example, three passes are needed for coverage.

Therefore, for the project described above, compacted with the roller specifications described, the roller should be operated at 3.2 mph over three passes to get full coverage.

To check this information against the paver speed, apply the following equation:

$$\frac{Effective\ Roller\ Speed}{Total\ number\ of\ Passes} = Paver\ Speed$$

The total number of passes will be the number of passes for full coverage (three in this example) times the number of passes established with the test strip. Assuming the passes from the test strips equal five for this example, then the total number of passes will be 15 (3×5).

Therefore, in this example, the paver speed will be:

$$\frac{280\ \left(\frac{ft}{min}\right)}{15\ Passes} = 18.7\ \left(\frac{ft}{min}\right) Paver\ Speed$$

What this says is that the fastest the paver could run, if controlled by compaction, is 18.7 ft/min. If the test strip showed that three passes would achieve the needed compaction, then the calculation would show a paving speed of 31.1 ft/min.

It should be noted that plant production (discussed in Chapter 4) or trucking (discussed in Chapter 6) could control the production–delivery–placement–compaction balance.

8.5.3 Rolling Zone

The "rolling zone" is the temperature range when compaction is accomplished. Compaction must be achieved while the viscosity of the asphalt binder in the mix and the stiffness of the mix are low enough to allow for reorientation of the aggregate particles under the action of the rollers. In other words, the mat must still be hot enough for effective compaction. As discussed in 8.4.1.3, density needs to be achieved before the cessation temperature is reached, effectively halting further densification.

To obtain the required density most quickly, initial compaction should occur directly behind the laydown machine. If the asphalt mixture is stable enough, breakdown rolling can be carried out very closely to the paver while the mat temperature is still high. More density is obtained with one pass when the mix temperature is hotter than after it has cooled.

Sometimes when a tender mix is placed, initial rolling is delayed to avoid excessive shoving or checking of the mix by the rollers. Depending on the mix characteristics, the required density can be achieved if the proper combination of rollers and compactive effort is applied. In those cases, however, when the mix is so tender that rolling must be delayed to the point that the desired density level cannot be achieved, other solutions must be tried. When a tender mix is encountered, the cause of the tenderness must be determined and changes made in the mix production and paving operation to ensure adequate density. Compaction of tender mixes is discussed later in this chapter.

8.5.4 Roller Operations

The improper use of rollers will prove frustrating at best and damaging to the newly laid material at worst. Therefore, it is imperative that the roller operators be properly trained so they will compact the mixture to its appropriate density effectively without harming it.

Compaction is to be done while the mat is in the rolling zone. Rollers will stay with the paver and achieve density if the established roller speed is maintained while getting the needed passes and coverages. The rolling zone is generally broken into three phases: breakdown rolling, intermediate rolling, and finish rolling. Each of these will be discussed further below.

While most contractors have developed roller patterns that consistently work well for them, verifying and altering this standard pattern must be done. Each mixture will behave differently, so the number and types of rollers needed, the number of passes and the corresponding mixture temperatures, and the roller settings will often need to be tweaked. Mixtures vary in their inherent stiffness or tenderness with different binders and aggregate combinations. The longitudinal joint can be especially tough for the contractor to achieve density. The next chapter is dedicated to the joint because of its challenges.

Starts and stops of the roller should be done gradually. Starting or stopping a roller too quickly can tear the fresh mat. Stops with steel-drum rollers should be made at an angle to prevent the formation of a bump that will remain even after the completion of all rolling operations. Roller operators should never turn the roller if it is stopped, as this will rip the mat. Also, vibratory or oscillatory rollers will need to have the compaction enhancers turned off when coming to a stop and not reengaged until the roller has sped up from its stop. Modern rollers do this automatically.

Each mixture will behave differently, so the number and types of rollers needed, the number of passes and the corresponding mixture temperatures, and the roller settings will often need to be tweaked.

The operator must be on the lookout for check cracking. These cracks are generally thin and very shallow. This is discussed further in Chapter 12.

8.6 DETERMINATION OF ROLLING PATTERN

The roller pattern is the number of passes and coverages that the respective rollers are seeking in each of the phases of densification. It is a notable challenge for a roller operator to maintain the pattern throughout a paving operation. Use of advanced technology such as IC has been shown to greatly assist this task.

8.6.1 Calculation of Rolling Pattern

The number and type of rollers needed on a project can vary. Regardless of the number of rollers, the basic sequence of rolling for a typical project can be broken down into the following three phases. Preferably, there is at least one roller for each of these phases.

- Breakdown (initial) rolling—the first sequence of passes performed by the roller(s) designated for breakdown on the freshly placed mat.
- Intermediate rolling—all subsequent passes by the roller(s) to obtain the required density before the mixture cools to the cessation temperature.
- Finish rolling—rolling done solely for the improvement of the surface appearance while the mixture is still warm enough to permit removal of any roller marks. Generally, increased density is not expected because of finish rolling.

A consistent roller pattern must be followed to ensure a mat of specified density, shape, and smoothness. The roller pattern dictates which parts of the mat are rolled first and which part is rolled last. Roller patterns will depend on many factors, including paving width, roller width, required number of passes to obtain specification density, and the specifics of the longitudinal joints (confined versus unconfined), as described in the next chapter.

As project conditions change, the contractor must be willing to modify the compaction operation to ensure that target density is obtained. Test strips are intended to evaluate the entire paving operation, from production through compaction. This allows the contractor to demonstrate their ability to meet specifications before going into full production.

8.6.1.1 Breakdown Rolling

The purpose of breakdown rolling is to achieve a high percentage of the target density while the mat is at its highest temperature. This is accomplished by using breakdown rollers with the highest compactive forces that are appropriate for the asphalt mixture type and lift thickness being used on the project.

It is important to start the breakdown rolling operation on the low side of the mat (usually the outside of the lane being paved) and progress toward the high side. The reason is that hot mixtures tend to migrate toward the low side of the mat during compaction. If rolling is started on the high side, migration is much more pronounced than if rolling starts from the low side.

When the asphalt mixture is relatively easy to compact, a single breakdown roller may be sufficient. In scenarios where high production rates dictate high paver speed or where the mix is difficult to compact, two or more breakdown rollers are often used. Figure 122 shows two vibratory rollers working together to speed up the compaction process and increase compactive effort while the mat is at optimum temperature.

Source: NAPA

Figure 122. Breakdown Rolling with Two Vibratory Rollers

8.6.1.2 Intermediate Rolling

Intermediate rolling should follow breakdown rolling as closely as possible while the asphalt mixture is still well above the cessation temperature. Intermediate rolling should be continuous until all the mix has been thoroughly compacted. Multiple rollers working together can also be used for intermediate compaction, especially on high-production projects where paver speeds are high. Occasionally this phase can be omitted if the breakdown rolling has achieved the needed density.

8.6.1.3 Finish Rolling

Finish rolling is the final phase in the compaction process, done solely to remove roller marks left by breakdown and intermediate rollers so the surface looks good and rides smoothly. Therefore, finish rolling is done at relatively low temperatures, and while the material is still warm enough for removal of roller marks. Vibratory rollers must be operated in static mode when used for finish rolling because the vibrations can damage the cool mat.

8.6.1.4 Compaction of Stiff Mixes

Asphalt mixtures that are properly designed will be reasonably stiff and stable and will require a considerable amount of compactive effort to attain the required degree of density. This type of mix will support the weight of the compaction equipment directly behind the paver. If the mix is placed at a temperature of 275 °F (135 °C) or higher, the rollers will typically be able to compact the mix properly before it cools to a cessation temperature.

Most often, three rollers are used: a breakdown roller, an intermediate roller, and a finish roller. For breakdown rolling, as discussed above, a vibratory steel-drum roller is most often used. For intermediate rolling, a pneumatic tire roller is generally employed, although sometimes a second vibratory or an oscillatory roller is used. Finish rolling is normally done with a static steel-wheel roller or a vibratory steel-drum roller used in static mode.

The breakdown and intermediate rollers should stay close to the paver. If the mix is stable, a bow wave will not occur in front of the vibratory roller drum, and the mix will not exhibit any cracking or checking. With a relatively stiff mix, the finish roller may also be close to the paver since there will be minimal marks from the breakdown and intermediate rollers to be removed.

Because of the internal stability and strength of a stiff mix, more compactive effort may be needed to obtain a given level of density (percent of TMD), but the mix will not creep outward under the compaction equipment during the rolling process. Stiff mixtures of this sort are most commonly found on airfield projects.

For very stiff mixes or when a high degree of density is desired, a pneumatic tire roller may be used for breakdown rolling. For intermediate rolling, a vibratory steel-wheel roller should follow directly behind the pneumatic tire roller, and the finish rolling should be done with a static steel-wheel roller.

8.6.2 Compaction of Tender Mixes

A tender mix is internally unstable, tending to displace laterally and shove while being compacted. Internal mix stability is a function of asphalt binder viscosity, mat temperature, and aggregate gradation and shape. Temperature-induced tenderness is usually one of two types: high-temperature tenderness or midrange temperature tenderness.

8.6.2.1 High-Temperature Tenderness

At high temperatures, some mixes may not be stable enough to support roller loads without laterally displacing. Since this occurs at high temperatures, it is most often encountered by the breakdown rollers when near the paver. Mats exhibiting high-temperature tenderness are typically compacted by merely waiting for the mat to cool to where the asphalt viscosity is high enough to support roller loads. Usually this is enough to solve the problem, but in rare instances the wait period may be so long that the mix cannot be adequately compacted before reaching cessation temperature. Oscillatory rollers have been shown to offer increases in density at lower temperatures than vibratory rollers. If no combination of rollers can successfully achieve density, a new mix design may be warranted. Mixes that exhibit high-temperature tenderness are often susceptible to rutting later in life.

8.6.2.2 Midrange Temperature Tenderness

Some mixes are stable at high temperatures but are unable to support roller loads without laterally displacing at midrange temperatures (typically between 240 °F [115 °C] and 190 °F [90 °C]). The "tender zone" is a term generally associated with this midrange temperature tenderness. There are several theories on the mechanism causing the tender zone, but arguably the most common is that when the mixture is placed, its temperature is relatively hot and uniform throughout. During compaction, the top and bottom layers of the mat cool more rapidly. The middle layer remains hotter and thus is less stiff than the top and bottom of the mat. When rolled in this condition, a steel-wheeled roller tends to push the top portion of the mat laterally past the bottom portion of the mat using the middle portion as a lubricating layer. Additionally, the mix is still fluid enough in the middle portion of the mat to cause the drum to sink into the mat and create a small wave in front.

Several different techniques can be used to compact a mat exhibiting midrange temperature tenderness. First, if done quickly and efficiently, breakdown rolling can be completed before the mat reaches the tender zone. A pneumatic tire roller can then be used during the intermediate phase. Finally, a static steel roller can be used for finish rolling if it is kept off the mat until its temperature has dropped below the tender zone.

8.6.2.3 Causes of Tender Mixes

Tender mixes can also be caused by any one or a combination of these additional factors:

- **Excessive moisture content**—Excess moisture can come from inadequately dried aggregate or, in the case of an overlay, moisture on or in the existing pavement surface. This moisture decreases the internal mix strength by increasing the liquid content of the mix. As the moisture is converted to steam, it effectively foams the hot liquid asphalt, causing it to expand and push the aggregate particles apart.
- **Excess asphalt binder content**—At paving temperatures, asphalt binders act as a lubricant during compaction. Mixes with high asphalt content will compact easily but may shove under roller loads.
- **Rounded aggregate particles**—Rounded particles, found in sands and gravels, tend to slip by one another during compaction, causing distortion and shoving during rolling.
- **Excess midsize fine aggregate (between the 0.60 and 0.30-mm [No. 30 and No. 50] sieves)**—This can be a result of excessive amounts of natural sands incorporated in the mix design or during mix production.

- **Insufficient fines (aggregate passing the 0.075-mm [No. 200] sieve)**—During production, dust and extremely fine aggregates become mixed with the asphalt binder and provide a certain amount of stiffness.
- **Poor bonding to the existing pavement (for overlays)**—If an overlay is poorly bonded to the existing surface, it may act tender as it displaces laterally rather than compacts under rollers. A poor bond can result from not using sufficient tack coat or best practices to apply it.
- **Excessive mix temperature**—At excessively high temperatures, the asphalt binder may not be viscous enough to support compaction. In some cases, the surface has cooled, but the center of the mix can still be too hot to support rollers. Mixes should generally be placed at an appropriate compaction temperature so rolling can begin immediately behind the paver.
- **Compaction techniques**—Poor compaction techniques can exacerbate tenderness problems. Quick stops and starts with a steel-wheeled roller will create excessive forces that promote lateral displacement. Operating a vibratory roller in the static mode during breakdown rolling and eliminating quick starts/stops will decrease the potential for lateral mix movement. Generally, mixes that appear tender under a steel-wheel roller will appear less tender under a pneumatic tire roller; therefore, use of a pneumatic roller for breakdown compaction should be considered.

8.7 ROLLER CHECKLISTS

8.7.1 Steel-wheeled Rollers

❑ Does the roller meet project specifications?

❑ Are the steel-wheels smooth, clean, and in good shape (not pitted or chipped)?

❑ Is the roller ballasted, if an option?

❑ Is the release agent tank full?

❑ Is the spray system for the drums functioning properly?

❑ Are the scraper(s) in good shape, clean, and set to function correctly?

❑ If vibratory, are the initial settings for frequency and amplitude appropriate for the lift thickness?

8.7.2 Pneumatic Tire Roller

❑ Does the roller meet project specifications?

❑ Are the tires smooth, clean, and in good shape (not cracked or marred)?

- ❑ Are all the tires properly and equally inflated?
- ❑ Is the release agent tank full?
- ❑ Is the spray system for the tires functioning properly?
- ❑ Are the scraper mats in good shape, clean, and set to function correctly?
- ❑ Is the roller ballasted, if an option?
- ❑ Are the skirts installed around the tires to retain heat?

9. Joint Construction

9.1 INTRODUCTION

During the construction of asphalt pavements, two types of joints are encountered. The first is a transverse joint, which is constructed whenever the paving operation is interrupted for a period—anywhere from 15 min to several weeks or more. The second is a longitudinal joint (LJ), built when a lane is constructed adjacent to a previously placed lane of mix (see Figure 123). Both types of joints are key to performance; transverse joints have a significant impact on smoothness, while LJs greatly impact long-term durability.

Source: NAPA

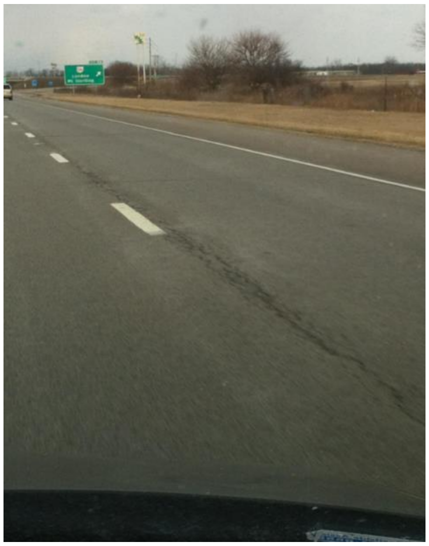
Figure 123. Longitudinal Joints on Airfield Runway

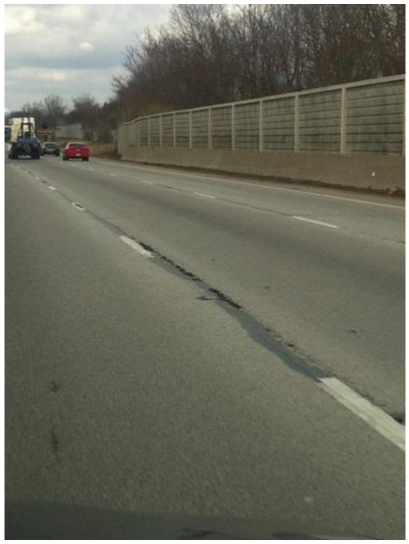
Joint deterioration starts when air, water, and contaminants find their way into the joint, through either segregation, poor density, or the two mats not bonding properly. Because the linear distance of LJs is so much greater than the linear distance of transverse joints, both on roadways and airfields, discussion around joint durability and joint deterioration is generally focused on the LJs.

Typical distresses near the LJ are cracking and raveling (see Figure 124). As the joint deteriorates, it will require additional maintenance such as joint sealing, patching, or premature resurfacing. Since there are typically numerous LJs on a

Transverse joints have a significant impact on smoothness, while longitudinal joints (LJs) greatly impact long-term durability.

pavement, their performance is vital for the overall performance of a project. Unsatisfactory LJ performance has often been the weakest link in an otherwise long-lasting asphalt pavement.





Source: Asphalt Institute

Figure 124. Premature Deterioration of Longitudinal Joints

For airfields, cracking and raveling around the LJ leads to loose material on the pavement surface and is a major source of FOD that can be ingested and damage aircraft engines, as discussed in Section 1.2.

9.1.1 Chapter Outline

The techniques for constructing each type of joint are discussed in this chapter and were intentionally omitted from the two previous chapters on Mix Placement and Compaction to consolidate the discussion of joints here.

Transverse joints, also referred to as construction joints, are covered first, followed by a lengthy section on LJs. Echelon paving, a method that reduces the number of cold LJs, has its own section. The last section mentions some new LJ treatments and methods. Airfield considerations and techniques that are more prevalent for airfield paving, such as cutting back the LJ, are integrated within the appropriate sections of this chapter.

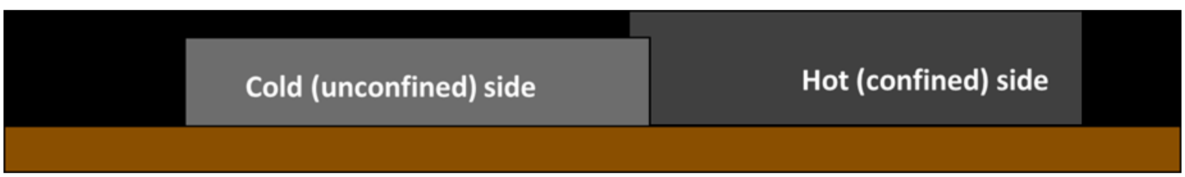
9.1.2 Terminology

When discussing both transverse joints and LJs, the following terms need to be defined (see also Figure 125):

Cold side, or unconfined side—the first side of the joint that was placed and allowed to cool before the other side of the joint was placed. This side has had the opportunity to cool after compaction and thus is referred to as the cold side of the joint. For LJs, it is also referred to as the cold lane. Because the mat was placed and compacted without any lateral confinement under the roller, it is also referred to as the unconfined side of the joint. The lack of confinement makes densification under the roller more challenging and is why specifications for airfield pavements call for cutting back and removing several inches of this lower density material.

Hot side, or confined side—the second side of the joint that was placed. This side is placed and compacted hot, next to the cold side, and thus is referred to as the hot side of the joint. For LJs, it is also referred to as the hot lane. Because the mat is placed next to a mat that has already cooled and stiffened, the mat under the roller is confined laterally. Because of the confinement, achieving density on this side of the joint is typically easier. One of the biggest problems on the hot side of the joint is failing to ensure that sufficient thickness of material (25 percent rolldown) is placed to allow for density to be obtained as the material is rolled down even with the cold side. This topic is covered in detail in Section 9.3.3.2.

Hot joint versus cold joint—The term hot joint refers to the circumstances where two lanes of mix are placed, and both lanes remain hot enough to allow for adequate compaction on both sides of the joint. A typical temperature limit in airfield specifications to distinguish between a hot joint and a cold joint is 175 °F, meaning if the mix temperature drops below 175 °F, it must be treated as a cold joint due to difficulty in achieving adequate density. Echelon paving is a technique that creates hot joints instead of cold joints.



Source: Asphalt Institute

Figure 125. Common Terms for Transverse and Longitudinal Joints

9.2 TRANSVERSE/CONSTRUCTION JOINTS

9.2.1 At End of Paving Operation

When a paving operation is suspended in the middle of a project, whether overnight or for an extended period, a transverse construction joint is required.

For airfields, it is desirable for the paving at the end of the day to end at the area being paved, such as the end of a runway, to reduce the number of transverse joints, which will tend to increase smoothness and minimize FOD.

When a transverse joint is required, it is important that the paver be run in normal fashion right up to the point at which the transverse joint will be located. The head of material in front of the screed should remain constant up to the location of the joint so the forces acting on the screed are constant and a consistent angle of attack is maintained.

For airfields, it is desirable for the paving at the end of the day to end at the area being paved, such as the end of a runway, to reduce the number of transverse joints

A good practice is to locate the transverse joint at a point where the head of material in front of the screed is normal. It is a poor practice to run the hopper out of mix before the location where a transverse joint is to be built. When this is done, the amount of mix carried on the augers is reduced, as is the head of material in front of the paver screed, causing the screed angle to fall. The thickness of the mat will then gradually decrease leading up to the joint location. This will result in a low point on the new pavement surface.

When paving resumes, an almost vertical face is needed on the cold side of the joint. Creating that vertical face, whether the joint was temporarily opened to traffic or not, is discussed in the next section.

If opened to traffic, the transverse joint needs to provide a safe, smooth transition for vehicles dropping from the level of the new surface down to the existing surface. The easiest way to do this is to build a temporary wedge of material to ramp traffic down to the underlying surface. This wedge is removed before paving operations resume.

9.2.1.1 Temporary Ramp for Traffic

There are three methods paving contractors can employ for properly building the sacrificial wedge:

1. Stop the paver and lift the screed over the head of material in the auger area. Then separate the excess material by shoveling a transverse trench in the fresh mix on the downstream side of the joint. Push back the face of the joint line with a lute or rake to make a sharp vertical edge on the side of the joint that remains in place. Use a bond-breaking material (plastic or Kraft paper) to line the bottom of the wedge area and cover the vertical face (see Figure 126). After lining the area with a bond breaker, move excess mix onto the bond breaker and rake it into a wedge. The whole area is then compacted.
2. In a variation of the previous method, insert a wooden block or bulkhead the same thickness and width as the compacted mat after lining the area downstream of the lateral joint with the bond breaker. This block will remain in place to provide a true vertical face on the cold side of the joint and facilitate the removal of the sacrificial wedge of material when paving resumes. Care should be taken to prevent a bulkhead from becoming dislodged if opened to traffic. Prolonged exposure to traffic may require pinning or nailing down blocks or bulkheads.

3. If the temporary wedge is going to be used by traffic for only a short time (e.g., overnight), the application of the tack coat under the wedge can be eliminated, which will greatly facilitate removal. After selecting and marking the joint location, stop the tack coat application at the marked joint location. As the paver passes the joint location, shut off the material delivery conveyors, stopping the flow of material into the screed area. As the screed is starved of material, the thickness of the mat drops until the mat thickness is feathered out to zero.

Note that these methods of building a temporary wedge for traffic to be opened will typically not be used for airfields.

Source: Asphalt Institute

Figure 126. Placement of Kraft Paper Bond Breaker on Transverse Joint

9.2.1.2 Rolling Transverse Joint at End of Paving Operation

Depending on whether the transverse joint is a butt joint or has a temporary wedge for traffic, the recommended rolling operation to compact each at the suspension of paving is different. For a butt joint, a board that is the thickness of the compacted layer should be placed at the end of the transverse joint to allow the front drum of the roller to compact past the end of the mat and to protect the vertical face. For a tapered wedge joint, the front drum of the roller can roll over the transverse joint and tapered mat without significant concern for rounding off the mat edge at the top of the joint.

9.2.1.3 Removing Temporary Ramp and Creating Vertical Face

When paving resumes, the sacrificial wedge of material and, if used, the wooden block and bond breaker material are removed and disposed of properly.

The cold mat is cut back on a straight line to the point where full mat thickness exists transversely. When doing the cutback, a power saw equipped with either a dry-cut diamond or abrasive-blade is used. A water-cooled saw should never be used as it will produce a wet slurry that leaves a dust film on the vertical face. Some specifications, particularly on airfields, require all transverse joints be cut back with a dry pavement saw to ensure a true vertical face.

A cold-milling machine running transversely across the pavement may also be used to remove the wedge, if allowed per the specification. Cold milling in the longitudinal direction to remove the wedge should not be allowed as the cutting mandrel cannot create a vertical face.

After removal of the wedge, the area underneath must be cleaned and dried. Tack is applied to both the vertical face of the transverse joint and the horizontal surface of the wedge area. The tack on the vertical face will allow the hot side of the joint to adhere to the cold side and seal out moisture and contaminants that will cause the joint to ravel. When constructing a transverse joint, it is a good practice to use a 10-ft (3-m) straightedge to check the pavement leading into and away from the joint for smoothness across the joint. However, the FAA and DoD specify a 12-ft straightedge for this purpose. Doing this check while the mat is still hot allows corrections by adding or removing material to achieve acceptable mat smoothness.

9.2.2 Restart of Paving

The screed should be checked for warping and/or wear and then aligned and lowered onto wood starting blocks or lath. When starting a paving pass, blocks should be stacked to the thickness of the new mat plus an additional 25 percent allowance for rolldown. Rolldown (covered in Section 7.5) may be less than 25 percent depending on the mix. When continuing a paving pass after the construction of a header, the starting blocks are placed on the previously laid cold mat with enough thickness to match only the anticipated rolldown under compaction.

The use of these “starter blocks” holds the screed flat at its anticipated equilibrium level as it moves into fresh mix in front of the screed. This minimizes the screed’s rising or falling (introducing roughness at the joint) and significantly shortens the length of travel required for the screed to find equilibrium.

The following are steps specific to the paver that should be accomplished at startup:

1. Center the tow points on both sides of the paver so they have the maximum amount of vertical adjustment to provide the necessary depth correction.
2. Zero or null out the screed angle of attack by turning the depth screws to a free-rotary movement of less than 1/2 to 3/4 of a turn in both clockwise and counterclockwise directions. Check both sides to ensure that the screed is resting

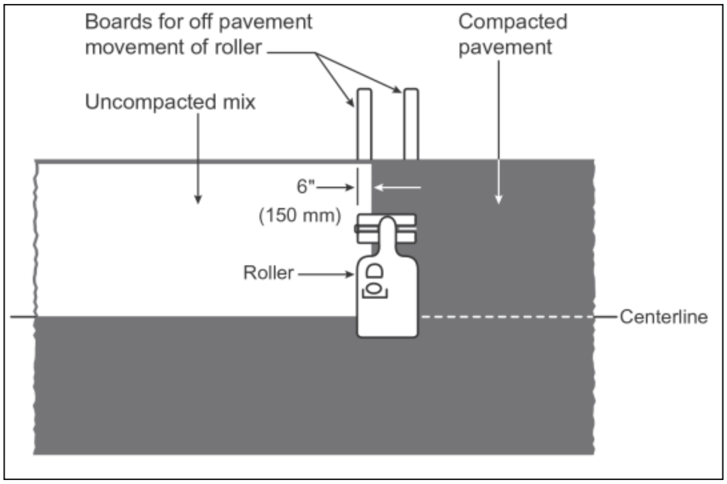
flat on the starting blocks. Induce the angle of attack by turning the depth screws in the appropriate direction. Previous experience with a similar mix will make setting the angle of attack easier.

3. If automatic grade and slope controls are used, position the grade sensor at the correct vertical distance off the grade reference. Once the grade sensor is set, the null or neutral button on the grade controller should be pushed to finish setting the automatic grade sensor. If using the slope control system, set the angle of attack, dial in the proper slope, and use the reset button to null out the system.
4. After filling the receiving hopper, monitor the mix as the drag-slat conveyor and augers fill the area in front of the screed. If material does not automatically fill the outside corners, shovel the mix to the ends to fill the screed properly. Then, check material sensors at the ends of the screed to ensure they are operating properly and set to index off the live (flowing) mass of material.
5. After the paver pulls off the joint, use a straightedge and a carpenter's level to double-check the specified slope. Also, repeatedly check the thickness with a depth probe over the first 25 ft (7.6 m). As soon as true grade and slope are established and confirmed, the controls should take over and maintain the desired profile.

9.2.3 Rolling Transverse Joints After Restart of Paving

The rolling procedure will depend on whether the LJ is confined or unconfined by the adjacent lane. When the LJ is confined by the adjacent lane, the first roller pass is made with a static steel-drum roller moving parallel to the LJ for a few feet, with the drum mostly on the cold side of the joint and overlapping the new mat by approximately 4 to 6 inches (100 to 150 mm). The surface is then checked with a straightedge and corrections made if necessary.

The transverse joint is then rolled transversely, with approximately 6 inches (150 mm) of the drum width on the newly laid material. This operation should be repeated with successive passes, each covering an additional 6 to 8 inches (150 to 200 mm) on the new mat, until the entire width of the roller is on the hot material. When the LJ is unconfined, this joint (edge) needs to be protected from the rollers. During transverse rolling, wooden boards the thickness of the compacted mat should be placed at the edge(s) of the pavement to give the roller a surface to drive onto and off the mat without causing the edge to deform (see Figure 127). The use of boards is recommended to avoid excessive shoving of the mix and to expedite the compaction process, but it may infringe on the adjacent pavement lane carrying traffic. If boards are not used, transverse rolling must stop 6 to 8 inches (150 to 200 mm) short of the outside edge to prevent damaging it, and the edge must be compacted later during longitudinal rolling.



Source: Asphalt Institute

Figure 127. Rolling the Hot Side of a Transverse Joint

Paving and compaction must be accomplished so that the completed transverse construction joint has a smooth transition across the joint and specification density has been achieved on both sides of the joint.

9.3 LONGITUDINAL JOINTS

The outline of this section follows the same sequence of steps as when an LJ is constructed:

1. Placing the Unconfined Side (Edge)
2. Rolling the Unconfined Side
3. Placing the Confined Side
4. Rolling the Confined Side

9.3.1 Placing the Unconfined Side (Edge)

Proper construction of LJs starts with the laydown of the first lane. When the cold lane is placed, there is at least one unconfined edge of the mat. The unconfined edge must be constructed in a straight line. In the case of paving in a curve, the edge should be smooth. The use of a stringline and paint, with a guide mounted to the paver, should be employed to ensure a straight edge on the cold lane (see Figure 128). Edges that are not straight (see Figure 129) will be difficult to match with a consistent overlap (as discussed later in the chapter) when paving the hot side of the joint. This significantly increases the potential for low-density areas near the joint.

The use of a stringline and paint, with a guide mounted to the paver, should be employed to ensure a straight edge on the cold lane.

Source: Asphalt Institute

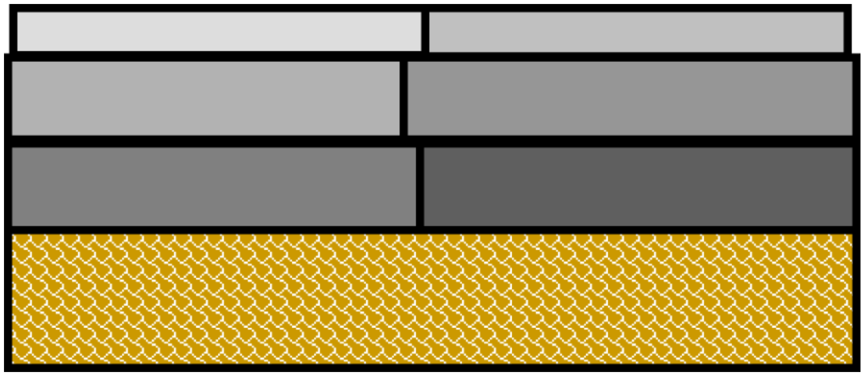
Figure 128. Paving in a Straight Line with Stringline, Skip Paint, and Guide on Paver

Source: Asphalt Institute

Figure 129. Not Paving Straight (or Smooth on a Curve) Makes It Impossible to Achieve a Consistent Overlay

9.3.1.1 Planning the Location of Longitudinal Joints

LJs should be located staggered (offset) from the underlying mat's LJ by at least 6 inches (see Figure 130). If LJs are placed directly on top of each other, there will be a greater tendency for cracking to occur at the joint through the various lifts. Many specifications, including the DoD and FAA airfield specs, require the LJ to be offset a minimum of 1 ft from the LJ of the underlying layer.

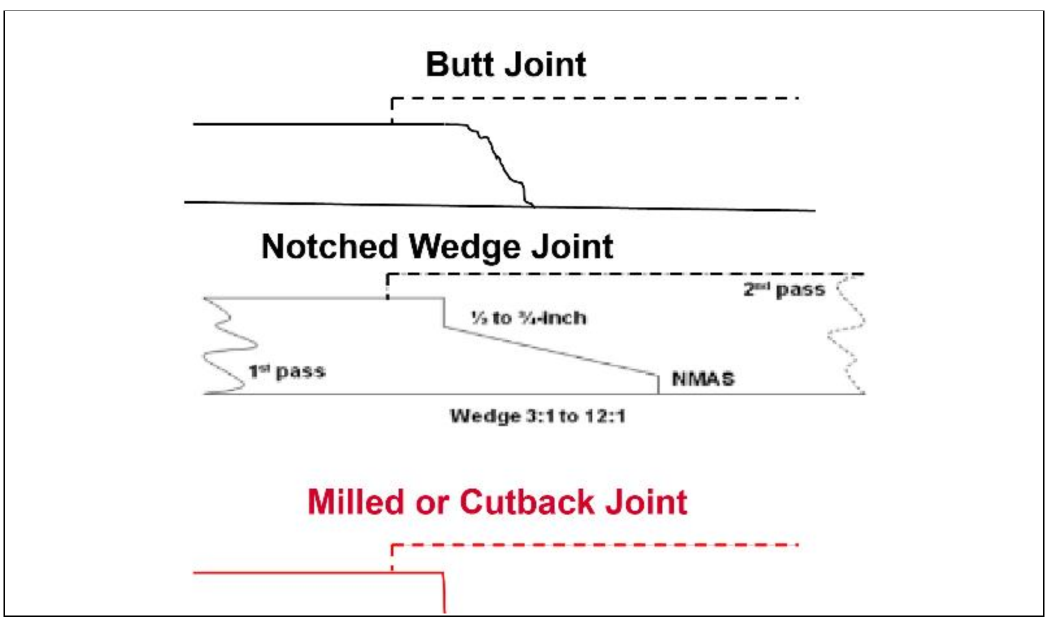


Source: Asphalt Institute

Figure 130. Staggered Joints

When paving projects with multiple lifts, the location of LJs on all lifts should be planned with this minimum offset in mind. If the roadway or airfield feature is crowned at the center, it is desired for the location of the LJ on the surface lift to also be at the centerline. When possible, it is best to plan LJ locations so that the LJs on the surface lift do not fall within traffic wheel paths, recessed pavement markings, or striping. This is not generally possible on airfields.

There are three types of conventional cold LJs, as seen in Figure 131: butt, notched-wedge, and milled or cutback. Each will be described in the next three sections.



Source: Asphalt Institute

Figure 131. Different Types of Longitudinal Joints

9.3.1.2 Butt Joints

The butt joint is the most common type of LJ. While placing the unconfined side, butt joints start with a fairly vertical edge, assuming the end gate is set down properly by riding on the existing surface. Full screed vibration (leaving the screed vibrator on) assists mix consolidation at the bottom of the joint. After the mat is placed and during compaction (discussed in the next section), the mat's edge tends to seek its own angle of repose (less vertical).

Figure 132 shows the poor practice of setting the end gate higher, which allows the mix to flow under the end gate, leading to very low density after compaction on the unconfined edge. Setting the end gate properly, firmly seated on the existing pavement surface, prevents this.

Source: Asphalt Institute

Figure 132. Poor Practice—End Gate Not Set to Be Seated on Existing Surface

Unsupported butt joints of substantial thickness opened to traffic may create hazardous drop-off conditions for motorists. The Manual on Uniform Traffic Control Devices (MUTCD) provides recommendations for signage to warn motorists of unexpected conditions. Where excessive drop-offs are necessary, it may be best to close the adjacent lane or use a notched-wedge joint (discussed next).

9.3.1.3 Notched-Wedge Joints

The notched-wedge joint technique (see Figure 133) was originally designed to provide traffic a safer transition when changing lanes between the newly paved surface and the lower, existing surface. Many overlay specifications do not allow a pavement edge drop-off to remain exposed to traffic and require adjacent lanes to be completed by the end of the day. This safety feature increases production by allowing paving to continue the entire paving shift in one lane, instead of moving back at mid-shift and switching traffic control to pave an adjacent lane.

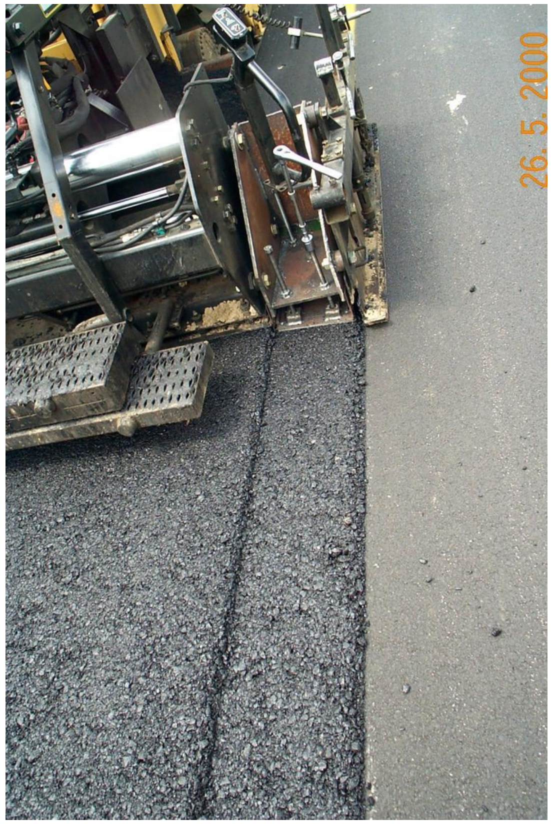
Source: Asphalt Institute

Figure 133. Notched-Wedge Joint with Taper at Top and Bottom of Wedge

The initial pass has a tapered face up to 1 ft (300 mm) in width, with a slope ranging from 3:1 to 12:1. The wedge configuration should include a notch at the top and a notch at the bottom. Notched depths of at least one NMAS are recommended.

Agencies that have adopted the use of the notched wedge generally note an increase in joint density and an improvement in the long-term performance of their LJs when compared to the butt joint. This is not the case when compared to the cutback joint. The notched wedge provides lateral support for the unconfined edge under compaction while increasing the bonding surface area between the two mats.

It is important to provide some type of compactive effort to the wedge material. Figure 134 shows a device that forms the wedge and provides some initial compaction through extrusion and vibration from the screed.



Source: Asphalt Institute

Figure 134. Notched-Wedge Device that Forms and Compacts through Screed Vibration

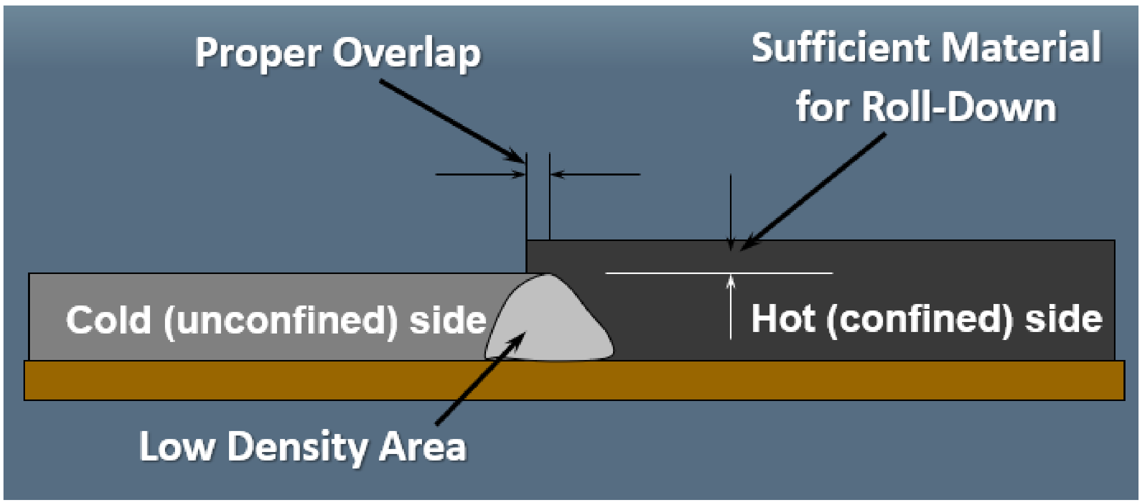
In Figure 135, a tow-behind wheel compactor and a tow-behind, self-vibrating plate compactor are shown.

Source: Asphalt Institute

Figure 135. Two Devices for Compacting the Wedge of a Notched-Wedge Joint

9.3.1.4 Milled or Cutback Joint

A milled or cutback joint (referred to as the cutback method) is created by physically removing 2 to 6 inches of material at the unconfined edge of the recently laid mat with either a cutting wheel (also known as a pizza cutter) or a milling machine. The cutback method offers two advantages to the LJ: providing a near-vertical edge to compact against and eliminating the area of low-density material at the unconfined edge of the first mat (see Figure 136).



Source: Asphalt Institute

Figure 136. Key Aspects to Constructing a Durable Longitudinal Joint

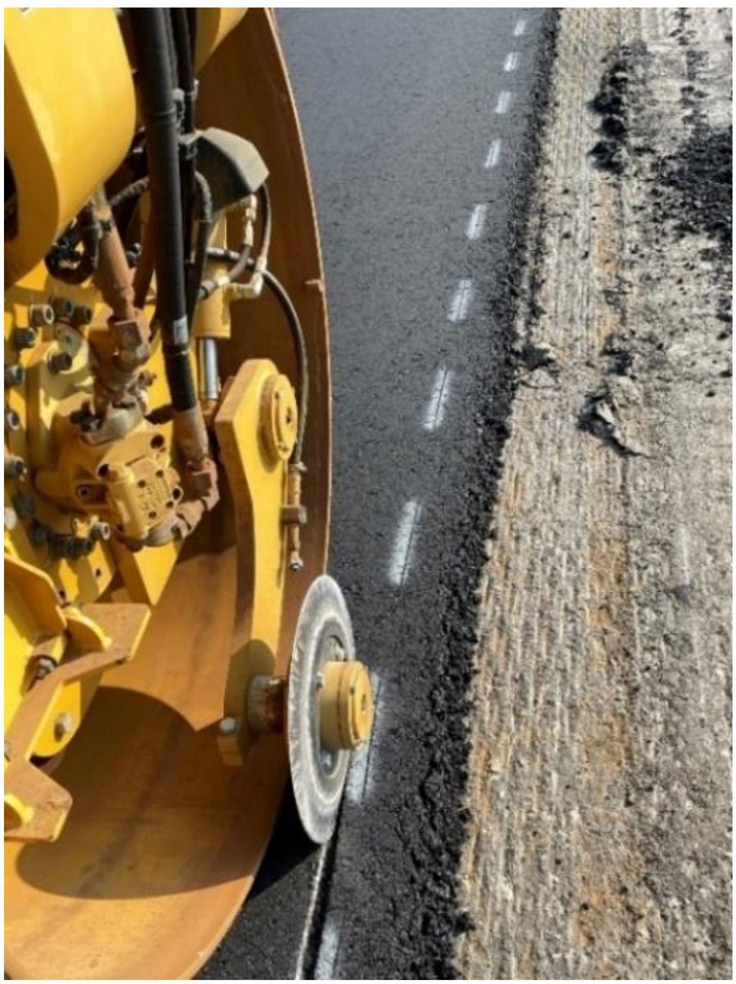
Both the FAA and DoD airfield paving specifications require cutting back the joint with a cutting wheel. While the cutting wheel is not common on roadway projects due to traffic control challenges and slowing production, milling back the joint is routine in Michigan for DOT work where the contractor is compensated for over-paving the joint by up to 2 inches (measured from the top of the mat).

The following standard practices should be followed when cutting back the LJ with a cutting wheel:

1. The amount of material that should be cut back is generally determined by the specification. The DoD airfield specification currently says to cut back between 3 and 6 inches, while the FAA specification currently says a maximum of 3 inches.
2. The cutting wheel is typically about 10 inches in diameter, with the cutting angle being about 10 to 20 degrees from vertical.
3. The mix is cut back while it is still warm (120 to 140 °F) to provide the cleanest cut. This is known as the temperature sweet spot.
4. The cutting wheel can be mounted on a steel-wheel roller (see Figure 137 and Figure 140) or on the blade or rear ripper of a motor grader (see Figure 138). Mounting on a short-wheelbase vehicle such as a skid steer should be avoided. If mounted on a

roller, the cutting wheel can be operated on the newly paved surface. If mounted on a grader, the cutting wheel can be operated on the adjacent lane to be paved to avoid rutting on the newly paved mat that has not fully cooled.

5. The trimmings should be carefully and completely removed prior to placing the hot lane. A kickout plate that pushes the trimmings away from the joint can help (see Figure 139). Any loose material must be removed, by hand if necessary. All the trimmings can be collected and used as RAP.
6. It is critical that the cuts are straight and without wander to facilitate a consistent overlap on the cold mat when the hot mat is placed. Using a stringline for reference, skip paint, and a guide mounted on the front of the roller or grader for the operator to follow can help ensure a straight cut (see Figure 137, Figure 138, and Figure 140).
7. No water and especially no release agent should be used to assist cutting, as this will deter the necessary bonding of the two mats.
8. The cut should provide a clean, sound, near-vertical face for the full depth of lift.

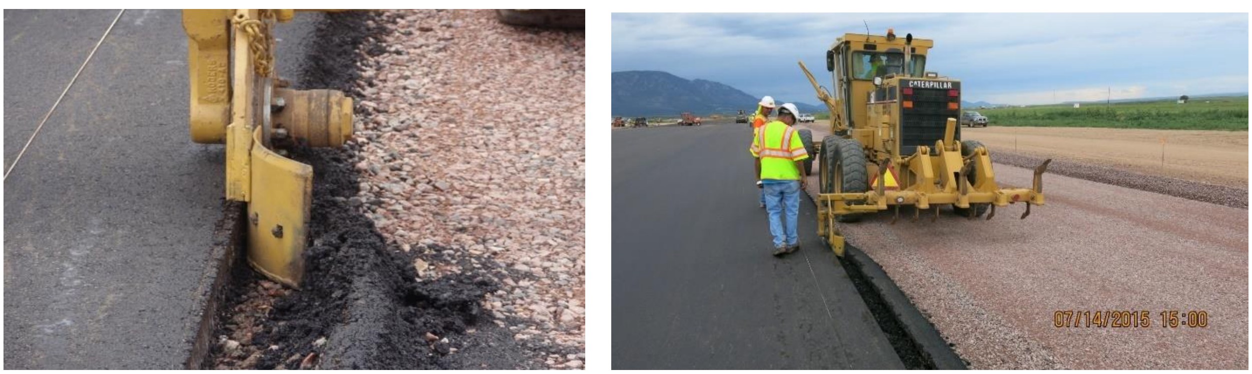


Source: U.S. Army Corps of Engineers

Figure 137. Cutting Wheel Mounted on a Roller

Source: U.S. Army Corps of Engineers

Figure 138. Cutting Wheel Attached to Rear Ripper of a Grader



Source: U.S. Army Corps of Engineers

Figure 139. Kick-Out Plate Aids in Removing the Cutback Mix

Source: U.S. Army Corps of Engineers

Figure 140. Stringline, Paint, and a Mounted Guide Allow Straight Cutting

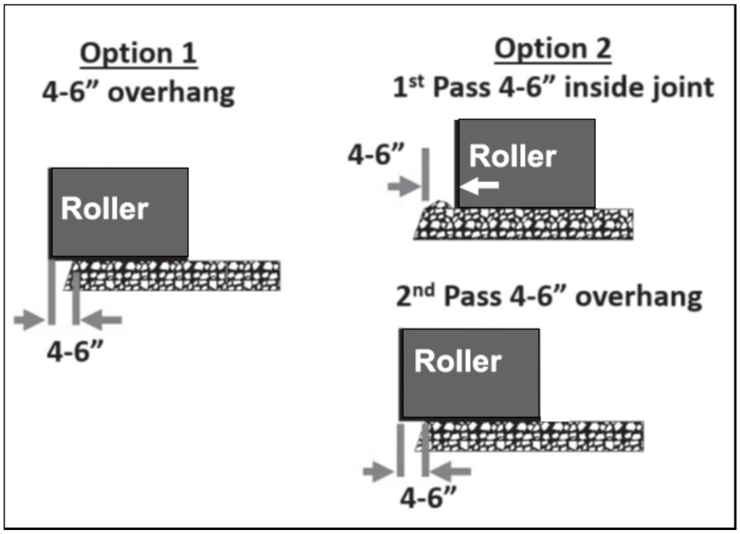
9.3.2 Rolling the Unconfined Side

Attention is key when rolling the unconfined joint because density across the mat is typically lowest at the unsupported edge. The unconfined edge should be compacted with a steel-drum roller as soon as possible while the mat is hottest.

There are two recommended options for a rolling pattern of the unconfined joint to optimize density. Option 1 is to roll the first pass with the steel drum overhanging the mat edge 4 to 6 inches (100 to 150 mm). More than a 6-inch overlap can cause too much force at the mat edge, resulting in excessive rolldown. Targeting less than a 4-inch overlap may result in the drum occasionally cutting into the edge of the unconfined joint. Option 2 is for the first pass to stay inside the mat edge 4 to 6 inches and the second pass overhanging the edge 4 to 6 inches. Both options are illustrated in Figure 141.

Proponents of option 2 believe there is less lateral movement of the unsupported edge under the mat. A concern with option 2 is that a stress crack can be induced at the edge of the steel drum during its first pass (4 to 6 inches inside the LJ). Such a potential stress crack may not be visible until months or years later. Proponents of option 1 are concerned with the potential for this stress crack and/or believe it is best to roll the edge when hottest.

Attention is key when rolling the unconfined joint because density across the mat is typically lowest at the unsupported edge. The unconfined edge should be compacted with a steel-drum roller as soon as possible while the mat is hottest.



Source: Asphalt Institute

Figure 141. Two Options for Compacting the Unconfined LJ

The following are factors to consider in deciding between option 1 and option 2:

- Density measurements close to the unsupported edge.
- Mix properties or other elements that may create excessive lateral movement.
- Excessive rolldown at the mat edge.
- Potential for stress cracks with option 2.

9.3.3 Placing the Confined Side

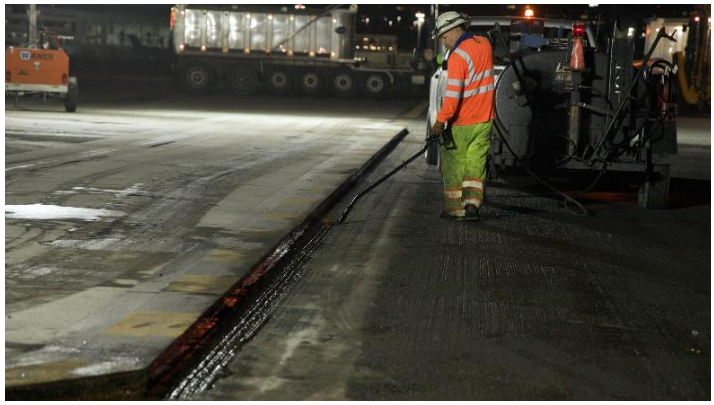
The following are three key considerations that should be understood when placing the hot side of the LJ that will be covered in this section:

- Tacking/bonding the near-vertical face prior to placement.
- Having sufficient rolldown mix to avoid rollers bridging on the cold mat.
- Achieving the proper overlap of the hot mat over the cold mat.

9.3.3.1 Tacking the Vertical Face

Before placing the hot lane, the cold near-vertical joint face should receive at minimum a heavy application of emulsified tack coat material, no matter whether it is a butt or cutback joint. Even a notched-wedge joint will benefit from being tacked as long as the material does not bleed up into the surface.

A more substantial treatment of the cold joint face is the application of an asphalt binder, or better yet, a rubberized joint sealant (also called joint adhesive), as seen in Figure 142. Spraying hot asphalt binder on the joint face results in more residual asphalt relative to an asphalt emulsion. The use of a rubberized joint adhesive provides the best bond at the cold joint. Many States require either the vertical face be painted with an asphalt binder or a rubberized joint adhesive be applied to improve the durability of the joint.



Source: NAPA

Figure 142. Joint Adhesive Being Applied to the Cold Joint Face

9.3.3.2 Sufficient Material for Rolldown

Figure 144 shows one of the key aspects to constructing a durable LJ is having sufficient material for rolldown. Material rolldown was discussed in Section 7.5, with the general rule of thumb being 25 percent but varying depending on the mix. The height of the uncompacted hot mat is established based on the rolldown factor. It is critical that there is sufficient thickness on the hot side of the joint for complete rolldown and compaction before the steel-wheel roller compacts down to the cold mat. If insufficient material is placed, "bridging" of the steel roller on the cold mat will occur before complete densification on the hot side is achieved. This creates a joint doomed to failure with the low-density material on the hot side of the joint, resulting in an area permeable to water and air with poor durability. A joint completed with insufficient mix thickness may initially look better but will perform worse than a well-compacted joint.

It is critical that there is sufficient thickness on the hot side of the joint for complete rolldown and compaction before the steel-wheel roller compacts down to the cold mat.

Projects with ride or smoothness specifications will require the use of mobile reference beams or skis (see Section 7.4.2.1) on the lower lifts. If the smoothness specification is met in the last intermediate lift before the surface is applied, then the surface can be paved at the required thickness with a matching grade sensor. If the surface layer requires the use of a ski to meet the final smoothness specification, the ski should only be used on the cold side of the joint and a matching grade sensor used on the hot side of the joint. Using the ski on the hot side of the joint will result in a nonuniform thickness across the joint, which can lead to lower density along the joint. This is because the ski averages the mat thickness required over the length of the ski (30 to 40 ft) and may not always provide the correct amount of mixture for the joint.

Using the grade sensor on the paver as a joint matcher device that takes a single reading just in front of the augers does a better job of getting the correct height of material at the joint. The joint matcher measures the mat thickness continuously along the joint and provides the required amount of material at each precise location. Section 7.4.2.2 covers joint-matching devices.

9.3.3.3 Proper Overlap

The other key aspect to constructing a durable LJ is to consistently maintain the correct amount of overlap from the hot mat onto the cold mat (illustrated in Figure 143). The correct amount of overlap is 1±1/2 inch (25±12.5 mm) for a butt joint. If the joint is cut back, the correct amount of overlap is less, targeting 1/2±1/2 inch (12.5±12.5 mm). As mentioned earlier, this correct overlap will be difficult to maintain if the first pass was not paved straight (or smooth for a curve). The screed operator should closely follow the joint line and monitor the overlap closely to maintain this tight tolerance. A variable-width screed (if equipped) can be helpful to move the screed in or out as necessary.

Not everyone may agree the correct amount of overlap is as recommended above, but there is no debate that some overlap is needed. Without targeting some overlap, there will be instances where there will be a gap at the joint, resulting in low density and a likely crack.

Luting (bumping) the overlap material off the cold mat and onto the hot mat is not necessary if the proper overlap (as prescribed in the above paragraph) is maintained. The small amount of overlap will not create much loose material at the surface after rolling, and that material will quickly ravel away.

Proper Overlap: 1.0 ± 0.5 inches

Exception: Milled or sawed joint should be 0.5 inches

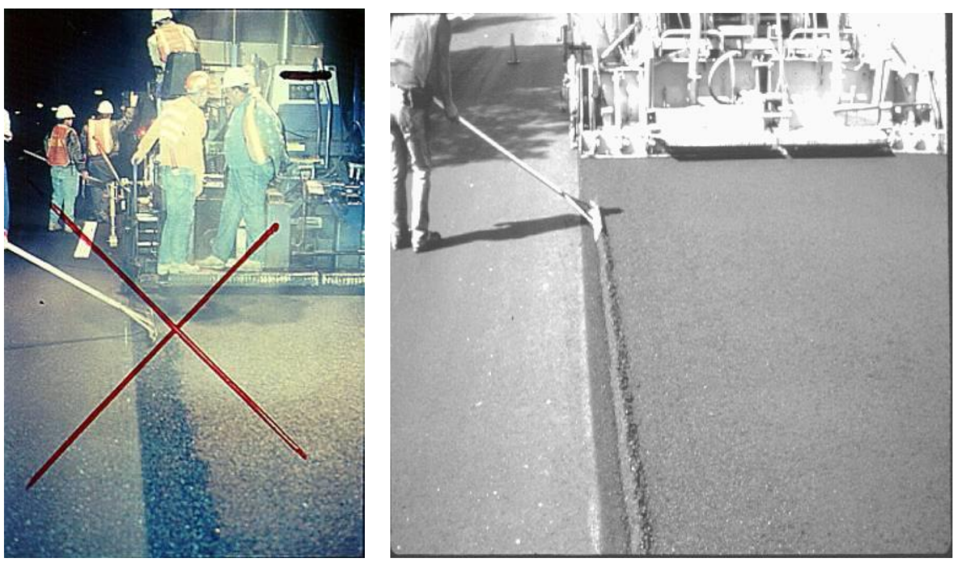
Source: Frank Colella

Figure 143. Proper Overlap When Placing the Confined Side of a Longitudinal Joint

If bumping of the overlap material is done, it is crucial that the overlap material only be bumped just across onto the hot mat and not pushed farther. The rolldown material just on the hot side of the joint should not be disturbed; it must remain to achieve proper density. Aggressive luting that extends across the hot joint must be avoided as it will remove the rolldown material just on the hot side of the joint, resulting in low density as described earlier in this section. This can also cause segregated material on the surface. Improper luting of the LJ is shown in the left picture of Figure 144, while proper luting is shown in the right picture.

Aggressive luting that extends across the hot joint must be avoided as it will remove the rolldown material just on the hot side of the joint, resulting in low density.

If done carefully and correctly, luting the overlap can be beneficial. If done incorrectly, luting the overlap can cause severe joint failure.



Source: Asphalt Institute

Figure 144. Improper Luting of the LJ *(left)*, which Starves the Hot Side of Rolldown Material, and Proper Luting of the LJ *(right)*

Another consideration of whether to lute or not is safety. On roadway projects, traffic in adjacent lanes can make the luting operation very dangerous. This is not a concern for airfield projects where the entire area is closed to traffic.

Broadcasting extra material onto the hot lane should be avoided as it will result in coarse aggregate on the surface that can pop out over time, especially on airfields where FOD is a major concern. Improper broadcasting and improper luting across the joint is shown in Figure 145.

Source: Asphalt Institute

Figure 145. Improper Broadcasting and Luting across the LJ

9.3.4 Rolling the Confined Side

The confined joint should be compacted with the first pass of a steel-drum roller on the hot mat, with the edge of the drum about 6 to 12 inches (150 to 300 mm) off the LJ. The second pass is then applied by overlapping onto the cold mat by 3 to 6 inches (75 to 150 mm). The first pass creates an uncompacted strip 6 to 12 inches wide where any lateral movement pushes extra mix into this strip. The second pass then compacts this uncompacted strip with the full weight of the roller.

The primary reason for staying off the joint on the first pass is to avoid bridging the roller drum on the cold edge. As described previously in Section 9.3.3.2, "bridging" results in no further compactive effort being applied. Staying off the joint 6 to 12 inches slightly migrates the mix laterally into the joint, which results in a little extra mix and higher density in this area. This recommended rolling pattern for compacting confined joints also ensures the first and second passes occur with most of the roller on the hot mat.

Rubber tire rollers, especially vibratory rubber tire rollers, have proven to be very effective in optimizing density at the confined side of the joint.

9.4 ECHELON PAVING AND ROLLING

Because LJs are often susceptible to early deterioration, it is wise to reduce the number of LJs on a project where possible. If project staging and traffic control allow paving multiple lanes or shoulders in a single pass with screed extensions, at least one joint can be eliminated. Section 7.3 covered screeds and screed extensions, including photos.

Another excellent option to reduce the number of LJs is to utilize echelon paving if project staging, logistics, and traffic control allow. In echelon paving, adjacent lanes are placed and compacted side by side at the same time with multiple paving trains. The LJ created between these paving trains is called a hot joint because both sides are hot when placed and compacted. Experience has found that hot joints from echelon paving have better long-term performance compared to cold joints.

Experience has found that hot joints from echelon paving have better long-term performance compared to cold joints.

Echelon paving is not common on roadway projects because there is typically a need to maintain traffic flow, so closing multiple lanes is difficult. Airfields, large commercial parking lots, and new highway construction are examples where echelon paving should be considered (see Figure 146).

Source: Dallas Fort Worth International Airport

Figure 146. Echelon Paving with Four Paving Trains on a Runway at DFW Airport

The limiting factor on the number of paving trains utilized with echelon paving is often the overall mix production to feed the pavers. Utilizing two paving trains is the most common occurrence with echelon paving, while utilizing four paving trains, as seen in Figure 146, is extremely rare.

Lanes are placed simultaneously with the pavers separated by only a short distance, usually less than 100 ft (30 m). This short distance allows the mats to effectively be welded together by the compaction train before the mix on either side of the joint cools. Overlap is typically targeted at 1 inch (25 mm).

Having a standard rolling train behind each paver is recommended. To maximize density at the hot joint, the breakdown roller following the lead paver should leave approximately 4 to 6 inches (100 to 150 mm) of the common edge or joint unrolled. This common joint is then compacted by the first pass of the breakdown roller following the second paver. To accomplish this effectively, the second paver must keep as close as possible to the first paver to minimize any temperature difference between each side of the joint. The material on each side becomes a single mass under the roller, and there is little or no difference in density between the two lanes.

9.5 UNCONVENTIONAL LONGITUDINAL JOINT METHODS

This chapter has already discussed many LJ techniques, options, and products that may not be considered "conventional." They include the following:

- Always having confinement when placing and rolling the LJ (Sections 9.3.3 and 9.3.4). This can be achieved by milling and then paving one lane at a time versus milling multiple lanes.
- Paving wider and echelon paving (Section 9.4).
- Milling or cutting back the joint (Section 9.3.1.4).
- Rubberized joint adhesives applied to the face of the joint (Section 9.3.3.1).
- Utilizing rubber-tire (pneumatic) rollers when compacting the hot side of the joint (Sections 9.3.4 and 8.3.2).

There are three other unconventional techniques not yet mentioned: joint heaters, surface sealers, and void-reducing asphalt membrane (VRAM). All three were developed with the intent of improving LJ performance. They are not being endorsed by the authors or sponsors of this Handbook but rather are mentioned to be inclusive of other unconventional techniques not already mentioned here.

Joint heaters—The use of infrared joint heaters to heat the face of the cold joint just prior to placing the confined side. These heaters are used most frequently in cold climates and cold-weather paving. Some recent studies have shown heaters can improve joint density by 1 to 2 percent. Care must be taken to not overheat the joint and cause damage to the binder. Heater technology has improved to include longer and more efficient infrared heaters and automation with paver speed to minimize overheating or underheating the joint. Figure 147 shows the two general types of joint heaters: those that are self-contained units operating in front of the paver and those mounted on the paver itself.

Source: Asphalt Institute

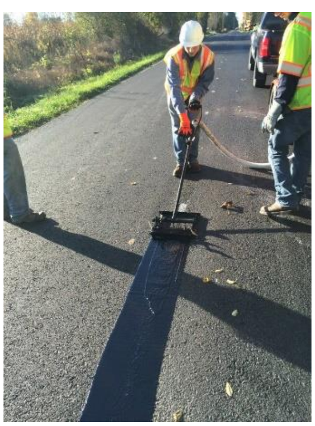
Figure 147. Joint Heaters: Self-Contained *(left)* and Paver-Mounted *(right)*

Surface sealer and rejuvenator products—These are sprayed on top of the completed joint with a typical width of 1 to 2 ft. These topical treatments are applied either when the joint is new or after the joint has been in service for some time. Some States use them as a remedial action for not meeting a minimum density at the joint. These products seal the joint from the top down to reduce absorption and permeability. They are also referred to as a joint stabilizer or joint enrichment. Another type of joint sealer product is called rapid penetrating emulsion (RPE), which is an asphalt emulsion containing about 30 to 40 percent asphalt binder designed to penetrate voids in the asphalt pavement. The penetrating nature of the RPE is important because it carries the asphalt residue into the voids and reduces air and water intrusion while maintaining pavement texture. Figure 148 shows an application of RPE and an application of a rejuvenator that dries clear. Restriping is necessary with RPE and other asphalt-based surface sealers such as fog seals or microsurfacing, but it is not necessary with many of the rejuvenator products that dry clear. These surface sealers are often used over centerline rumble strips. Like all these unconventional techniques, more research is needed on long-term benefits.


Source: Asphalt Materials, Inc.

Figure 148. Surface Sealers on LJs: RPE *(left)* and Rejuvenator VRAM *(right)*

Rather than sealing the LJs from the top down, the product called VRAM is designed to seal the LJ from the bottom up. Use of VRAM involves applying a heavy band (1 gal/yd^2 for a 1.5-inch overlay) about 18 inches wide of polymer-modified asphalt binder to the area where the new joint will be centered. The cold side is placed and compacted, passing over half the width of the band. Figure 149 shows two methods of placing the thick band and then paving over it. The hot side is placed and compacted as a conventional joint. The polymer-modified binder migrates into the mix at the joint, filling voids from the bottom up, reducing water intrusion at the joint and protecting underlying pavement layers. There currently is no proven way to get an exact measurement of in-place air voids of mixes where VRAM is used.



Source: Asphalt Materials, Inc.

Figure 149. VRAM Is Applied with Manual Strike-Off Box *(left)* or Modified Distributor *(middle)*, then Paved Over *(right)*

10. Segregation

10.1 INTRODUCTION

Segregation is the physical and/or thermal nonuniformity of an asphalt mixture. Segregation is a construction defect and is detrimental to the performance of the pavement.

Physical segregation is simply a nonuniform distribution of aggregate particles within an asphalt mixture. Areas of mix placed with concentrations of larger particle sizes will have larger air voids after compaction, which are likely interconnected, causing the compacted mat to be permeable.

Segregation is a construction defect and is detrimental to the performance of the pavement.

Thermally segregated mix can meet mix design parameters but suffer from thermal differentials within a freshly placed mat that results in nonuniform and poor compaction.

Where segregation occurs, the finished mat will have a varied texture and may not meet specification requirements for surface texture, smoothness, or density. Segregated areas differ from the approved mix design, and the areas will not meet the required volumetric properties.

Segregation is typically understood to be physical segregation, therefore thermal segregation should be explicitly identified as such in discussions and text.

10.1.1 Reasons for Segregation and Consequences

The ratio of weight to surface area of a large aggregate particle is greater than that of a small aggregate, and therefore large aggregates tend to be more prone to migrate away from the mass. This migration of aggregate is typically the result of gravitational forces while the aggregate is in motion. Thus, physical segregation occurs when aggregates are being stockpiled and the larger aggregates tumble down the outside of the pile, leaving the smaller aggregates behind. Somewhat similar behavior occurs when a mix is dropped in storage silos, in truck loading and unloading, and in the paving machine when the mix is being pushed forward without confinement. These activities allow the largest aggregate in the mix, even while coated with binder, to migrate.

Physical and thermal segregation result in reduced density, a higher percentage of air voids, and mat permeability. Air and water intrusion will cause disintegration of the compacted mix. With time this results in early pavement failures and, on airports, the occurrence of FOD. The consequence is early maintenance with localized fixes or, depending on the extent and severity, complete removal and replacement.

Permeability testing of compacted mixes can determine the critical percentage of air voids at which the air voids become interconnected, allowing air and water intrusion into the mat. For dense-graded 1/2- and 3/4-inch NMAS mixes, the air voids typically become interconnected at or above 8 percent. For larger NMAS mixes, this transition to being permeable will occur at even lower air void contents. Permeability increases as NMAS increases and density decreases.

10.1.2 Locations Where Segregation Can Originate

Segregation is prone to occur most often at five stages: aggregate handling, mix production, mix storage, trucking, and laydown. Areas where handwork is required are also easier to segregate. Careful observation and control of mixing and placing operations during these stages can reduce or eliminate segregation in most asphalt mixes. The economic benefit of reducing or eliminating segregation has been universally recognized, and agencies that specify asphalt pavements are increasingly addressing ways to control segregation.

Some mixes are more prone to segregation than others, so designers should consider the propensity for segregation of a particular mix. Asphalt mixes that have large-sized coarse aggregate or have low asphalt binder content or are gap-graded will tend to segregate more than a dense-graded mix containing higher asphalt contents and smaller-sized coarse aggregate.

When segregation is observed, there are many process locations to inspect. The inspection starts with aggregate handling and stockpiling, then the many details of the mix production facility, the storage silos and batchers, the truck loading and unloading procedures, and finally the paving machine operations. There are many steps in the mix production process that remix materials to help alleviate mix segregation.

The practice of excessively raking the mat edges and joints should be minimized, as this can also cause segregation.

10.1.3 Early Opportunity to Observe and Correct

Physical segregation is typically first recognized visually in the paved mat. This is when early action is needed to avoid continuation of the problem. Cause(s) need to be determined and adjustments made. Identifying causes and correcting segregation in the mat is a process of working backward: from the paving process, to trucking and loading, to mix storage, to mix production, to aggregate handling.

At the paver screed, a check should be done to ensure the mix is handled correctly by the augers. When paving wide without proper auger and tunnel extensions, the mix tumbles due to lack of support, and segregation potential increases significantly (see Figure 150).

Source: Hawaii Asphalt Paving Industry

Figure 150. Improper Auger and Tunnel Extensions Cause Segregation

At the paver hopper, the hopper should be kept at least 1/3 full, above the top of the slat conveyor tunnel opening(s).

The hopper wings should only be folded at the end of the paving shift. The mix caught in the corners should be left so that all newly deposited mix keeps flowing without being caught in dead corners of the paver hopper.

The use of an MTV can help eliminate both the physical and thermal segregation that occurs before the mix reaches the paver. Dumping mix from a truck directly into a paver hopper can cause segregation, especially over time. MTVs that convey mix directly into a hopper insert will reduce the potential for segregation in this area of the paver. Windrow elevators can also be used for remixing, as discussed in Section 7.2.3.

The use of an MTV can help eliminate both the physical and thermal segregation that occurs before the mix reaches the paver.

Recognizing the many possible segregation opportunities at the mix production facility is the responsibility of the plant operator and inspector and the contractor, and it may also require involvement by the equipment manufacturer.

Incorrect milling that leaves scabs behind (especially for thinner paving lifts) can cause segregation because of fluctuations in how the mix flows under the screed. Overlay lift thicknesses less than three times the NMAS are prone to segregation when placed on a milled surface.

In addition, poorly processed RAP that contains oversized agglomerations of material can inhibit smooth and uniform mat placement.

10.2 RECOGNIZING PHYSICAL SEGREGATION, CAUSES, AND SOLUTIONS

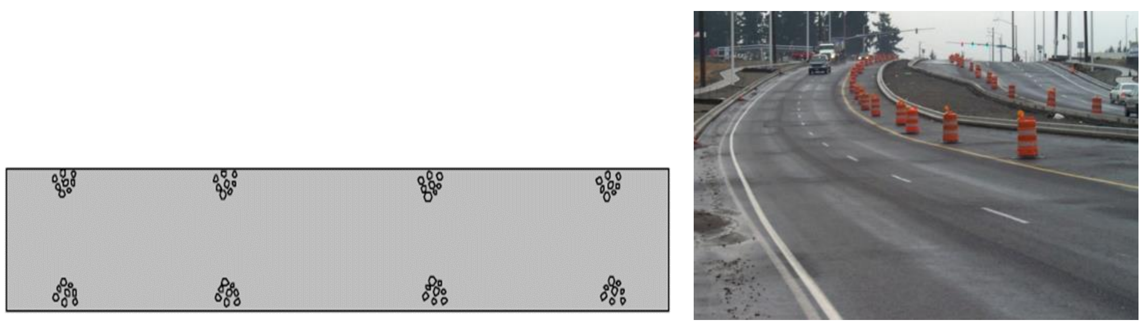
The following are the most common types of segregation in the mat:

- Chevron-shaped spots at the beginning and end of truckloads.
- Center of paver streaks.
- Edge segregation.
- Continuous longitudinal streaks at either or both sides of the lane.
- Random spots that occur intermittently throughout the roadway.

Recognizing the type of segregation will make identifying its cause easier.

10.2.1 End-of-Truck Segregation

Truck-end (end of truckload) segregation shows up at regular intervals coinciding with the beginning and ending of each truckload discharge cycle. If the trucks are improperly loaded and unloaded, a segregation-prone mix will segregate when the mix starts being unloaded and then again when the last amount of mix comes out of the truck bed. It can be seen as a regularly spaced repetition of segregated areas down the road (see Figure 151).



Source: Asphalt Institute

Figure 151. Examples of Truck-End Segregation

Truck-end segregation has many potential causes. The most common is improper loading of the haul truck from the silo. If the mix is placed in the truck bed in one drop from the silo, the coarse aggregate particles in the mix tend to run to both the front of the bed and the back tailgate. This rolling of the coarse aggregate is exacerbated if the plant operator continuously opens and closes the silo gates near the end of the truck loading procedure to ensure that the full allowable weight of mix is placed on the truck. Segregation occurring along the sides of the truck bed during loading translates to the paver when unloading into the paver hopper. Segregated material, or material trickling into the hopper at the outer box edge, will accumulate in the outer area of the hopper wings. All these segregation locations (front, side, and rear) exacerbate segregated mat areas behind the paver when the hopper wings are folded between every load.

10.2.2 Centerline Segregation

Centerline segregation (see Figure 152) is caused by the gear assembly that powers the augers. When placed too low, the augers and gear assembly may not provide enough clearance for the mix to counterflow to the center of the mat being placed. The result will be an insufficient, segregated mix in the center of the mat. When this occurs, the solution is to raise the auger gear assembly to give more clearance for the mix to flow to the center.

Source: Asphalt Institute

Figure 152. Examples of Centerline Segregation

Most paving machines have reverse flow or "kickback" augers right next to the auger drive assembly to alleviate centerline segregation. Sometimes these augers are worn or broken and need to be replaced.

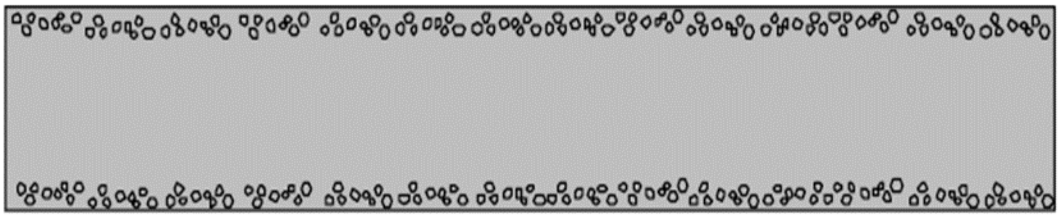
10.2.3 Joint and Edge Segregation

When the mix is not confined properly at the outer ends of the screed, the mix can segregate. This is especially possible when paving wide without auger and tunnel extensions. The further the mix is pushed to the sides by the augers without an auger extension, the more segregation can be expected. In addition, it is recommended that the tunnel (confining plate) is extended to prevent the mix from segregating forward. When the mix flows forward, vertical segregation may occur, which is less visible on the surface. However, cores will show the larger aggregates at the bottom of the lift (see Figure 153).

Source: American Society of Civil Engineers

Figure 153. Vertical Segregation (Top Different than Bottom of Cross Section)

Joint segregation can also occur when the rakers make corrections near the joint (see Figure 154). Recommendations are to overlap the joint approximately 1 inch and let the roller compact this overlap down without raking or luting the overlap. Any crushed aggregate will soon weather away.



Source: Asphalt Institute

Figure 154. Illustration of Joint Segregation

10.2.4 Whole- or Half-Width Mat Segregation

Whole- or half-width segregation (see Figure 155) can occur for several reasons.

The first reason is that one or both augers were provided insufficient mix. To avoid this, the mix should always be held close to the axle of the augers and at an even height across the auger chamber.

The second reason is that the mix was improperly loaded into the haul truck. If the mix is not loaded in the center of the width of the truck bed, the coarse aggregate particles in the mix may roll to one side of the truck bed and accumulate along that side. When the mix is delivered to the paver hopper, the segregated mix will be placed on the roadway along the same side, and the segregation will appear as a longitudinal streak on one side of the paver only.

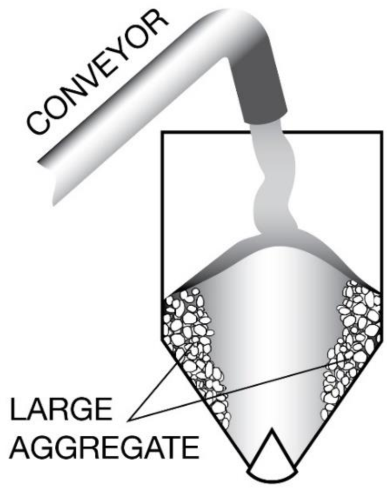
Source: Texas Department of Transportation

Figure 155. Example of Half-Width Mat Segregation

A third reason is that the mix was improperly loaded into the silo. As the mix is deposited into the silo from the conveying device (slat conveyors, belt conveyor, or bucket elevator), the mix may be thrown to one side, causing the coarse aggregate particles to be separated from the finer materials (see Figure 156).

When the silo is emptied, the coarse aggregate is deposited on only one side of the truck. This segregated material then passes through the paver and is seen on one side of the mix after laydown. Further, if the truck is not loaded in the center of its width under the silo, rolling of the coarse aggregate particles may occur, and longitudinal segregation can appear on one side of the mat. The illustration in Figure 156 shows the mix being conveyed into a gob hopper, which should reduce segregation as it deposits the mix into the silo in batches.

These first four types of segregation (end-of-truck, centerline, joint and edge, and whole- or half-width mat) originate at the trucking and paving operations. People working onsite should be able to notice, recognize, and correct these types of segregation as soon as possible.

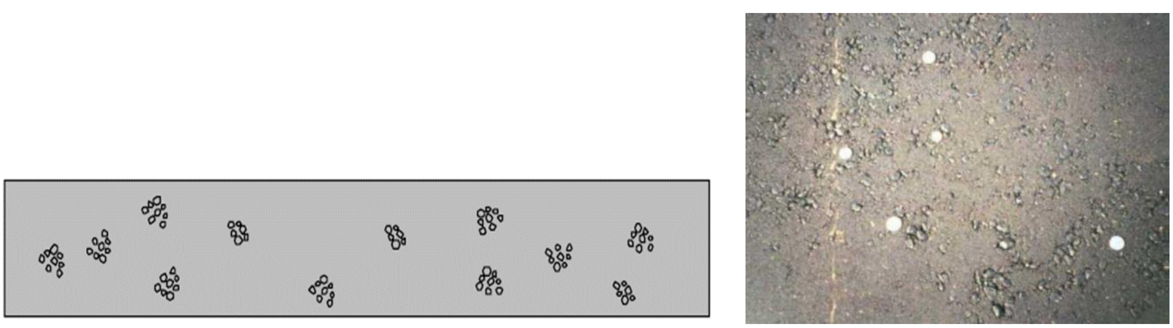


Source: NAPA

Figure 156. Segregation in the Silo at the Plant

10.2.5 Random Segregation

Contrary to the previous four examples of segregation, random segregation typically originates at one or a combination of locations upstream from the trucking and paving operation. It is less easy to identify in the mat because of its randomness, in part due to remixing opportunities (see Figure 157). This is the type of segregation the paving crew has little to no possibility of correcting. Investigations as to the location and cause are more complicated and involve inspections starting at aggregate handling and then going through the mix production, storage, and discharge process. Its level of severity in the mat will dictate if and what remedy is required. Large aggregate, gap-graded, and SMA mixes are more prone to this type of segregation.



Source: Iowa Department of Transportation

Figure 157. Random Segregation

Segregated rock pockets are generally caused by improper handling of the aggregate in the stockpiles or cold-feed bins or improper storage of the HMA at the asphalt plant.

These problems are reduced when a batch plant is used to produce the mix without a silo, because the screens and hot bins in the plant recombine any segregated material before it is fed into the pugmill. Further, the pugmill blends all the aggregates together and normally eliminates any segregation that might have occurred previously. If a silo is used on a batch plant, however, the mix may segregate for all the same reasons that affect a mix produced in a drum-mix plant and passed through a surge or storage silo.

10.3 FOUR STAGES WHERE SEGREGATION CAN ORIGINATE

Segregation most commonly occurs at these four stages:

- Aggregate handling and stockpiling.
- Asphalt plant production.
- Trucking operations.
- Paver operation.

Segregation caused by the trucking and paving operations can generally be noticed by the paving crew, foreman, or inspector, and corrections can be made quickly. Conversely, segregation caused by aggregate handling and mix production may be more complex to pinpoint and therefore may not be corrected on the day the segregation was noticed.

The following sections address each of the four stages.

10.3.1 Aggregate Handling and Stockpiling

Stockpiles can be built properly, with minimum segregation, by end-dumping the aggregate from trucks to form piles that are only one layer deep. The challenge with this method is that it requires a lot of space since the stockpiles are not high.

Tall, conical stockpiles of aggregates should be avoided because coarser particles tend to roll down the sides of the pile. Stockpiles constructed in layers or material inclines with less than 30 percent slopes are preferred.

10.3.2 Asphalt Plant Production

Segregation issues in the asphalt plant are beyond what the paving crew at the jobsite can solve. Given the complexity of the asphalt production facility, the many locations where segregation may occur will require a lengthy investigation by contractor plant maintenance personnel and possibly the manufacturer's technical assistance.

One of the most common causes of plant segregation is improper loader operation at the plant, which can contribute significantly to sporadic nonuniform segregation. Loading cold-feed bins from segregated stockpiles, placing the wrong material in the wrong bin, allowing the aggregate in the cold-feed bin to bridge (thereby halting the feed from that bin), or letting bins run dry will produce segregation in the mat behind the paver.

The following are additional locations in the mix production facility that may need to be looked at to ensure a uniform flow of material through the plant:

- Cold bins.
- Hot bins.
- Drum dryer flights.
- Hot elevator.
- Pugmill and bin gates.
- Surge and storage bins.
- Discharge systems.

Broken or poorly maintained equipment may require repair, fabrication, or even retrofitting plant equipment.

10.3.3 Trucking Operations

Segregation occurring due to the truck loading and unloading can typically be observed by field personnel and corrected quickly.

Asphalt mix can segregate as it is loaded into trucks from either the pugmill, silo, or surge systems. Trucks are much larger today, and care should be taken during loading to prevent coning within the truck bed.

Pugmills, silos, and surge systems all have the same truck loading recommendations. There should be at least three drops of material—front, back, and then center (see Figure 76 in Chapter 6). A single discharge into the truck allows larger particles to segregate. The mix should be placed first near the bulkhead to produce a stacking effect for the front and sides. The second drop produces the same conditions at the rear of the truck. The third drop, in the middle, should overlap the conical sides of the first two. This procedure does not eliminate segregation entirely but spreads it out and minimizes the effect.

The method used to unload the haul truck into the paver hopper may also contribute to segregation by generating longer slopes over which the particles may separate during dumping. Most problems of this kind develop from slowly raising the truck bed while dumping. When the truck is in place to dump into the hopper, the bed should be partially elevated before the tailgate is released. This permits the mix to move in mass and to flood the hopper, thus preventing the coarse aggregate from trickling out first and causing spotty segregation patterns.

10.3.4 Paver Operation

The paving operation is more than just knowing how to operate the equipment. Many mistakes in handling the mix in the hopper and in the auger compartment, and in operating the screed, can cause non-correctable segregation in the finished mat. The cause of such segregation should be corrected as soon as it is observed. If the cause cannot be identified and the segregation persists, the paving operation should be halted.

In the ideal paving operation, the paver should move forward at a constant speed all day without stopping and starting. However, some incidental stopping and starting is unavoidable. When this happens, both physical and thermal segregation is minimized by making a hard stop with sufficient mix in the hopper and in the auger chamber at the correct mix height. If the interruption in paving is expected to take too long (typically more than 30 min), actions comparable to what is done at the end of the paving day need to take place and a transverse joint created.

If segregation does occur during paving operations, the following are common causes.

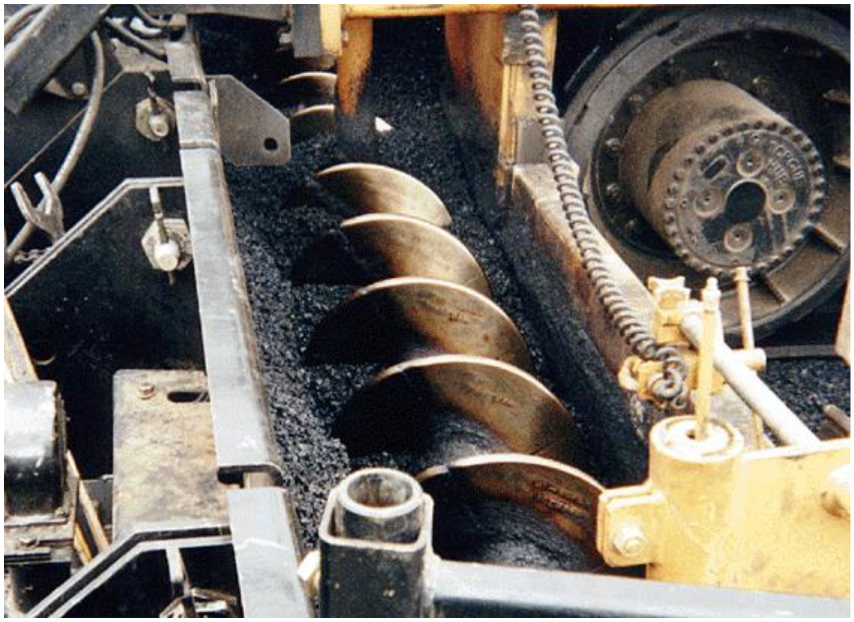
Causes of segregation in the hopper:

- The hopper is allowed to be emptied below 1/3 of the hopper's capacity.
- The hopper wings are folded at frequent intervals.
- The slat conveyors are allowed to be starved of mix and become visible.
- The flow gates are set incorrectly for the speed of paving.
- Spilled mix is being returned to the hopper.

Causes of segregation in the auger chamber:

- The mix is **not** kept at a constant height and at the same level as the auger axle across the full width of the screed (see Figure 158).
- The height of the mix differs between the left and right side.
- If paving wider, the augers and the confining tunnel are not extended close to the end gate.
- The augers are not set high enough to allow reverse flow under the auger gearbox.
- The reverse augers near the auger gearbox are not present or working.
- The rotation speed of the augers is not within acceptable limits.

Any of the issues listed above have the potential of causing segregation.



Source: Reway

Figure 158. Proper Mix Height in the Auger Box

Continuous segregation can generally be attributed to operations and material handling at the paver. Regular spacing of segregated areas is typically end-of-load related.

10.4 THERMAL SEGREGATION

Thermal segregation is not identifiable without infrared monitoring, and therefore it will often go unnoticed. As with physical segregation, there are many locations where thermal segregation may originate. This type of segregation occurs most often in trucking procedures and paver operation.

Thermal segregation is not identifiable without infrared monitoring, and therefore it will often go unnoticed.

In trucking, the mix cools more quickly near the edge, bottom, and top of the haul truck. This cooler material is not always remixed with the hotter material, leading to temperature segregation during laydown and compaction. The result can be more variability with in-place density and a nonuniform surface. This problem can only be detected by infrared technology. Truck beds are often insulated for longer haul distances to reduce the potential for temperature segregation.

The use of MTVs has shown benefit in reducing segregation. The MTV remixes the mix, reducing both physical and thermal segregation. Temperature segregation can be minimized with a balanced, uninterrupted paving operation.

There are various ways to detect thermal segregation. These range from using a handheld infrared "gun" that spot checks surface temperature to more automated systems. These automated systems can scan the full width of the mat, record surface temperatures and location, and send the results in real time for analysis (see Figure 159). This allows for decisions regarding the construction operation and timely corrections if needed.

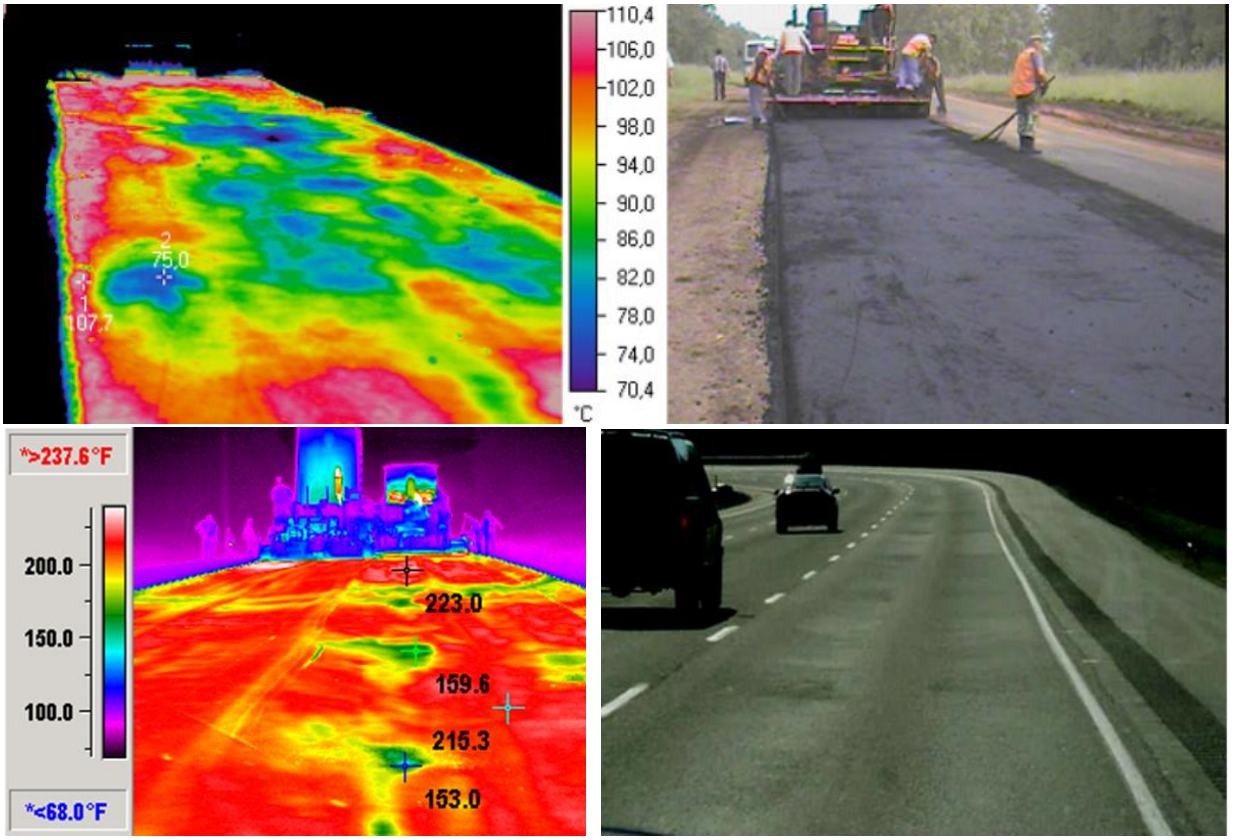
Source: VÖGELE

Figure 159. Paver Equipped with an Automated Infrared Scanner

Research by Willoughby et al. (2001)[1] concluded that if the mix temperature differential is less than 25 °F (~15 °C), generally consistent compaction can be expected. But if the mix temperature differential is 25 °F (~15 °C) or greater, differential compaction can occur, and the in-place air void content will fluctuate.

Highly segregated areas of coarse materials will tend to lose heat faster than surrounding areas of the freshly placed mat and appear in thermal imaging. Thermal segregation can be an indicator of the presence of physical segregation. Infrared data can identify cool spots in the mat and predict segregated areas (see Figure 160).

[1] K. Willoughby, J. Mahoney, L. Pierce, J. Uhlmeyer, K. Anderson, S. Read, . . . R. Moore, *Construction-Related Asphalt Concrete Pavement Temperature Differentials and the Corresponding Density Differentials* (Washington State Department of Transportation, 2001).



Source: Dorogi i Mosti Journal (top) and Pavement Interactive (bottom)

Figure 160. Segregated Areas *(on right)* Predicted by Cool Spots on Infrared

10.5 CONFIRMING AND QUANTIFYING SEGREGATION

Identifying the presence of physical segregation can too often be subjective.

It is best to recognize segregation as it is occurring and make corrections as soon as possible. Unacceptable areas of segregation should be replaced as part of the project contract during construction.

The severity of segregation falls into three general categories:

- Slight—Area where there is slightly more coarse aggregate than in the surrounding acceptable mix.
- Medium—Area has significantly more coarse aggregate than the surrounding acceptable mat and usually exhibits some lack of surface fines.
- Severe—Area appears very coarse in comparison to the surrounding acceptable mat, with stone against stone and little or no fines present.

Work is typically suspended when the medium or severe level of segregation is identified. This allows the contractor the opportunity to address and take corrective action against any further segregation on the project.

If the contractor and the agency agree that an area is significantly segregated, the repair, or even a remove/replace, often takes place quickly. However, if there is disagreement regarding the existence, severity, and extent of the segregation, a method to quantify segregation is helpful in reaching a resolution.

Physical and thermal segregation will cause the mix to be outside of the tolerances for one or several of the specification requirements. Comparing the segregated area test results with the test average, standard deviation, and range representing the rest of the lot's test results is a way to quantify segregation.

Tests that can help identify and quantify segregation include the following:

- Infrared temperature readings (by scan).
- Density readings (nuclear or lab).
- Binder content (extraction/ignition oven).
- Aggregate gradation (after binder extraction/ignition oven).
- Permeability testing (field or lab).
- Sand patch test (ASTM E965).

Many of these tests are already performed for the general acceptance of the lots. Comparison can also be made to the tolerances from the approved JMF.

Permeability testing can be performed with either a laboratory falling head permeameter or a field permeameter.

A core taken from a visually segregated coarse area in the mat (also known as a rock pocket) will naturally have a lower binder content relative to an area that is not visually segregated.

A series of nuclear density gauge readings can be used to quantify segregation. Typically, a specified number of readings are taken in a prescribed pattern. If the range between readings exceeds specified limits, the mat is deemed segregated in that area.

11. Quality Assurance

11.1 INTRODUCTION

Highway and airfield construction specifications are a means to an end. Their objective is to provide the traveling public with an adequate and economical pavement on which vehicles and aircraft can move easily and safely from point to point. A practical specification is designed to ensure adequate performance at minimum cost; a realistic specification takes account of variations in materials and construction that are inevitable and characteristic of the best construction possible today.

Most agencies currently use a combination of method specifications, statistically based specifications, and end-result specifications, all of which will be discussed in Section 11.3. This combination shares the risk between agency and contractor, directly specifying some materials, equipment, and methods, but allowing the contractor to choose some also. What "acceptable" looks like is defined, and random sampling and statistical analysis of test results evaluate whether the contractor's work is acceptable.

Although other QA topics will be introduced, the primary focus of this chapter will be on several elements of QC. The following subsections will discuss definitions of the primary aspects of QA.

11.2 DEFINITIONS

11.2.1 Quality Assurance

The definition of QA has evolved over the years. Earlier definitions described QA primarily as the methods employed by the owner/agency to ensure that they receive a quality product, a definition now closer to the term "acceptance." Two documents are now referenced for definitions in this area: AASHTO R 10, "Definition of Terms Related to Quality and Statistics as Used in Highway Construction," and TRB Circular E-C173, "Glossary of Transportation Construction Quality Assurance Terms." Airfield specifications such as FAA's P-401 and the DoD UFGS 32 12 15.13 use most of the terms synonymously with the AASHTO and TRB documents, but not always.

AASHTO R 10 defines QA as, *"(1) All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) making sure the quality of a product is what it should be."* QA addresses the overall process of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. QA includes the elements of QC, independent assurance, acceptance, dispute resolution, etc. QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction and maintenance, and the interactions of these activities.

11.2.2 Quality Control

AASHTO R 10 defines QC as, "*The system used by a contractor to monitor, assess, and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. Quality control includes sampling, testing, inspection, and corrective action (where required) to maintain continuous control of a production or placement process.*" QC is also known as "process control."

Airfield agencies like FAA and DoD generally rely on different mechanisms than DOTs to accomplish the same goal of quality.

Public and private airfields often rely on contractor QC as a major part of their QA program, providing few, if any, agency inspectors. This does not mean that inspection is not done, or that quality suffers. Airfield agencies like FAA and DoD generally rely on different mechanisms than DOTs to accomplish the same goal of quality.

11.2.3 Acceptance

AASHTO R 10 defines acceptance as, "*The process whereby all factors used by the agency (i.e., sampling, testing, and inspection) are evaluated to determine the degree of compliance with contract requirements and to determine the corresponding value for a given product.*"

QC measurements (sampling, testing, and inspection) may or may not be used in the acceptance decision process. When contractor test results are used in the agency's acceptance decision, the process often includes agency verification and/or dispute resolution mechanisms.

11.2.4 Dispute Resolution

Agency and contractor labs sometimes generate conflicting test results. It is important for specifying agencies to outline a process to resolve conflicts that may occur. AASHTO R 10 defines dispute resolution as, "*The procedure used to resolve conflicts resulting from discrepancies between the agency's and contractor's results of sufficient magnitude to impact payment.*"

As an initial step, agencies may simply review multi-laboratory precision statements in AASHTO and/or ASTM to see if test results are within the acceptable range of two test results. A dispute resolution procedure may also include the testing and comparison of independent samples. Agencies may apply some type of statistical test (t-test) to determine for a group of test results how far apart is too far apart. The independent t-test is used to compare the means of two independently obtained sets of data. The paired t-test compares test results of split samples. If disputes cannot be resolved between the agency and contractor, third-party arbitration may be the final step.

11.3 GENERAL TYPES OF SPECIFICATIONS

Agencies need some method of communicating their expectations to the contractor. Specifications are part of the contract, and they communicate the requirements under which a contractor must successfully deliver a project. They should be clearly written so all parties can properly evaluate the degree of conformance and what happens if the work does not conform to the specifications.

11.3.1 Method Specifications

Method specifications (or prescriptive specifications) were probably the most widely used type of specification in highway and airfield construction until the mid-1980s. With this type of specification, the agency directs the contractor to use specific methods, including materials, proportions, processes, and equipment. If the contractor follows the requirements, the agency accepts the completed work and bears the complete burden of responsibility for the quality and performance. Terminology such as “substantial compliance” and “reasonably close conformity” is associated with method specifications.

An advantage of method specifications is that they offer extreme agency control when the expertise for a particular product or process is largely on the agency side. They may also offer an advantage when a measure of quality is particularly difficult to define. Asphalt mix segregation is one such case. Segregation is an undesirable feature (covered in detail in Chapter 10), but the allowable degree of segregation is difficult to measure or to specify. Thus, method specifications can be used to specify what a contractor must do to prevent segregation.

However, method specifications also have several disadvantages. Contractors may not be allowed to use the most economical or innovative procedures to produce the product. The corresponding inspection to ensure conformity is labor-intensive. If the quality of the product is measured and found to be less than desirable, the contractor has no legal responsibility to improve it if the methods were followed. The agency assumes the bulk of the specification risk.

The major weakness of this type of specification is that there is no guarantee it will produce the desired quality of construction. Most importantly, by explicitly specifying the material and procedures, the owner or agency obligates itself to a large degree to accept the end product. Such a specification is also very difficult to enforce uniformly. The terms “reasonably close conformity” and “substantial compliance” cannot be precisely defined. In the absence of a clearly established quality level and a uniform means of measuring compliance, decisions can become arbitrary, and acceptance procedures become inconsistent in their application.

11.3.2 End-result Specifications

The construction of the American Association of State Highway Officials (AASHO) Road Test in 1958 provided the first step toward end-result specifications. This type of specification offered a way to better assess and quantify the quality of construction than imprecise verbiage like “reasonably close conformity.” True end-result specifications require the contractor to take the entire responsibility for producing and placing a product. The agency’s responsibility is to either accept or reject the final product or to apply a pay adjustment that is commensurate with the measured degree of compliance with the specifications.

End-result specifications have the advantage of allowing the contractor flexibility in exercising options for new materials, techniques, and procedures to improve the quality and/or economy of the end product.

End-result specifications typically do the following:

- Assign the contractor complete responsibility and latitude in determining the procedures and equipment used to produce the product.
- Leave QC sampling, testing, and inspection entirely at the discretion of the contractor or producer.
- Base agency acceptance on sampling and testing of the final in-place product.
- Determine a price adjustment based upon the measured degree of compliance with the specification criteria.

End-result specifications stress sampling and testing of the final product, as opposed to inspection, as the main measure of agency acceptance. A large quantity of material may be found to be defective after it is already in place, when there is very little opportunity for correction. This is risky because the specifying agency may accept a certain amount of undesirable product. Because only the final product is tested, this also discourages accumulating testing results throughout construction to obtain a more representative picture of the product quality.

11.3.3 Quality Assurance Specifications

QA specifications evolved from complications with method specifications and end-result specifications. This type of specification is the most used today. AASHTO R10 defines them as specifications that require contractor QC and agency acceptance activities throughout the production and placement of a product. Final acceptance of the

QA specifications evolved from complications with method specifications and end-result specifications. This type of specification is the most used today.

product is usually based on a statistical sampling of the measured quality level for key quality characteristics.

The contractor's QC and agency responsibilities should be clearly defined. On the contractor side, a QC plan should be documented that identifies all QC personnel and procedures that will be used to maintain production and placement processes in control and meet agency specification requirements. The plan must also address corrective action to be taken if the process goes out of control. More information about QC plans can be found in Section 11.4.

Other key areas to document in a QA specification include the following:

- How asphalt mix designs are submitted and how they are verified.
- How plant and field performance is verified (e.g., trial batches, control strips).
- How QC testing and inspection will be used to monitor work.
- Whether and how QC test results will be used for acceptance.
- Details regarding agency inspection and acceptance procedures.

As part of QA specifications, the material quality characteristics to be sampled, tested, and inspected for QC and acceptance must be identified and clearly outlined. For example, a specification might identify mix gradation, binder content, thickness, VMA, laboratory air voids, and in-place air voids as contract quality characteristics. Other characteristics that measure smoothness, runway grooving, rut resistance, crack resistance, etc., might be included, depending on the project size.

Other important information to include in a QA specification would be the location of sampling, sampling methods, lab handling methods, and test methods to be used on the samples. How often to sample and test should be clearly spelled out, as well as how and to whom test results will be reported. The selected quality characteristics should be related to product performance and should be clearly measurable.

The measure of quality (MOQ) to be used for acceptance must be specified. The MOQ is any of several mathematical tools that are used to quantify the level of quality of an individual quality characteristic. Common MOQs include the mean, standard deviation, average absolute deviation (AAD), and percent within limits (PWL). AAD and PWL are two of the most common MOQs.

11.3.3.1 Absolute Average Deviation

If a specification merely required the average result to be within a certain range, initial high values could purposely be later offset by low values to bring the mean into the target range. The same would be true for the average deviation, which would include whether the deviation from the target was positive or negative. While using the mean or average deviation might be valuable QC tools for monitoring trends, they are not appropriate for acceptance.

The AAD uses the absolute deviation of a test result from the target value, without regard to signs. An advantage of AAD is that it is very easy for any technician to understand the mathematics of averaging individual test values' differences from the target value and be able to picture that AAD shows, on average, by how much a target was missed. A low AAD implies that the data is both close to the target and has low variability.

However, there are disadvantages to AAD. Using absolute deviations, AAD does not signify whether deviations are always low, always high, or some mix of the two. A high AAD does not necessarily mean that there is both poor precision and accuracy. The results could be very precise but not accurate. Therefore, AAD does not fully measure variability. And for one-sided specifications like VMA, there is no target from which to calculate AAD, only a minimum.

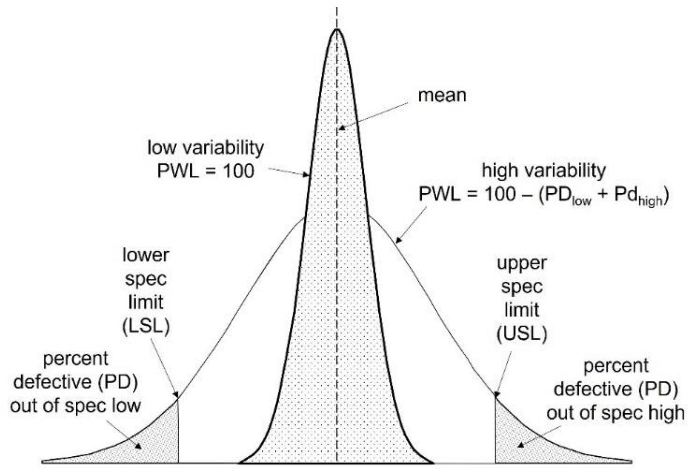
A similar MOQ, Conformal Index, measures the squared deviation from the target. While the Conformal Index may be a better measure of accuracy, it presents the same disadvantages as AAD.

11.3.3.2 Percent Within Limits

For pure statistical accuracy, the MOQ adopted by most agencies is PWL. It is more discerning than other quality measures. The PWL procedure is based on the normal distribution, which is a continuous probability distribution having a bell-shaped curve defined by the sample mean and the sample standard deviation. The area under the normal curve can be calculated to determine the percentage of the population that is within certain limits.

Figure 161 illustrates the concept. All the data is represented by the area under the curve. The figure shows two datasets with the same mean at the target value, one with low variability and one with a higher variability. The lower limit set by agency specification is shown as the lower specification limit (LSL), and the upper limit set by agency specification is shown as the upper specification limit (USL). The lightly shaded, low-variability data is completely within the specification limits (100 PWL) and would receive full pay and perhaps some type of bonus. This data would be both accurate and precise.

The wider high variability curve data averages the same as the low variability curve but is much more variable. It contains data both below the lower specification limit and above the upper specification limit. These areas can be calculated and are referred to as the percent defective (PD). The PWL of the wider variability data would be calculated as 100 – (lower PD + upper PD). This data would be accurate but not precise. Most agencies allow down to 90 PWL (10 PD) for 100 percent pay.



Source: Asphalt Institute

Figure 161. Percent Within Limits

Both datasets in Figure 161 are centered around the target value. If, for example, the dataset had low variability but was off target on the low side, the curve would shift to the left. If the average of the data was low enough, there would be some PD on the low side, but none on the high side due to the low variability of the data. In this example, the data would be precise but not accurate.

Although PWL is not as easy as AAD for technicians to understand and calculate, it offers some advantages. It is more statistically discerning than other MOQs. It efficiently captures the mean and standard deviation of the data into one MOQ. Like other QA specifications, PWL encourages uniformity. Uniformity is a proven predictor of performance.

11.3.4 Performance Specifications

Many agencies are working toward performance specifications. AASHTO R 10 defines performance specifications as those that describe how the finished product should perform over time. Although there are several types of performance specifications, warranties often come to mind when discussing them. In a warranty specification, the contractor assumes all the risk for how the pavement performs and takes on all maintenance activities required to maintain the performance at a specified level.

The following are shortcomings to using warranty specifications:

- They require long-term monitoring, with associated administrative needs.
- They require distinguishing between design- and construction-related problems.
- They typically are subject to reduced bonding capacity.

Because of risks associated with future uncertainties, bonding companies are typically not willing to provide warranties to contractors beyond 5 years. This increases the overall cost of the project to an agency.

Two other categories of specifications that fall under the umbrella of performance specifications are performance-related specifications and performance-based specifications.

Performance-related specifications describe the desired levels of key materials and construction quality characteristics that, in clearly defined conditions, have been found to correlate with fundamental engineering properties that predict performance. These characteristics, for example air voids, tend to lend themselves to acceptance testing at the time of construction.

Performance-based specifications describe the desired levels of fundamental engineering properties (e.g., resilient modulus, creep properties, and fatigue) that are predictors of performance and appear in primary prediction relationships. These models can be used to predict stress, distress, or performance from combinations of predictors that represent traffic, environment, supporting materials, and structural conditions. Most fundamental engineering properties generally do not lend themselves to timely acceptance testing.

NCHRP Synthesis 492, Performance Specifications for Asphalt Mixtures, is a good, comprehensive reference on this topic.

11.4 QUALITY CONTROL PLAN

Some form of QC (or process control) is provided during the production of all asphalt mixes. There are two key aspects of QC testing. The first is measuring specific characteristics and inspecting those activities that affect the quality of the finished product. The second aspect is providing the results of those measurements and inspections in a meaningful and timely way that allows adjustments during the production process. The subsequent adjustments or corrective action can thus minimize non-complying materials from being incorporated into the finished work.

The amount of QC data and the level of control vary greatly from one project to another. Some project specifications require the contractor to exercise extensive control and mandate specific tests and test frequencies. Other specifications allow the contractor or the supplier to determine the level of testing based on their own judgment of what data is needed to adequately control the production process.

There are two key aspects of QC testing. The first is measuring specific characteristics and inspecting those activities that affect the quality of the finished product. The second aspect is providing the results of those measurements and inspections in a meaningful and timely way that allows adjustments during the production process.

11.4.1 Selection of Sampling Methods and Sample Frequency

Methods and locations of sampling can have a significant influence on the outcome of the parameters being measured for QC. Sampling, therefore, is an important aspect of the overall QC program.

The methods and frequencies selected for sampling are not always the same for QC as they are for acceptance. The sampling methods used to determine the aggregate gradation are one example. Some contractors use cold-feed belt sampling methods for testing aggregate gradation for QC purposes. These samples are taken at the asphalt mixing plant and can provide test results within hours of sampling. These QC results allow any necessary adjustments to be made throughout the day.

Acceptance results should be communicated to the contractor in time to make any necessary adjustments, typically within 24 hours. But sometimes they may not be received until days after placement, potentially causing several days of mix to be placed out of specification. The amount of time needed to get results is an important factor in the selection of sampling methods during production.

11.4.2 Selection of Testing Methods

Traditionally, control of mix production was almost exclusively driven by binder content and aggregate gradation. As QC testing during mixture production improved, and as the technical understanding of the volumetric factors affecting longevity of asphalt pavements progressed, there has been an increased emphasis on controlling these properties in the mix. Most agencies now include mixture volumetric tests in their requirements for both QC and acceptance.

To predict long-term durability, some agencies are now including performance tests in their QA or acceptance criteria. The balanced mix design philosophy (as discussed in Chapter 3) combines performance testing and traditional mix testing to enhance the mixture's ability to perform over time.

Based on NCHRP Synthesis 346 "State Construction Quality Assurance Programs," most State DOTs in the United States select specific sampling and testing methods that are to be used at minimum for QC on their projects. These testing requirements are typically identified in the standard specifications. Many agencies include QC line items in bids to reimburse contractors for costs associated with providing the tests. The synthesis report identified the following parameters that may be required for QC testing programs:

- Asphalt binder content.
- Aggregate gradation.
- Compaction.
- Volumetric properties (air voids, VMA, VFA).

- Ride quality.
- Aggregate characteristics (course aggregate angularity, fine aggregate angularity, flat and elongated particles, sand equivalent, etc.).
- Pavement thickness.

Many of the test values are compared with the JMF. When that is the case, the same tests should be used for QC as were used in the development of the JMF. It would not be advisable, for example, to use Marshall density values to evaluate air voids on mixes that were designed using Superpave.

For tests that are not compared with the JMF, the test methods selected for QC purposes may be different from the test methods used for acceptance of the same parameter. For example, QC testing often uses nuclear or non-nuclear density gauges to give an indication of roadway density during rolling operations. Agencies commonly require cores to be cut from the finished pavement for final acceptance of density. Test results from cores come too late to be used for adjusting the compaction operation in real time because the asphalt has already cooled. Density gauge readings can be taken while the mix is still hot and the compaction operation is ongoing. Thus, gauge test results can be an important part of the overall QC program for asphalt compaction.

Since QC methods must emphasize timeliness and convenience, the results can be less accurate and more variable. If the QC test method is different than the acceptance method, a minor shift in the data should be anticipated. It would be unreasonable, for example, to stop compaction operations when a reading of 92.6 percent compaction was read on a nuclear density gauge if the minimum required compaction was 93 percent using core densities. A higher target could be established to account for the likely variation and the possible shift of compaction values from the nuclear density method to the core density method. It is also a prudent QC measure to correlate QC test methods and laboratories to the acceptance methods performed by the acceptance laboratory. This can be accomplished by comparing gauge readings to core densities obtained at the same locations from a test strip or at the beginning of mix production.

If a gauge is being used to control density, an accurate correlation to core densities should be established. For each density gauge, it is reasonable to expect a consistent offset value from a gauge reading and that obtained from a core. Most agencies have established methods for correlating gauge values to those from cores.

11.4.3 Written Quality Control Plan

Most agencies that specify QC sampling and testing on their projects also require the contractor to submit a "Quality Control Plan" before beginning paving operations. The requirements for these plans can be extensive and usually involve more than just sampling and testing plans. They will generally require documentation verifying compliance with certain project requirements related to the QC program. NCHRP Synthesis 346 indicates the following items are usually required as part of written QC plans for plant mix production:

- Responsibility matrix showing who is responsible for reviewing QC results and directing any corrective action.
- Sampling and testing plan identifying specific tests and frequencies to be used for the project.
- Documentation demonstrating that the plant meets the required qualifications, certifications, and inspection frequencies.
- Documentation demonstrating that the laboratory that will provide the QC testing meets the required qualifications and accreditations.
- Documentation of the equipment contained within the laboratory and any calibration certifications that may be necessary.
- Documentation demonstrating that the technicians who will provide the sampling and testing meet the required qualifications and certifications.
- Example report forms, including control charts that summarize certain key data on plots that can rapidly show trends that need attention.
- Written procedures describing criteria that will be used to identify “out of control” production, what actions will be taken when materials fall outside of those criteria, and what the timing/deadlines of these actions will be.

An example sampling and testing plan that would be a part of the QC plan for mixture production is presented in Table 10, showing both the ASTM and the AASHTO methods. The methods are not interchangeable because they are not always the same. Therefore, standard specifications should designate the method to be followed.

Table 10. Example QC Sampling and Testing Plan

Test Parameter	Sample Point/Method	Test Method, AASHTO	Test Method, ASTM	Sample Frequency	Estimated Quantity	No. of Tests
Aggregate Gradation	Cold Feed Belt, ASTM D 75	T 27, T 11	C 136, C 117	1,000 tons (907 tons)	28,000 tons (25,400 tons)	28
Fine Aggregate Angularity	Cold Feed Belt, ASTM D 75	T 304	C 1252	Each day	7 days	7
Asphalt Content	Plant or Truck, ASTM D 140	T 308	D 6307	1,000 tons (907 tons)	28,000 tons (25,400 tons)	28
Laboratory Air Voids	Plant or Truck, ASTM D 140	T 312, T 166, T 209, T 269	D 4013, D 2726, D 2041, D 3203	1,000 tons (907 tons)	28,000 tons (25,400 tons)	28
Compaction	Pavement Surface		D 2950	1,000 ft (305 m) for each paving lane	53,000 ft (16,154 m)	53

Test Parameter	Sample Point/Method	Test Method, AASHTO	Test Method, ASTM	Sample Frequency	Estimated Quantity	No. of Tests
Pavement Thickness	Pavement Surface, by coring		D 3549	1,000 ft (305 m) per paving lane	53,000 ft (16,154 m)	53
Ride Quality Smoothness	Pavement Surface	10-ft (3-m) straightedge (see spec.)	10-ft (3-m) straightedge (see spec.)	50 ft (15 m)	53,000 ft (16,154 m)	1,060

Source: Asphalt Institute

After the project is awarded, the written QC plan is generally submitted to the owner for review and approval. The plan is usually submitted with other project documents related to the mix production, like the asphalt mix designs for all the mixtures to be used on the project, aggregate source qualification testing, certifications for commercially provided materials that will be incorporated into the mix, designation of what plant or plants will be used for production, and the paving plans. After the review and approval process is completed, the contractor is generally authorized to begin production, unless the project specifications call for production of a trial batch and/or test strip.

11.5 SAMPLING METHODS

The methods used for sampling asphalt mix can have a significant effect on the outcome of the test results. If a sample is not representative of the material, there is no point in following through with the testing program. Proper sampling techniques and specified procedures must be followed for an accurate representation of the materials being produced.

11.5.1 Representative Sampling

A primary goal is to obtain samples that are representative of the products being evaluated. Since test results are used to adjust mixture production, it would be counterproductive to make plant adjustments based on a non-representative sample.

Representative samples are critical for effective QC and acceptance programs. Inspection is more appropriate for identifying nonuniform portions of the work. Once inspection has identified a portion of the work that is nonuniform (different from the rest of the work) or defective materials are suspected, additional samples representing that specific element of the work should be taken. Test results from such samples should never be used as part of the lot averages—and certainly not for lot acceptance. They only represent the specific problem areas identified by inspection. Standard specifications should offer guidance on how to handle suspect areas.

It is important to collect enough material when sampling. The sample size is important not only to obtain enough material to complete the required tests but also to achieve a representative sample. Most standards will indicate a minimum sample size requirement.

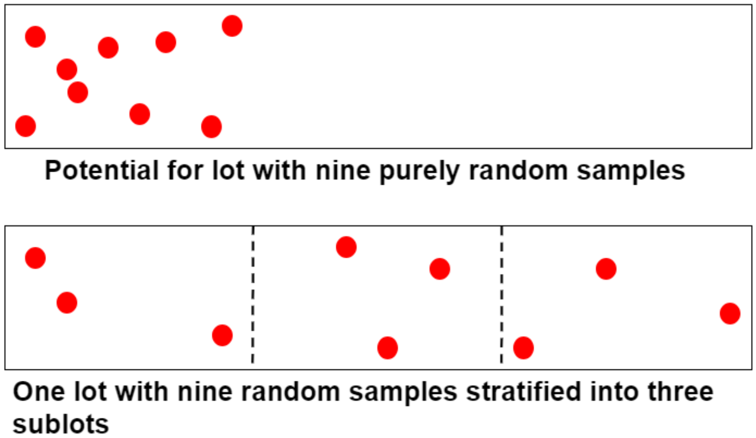
The quantity of asphalt mix produced on a given project is usually divided into predefined portions called “lots.” QA and QC plans usually require samples to be taken at intervals within these lots. The intervals are generally measured in one of the following three ways:

1. **Time intervals**—Typical lot sizes when sampling by time interval would include either a half day’s production or a full day’s production.
2. **Quantity intervals**—Typical lot sizes when sampling by quantity interval would include 5,000 or 10,000 tons (tonnes), depending on anticipated production rates.
3. **Distance intervals**—Typical lot sizes based on linear feet (meters) of paving. For example, cores are commonly taken based on a linear distance relative to stationing (a length of 100 ft [or 100 or 1,000 m] along a survey route) and an offset from a fixed longitudinal line.

Lot sizes are normally established by standard specifications, as defined well in advance of construction. The size and method of measurement of a lot will be used to determine locations and quantities of QC and acceptance tests. The lot will also be used to define what portion of the work is represented by a given set of test results. The limits of the lot are especially significant if corrective action or removal is required.

11.5.2 Random Sampling

The use of random sampling techniques helps to obtain unbiased representative samples, where every element in the population has an equal chance of being selected for sampling. As shown in Figure 162, it is theoretically possible for the purely random numbers to require that all samples for the entire project be taken over a very small area. The best and most practical method of ensuring that samples include the full range of construction is a process called stratified random sampling. This practice separates lots into equally sized sublots, from which random samples are then obtained. ASTM D3665 provides the standard practice for random sampling of construction materials.



Source: Asphalt Institute

Figure 162. Purely Random Sampling vs. Stratified Random Sampling

Stratified random sampling can be applied to different types of intervals by taking the number of samples needed and distributing them over times, quantities, or locations.

Table 11 illustrates how to calculate random sampling tonnage for loose asphalt samples from truck beds. The example is for a project with 4,000-ton (tonne) lots and 1,000-ton sublots. Random numbers can easily be generated by computer. In the example, the random number is applied to the sublot amount only, then the cumulative amount is calculated. For sublot 3, remember 2,000 tons have already been produced in sublots 1 and 2. Therefore, the random tonnage within sublot 3 (263.7) is added to the 2,000 tons, and the truck containing ton 2263.7 is sampled.

Table 11. Example Random Sampling by Tonnage Table

Lot-Sublot	Random #	Tons/Sublot	Sample Ton # in Truck	Cumulative Sample Ton #
1 - 1	0.7101	1000	710.1	710.1
1 - 2	0.9632	1000	963.2	1963.2
1 - 3	0.2637	1000	263.7	2263.7
1 - 4	0.3199	1000	319.9	3319.9
2 - 1	0.8711	1000	871.1	4871.1

Source: Asphalt Institute

The above example presents sampling based on quantity increments. They are useful for planning random samples of loose mix during plant production. These same methods and spreadsheet solutions could be applied if samples were to be obtained based on location. For example, sampling increments for roadway coring would be planned at both a given station and a distance from the centerline. The random numbers could be generated by hour if lots were assessed by half-day or one-day intervals.

11.5.3 Sampling Asphalt Mixtures

Sampling requirements are typically set by the agency and should be identified in the contractor's written QC plan. Acceptance sampling is often performed by the contractor but is required to be witnessed by agency personnel. Agency personnel typically take possession of the samples immediately after they are taken. It is important that all samples be properly documented with, at minimum, the project number, the date sampled, the material type, and sampling location (lot and/or sublot number). Other identifying information may also be required by the agency.

Sampling methods are available for sampling plant mix at many points along the construction process, including at the plant, from delivery trucks, from windrows at the jobsite, and from behind the paving machine. Some agencies may require one sampling point for QC and a different sampling point for acceptance.

For these sampling methods, the procedures described in AASHTO R 97 or ASTM D979 should be followed. Specifiers should carefully consider the sampling location. Each allowable sampling location in these standards has pros and cons related to the probability of obtaining a representative sample, the probability of causing permanent defects in the new mat, and the relative safety of the technician while sampling.

A common thread throughout the procedures is that they all require at least three randomly selected increments, combined to make a field sample meeting the minimum size requirement.

Samples of the compacted plant mix can also be taken by cutting cores from the cooled pavement following methods described in ASTM D5361 or AASHTO R 67. A brief discussion of each preferred sampling location is presented below.

11.5.3.1 Sampling at the Plant

Some asphalt mixing plants are equipped with sampling devices to obtain samples before delivering to the haul units. Such devices often include a sampling receptacle to pass perpendicularly through the entire stream of asphalt mixture, or they may include a sampling device that diverts the entire stream into a sampling receptacle. It is important that 1) the entire stream is sampled and 2) the sampling receptacle does not become overfilled during sampling and spill over the edges, losing part of the sample.

11.5.3.2 Sampling from Trucks

Truck sampling techniques are used to obtain samples of the plant mix. Quite often, the samples are taken immediately after loading from the plant, where sampling platforms allow the technicians to stand at the height of the truck bed. The truck bed is visually divided into three or four equal sections, and a sample is collected from each section. The top 6 to 12 inches (0.15 to 0.3 m) of material is removed before sampling from the exposed area.

11.5.3.3 Sampling from Windrows

Representative samples can also be taken from the windrow of a transport unit, avoiding the beginning or end of the windrow section. The windrow is visually divided into approximately three equal sections, and the top 1 ft (0.3 m) of the windrow is removed before sampling. The mix can become segregated in the windrow, so care should be taken in using the sample as QC for plant adjustments.

11.5.3.4 Sampling Loose In-place Mix

Representative portions of plant mix can be obtained by sampling behind the paving machine. These samples are taken immediately after placement but before any rolling takes place. The use of plates can help with obtaining a full sample, but any method must include the full depth of material. The holes from where the sample was obtained must be refilled before the roller reaches it. The mix can become segregated in the paver augers, so care should be taken in using the sample as QC for plant adjustments.

11.5.3.5 Sampling Compacted In-place Mix

Core sampling is the most common method for compacted asphalt pavements. Portable electric drills with wet-cut, diamond-studded core barrels provide rapid removal with little or no damage to the specimens. These samples are normally used to evaluate compaction and thickness.

Once removed from the pavement, the test specimens must be handled with care because they can be sensitive to damage from heat, impacts, and point loads. To protect the specimen, some QC plans require specially designed and padded transport containers. It is very important to ensure that the core holes are properly refilled and recompacted.

11.6 QUALITY CONTROL AT THE PLANT

Every successful asphalt contractor controls the quality of the asphalt mix throughout the production process. The plant itself must be calibrated/verified to be operating properly, as discussed in Chapter 4. All weighing mechanisms must be regularly certified for accuracy. Belts and gate openings must be properly adjusted for uniform material flow. Binder tanks must be maintained for proper circulation, temperature uniformity, and flow. Emissions must meet local environmental regulations and be adjusted for proper return of fines to the mix. All ancillary tanks and feeders must constantly be maintained and managed. The following sections provide more considerations about control of the mix and component materials.

11.6.1 Plant Control of Aggregate

Design qualities are the main consideration when selecting aggregates for a JMF. The decision concerning which aggregate to use is based on laboratory test data and mix economics, long before the material reaches the mix production plant (general characteristics and physical properties of aggregates for surface and base courses were discussed in Chapter 3). The raw aggregates should come from sources approved by the agency and should be stored (most often in stockpiles) and tested for compliance with designated quality standards.

11.6.2 Plant Control of Asphalt Binder

Asphalt binders are generally purchased from a source tested and accepted by the agency or accepted based on the supplier's certification or agency testing. Cost and local preference will affect the selection of a supplier. In many areas the purchase agreement with the asphalt supplier requires certification of the test results from a production run of material or an identifiable lot of material. Strict QC procedures may also require that the hauler supplying material to the plant furnish a "prior load certificate," which protects the supplier of the load from disputes resulting from contamination during transport. These requirements should be specified when executing a purchase agreement.

Tests for asphalt are rarely performed by the plant QC personnel. It is good practice to randomly sample incoming loads of asphalt binder for future testing if necessary. The agency may also sample asphalt binder at the plant and run tests in the agency laboratory. In this case, samples stored on-site are useful should any question arise about the quality of the asphalt binder.

Asphalt suppliers generally have very robust, well-documented QC programs. Binder quality at the gate is the expected standard. However, even if the binder itself meets specifications, plant operators must ensure that they are receiving the proper grades and storing them in the proper tanks, with no contamination. If the incorrect binder was used, the mix properties and laydown characteristics will change. QC technicians and agency inspectors should regularly verify the purchase invoices and certificates of tests submitted by the asphalt supplier to help ensure the correct binder is being used on the project.

The temperature of the incoming asphalt binder must be closely monitored. Specifications set limits on the allowable temperature in the asphalt storage tanks. Overheating by the supplier or hauler is cause for rejection of the asphalt binder.

11.6.3 Plant Control of Asphalt Mixtures

Plant control of mixtures includes a series of elements so closely interrelated that they are difficult to separate. One test may perform a variety of functions, satisfying a number of these QC needs. The day-to-day plant control that requires QC testing is as follows:

- Stockpile or cold-feed gradations.
- Hot-bin gradations (for batch plants).
- Cold-feed adjustments.
- Hot-bin weight adjustments (for batch plants).
- Asphalt content tests.
- Gradation of aggregate in mix.
- Adjustments of mixing time and temperature.
- Preparation of compacted specimens for applicable testing of the following:
    - Voids.
    - VMA.
    - VFA.
    - Density.
    - Flow (Marshall only).
    - Stability (Marshall only).

11.6.4 Trial Batches

Even with an approved mix design, some agency specifications will require the contractor to produce a trial batch of mix several days prior to the initiation of general production. As a best practice of plant QC, the contractor may independently choose to run a trial batch, especially if they are less familiar with the materials, such as might be the case for a portable plant in a remote location.

Trial batches are a limited production run of the mixture to be sampled for testing purposes and then placed in the recycling pile. Alternatively, the mix could be used to pave a portion of the plant site or placed on another of the contractor's non-agency projects. However the mixture is used, the purpose of the trial batch is twofold:

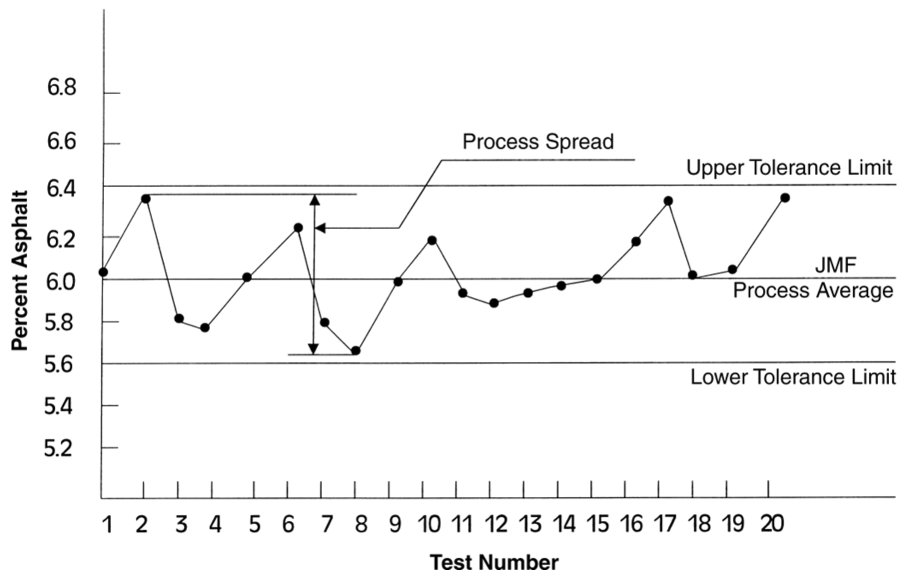
- It demonstrates that the plant can produce the required mix within specifications.
- It provides the first opportunity to ensure that contractor and agency technicians get acceptably consistent results on a split sample.

Trouble can be avoided if these two issues are settled before any permanent mix is placed on the project. If the mix is not within specifications, the plant production can be tweaked until the mix meets specifications. If it cannot meet specifications, a new mix design would be required. If a non-specification mix is already placed, the agency is put in the position of either accepting substandard mix at a lower negotiated price or requiring the contractor to remove and replace the mix. Any issues related to the contractor matching agency test results can be resolved beforehand with split samples from the trial batch.

Once the trial batch and lab comparison are satisfactory, the contractor can move on to the test strip or full production.

11.6.5 Control Charts

A final way plants can maintain control of the mixes they are producing is through regular monitoring of lab-generated control charts. Control charts are graphical plots of QC measurements or test results used to identify variation in a production or placement process, as shown in Figure 163. They can plot individual tests or moving averages. The specification limits may also be plotted, as in this example. The difference between the high and low result is the process spread (moving range), which should be minimized as much as possible.



Source: Hot-Mix Asphalt Paving Handbook 2000, 2nd Edition

Figure 163. Example Control Chart

Control charts can be an invaluable quick visual reference for spotting data trends and how close to the specification limits the test data are. A review of the example in Figure 163 shows that all the data fall within the specification limits. In this example, no discernible trend is evident. However, control charts are an excellent tool to reveal trends in production, such as test results that are consistently rising or falling over time. For example, a binder content that is consistently falling over time might reveal a blockage in the binder pump screen that is getting progressively worse. If results are consistently high or low, then the plant is producing at the wrong target, and adjustments must be made. Test results regularly above the upper control limit and below the lower control limit indicate high variability in the production process. The plant operator must actively address the issues that are preventing production of a consistent mix.

Control charts, especially for percent binder and gradations for each sieve, should be maintained and regularly shared with plant personnel. Continued monitoring of these test results is a valuable tool for ensuring the plant aggregate and binder feeds are at the targeted values. Control charts for other mix properties, such as air voids and VMA, are also important to maintain. If they begin to drift out of specification, the QC manager may need to investigate reasons why and then translate solutions into specific actions to be taken by plant personnel.

Roadway density control charts should be maintained and regularly shared with field supervisors. Tracking how the crew is achieving proper density will help the field supervisor use field personnel and equipment effectively.

Control charts are used by the contractor to decrease variability, establish process capability, reduce price adjustment costs, serve as a permanent record of quality, provide a basis for acceptance, and instill quality awareness.

All QC test data and control charts should be well documented and shared with agency personnel to ensure continued uniformity in testing between the two labs is maintained. If QC and agency test results begin to drift apart, immediate action should be taken to understand why the differences are occurring and take remedial action.

11.7 QUALITY CONTROL IN THE FIELD: PLACEMENT AND COMPACTION

QC tests and measurements should take place throughout the day during placement and compaction. The success of QC during placement depends on making corrections while the mix is hot and when a problem can be actively corrected.

11.7.1 Temperature Requirements

Because asphalt binder is a thermoplastic material, its properties change considerably with changes in temperature. Asphalt mixture is most workable and compactible when the material is hot. Most specifications have temperature requirements in several key areas.

11.7.1.1 Maximum Mixture Temperature

The asphalt mixture's maximum temperature is often specified to avoid premature aging and oxidation of the mix. A typical maximum limit is 325 °F (163 °C). Sometimes the maximum limit is extended to 350 °F (177 °C) for polymer-modified mixtures. Of course, the limit is lowered when producing WMA to be used at cooler temperatures. The actual limit may be different for different WMA technologies. Contractors often use WMA technology as a compaction aid at HMA temperatures. This practice should not be discouraged because of the great importance of proper mat compaction.

The maximum temperature is best verified in a location close to where the mix is discharged, as soon as possible after mixing. A great location for drum-mix plants is the discharge chute from the drum to the slat conveyor, as shown in Figure 164. Infrared thermometers are the best tool for measuring temperature in this location.

Source: Asphalt Institute

Figure 164. Mix Being Discharged from the Drum

11.7.1.2 Minimum Temperature Immediately Behind the Screed

The loose mat's minimum temperature immediately behind the screed is often specified to facilitate compaction. If a mat is too cool before the rollers hit it, it will be impossible to achieve proper mat density. A typical minimum limit is 250 °F (121 °C). It should be clearly understood that this temperature is a minimum, not a target. Again, the limit is often lowered when placing WMA.

The measuring location should be as close as possible to the back of the screed. Again, infrared thermometers are a great tool as long as a roller has not yet reached the measurement location. Roller drums are typically sprayed with a soapy water solution to keep the mix from sticking to the drum. This solution can lower the temperature of the extreme top surface of the mat and result in erroneous information from an infrared gun. If a roller has already made a pass over the measurement location, a stab thermometer will give the best results for the true mat temperature.

11.7.1.3 Minimum Ambient or Surface Temperature

An asphalt mixture will retain heat well while it is in the back of a truck. As discussed in Section 8.4.2, the heat dissipates rapidly once it is placed, especially with thinner lifts. This is one reason why paver operators should not speed up if several trucks are lined up in front of the paver, leaving roller operators behind. If the existing surface is already cool, the heat in the mix will dissipate even more rapidly. Most specifications have a minimum ambient temperature or a minimum surface temperature to facilitate the mat's heat retention. Thicker mats retain heat better than thinner mats, so there is often a mat thickness component to the specification as well. Allowances may also be made for WMA versus HMA. As an example, Table 12 shows base temperature requirements from the FAA's P-401 specification for airport construction.

Table 12. FAA Surface Temperature Specification

Mat Thickness	Base Temperature (Minimum)	
	°F	°C
3 inches (7.5 cm) or greater	40[1]	4
Greater than 2 inches (50 mm) but less than 3 inches (7.5 cm)	45	7

Source: FAA advisory circular 150/5370-10H (Table 4 of Item P-401)

11.7.1.4 Minimum Surface Temperature for Finish Rolling

An asphalt mat will remain compactible until the binder temperature becomes so low that aggregate in the mat begins to break under the finish roller. To protect the mat, many agencies specify a minimum surface temperature for finish rolling, often around 140 °F (60 °C). Because the job of the finish roller is to iron out any marks and achieve final smoothness, mat density should have already been achieved well before the mat temperature drops to this level.

11.7.2 Test Strips

Test strips, or "control strips," are often constructed before beginning regular production paving for each asphalt mixture. Just as a trial batch ensures that the plant can *produce* a mix that meets specifications, a test strip ensures that the field crew can *place and compact* a mat that meets specifications. They also allow a second opportunity to verify the mix and the agreement of test results between labs. Test strips are composed of shorter lengths of pavement, typically 500–1,000 ft (150–300 m). The FAA control strip requirements for airfields are based on either tonnage (minimum 250) or 1/2 sublot, whichever is greater. FAA and DoD airfield test strips are also required to include two paving lanes with a longitudinal cold joint between them.

If possible, the test strips should be constructed on the project, with the same equipment and materials that will be used for the rest of the project. Some circumstances may warrant the test strip being placed in another location.

If the results of the test strip indicate the JMF is suitable for producing complying materials, and the appropriate spreading, placing, and compaction can be achieved, then production paving can proceed. If the results of the test strip do not meet project specifications, or if the typical existing cross-section changes, then adjustments can be made and a new test strip produced.

Just as a trial batch ensures that the plant can produce a mix that meets specifications, a test strip ensures that the field crew can place and compact a mat that meets specifications.

The following listing of placement controls should be closely monitored by the contractor:

- Tack coat application.
- Asphalt mix delivery rate.
- Paver speed.
- Paver adjustments.
- Grade control.
- Thickness control.
- Density control—
    - Temperature of air and mixture.
    - Roller type.
    - Rolling pattern and coverage.
    - Roller speed.
- Yield thickness control.
- Smoothness control.

11.7.3 Mat Density

The goal of compacting an asphalt pavement is to achieve proper density. The resulting in-place air void content of the asphalt mat is, in many ways, the single most important factor that affects the performance of the mixture throughout the life of the pavement.

Compaction is affected by many factors other than those specifically measured during placement of the mixture. This means that low density problems on a project may not be resolved simply by adjusting the rolling pattern or the temperatures. The QC manager and project superintendent may need to analyze all the QC data, including that from the mixture production, to address compaction problems.

The goal of compacting an asphalt pavement is to achieve proper density. The resulting in-place air void content of the asphalt mat is, in many ways, the single most important factor that affects the performance of the mixture throughout the life of the pavement.

In addressing a compaction problem, the paving crew must review their own operations and procedures for the placement and compaction operation, paying particular attention to temperatures and to having a disciplined adherence to good rolling technique and consistent and tested rolling patterns.

A variety of methods are available to control the quality of the compaction for an asphalt mixture. Those methods will be discussed in more detail below. These methods are usually driven by specification, however, so the QC will be based on the specified methods for acceptance of compaction. The QC efforts should be centered on establishing and documenting compliance with the actual specifications.

There are three ways to calculate compaction values, and they each give very different results. Compaction can be specified by the percentage of the TMD, the bulk laboratory density, or a control strip density. It is best practice, and most commonly specified, to measure density as a percentage of the TMD. For airfields, the FAA and DoD formerly specified density as a percentage of laboratory density, but the current P-401 and UFGS 32 12 13.15 specifications have moved to a percentage of theoretical maximum. The method specified should be clearly understood by both the agency and the contractor.

A common control method for compaction is to simply measure the in-place density. These measured densities will be compared with the specified reference density (typically TMD), and a percentage of the reference density will be calculated. Nuclear density measurements are the most common form of QC density testing for quick feedback to guide roller patterns. Non-nuclear devices have been developed and are gaining popularity for QC density testing. QC testing for density can also be done using cores; however, this imparts a delay in the results. Use cores to correlate and/or calibrate other test methods, especially if gauge readings are to be used for acceptance. Many agencies and gauge manufacturers have devised methods to properly correlate gauge readings to core results.

11.7.4 Mat Smoothness

Mat smoothness for QC and acceptance purposes is measured after compaction, typically with either a 10-ft straightedge (FAA and DoD specify 12-ft), a profilograph, or an inertial profiler.

Spot checks are typically done with the straightedge laid on the pavement and the deviation of the surface measured and recorded. Typically, no bumps or dips greater than 1/8 inch are allowed when measured from the two outer edges of the straightedge. Specifications usually require these measurements be taken in both the longitudinal and the transverse direction. By mounting a small set of wheels on the straightedge, spot checks can be performed immediately behind the finish roller while compaction is ongoing. This immediate feedback to the paver and the roller operators allows them to make the appropriate adjustments to correct smoothness issues before the mix cools. FAA requires that deviations greater than 1/4 inch that will trap water on the final surface in either the transverse or longitudinal direction be diamond ground and sealed.

The profilograph has historically been the method used to measure the roughness of new construction and overlay projects for acceptance. The profilograph is typically manually pushed along by the technician, requiring a lane closure for safety reasons. The use of this technology has waned in recent years as faster, more accurate inertial profilers are now preferred.

Inertial profilers can collect true pavement profile data and longitudinal distance data at highway speeds. Lightweight versions of the inertial profilers operate at slower speeds and can be used almost immediately after finish rolling to provide more timely measurements.

11.8 ACCEPTANCE

Acceptance is the process whereby all factors used by the agency (i.e., sampling, testing, and inspection) are evaluated to determine the degree of compliance with contract requirements and to determine the corresponding value for a given product. QC measurements may or may not be used in the acceptance decision process, depending on the way the specification is written. If the contractor's QC measurements are used, the contractor is typically required to perform specific tests at stated frequencies.

The agency may also rely on supplier/vendor testing or certification for the acceptance of some items. All persons directly participating in acceptance activities must be qualified for their assigned responsibilities and are usually certified by the State DOT or airfield groups. Only qualified laboratories should perform the required tests.

QA specifications usually contain an acceptance plan that identifies a method of taking measurements for the purpose of determining the acceptability of a lot of asphalt mixture production and construction. The acceptance plan usually contains the following:

- Test method and point of sampling.
- Lot size.
- Sample size.
- Quality measure.
- Acceptance limits.
- Risk evaluation.
- Pay adjustment provisions (outlines pay deductions/bonuses).

11.8.1 Material Acceptance

There are often several components to how project work is accepted. Some work is not tested by QC or a representative of the owner. Certain products, such as lighting to be used on airfield runways, are accepted based on some type of manufacturer certification. Other products, like asphalt mixtures, are sampled and tested for acceptance. Specified tests may include some or all of the following:

- Asphalt content.
- Gradation (usually specific sieve sizes).
- Volumetrics (air voids, VMA, VFA).
- Performance tests (for rutting, cracking potential).
- Mat density tests (cores, nuclear density gauge, non-nuclear density gauge).
- Smoothness.

Specified testing (and thereby testing costs) should be relative to the project size and/or importance. Smaller projects may specify very few tests at infrequent intervals to help ensure the owner is receiving a quality product without spending too much relative to the project cost. Larger projects, or even smaller projects assigned a high level of importance for various reasons, will typically require a greater number of tests at more frequent intervals.

11.8.2 Responses to Failing Test Results

Contract language often falls short when the consequences of work not meeting contract requirements are not detailed. The responses could vary widely, depending on what work is out of specification and by how much. Potential responses, ranging from least to most expensive, could include the following:

11.8.2.1 Do Nothing

An owner may elect to do nothing in response to out-of-specification work if the anticipated functionality would have no long-term detrimental effect. For example, if the binder content is too low on a temporary crossover. If the crossover functions by safely moving traffic from one area to another for the planned duration and is then removed, there is no reason to apply any type of penalty for a low binder content. It is not necessarily reasonable to apply requirements for asphalt mixtures intended to last 20 years to asphalt mixtures intended to last 6 months.

11.8.2.2 Leave in Place but Require an Extended Warranty

This option may be viable when the anticipated effects of out-of-specification material reveal themselves in a relatively short time, perhaps within a few months or years. An example of this is a mixture meeting rut testing requirements during mix design but failing rut testing requirements during required QC or acceptance testing during production. Most rutting that occurs on a mat will happen during the first summer of service. Any additional rutting will likely take place during the second summer of service. Therefore, a 2-year warranty outlining maximum rut allowances and required contractor responses to repair the issue would likely serve the interests of the owner. Because cracking typically occurs later in the mat service life, this may not be a good option for failed cracking tests.

11.8.2.3 Grind Rough Areas So They Meet Smoothness Requirements

Rather than applying a penalty, contractors are sometimes allowed to diamond-grind rough areas that cause failures in the smoothness specifications. For example, for airfields, P-401 says that areas with humps or depressions that exceed grade or smoothness criteria and that retain water on the surface must be ground off, provided the course thickness after grinding is not more than 1/2 inch (12 mm) less than the thickness specified on the plans. Of course, the grinding work must be done with appropriate equipment and enough blades to keep the process from causing raveling, aggregate fractures, spalls, or other pavement distress. It must also provide smooth transitions to areas that did not require grinding.

11.8.2.4 Deduct Pay

A more severe penalty for results not meeting specifications is a pay deduction. In statistically based specifications, the MOQ is any of several mathematical tools that are used to quantify the level of quality of an individual quality characteristic. These tools, such as AAD and PWL (discussed in sections 11.2.3.1 and 11.2.3.2), allow an assessment of test data showing defective results. The pay adjustment provision in the contract penalizes the contractor a percentage of the bid cost. The further out of specification, the higher the penalty. The worst-case pay deduction is to leave the material in place but assess a 100-percent pay deduction.

11.8.2.5 Place Surface Seal or Thin Overlay

This option does not penalize the contractor by lowering the percent paid on a particular bid item. Rather, it requires the contractor to do some type of extra work at no expense to the owner. This option might be pursued if the surface of the mat had some type of defect that was not structural. Perhaps the surface might appear to have an open texture, and field permeability testing showed high permeability where it was not desired. Surface sealing would lower the permeability of the mat. Another example might be that the contractor did not use a specified skid- or polish-resistant aggregate in the surface mix. A thin overlay would provide a new wearing surface. The contractor might place one of these surface types at no cost if the penalty for not doing so exceeded the cost of the new surface.

11.8.2.6 Remove and Replace

This option is the harshest penalty that owners could assess. If the work quality is so poor that the owner would incur high costs to rehabilitate or maintain it, the order would be given to remove the work and replace it—all at the contractor's expense. Not only is there a 100-percent penalty for the first attempt at the work, but there is also the additional cost of doing it all again.

It would be best if the situations leading to these punitive actions were clearly described in the contract documents. Both the owner and the contractor would clearly understand the ramifications of any substandard work. If the situations were not agreed to in the contract, legal action is often pursued, which could be costly to both parties.

It should also be noted that the opposite is true: many specifications provide incentives to the contractor for measured quality above a prescribed threshold. These incentives most often come in the form of some type of bonus pay but can also come in the form of relaxed requirements in related areas of the specifications.

11.8.3 Project Acceptance

The focus of QC is material acceptance. However, when the project work is essentially complete, a final inspection takes place regarding final project acceptance. The completion of major tasks is verified and a punch list of relatively minor tasks to be completed is generated before the project is accepted.

A final estimate is generally produced to reflect items remaining to be resolved, such as the following:

- Agreement of price reductions assessed for work or materials not meeting contract specifications.
- Incentives to be paid for qualifying work or materials.
- Liquidated damages assessed for failure to complete project work within a specified timeframe.
- Payroll records, if required.
- Copies of any manufacturer's warranties for materials, equipment, and installations.
- Verification of final cleanup.
- Complete release of all claims for labor and materials.
- Statements signed by subcontractors indicating payment was received.
- Sales tax completion forms.
- All required as-built or as-constructed drawings.
- Any other adjustments as required by the contract.

Project acceptance is simply the process of making sure the project activities and paperwork are complete—that every detail is meticulously addressed so that no further payment or correspondence is required between owner and contractor.

12. Mat Problems

Mat problems can be defined as defects that occur in the asphalt mixture during or soon after the laydown and compaction operations have been completed. These problems fall into two primary categories: 1) equipment-related problems and 2) mixture-related problems. Within each of these two categories, poor workmanship and failure to adhere to best practices lead to many of the mat problems described below. In this section, major mat problems are reviewed, and a description of each problem is presented, including its causes, solutions, and effects on long-term pavement performance. Since segregation can be a serious mat problem, Chapter 10 of this manual is dedicated to this issue.

Table 13 summarizes the mat problems reviewed. The first column lists the various problems, while the remaining columns enumerate possible causes for each. The checks indicate equipment-related causes, while the x's indicate mix-related causes, which should generally be corrected by changes in the mix design. Provided throughout the discussion of causes are cross-references to earlier sections where greater detail can be found. Note that because of the interaction of various equipment-related and mix-related causes, no attempt has been made to rank the various causes.

Table 13. Mat Problems and Their Causes

PROBLEM	PAVER-RELATED CAUSES																									OTHER RELATED CAUSES												
	Fluctuating Head of Material	Feeder Screws Overloaded	Finisher Speed Too Fast	Too Much Lead Crown in the Screed	Too Little Lead Crown in the Screed	Overcorrection of Thickness Control	Excessive Play in Screed Mechanical	Screed Riding on Lift Cylinders	Screed Plates Worn Out or Warped	Screed Plates Not Tight	Cold Screed	Moldboard On Strike off Too Low	Running Hopper Empty Between Loads	Feeder Gates Set Incorrectly	Kicker Screws Worn Out or Installed	Incorrect Nulling of Screed	Screed Starting Blocks Too Short	Screed Extensions Installed Incorrectly	Vibrators Running Too Slow	Grade Control Mounted Incorrectly	Grade Control Hunting (Sensitivity Too	Grade Control Wand Bouncing on	Grade Reference Inadequate	Sitting Long Period Between Loads	Improper Joint Overlap	Improper Mat Thickness for Max. Agg. Size	Trucks Bumping Finisher	Truck Holding Brakes	Improper Base Preparation	Improper Rolling Operation	Reversing or Too Rapidly Turning Rollers	Parking of Roller on Hot Mat	Improper Mix Design (Aggregate)	Improper Mix Design (Asphalt)	Mix Segregation	Moisture in Mix	Variation of Mix Temperature	Cold Mix Temperature
Wavy Surface: Short Waves (Ripples)	✓	✓	✓				✓	✓		✓										✓	✓	✓	✓						X	X			X	X	X		X	
Wavy Surface: Long Waves	✓	✓				✓	✓	✓					✓	✓						✓			✓	✓			X	X	X		X	X			X		X	
Tearing of Mat: Full Width			✓						✓		✓															X							X	X	X	X	X	X
Tearing of Mat: Center Streak					✓				✓		✓			✓	✓																							X
Tearing of Mat: Outside Streaks				✓					✓			✓																										X
Mat Texture: Non-Uniform	✓	✓	✓					✓	✓	✓	✓		✓					✓	✓					✓		X			X				X	X	X		X	X
Screed Marks							✓																				X	X										
Screed Not Responding to Correction			✓				✓	✓		✓										✓						X											X	X
Auger Shadows		✓																															X	X	X			
Poor Pre-compaction			✓					✓											✓							X			X									X
Poor Longitudinal Joint	✓	✓				✓		✓												✓	✓	✓			✓					X								X
Poor Transverse Joint		✓					✓	✓		✓						✓	✓													X								X
Transverse Cracking (Checking)																													X	X			X	X		X	X	
Mat Shoving Under the Roller																													X	X	X		X	X		X	X	
Bleeding or Fat Spots in the Mat																																	X	X		X	X	
Roller Marks																													X	X	X	X					X	
Poor Mix Compaction																													X	X	X	X	X	X		X	X	X

Find problem above: ✓ indicates causes related to the paver and X indicates other problems to be investigated

NOTE: Many times a problem can be caused by more than one item; therefore, it is important that each cause listed be eliminated to ensure that the problem will be solved.

12.1 SURFACE WAVES

12.1.1 Description

An asphalt surface can have two types of waves: short and long. Short waves, also sometimes called ripples or auger shadows, are generally 1 to 3 ft (0.3 to 0.9 m) apart, with 1-1/2 to 2 ft (0.45 to 0.60 m) being the most common separation. Long waves are considerably farther apart. The distance between them may correspond to the distance between truckloads of mix. Long waves may also be associated with the reversal points of the compaction equipment, particularly on thick-lift construction or when the mixture being placed is tender and moving longitudinally under the compaction equipment.

An additional type of defect in the pavement surface is a roughness or washboard effect caused by improper operation of a vibratory roller. The distance between these waves is generally very small, typically less than 3 or 4 inches (75 or 100 mm).

Transverse bumps may also appear in new asphalt overlays on top of crack sealants. This is caused by the sliding or shoving of the new mix during the first pass of the breakdown roller.

12.1.2 Causes

A major cause of short waves or ripples is a fluctuating head of material in front of the paver screed. The variation in the amount of mix being carried back to the augers by the slat conveyors and deposited in front of the screed causes the screed to rise and fall as the force pushing against it changes. Too much mix (at the top of the augers) and then too little mix (at the bottom of the augers) being carried in the auger chamber in front of the screed causes the wavy surface as the screed reacts to this variation in force. The fluctuating head of material causes the screed to rotate around its pivot point and "hunt" for an angle of attack. As the angle of attack of the screed changes, the thickness of the mat being placed also changes, and the smoothness of the new layer is directly affected (see Section 7.3.3).

> *A major cause of short waves or ripples is a fluctuating head of material in front of the paver screed.*

Another cause of short waves is a screed that is in poor mechanical condition—one with excessive play in the screed control connections (see Section 7.3). Short waves can also be formed in the mat by improper mounting or sensitivity of the automatic grade control on the paver or by use of an inadequate grade reference device. The problem may also be related to a mobile reference (floating beam) that is bouncing or to the truck driver holding the brakes while the truck is being pushed by the paver (see Section 6.6.1).

Short waves can also be related to the mix design, particularly with a mix that varies in stiffness because of changes in the mix temperature or composition (see Chapter 3). As the stiffness of the mix varies, the forces of the mix pushing on the screed vary as well, causing the screed to rise and fall and resulting in a mat with short waves. Finally, if the mix design is improper in aggregate gradation, asphalt content, mix temperature, or moisture content (the mix is tender), the rollers may shove and displace the mix during the compaction process. However, short waves are typically placed in the mat by the paver because of either its operation or changes in mix stiffness, rather than by the operation of the compaction equipment. Long waves are caused by some of the same variables that result in short waves. Fluctuation in the amount of material in front of the screed and variation in mix stiffness cause the screed to react to the change in the force exerted on it.

If the distance between the wave peaks corresponds to the length of pavement between truckloads of mix, however, the waves may have been caused by incorrectly set hopper flow gates on the paver (see Section 7.2.2) or by the paver hopper and slat conveyors being emptied between loads of mix (see Section 7.2.3). Poor mechanical condition and improper operation of the screed (continually changing the manual thickness control cranks, for example; see Section 7.3.4), as well as incorrectly mounted automatic grade controls (see Section 7.4.2), can cause a long-wave problem. If a stringline is being used as a grade reference, a sag in that line between support posts can also be a cause of long waves (see Section 7.4.2.7). Another factor contributing to long-wave roughness is improper delivery of the mix to the paver, particularly if the haul truck bumps into the paver or if the truck driver holds the brakes while the truck is being pushed by the paver (see Section 6.6.1). One additional factor can be the condition of the underlying surface: the long waves may reflect the waves in the base material.

Long waves may also be found at those points where the compaction equipment reverses direction. This problem is most prevalent when the asphalt layer being placed is more than about 4 inches (100 mm) thick. The problem may be exacerbated when the maximum-size aggregate used in the mix is relatively small compared with the lift thickness. The waves are caused by a bow wave that forms in front of the roller when the mix is tender.

Long waves can be caused by truckload-to-truckload segregation of the mix (see Section 6.4) and by changes in mix temperature (see Section 3.2.5). Both of these deficiencies cause the forces on the screed to vary, resulting in a wavy surface. The compaction equipment can also create a wavy mat if the roller operator turns or reverses the machine too abruptly.

Roughness or washboarding is normally caused by improper operation of a vibratory roller (see Section 8.5). This type of equipment should be operated at a high frequency and corresponding speed to achieve a minimum of 10 IPF; it is, however, generally good practice for rollers not to exceed 2-1/2 to 3 mph (typically walking speed) to ensure sufficient dwell time. The amplitude should be set in relation to the thickness of the layer being compacted—usually a higher amplitude setting for a thicker layer of mix and a lower amplitude setting for a thinner lift. The washboard effect can be worse if the roller is operated at a high speed, particularly if the frequency setting is less than 2,400 VPM.

Transverse bump formation is the result of the breakdown roller creating a bow wave or shoving of the overlay asphalt during the first pass. Heat from the overlay is transferred down into the substrate pavement and crack sealant. The adhesive nature of the crack sealant produces a resistant force greater than the surrounding pavement friction. As the bow wave in front of the breakdown roller passes over the higher-friction adhesive sealant, a reduction in speed of the bow wave occurs and the breakdown roller passes over the bow wave, creating a bump slightly offset from the crack below in the direction of the paving machine.

12.1.3 Solutions

Short waves (ripples) can be eliminated only by preventing their formation. The most important factor in preventing short waves is to keep the amount of mix (head of material) in front of the screed as consistent as possible. In addition, the stiffness of the mix, which is related to both its temperature and its composition, should be maintained as constant as possible. The amount of mix is controlled by properly setting the hopper flow gates and by keeping the slat conveyors and augers operating as much of the time as possible (close to 100 percent) while the machine is moving forward. Mix stiffness is controlled at the asphalt plant by keeping the mix temperature, aggregate gradation, and fluids content (asphalt content plus moisture content) as constant as possible. Any factors that cause either the volume or stiffness of the mix at the screed to change can cause short waves or ripples in the mat.

Short waves (ripples) can be eliminated only by preventing their formation. The most important factor in preventing short waves is to keep the amount of mix (head of material) in front of the screed as consistent as possible.

Surface waves caused by problems with automatic grade controls can be detected by shutting off the grade controls and determining whether the waves continue to form. If the grade controls are at fault, the operation and maintenance manual supplied with those controls should be consulted to determine the proper corrective action. Sags in a stringline reference can be found by sighting down the line as the grade sensor wand passes along the string. Short or long waves caused by the mechanical condition or operation of the paver screed can usually be detected by careful observation of the paver during mix laydown. The long waves formed by incorrect operation of the haul truck or compaction equipment can also be detected easily by observing those operations.

If washboarding is caused by incorrect operation of a vibratory roller, a change should be made in one or more of the following: the vibratory amplitude setting, the vibratory frequency, and the speed of the roller.

Methods to prevent the transverse bumps from crack sealant on the existing surface include the use of asphalt overlay mixtures with high frictional properties such as open-graded mixtures, stone mastic asphalt, or dense-graded mixtures with highly angular and fractured aggregate. Breakdown rolling with the nondriven front drum moving forward tends to push the mixture instead of pulling the mixture under the drive drum. This push creates a larger bow wave in the mixture, often resulting in transverse bumps. Use of a stiffer tack coat and/or allowing the tack coat to completely set to improve the adhesive bond between the overlay and the substrate has also resulted in less overlay shoving and less bump formation.

12.1.4 Effects on Performance

Long-term pavement performance is affected by surface waves, both short and long, in two ways. First, the waves reduce the smoothness of the pavement, which lowers the pavement condition rating or the present serviceability index of the roadway. The structural performance of the pavement will be changed, however, only if the waves are severe enough to increase the dynamic or impact loading of the pavement under aircraft loading or heavy truck traffic. Aircraft are, however, susceptible to excessive vibrations and subsequent component fatigue, particularly in response to long surface waves. Second, short waves and the factors that cause them can affect pavement density levels. A tender mix is generally more difficult to compact properly than is a stable mix; the result may be a decrease in density and a corresponding increase in air void content—leading to a reduction in pavement service life.

Washboarding is basically roughness built into the pavement surface during the compaction operation. Because it affects the degree of density obtained during the compaction process, this type of defect can significantly reduce the long-term durability of the pavement layer. In addition, washboarding contributes to a rough ride for the vehicles using the pavement.

Transverse bumps also contribute to loss in ride quality.

12.2 TEARING (STREAKS)

12.2.1 Description

There are three general types of mat tearing or pulling of the asphalt mix under the screed of the paver. The three types are defined by the location of the tear marks in the mat: (a) in the center of the lane, (b) on the outside edges, and (c) across the full lane width.

12.2.2 Causes

A gearbox streak can sometimes be seen in the surface of the mat directly behind the center of the main screed. This streak is typically 6 to 8 inches (150 to 200 mm) wide and is normally caused by a lack of asphalt mix being pushed under the auger gearbox located in front of the center of the screed. This lack of mix may be the result of improper flow gate settings—not enough mix being fed back to the screed. It is more likely to be caused, however, by missing, worn, or improperly set reverse augers or paddles on the augers (located adjacent to the gearbox) that are used to force mix underneath the gearbox (see Section 7.2.2.4).

The rough surface texture is the result of a lack of mix at that point in the pavement width—less mix passes under the screed at the auger gearbox than passes under the screed on either side of the gearbox. The rougher texture, or tearing, makes the surface appear more open or segregated. However, this streak can be a form of segregation when gravity allows the mix from the two conveyors to flow under the gearbox. The surface texture of the mat at that location can be more open than that of the adjacent mix and is generally darker in color. Gearbox streaks are more prevalent with harsher mixes—those containing larger-size aggregate, more crushed aggregate, or lesser amounts of asphalt.

A centerline streak can also be caused by improper setting of the crown on the main paver screed. The appearance of streaks behind the screed is caused primarily by an improper relationship between the crowns at the leading (front) and trailing (back) edges of the screed (see Section 7.3.9). A tearing or open texture several ft (m) wide in the center of the mat may be caused by a lack of lead crown in the screed. Conversely, a tearing or open texture along both outside edges of the asphalt mixture is normally caused by an excess of lead crown in the screed. For most mixes, the lead crown of the screed should be set slightly higher (approximately 1/8 inch [3 mm]) than the tail crown. A proper relationship between lead and tail crowns will result in a uniform texture of the mat across its full width. Edge streaks can be caused by improper flow gate settings or incorrect installation of the screed extensions. Partial width tearing can also result from a cold screed plate if the screed has not been uniformly preheated before paving begins (see Section 7.3.8).

Full-width tearing of the mat can be attributed to a number of factors. One such factor is warped or worn screed plates. Another is the forward speed of the paver being too high for a particular mix. The use of a mixture with aggregate that is large compared with the mat thickness being laid can also be responsible for full-width tearing of the mat. A good rule of thumb for the relationship between the maximum aggregate size in the mix and the minimum compacted course thickness is that the depth of the compacted layer should be at least twice the largest coarse aggregate particle size or three times the NMAS. Thus, a mix containing a maximum aggregate size of 19.0 mm (3/4 inch) (NMAS of 12.5 mm [1/2 inch]) should be placed at least 38 mm (1-1/2 inch) thick. Lastly, cold mix temperatures, particularly when combined with a cold paver screed, can significantly affect the amount of tearing that occurs (see Chapter 7).

12.2.3 Solutions

A gearbox streak can usually be eliminated only by changing the amount of mix being forced under the screed at the auger gearbox. This change is made by installing reverse paddles or reverse augers on each side of the gearbox to push more mix under the gearbox. If the paver is already equipped with such devices, they should be checked to see whether they are worn and need to be replaced.

Constant center or outside edge mat tearing can usually be eliminated by adjusting the relationship between the lead and tail crowns on the paver screed. If this change does not solve the problem, the setting of the paver flow gates should be modified. Full-width tearing can be eliminated by increasing the mix temperature, preheating the screed properly before paving starts, replacing warped or worn screed plates, or increasing the lift thickness.

12.2.4 Effects on Performance

Tearing of the mat affects long-term pavement performance by causing changes in density in those areas where the tearing has occurred. Torn areas may appear segregated and are usually deficient in mix quantity. Pavement performance will be reduced in relation to the degree to which the tearing reduces the density and increases the air void content of the mat. In addition, the torn areas will be more susceptible to raveling and to the effects of moisture (stripping).

12.3 NONUNIFORM TEXTURE

12.3.1 Description

Nonuniform mat texture (see Figure 165) can be described as differences in the appearance of the mix, both transversely and longitudinally, as it is placed and compacted. Normally, minor differences in surface texture will be apparent because of differences in the alignment of the larger coarse aggregate particles as the mix passes out from beneath the paver screed. In addition, a mix with a higher fine aggregate (sand) content will have a more uniform surface texture than a mix containing a larger percentage of coarse aggregate.

12.3.2 Causes

Many factors related to the operation of the asphalt paver affect the uniformity of the surface texture of the mix (see Chapter 7). A variable amount of mix against the screed, caused by overloading the augers or running the hopper empty between truckloads, can cause variations in the amount of mix tucked under the screed and thus produce a nonuniform texture.

Source: NAPA

Figure 165. Nonuniform Mat Texture

Improper screed maintenance, including worn or loose screed plates or screed extensions incorrectly installed, as well as low screed vibratory frequency, may alter the mat texture and cause nonuniformity. In addition, a low mix temperature, caused either by plant problems or by the paver sitting too long between truckloads of mix, can be a factor in uneven mat texture, especially if the paver screed is also cold. The tearing that results when the compacted layer thickness is less than twice the dimension of the largest aggregate particles is still another contributing factor.

A soft or yielding base under the course being constructed may cause the new layer to have a variable surface texture (see Section 5.2). Moreover, segregation of the mix caused by poor mix design (Section 3.4.4) or improper handling of the mix during production (Section 4), loading (Section 6.4), hauling (Section 6.5), unloading (Section 6.6), or placing (Chapter 7) operations can contribute to a nonuniform surface texture. The variability of the texture will be affected as well by any factors that cause nonuniformity in the mix, such as deviations in aggregate gradation, asphalt content, or mix temperature (see Chapter 3).

12.3.3 Solutions

The solutions for nonuniform surface texture are as varied as the causes. Paver operation, particularly regarding the need for a constant head of material in front of the screed, should be monitored closely. The paver and screed should both be well maintained and in good operating condition. The compacted thickness of the mat being placed should be designed so that dense-graded mixes have a lift thickness of at least four times the NMAS when compacted. Lift thicknesses for fine-graded mixtures should be at least three times the NMAS.

Finally, a mix that is tender, variable in aggregate gradation or asphalt content, or easily segregated should be modified to increase its stiffness and improve its properties before it is produced at the plant and delivered to the paver for laydown.

12.3.4 Effects on Performance

Nonuniform surface texture is usually associated with nonuniform density. The same compactive effort will generally achieve lower density in areas in which the coarse aggregate has been dragged by the paver screed or segregation of the mix has occurred, as compared with areas having uniform surface texture. As density decreases and air void content increases, the durability and serviceability of the asphalt mat decrease markedly.

12.4 SCREED MARKS

12.4.1 Description

Screed marks are transverse indentations in the surface of the asphalt mat. They occur when the paver stops between truckloads of mix. Depending on the mixture being placed, some screed marks are barely noticeable, whereas others are very distinct and deep. Screed marks can also occur in the longitudinal direction when rigid or hydraulic extensions are used, and the elevation of the extension is not the same as that of the main screed.

12.4.2 Causes

There are several causes of transverse screed marks (see Section 7.3 for a discussion of screed operations). One is excessive play in the mechanical connections on the screed. Such marks also result when the screed is set up incorrectly and rides heavily on its rear end. If the asphalt mix is tender and if the paver is equipped with a very heavy screed, such as hydraulic extensions with additional rigid extensions attached, the screed will tend to settle into the mix and leave marks. If any of these causes are involved, the screed marks will be visible each time the paver stops.

> *There are several causes of transverse screed. One is excessive play in the mechanical connections on the screed. Another cause is the haul truck bumping into the paver.*

Another cause is the haul truck bumping into the paver when preparing to discharge the mix or the truck driver holding the brakes on the truck when the paver starts to push the truck (see Section 6.6.1). In these cases, the screed marks will appear only when the truck–paver interchange is improper.

Longitudinal screed marks are caused by improper setting of the screed extensions relative to the main screed. When extensions are used, their vertical position shall be set on the same plane and with the same angle of attack as the main screed. If rigid extensions are set at the wrong elevation, a longitudinal mark will occur at the point where the different screed sections are joined. If hydraulic extensions are used, two longitudinal marks may occur—one at the end of the main screed and one at the inside edge of the extension on each side of the machine.

12.4.3 Solutions

If the transverse screed marks are a result of the mechanical condition or improper setup of the paver screed, the screed should be repaired. If the marks are caused by the truck bumping into the paver, the laydown operation should be altered so that the paver picks up the haul truck instead of the truck backing into the paver. In addition, once the paver has established contact with the truck, the truck driver should apply only enough pressure to the brakes to keep the truck in contact with the paver if a truck hitch is not used (see Section 7.2.1).

In some cases, particularly if the mix is very tender, screed marks can be eliminated by not stopping the paver between truckloads of mix. This can be accomplished by using a windrow elevator or MTV to deliver mix to the paver hopper. If dump trucks are used to haul the mix, however, it is generally better to stop the paver between truckloads of material (stopping and restarting the paver as quickly as practical) instead of allowing the paver operator to run the paver hopper dry, reduce the head of mix in front of the paver screed, and increase the opportunity for truckload-to-truckload segregation. In the event the paver stops for an extended period, the operator should use screed assist (boost), which pressurizes the bottom of the screed lift cylinders during stops and thus prevents the screed from settling and causing a dent in the mat.

To achieve a uniform surface texture, the elevation and angle of attack of the screed extensions must be matched to those of the main screed. Longitudinal screed marks caused by improperly setting the elevation of the extensions can be eliminated by correcting the position of each extension relative to that of the main screed. Adjustments to both the vertical position and the angle of attack of the extensions may be needed. These adjustments should be made whenever hydraulic or rigid extensions are used.

12.4.4 Effects on Performance

Transverse screed marks generally are not detrimental to the durability of the mat. They may, however, affect the ride by creating a bump whenever the marks cannot be completely rolled out by the compaction equipment. In many cases, the screed marks have less of an effect on the performance of the mix than does the slowdown and startup of the paver when the operator attempts to keep it moving as the empty truck pulls away and the loaded truck backs into the hopper.

Longitudinal screed marks indicate that the level of the mix under the screed extensions is different from that under the main screed. If the screed marks are severe, differential compaction may occur across the mark or "joint," with the compaction equipment initially riding on the higher mat. The marks can leave a ridge in the mix if they cannot be completely rolled out.

12.5 SCREED RESPONSIVENESS

12.5.1 Description

As the thickness control cranks on the screed are changed, the screed's angle of attack increases or decreases. As the paver moves forward to place the mix, the screed moves up or down to the new equilibrium point for the newly set mat thickness. When the screed fails to respond to changes in the setting of the thickness control cranks, the operator is unable to alter the depth of the layer being placed. The paver also loses its inherent ability, through the principle of the floating screed, to provide the self-leveling action needed to place a smooth asphalt mat.

12.5.2 Causes

An extremely high paver speed (more than 83 ft [25 m] per min for thin lifts or more than 50 ft [15 m] per min for layers more than 2-1/2 inches [63 mm] thick) may cause a lack of responsiveness of the screed (see Section 7.3.4). The mechanical condition of the screed affects its ability to react. The screed riding on its lift cylinders or loose connections on the thickness control cranks will cause the screed to be unresponsive. If automatic grade controls are used (see Section 7.4.2), an incorrect sensor location will render the screed unable to react to input signals from the grade sensors.

If the maximum aggregate size used in the mix is too great compared with the depth of mix being placed, the screed will ride on or drag the largest aggregate pieces. As a result, the screed will be unable to change its angle and will thus be unresponsive to changes in the thickness control settings. Variations in mix temperature will also cause the screed to be unresponsive to changes in the angle of attack because the mix stiffness variations themselves will cause the screed to continually seek new equilibrium levels for the forces acting on it.

12.5.3 Solutions

The paver and screed must be in good operating condition. The sensor for automatic grade controls must not be located either at the tow points or behind the pivot points of the screed; rather, it should be located in the area between one-third and two-thirds of the length of the leveling arms. If the mix texture is uniform (indicating a proper relationship between course thickness and maximum aggregate size), the screed will be able to respond to changes in the thickness control settings.

12.5.4 Effects on Performance

An unresponsive screed causes a rough asphalt mat. The screed is unable to react to manual changes in the thickness settings. It also loses its ability to self-level on an existing pavement surface because it cannot reduce the thickness of the mix placed over the high points in that surface and increase the thickness placed in the low areas.

Thus, the rideability of the course being placed can be affected significantly if the paver screed is unresponsive.

12.6 SURFACE (AUGER) SHADOWS

12.6.1 Description

Surface (auger) shadows are dark areas that appear in the surface of a mix. In most cases, the shadows cannot be seen until sometime after the pavement has been used by traffic and some of the asphalt binder film has been worn off the exposed aggregate particles by the vehicle tires. Surface shadows are seen most easily when the sun is low on the horizon and the pavement is viewed when looking toward the sun. The shadows are also visible when the pavement surface is damp or when the surface is viewed from the shoulder of the roadway at night and vehicle headlights are shining on the surface.

In severe cases, surface shadows may be visible immediately behind the screed during the laydown operation. Even in this latter case, the shadows will disappear when the mix is being compacted by the rollers, only to be visible again later under the conditions described above. The shadows may be completely across the lane width being placed, or they may be only partially across the width. The extent of the shadows depends on how the paver is operated, particularly the portion of on/off time of the augers on each side of the machine.

12.6.2 Causes

Surface shadows are caused primarily by overloading of the augers on the paver (see Section 7.2.2.4). If the head of material in the auger chamber is large enough to "bury" the augers, the screed will react to the variable forces acting on it. The spacing between the shadows will normally correspond to the starting of the augers when operated in a stop–start manner. Whenever the amount of mix in front of the screed is at or above the top of the augers, the shadows will be formed and seen later in the pavement.

On most pavers it is possible to adjust the distance between the screed and the tractor unit. This is accomplished by unbolting connections on the leveling or tow arms of the paver and moving the tractor forward or backward while the screed remains stationary on the pavement surface. Depending on the make and model of the paver, there is typically 4 inches (100 mm) of adjustment for the screed connection. The severity of surface shadows may increase with the screed in the back position—when more mix is being carried in the auger chamber and the augers are being overloaded. The shadows are thought to be the result of a slight increase in mix density caused by the restarting of the augers and the subsequent forcing of additional mix under the screed. There is no difference in surface texture associated with the location of the surface shadows; they can be seen only from an angle. Their intensity often increases when a tender mix is being laid.

12.6.3 Solutions

The asphalt mixture carried in the auger chamber should be maintained at a level near the center of the auger shaft. This means the flow gates should be set so that the augers operate as close to 100 percent of the time as possible and stopping and starting of the augers is minimized. In no case should the top of the augers be completely covered with mix. Further, the location of the screed should be set as far forward as possible so that the amount of material in the auger chamber is reduced and the head of material in front of the screed is kept to a minimum. The screed should not be set in the back position unless a large-stone mix (one in which the maximum size of the aggregate is more than 1-1/2 inches [37.5 mm]) is being placed.

12.6.4 Effect on Performance

Surface shadows are not necessarily detrimental to the performance of the mix, except for a minor effect on rideability. The difference in the density of the mix in areas with and between shadows is generally not great enough to be determined accurately. The main concern with surface shadows is the visual appearance of the mix to vehicle drivers.

12.7 POOR PRECOMPACTION

12.7.1 Description

A modern asphalt paver is normally equipped with a vibratory screed. This type of screed allows the mix to be partially compacted as it passes beneath the screed. Depending on such variables as forward paver speed, layer thickness, mix temperature, and ambient environmental conditions, the density of the asphalt mixture measured behind the screed before compaction is usually around 70 to 90 percent of the TMD (a voidless mix).

A few pavers are equipped with combination screeds, which have both tamper bars and vibrators. At slow paver speeds, the combination screed typically achieves greater compaction of the mix than is obtained with the vibratory screed alone. At paver speeds greater than 25 ft (7.5 m) per min, however, the increased compactive effort achieved with the tamper bar is typically lost, and the degree of compaction obtained is similar to that achieved with a simple vibratory screed.

12.7.2 Causes

The amount of precompaction achieved with the screed decreases as the paver speed increases (see Section 7.3.6). Precompaction generally increases slightly as the frequency of the screed vibration increases. Precompaction decreases significantly, however, if the screed is riding on the screed lift cylinders, thereby limiting the available compactive effort. The level of precompaction obtained is also limited if the mat is too thin for the maximum aggregate size used in the mix (less than four times the mixture's NMAS for coarse-graded mixes or less than three times the mixture's NMAS for fine-graded mixes; see the earlier discussion of nonuniform texture), if the mix being placed is too cold, or if the base on which the new layer is being laid is soft and yielding (see Section 5.2).

12.7.3 Solutions

Decreasing the paver speed and increasing the frequency of vibration of the screed should, within limits, increase the level of precompaction achieved during the laydown operation. It is also possible on some pavers to increase the amplitude of the vibration to increase the impact force of the screed on the mix. Proper maintenance of the screed helps as well in obtaining a uniform compactive effort from the screed.

12.7.4 Effects on Performance

If the required density level is obtained using conventional rollers behind the paver, the level of precompaction accomplished by the screed will not affect the long-term performance of the layer. It may be possible, however, to reduce the number of roller passes needed to meet the density and air void content criteria if the amount of precompaction obtained by the screed is higher. In addition, increased precompaction density can reduce the amount of differential compaction that occurs in low spots and rutted areas.

12.8 JOINT PROBLEMS

12.8.1 Description

Poor transverse joints are associated either with a bump at the joint, a dip in the pavement surface several feet (meters) beyond the joint, or both. Poor LJs (see Figure 166) between passes of the paver are usually characterized by a difference in elevation between the two lanes, by raveling of the asphalt mix at the joint, or both. The area adjacent to the LJ is usually depressed below the level of the surrounding pavement surface.

Source: Asphalt Institute

Figure 166. Poor Longitudinal Joint Due to Unsatisfactory Construction

12.8.2 Causes

Joint problems are caused by poor construction of the joint, inadequate compaction of mix placed along the joint, improper startup procedures when paving resumes after a stoppage, or improper construction and removal of tapers.

12.8.3 Solutions

One key to a good transverse joint is to construct the joint at the end of the paving day at a location in the mat where the layer thickness is constant (see Section 9.2 for a discussion of joint construction). This means the compacted thickness of the mat at the end of the paver run is the same as that of the previously placed mat. For airfields, a good point is at the end of the pavement, since this will eliminate a transverse joint.

At the start of paving the following day, the paver screed should be placed on blocks on the cold side of the transverse joint. The thickness of the blocks should be related to the depth of the course being laid—approximately 1/4 inch (5 mm) thick for each 1 inch (25 mm) of compacted layer thickness. The front edge of the paver screed should then be placed directly over the vertical face of the joint. Once the paver pulls away from the joint, the right amount of mix should be in the right place, and only minimal raking, if any, normally needs to be done. The mix at the joint should then be compacted as quickly as possible.

For LJ construction (see Section 9.3), it is extremely important to compact the edge of the first lane properly. Doing so requires that the vibratory or static steel-wheel roller hang out over the unsupported edge of the mat by about 6 inches. This practice provides the most compactive effort along the unconfined edge without causing undue lateral displacement of the mix along the edge of the pavement.

For LJ construction, it is extremely important to compact the edge of the first lane properly. Doing so requires that the vibratory or static steel-wheel roller hang out over the unsupported edge of the mat by about 6 inches.

When placing the second (adjacent) pavement lane, the end plate on the paver screed should overlap the first lane by 1 to 1-1/2 inches. Minimal raking, if any, should be done on the mix placed over the first lane. The rollers—vibratory, pneumatic tire, and static steel-wheel—should operate on the hot side of the joint and extend over the joint on the cold side by approximately 6 inches. The same number of roller passes should be made over the LJ as over each point in the interior of the HMA mat.

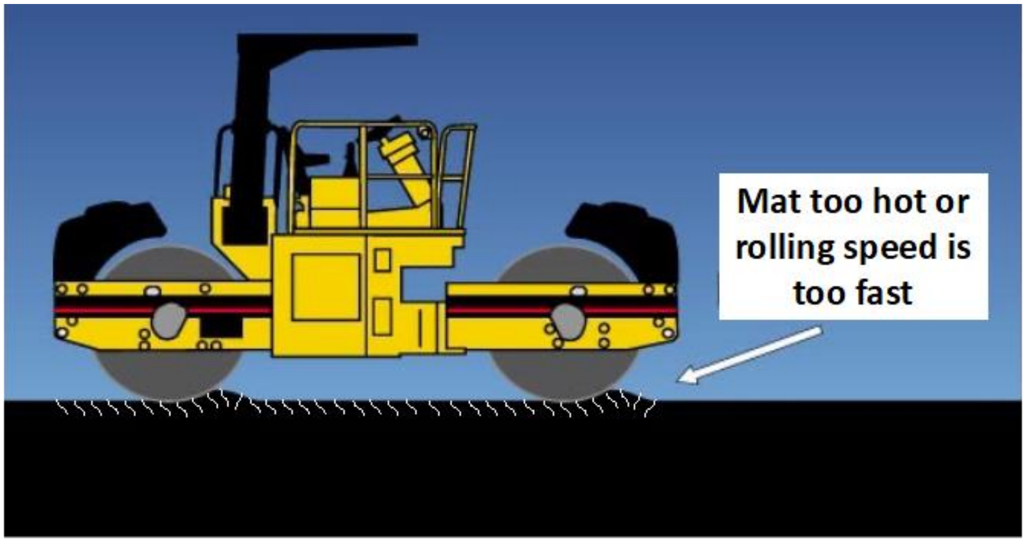
12.8.4 Effects on Performance

A poor transverse joint will not affect pavement performance to any significant degree if proper density levels are obtained by the compaction equipment. A poor ride will usually be the only negative result. An improperly constructed LJ, however, can seriously decrease the serviceability of the pavement structure. A poorly placed and compacted joint will ravel and cause one side of the joint to be lower than the other. FOD from the raveling of the pavement is a huge concern on all airfields. If the density level is too low, the whole pavement layer thickness at the LJ may wear away under the action of traffic. A poor joint will also be porous, allowing water to enter the underlying pavement courses.

12.9 CHECKING

12.9.1 Description

Checking can be defined as short transverse cracks, usually 1 to 3 inches in length and 1 to 3 inches (25 to 75 mm) apart, that occur in the surface of the asphalt mat at some time during the compaction process (see Figure 167 and Figure 168). The checks are not visible immediately behind the paver screed. Rarely does checking occur during the first or second pass of the compaction equipment over the mat except when the mixture is excessively hot. If checking is going to occur, it will normally take place after the mix has cooled to a temperature of less than 240 °F (115 °C) and additional passes of vibratory or static steel-wheel rollers (or both) are made over the mat. Checking does not usually occur when the mix is compacted with a pneumatic tire roller. Most asphalt mixtures do not check at all during compaction, whereas others exhibit tender characteristics and check readily. As checking becomes severe, the cracks become longer and are spaced closer together.



Source: Asphalt Institute

Figure 167. Roller Checking During Compaction

The cracks do not extend completely through the depth of the course but are only 3/8 to 1/2 inch (10 to 13 mm) deep.

12.9.2 Causes

A mix that checks during compaction is a tender mix. The mix shoves or moves in front of the drums on either vibratory or static steel-wheel rollers. Checks or cracks are formed when a bow wave occurs in front of the roller drums as the mix moves longitudinally before the roller reaches that location.

Checking may be caused by two primary factors: (a) excessive deflection of the pavement structure under the compaction equipment (see Chapter 5) and (b) one or more deficiencies in the asphalt mix design (see Chapter 3). A mix that checks is not internally stable enough—does not have enough internal strength at elevated temperatures—to support the weight of the compaction equipment during the rolling process.

Source: NAPA

Figure 168. Hairline Cracks Caused by Roller Checking

When a yielding foundation is the cause of the checking problem, the underlying pavement on which the new asphalt layer is being placed is weak and yields under the movement of the compaction equipment. The weight of the rollers causes the layers in the pavement structure to move, shove, and bend excessively, placing the new mix in tension at its surface. The checkmarks are then formed when the surface of the new asphalt is pulled apart as the pavement structure deflects during the rolling operation. The checks should appear in the new mix surface only at locations where there is movement of the pavement structure under the compaction equipment. If the paver passes over a soft spot in the underlying structure, for example, checking should occur only where the soft spot exists.

A more common cause of checking is one or more deficiencies in the mixture: (a) an excess of fluids in the mix—too much asphalt binder or too much moisture in the mix, or both; (b) a hump in the sand gradation curve—too much midsize sand material (1.18-mm and 0.600-mm [No. 16 and No. 30] sieve size) and too little fine sand material (0.300-mm and 0.150-mm [No. 50 and No. 100] sieve size); and (c) a lack of room in the aggregate gradation for the asphalt binder (low VMA).

An excess of fluids in the asphalt mix makes the mix tender and allows it to be displaced easily under the applied compactive effort of the rollers. The mix will be tender if the binder content is too high for the gradation and characteristics of the aggregate used, particularly if the mix has a low VMA content. If the mix contains too much moisture because the aggregate was not completely dried when passing through the batch plant drier or drum mixer, the excess moisture will act as asphalt binder at elevated temperatures and overlubricate the mix. The moisture remaining in the aggregate pores will prevent the binder material from entering those pores in the aggregate, in effect leaving more binder material between the aggregate particles instead of partly inside the aggregate.

If tenderness is due to an excess of asphalt binder in the mix, checking should occur in the mix on a regular, daily basis. If tenderness is due to an excess of moisture in the mix, checking should occur whenever the plant is not being operated properly. For example, checking may occur in the mat the day after a rain, but not the day before. If operations at the asphalt plant do not include removing the extra moisture in the aggregate resulting from the rainfall on the stockpiles, that moisture will add to the asphalt binder fluids and cause the mix to be tender.

A hump in the fine aggregate gradation curve—an excess of midsize sand in the mix—can also cause the mix to be tender. In addition, mixes low in VMA content will generally be tender and move easily under the force of a vibratory or static steel-wheel roller. Further, the various characteristics of the aggregate particles, such as surface texture, angularity, crushed faces, and amount of dust coating, can play a major role in the amount of checking that occurs during compaction. Mixes that are deficient in fine aggregate gradation or lack adequate VMA content will normally check continuously, not periodically. If the sand gradation is variable, however, checking may occur only when the sand gradation is improper. The above mix deficiencies are compounded, and the amount of checking that occurs may be increased, when the mix temperature is too high for the particular asphalt binder grade being used in the mix. As the mix temperature increases, the viscosity of the asphalt binder decreases, causing the mixture to be more tender. An additional factor that can affect the amount of checking is the temperature susceptibility of the asphalt binder itself: the greater the degree of temperature susceptibility of the binder material, the more checking may occur in the mix.

Occasionally, checking can be caused by temperature differentials within a layer of the mixture (heat checking). On a cool day and under windy conditions, the temperature of the mix that is in contact with the existing pavement surface may decrease quickly. The top surface of the mix will also cool quickly. The temperature of the mix in the middle of the layer, however, will remain high. This temperature differential can cause the mix to check under the compactive effort of the rollers.

There are also several secondary causes of checking. One is a mix whose temperature is too high because the mix was overheated in the plant. In addition, improper rolling techniques can cause checking—rolling too fast, stopping too quickly, making sharp turns on the hot mat, or making an excessive number of passes with the finish roller or finish rolling when the mat is still at too high a temperature (see Section 8). Finally, checking may be increased by a poor bond between the new mat and the underlying surface because of a dirty surface or the lack of or poor application of tack coat.

12.9.3 Solutions

If checking is caused by the presence of a yielding foundation underneath the new asphalt layer, the solution is to repair and properly prepare the existing pavement structure before the new asphalt is placed. Soft spots should be removed and replaced. All areas of excessive deflection should be removed and replaced or stabilized. Uniform support is needed in the underlying pavement structure if the new pavement layers are to perform adequately.

If checking is caused by a deficiency in the mix design—an excess of fluids in the mix or a problem with the gradation of the fine aggregate or the VMA content of the mix—the long-term solution is to change the mix properties. Those changes must be made at the asphalt plant and cannot be made at the paving site. If the mix contains an excess of fluids—either asphalt binder or moisture—the binder content should be reduced or the aggregate properly dried to remove all of the moisture. In some cases, the production rate of the plant will have to be reduced for the moisture to be completely removed from the aggregate. In other cases, plant operating conditions may need to be changed (e.g., flights and drum angle). If checking is caused by the gradation of the fine aggregate incorporated into the mix, the gradation should be changed. It may be necessary to increase or decrease the amount of fine aggregate used, add a small amount of fine aggregate with a different gradation, increase the angularity of the fine aggregate, or use a completely different material from a different source. If checking is caused by a lack of VMA in the asphalt mix, changes need to be made to increase the VMA.

Checking is often thought to result from the mix being too hot. This is only partially correct; the mix is too hot at some temperatures to support the weight of the compaction equipment because the mix lacks internal strength and stability. If the mix were properly designed, it would not be too hot to be compacted at any temperature below about 300 °F (150 °C). Most checking occurs when the mix temperature is decreasing from about 240 °F (115 °C) down to about 190 °F (90 °C); rarely does checking occur when the mix temperature is above approximately 240 °F (115 °C) or below approximately 190 °F (90 °C). However, with the use of a warm mix technologies and the number of different warm mix technologies currently available, these temperatures may vary.

In the short term, changes in both the rolling zone and the type of rollers used to densify the mix can be made to reduce the amount of checking that occurs. If the mix is tender because of excess fluids, a problem with the fine aggregate gradation, or lack of VMA, it may be possible to densify the mix properly at an elevated temperature without causing the checking.

A mix that checks is tender, but this mix can usually be compacted satisfactorily at high temperatures—above 250 °F (120 °C). The required level of density can generally be obtained if enough roller passes can be applied to the mix before it cools to the point at which the checking begins. This can be done by using two breakdown rollers instead of one—using two rollers operating in echelon (side by side) instead of using a breakdown roller followed by an intermediate roller. The two breakdown rollers each apply their compactive effort to one side of the newly placed lane. Many passes are made over each point in the pavement surface before the mix begins to check. Once checking starts, the rolling process is temporarily suspended.

If compaction operations are attempted when the mix is moving, shoving, and checking under the action of vibratory or static steel-wheel rollers, the mix will decompact rather than compact. Rolling should not be carried out with steel-wheel rollers when the mix is tender and checking. Most tender mixes will remain tender until the surface of the mix cools to a temperature of approximately 190 °F (90 °C). At this temperature, the mix has cooled sufficiently so that the viscosity of the asphalt binder has increased to the point where the mix can again support the weight of the compaction equipment. Static steel-wheel rollers can then be used to achieve the final density in the mix and remove any roller marks in the pavement surface.

When a tender mix is in the middle temperature range, between about 240 °F (115 °C) and 190 °F (90 °C), rolling should not be attempted, as discussed above, with either vibratory or static steel-wheel rollers. A pneumatic tire roller, however, can be used in this temperature zone since the rubber tires on this roller will typically not shove the mix and a bow wave will not form in front of the tires. The tender mix will densify, instead of check, under the compactive effort of the pneumatic tire roller. Finish rolling using a static steel-wheel roller can be completed once the mix has cooled to a temperature below about 190 °F (90 °C).

In most cases when checking occurs in the mix, the roller operators tend to back off the mix and allow it to cool. This is the wrong approach to the problem. Delaying the compaction permits the mix to cool and stiffen but most often does not then allow enough time for the mix to achieve the required level of density. With a tender mix, it may not be possible to accomplish both objectives (no checking and adequate density) at the same time if the mix is allowed to cool before rolling operations are started. It is much better to compact the mix as much as possible before checking starts, stay off the mix in the middle temperature zone when checking is most likely to occur, and then finish-roll the mix once it has cooled enough to support the weight of the final roller.

If the mix delivered to the paver is too hot—above 325 °F (165 °C)—it should be allowed to cool after laydown before the compaction process is started. Improper rolling techniques should be corrected. The surface of the underlying pavement should be clean and properly tack coated before placement of the new mix begins.

None of the solutions to the checking problem will work in all cases. Each mix will have its own compaction characteristics. For some extremely tender mixes, checking may occur at a wider range of temperatures, from as high as 270 °F (130 °C) down to as low as 170 °F

(75 °C). As noted, mixes that lack internal stability will generally check under steel-wheel rollers (operated in either the vibratory or static mode), and thus these mixes should be redesigned.

12.9.4 Effects on Performance

Although checks extend only a short distance down from the surface, they are highly detrimental to long-term performance because the tender mix characteristics affect the level of density obtained. If the rollers are kept back from the paver in an attempt to decrease the amount of checking that occurs, the level of density obtained by the compaction equipment will normally be reduced significantly. Thus, the air void content of the mat will increase. A mix that contains checks will therefore lack density and have a greatly reduced pavement life under traffic. Additionally, the check cracks themselves are an entry point for water into the mat and an initiation point for later cracking under traffic loads and temperature changes.

12.10 SHOVING AND RUTTING

12.10.1 Description

Shoving of an asphalt layer is displacement of the mixture in a longitudinal direction. Such displacement may take place during the compaction operation or later under traffic. In most cases, shoving during construction is accompanied by a large bow wave in front of the breakdown roller, particularly if that roller is a vibratory or static steel-wheel machine. Shoving may also occur in conjunction with mix checking if the mix is tender enough because of faulty aggregate gradation or excess fluids (asphalt binder or moisture) content. Finally, mat or mix shoving can occur at the reversal point of the rollers, especially at the location closest to the paver. A pavement layer that has shoved under the action of traffic is shown in Figure 169.

Rutting, illustrated in Figure 170, shows displacement of the mixture in both vertical and transverse directions. Rutting occurs when heavy traffic passes over an unstable mix. In a few cases, the rutting is purely vertical (consolidation rutting). In this situation, the mix (or underlying materials) was not adequately compacted at the time of construction, and the traffic loads are essentially finishing the compaction process. The most common form of rutting is transverse distortion—the mix distorts or shoves transversely as a result of lateral flow of the mix under applied traffic loads.

Source: Asphalt Institute

Figure 169. Shoving Due to Unsatisfactory Mix

12.10.2 Causes

Shoving and rutting are due primarily to an unstable mixture (see Chapter 3). This instability can be caused by the same variables that are responsible for checking—an excess of fluids (asphalt binder or moisture) in the mix, a hump in the fine aggregate grading curve, or the properties of the aggregate and the asphalt cement. Shoving and rutting can be highly prevalent when a sand mix is placed in a thick layer (more than 1-1/2 inch [40 mm]) at a high temperature (more than 280 °F [140 °C]). Further, thicker lifts of an unstable mix in proportion to the maximum aggregate size used will tend to shove more than thinner lifts with the same aggregate size and grading.

Source: East Carolina University

Figure 170. Rutting of Unstable Asphalt Mixture

Improper roller operation, particularly the sudden reversal of the roller, can also contribute to the shoving of the mix during construction (see Chapter 8). If a vibratory roller is run at too great a speed and the impact spacing is too far apart, the mat may develop a washboard effect, where the peak-to-peak distance is equivalent to the impact spacing. Washboarding, or shoving, is more likely to occur at normal frequencies but at high speeds where the impact force is greater. If a pneumatic tire roller with high tire pressure is used for breakdown compaction, a tender mix may shove laterally under the tires. Shoving can occur under any roller that is operated improperly.

Another possible cause of shoving is an excess of tack coat material that may be pulled into the mix. In a similar manner, excess asphalt from a bleeding underlying surface or from joint filler material can be pulled into the mix and increase its fluidity and tenderness. Shoving may occur as well when the underlying surface is dusty or dirty—a slippage failure (see Section 5.5).

12.10.3 Solutions

The solution to a mix that shoves under the compaction equipment is to increase its internal stability. This can be accomplished by reducing the fluids content (asphalt or moisture, or both) of the mix, but only after determining the effect of a change in asphalt binder content on the mechanical properties of the mix. The internal friction can be increased by lowering the mix temperature. Alternatively, the internal friction among the aggregate particles can be increased by changing the aggregate gradation or increasing the amount of angular (crushed) particles in the mix.

The compaction process for a tender mix should be changed, as discussed above under checking, to obtain sufficient density at the time of construction. An increase in the density achieved during the construction process will generally reduce the amount of shoving and rutting that may occur later under applied traffic. Sand mixes, because of their inherent tender nature, should be placed in several thin layers instead of one thick layer when used as base or binder courses.

The compaction equipment should be operated properly so as to reduce the opportunity to displace the mix during the rolling operation. Further, if the underlying pavement surface is dirty, it should be cleaned and a proper tack coat applied.

12.10.4 Effects on Performance

Mats that tend to shove under the compaction equipment are basically unstable. These mixtures will usually continue to distort under traffic, both longitudinally and laterally. Shoving of the mixture during construction is a strong indication that the pavement will rut later and not perform properly under traffic.

12.11 BLEEDING AND FAT SPOTS

12.11.1 Description

Bleeding of an asphalt mixture (see Figure 171) occurs when the asphalt binder flows to the top of the mix surface under the action of traffic loading. Bleeding is often seen as two flushed longitudinal streaks in the wheel paths of the roadway. Fat spots in an asphalt mixture (see Figure 172) are isolated areas where asphalt binder has come to the surface of the mix during the laydown and compaction operation or later under traffic. These spots can occur erratically and irregularly, or they may be numerous and in a fairly regular pattern.

Source: Pavement Interactive

Figure 171. Asphalt Bleeding in the Travel Lane

12.11.2 Causes

Fat spots are caused primarily by excessive moisture in the mix (see Chapter 3). The problem is more common with mixtures that contain a high percentage of fine aggregate (oversanded mixes) and those that contain aggregates with a high porosity. If all the moisture in the coarse and fine aggregate is not removed during the drying and mixing operation at the asphalt plant, the moisture vapor will force asphalt binder to the surface of the mix behind the paver as the moisture escapes from the mix and evaporates. Fat spots occur more frequently when aggregate stockpiles are wet or when the moisture content varies in different portions of the stockpiles.

Fat spots sometimes occur in areas where petroleum products, such as oil or diesel fuel, were spilled onto the pavement surface prior to overlay (see Figure 173Figure 172)

Fat spots are caused primarily by excessive moisture in the mix. The problem is more common with mixtures that contain a high percentage of fine aggregate (oversanded mixes) and those that contain aggregates with a high porosity.

or have contaminated the mix. Use of petroleum-based release agents in the mix haul vehicles can also cause fat spots in the asphalt mix (see Section 6.5.1). In addition, fat spots can be associated with segregated areas in the mix (see Chapter 10). If the mix deposited on the roadway by the paver is segregated, areas in which excess asphalt binder is present in the mix can result in free binder material on the top of the layer being placed.

The causes of bleeding normally fall into two categories. The first is an excess of fluids in the asphalt mixture—either asphalt binder or moisture or both. Under traffic, the extra moisture and asphalt binder will be pulled to the surface by the passage of vehicle tires. This bleeding phenomenon usually occurs on new mix and during hot weather when the viscosity of the asphalt binder is at its lowest level. Typically, the bleeding occurs shortly after traffic is allowed to travel over the fresh mix—while there is still some moisture in the mix and while the viscosity of the asphalt binder is still relatively low.

The causes of bleeding normally fall into two categories: an excess of fluids in the asphalt mixture or a lack of adequate space in the mix for the asphalt binder.

Source: Pavement Interactive

Figure 172. Fat Spot Caused by Localized Excess Asphalt

Source: Asphalt Institute

Figure 173. Fat Spot Caused by Fuel Oil Spill Prior to Overlay Construction

Bleeding may also be associated with a lack of adequate space in the mix for the asphalt binder. If the VMA content and air void content of the mix do not provide enough room for the binder material, bleeding can occur as the mix is densified by traffic, both shortly after construction and later. The traffic compaction process will decrease the air void content of the mix and may, in turn, squeeze some of the asphalt binder out of the mix. The “extra” asphalt will appear as a longitudinal streak or fat spot throughout the length of each wheel path.

One additional possible cause of bleeding is the condition of the pavement layer on which the new mix is placed. If the underlying layer has excess asphalt on its surface or excess crack seal material in the cracks and joints, some of this material may be drawn up through a thin new mix layer. Further, if too much tack coat is applied to the original pavement layer, the excess material may be pulled up through a thin overlay and contribute to the bleeding problem. However, neither of these two causes is common.

12.11.3 Solutions

Variations in the asphalt mix temperature behind the paver indicate that the moisture content of the mix may also be variable. Where moisture has evaporated, the temperature is lower. This latter phenomenon can contribute to both the bleeding of the mix later under traffic and the generation of fat spots in the mix during construction. It is important, therefore, that the aggregate used in the mix be relatively dry and that the moisture content of the mix upon discharge from the asphalt plant be as low as possible, but not more than 0.5 percent. Extra care needs to be taken in drying when producing mixtures that incorporate highly absorptive aggregate.

Bleeding problems caused by excess asphalt binder in the mix can most easily be solved by reducing the binder content, consistent with other properties of the mix, such as air voids, VMA, and strength or stability. Bleeding problems that occur in conjunction with pavement rutting usually can be solved, however, only by a complete redesign of the mixture, with emphasis on proper air void content and VMA criteria.

12.11.4 Effects on Performance

Occasional fat spots in the mix should not affect the ultimate durability of the pavement to a significant degree. The presence of many fat spots, or significant amounts of bleeding in the wheel paths, does affect pavement performance, however, because of variable binder and air void content in different parts of the mix. In addition, other mix problems, such as shoving, rutting, and loss of skid resistance, may occur in a mix that contains many fat areas or areas of bleeding in the wheel paths. The design of the mixture, the operation of the asphalt plant (more complete removal of moisture), or both should be checked to ensure that the mix produced will provide adequate pavement performance under vehicular loading.

12.12 ROLLER MARKS

12.12.1 Description

During the compaction process—whether vibratory static steel-wheel or pneumatic tire rollers are used—longitudinal creases or marks are left in the surface of the mix. Once the mix has cooled to a temperature range of 160 °F to 140 °F (70 °C to 60 °C), these marks are typically removed by the finish roller. Roller marks are indentations that remain in the surface of the mix after rolling has been completed (see Figure 174). With some mixes, pneumatic tire rollers may sometimes leave shadows on the surface of the mix after rolling has been completed (see Figure 175).

Roller marks may also exist in the asphalt surface when any roller is parked on the hot mat for a period of time or when a vibratory roller is vibrated in place. Particularly when used in the breakdown position, pneumatic tire rollers can leave visible longitudinal marks that can still be seen after the finish rolling has been completed. Vibratory washboard marks may be visible if that roller is operated at an improper vibratory amplitude, frequency setting, or speed, as shown in Figure 176.

12.12.2 Causes

Roller marks can be an indication that the proper number of roller passes has not been made over the mix (see Chapter 8).

Source: NCAT

Figure 174. Roller Marks in a Freshly Laid Asphalt Pavement

Source: Asphalt Institute

Figure 175. Pneumatic Roller Shadows in a New Asphalt Pavement

Source: Asphalt Institute

Figure 176. Washboard Marks Left by an Improperly Operated Vibratory Roller

If the compaction process is halted before the required amount of rolling has been completed or if the mix cools before the compaction process has been finished, the longitudinal marks or creases made by the rolling process will remain in the surface of the mix.

Roller marks left in an asphalt layer also may indicate a tender mix (see Section 8.6.2). The roller operator will normally be unable to remove all the marks left by the compaction equipment if the mix is tender or unstable. A tender mix usually will not support the weight of the finish roller until it has cooled to the point at which the viscosity of the asphalt binder has increased enough to stiffen the mix. By the time the mix has decreased in temperature to this point, however, the required level of density can generally no longer be achieved because the mix has lost its workability. For this reason, the roller marks or indentations left during the breakdown and intermediate roller passes usually cannot be removed during the finish rolling process. All the asphalt binder, aggregate, and mix properties that contribute to the formation of a tender mix, as discussed above, also contribute to the inability of the finish roller to eliminate roller marks.

12.12.3 Solutions

If the cause of roller marks is inadequate compaction, additional roller passes should be made with the breakdown, intermediate, or finish rollers to properly densify the mix. The solutions for inadequate compaction related to mix design deficiencies all involve changes to the mix design and to the production of the mix at the asphalt plant. Asphalt binder quality and content, aggregate properties and characteristics, and mix temperature all play a significant role in the workability and stability of the asphalt material under the compaction equipment.

Asphalt binder quality and content, aggregate properties and characteristics, and mix temperature all play a significant role in the workability and stability of the asphalt material under the compaction equipment.

Roller marks normally cannot be removed from a tender mix until the mix temperature has decreased to a relatively low level—usually less than 160 °F (70 °C).

Sometimes it is possible, depending on environmental conditions and the properties of the mix, to remove roller marks left in the mix by using a pneumatic tire roller. If the surface of the mix is hot enough (140 °F [60 °C] or more), several passes with a pneumatic tire roller can be made to "iron out" the surface of the pavement. Finally, roughness or washboarding caused by incorrect operation of a vibratory roller should be eliminated by using proper operating techniques with this equipment.

12.12.4 Effects on Performance

Roller marks are normally an indication that the proper level of compaction has not been achieved. In terms of ultimate pavement durability, the air void content or density of the mix is the single most important characteristic that governs the performance of the asphalt mixture under traffic. If the air void content of a dense-graded mix is high—the density is too low—the pavement generally will not perform well under traffic. Shadows from pneumatic tire rollers have no detrimental effect on performance and will typically disappear soon after the pavement is opened to traffic.

12.13 POOR MIX COMPACTION

12.13.1 Description

Dense-graded mixtures should be compacted so that the in-place air voids are at an acceptable level. The NMAS of dense-graded asphalt mixtures has a significant effect on the in-place permeability of the mat (see Section 3.5.3). As the NMAS of the mix decreases, the impermeability increases. If not adequately compacted, the mix will be permeable to air and water and will not have the required durability. If the initial compaction results in air voids of approximately 4 percent or lower, the mix may become unstable under traffic after additional densification; the result will be shoving and rutting of the mixture, as discussed earlier. However, the use of polymer-modified binders in these mixtures, coupled with high-quality angular aggregates, will help mitigate this potential for shoving and rutting. Some specialty mixtures using highly modified binders are actually designed for 2 to 3 percent in-place air voids. Most mixes require a significant level of compaction to reach the desired level of air voids.

12.13.2 Causes

When the mix is too stiff or too tender, compaction is difficult. The primary cause of poor compaction is low design mix density (high design air voids), effectively resulting in a mixture with low design binder content (see Chapter 3). Other causes include inadequate underlying support (see Chapter 5), improper type and weight of rollers, improper tire pressure in rubber-tire rollers, improper rolling procedure (Chapter 8), improper mix design (Chapter 3), mix segregation (Chapter 10), moisture in the mix (Chapter 3), variation in mix temperature, and low mix temperature.

12.13.3 Solutions

Solutions to compaction problems include taking the necessary steps to ensure adequate support, producing an acceptable mixture, and using satisfactory laydown and rolling techniques. When support is inadequate, the compaction requirements may have to be relaxed, or the mix may have to be redesigned to allow for satisfactory compaction.

When the asphalt content is too high, the mix may compact too easily, resulting in low air voids (which may lead to rutting; see earlier discussion). When the asphalt content is too low, the mix may be stiff and difficult to compact to the specified density. A satisfactory mix design will produce a mix with optimum asphalt content that can be compacted with reasonable effort to the required density.

Good laydown and rolling techniques, as discussed earlier throughout this manual, are necessary for good compaction. Density can normally be increased by reducing the speed of the paver or rollers. Density can also be increased by increasing the weight and number of rollers. The compaction process must be adjusted to produce optimum density.

12.13.4 Effects on Performance

When the compaction is inadequate, the mix will be permeable to air and water. Water can flow through the asphalt mixture and reduce the strength of the underlying base course. The high voids also result in excessive oxidation of the asphalt mix, which leads to raveling, cracking, and general deterioration of the asphalt pavement over a period of time. A one percent increase in density has been found to conservatively increase the service life of pavement by 10 percent.

When the air voids are excessively low after compaction (less than 4 percent) for dense-graded mixes, the mix is likely to rut and shove under traffic. Again, the use of polymer-modified binders in these mixtures coupled with high-quality angular aggregates will help to mitigate this potential for shoving and rutting. The low voids are not the result of too much compaction but of an unsatisfactory mixture.

12.14 OTHER PAVEMENT PROBLEMS

The above discussion has addressed only those problems that occur at the time of the asphalt mix production, laydown, and compaction. Several other deficiencies can occur on an asphalt pavement structure with time and traffic loading once construction has been completed. Those distresses include fatigue cracking, rutting, shoving, raveling, and disintegration. A discussion of such distresses is beyond the scope of this Handbook.