Airport Asphalt Pavement Technology Program

Balanced Mix Design: Rutting Performance Tests

Technical Memo 1: Analysis of In-Place Density Data from Airfield Projects

Appendix A

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Airport Asphalt Pavement Technology Program

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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 Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
APA	Asphalt Pavement Analyzer
AV	Air voids
BMD	Balanced Mix Design
CI	Confidence interval
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
GAW	Gross aircraft weight
JMF	Job mix formula
LTPP	Long-Term Pavement Performance
NBC	Beaufort Marine Corps Air Station Airport
NMAS	Nominal maximum aggregate size
PANYNJ	Port Authority of New York and New Jersey
PG	Performance grade
PMLC	Plant-mixed laboratory-compacted
PWL	Percentage within limits
QA	Quality assurance
QC	Quality control
RAP	Reclaimed asphalt pavement
TEB	Teterboro Airport

Executive Summary

This study aimed to establish representative rutting test protocols and criteria tailored to airfield asphalt mixtures, supporting the Federal Aviation Administration's (FAA's) Balanced Mix Design (BMD) efforts at both the mix design and production stages. Four rutting test methods were evaluated, emphasizing laboratory protocols that simulate field conditions by accounting for specimen preparation, air void (AV) levels, aging, conditioning, and test temperatures.

Experimental results revealed strong correlations between the Asphalt Pavement Analyzer (APA) (100 psi/100 lb and 250 psi/250 lb tests), high temperature indirect tensile strength test, and ideal rutting test. Enhanced correlations were observed when using Hamburg wheel tracking test rut depths at 5,000 passes rather than 20,000 passes. An AV level of 7±0.5 percent was recommended for all rutting tests to ensure consistent specimen preparation.

A mechanistic-empirical approach was used to refine the FAA's APA 250 psi/250 lb rutting test criterion by incorporating aircraft speed and load. This framework used 3D-Move Analysis software to model pavement responses under varying temperatures, speeds, and loads, generating stress states for realistic field simulations. The resulting rutting performance models quantified mixture sensitivity to operational conditions, leading to revised test criteria for slow or stationary aircraft and general airfield pavements.

Laboratory verification of the recommended criteria was conducted using field cores from airfield sections with known performance. Revisions to FAA's P-401/P-403 asphalt mixture specifications are proposed. To expand BMD implementation into production, pilot projects are recommended to validate the proposed protocols and identify practical challenges. Long-term monitoring of sampled pavement sections will further refine the correlations between laboratory criteria and in-service performance of airfield asphalt pavements.

Chapter 1. Introduction

In-place density of asphalt concrete (AC) pavements is an important contributor to pavement service life. A higher in-place density or a lower percentage of air voids (AV) in the asphalt mixture is associated with improved pavement performance (Allick Jr., Choubane, Kwon, & Hernando, 2018; Aschenbrener, Brown, Tran, & Blankenship, 2018; Kumar, Coleri, & Obaid, 2021). The Federal Aviation Administration's (FAA's) acceptance criteria for AC pavement involve meeting target percentage of AV on plant-mixed laboratory-compacted (PMLC) specimens, along with mat and joint density on field cores sampled on a sublot basis (FAA, 2018).

The FAA is exploring the adoption of a Balanced Mix Design (BMD) framework in their subsequent specifications update for airfield pavements. The prospective BMD framework will incorporate rutting and cracking performance criteria based on laboratory performance tests. However, the laboratory testing and criteria need to be thoroughly tailored to airfield conditions in terms of test temperature, wheel load, specimen AV level, tire pressure, etc. Accordingly, performance criteria for highway pavements commonly used for rutting and cracking will need to be reevaluated for airfield conditions.

One of the key elements in deriving appropriate performance criteria is to establish representative laboratory testing conditions that best simulate actual field conditions for airfield pavements. In particular, the specimen AV level is known to have an impact on performance testing results. Thus, specimen AV levels that replicate the in-place AV percentage of airfield AC pavements need to be established for laboratory performance testing. To this end, asphalt mixture AV data on PMLC specimens, as well as in-place asphalt density data for an array of airport projects, were acquired and analyzed by the research team.

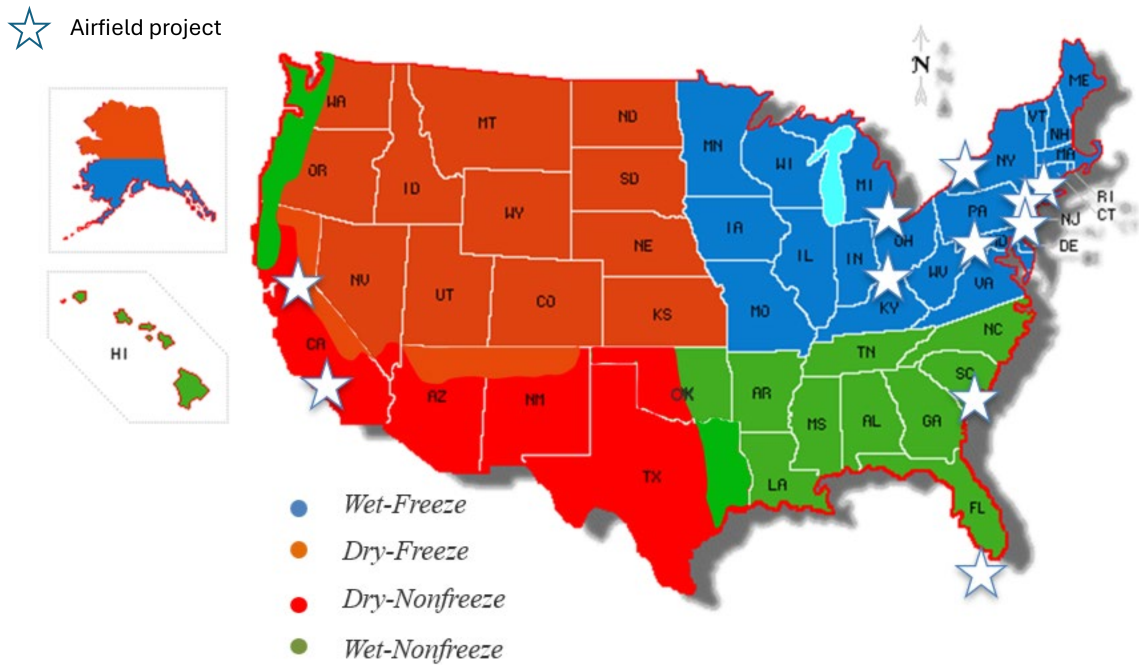
The following terminologies are used in this memorandum in accordance with AC 150/5370-10H (FAA, 2018):

- **Air voids (AV)** refers to the percentage of AV in the asphalt mixture determined in accordance with ASTM D3203 for compacted specimens prepared in accordance with ASTM D6926 (ASTM, 2017; ASTM, 2020).
- **In-place density** refers to the percent compaction of field cores taken from the mat or joint. The percent compaction (density) of each core sample is determined by dividing the bulk specific gravity of the sample (determined in accordance with ASTM D2726) by the theoretical maximum density (ASTM, 2021). The AV percentage of AV in the core sample can then be calculated as 100 minus the percent compaction.

Rutting in airfield AC pavements is observed in the mat or near a longitudinal joint that is being traversed by aircraft. Rutting at or next to a joint is primarily driven by the lower in-place density (i.e., higher percentage of AV in the asphalt mixture) at this location than the rest of the mat. Thus, both in-place asphalt mat and joint density were considered in this analysis to recommend a suitable specimen AV level(s) for laboratory performance testing.

Chapter 2. Airfield Pavements

A total of 11 airports around the United States with 12 airfield AC pavement projects were evaluated in this analysis. Figure 1 illustrates the geographical distribution of the evaluated airports located within three of the Long-Term Pavement Performance (LTPP) climatic zones (Schwartz, et al., 2015). Table 1 summarizes the considered airports along with their respective FAA identification code, category, and hub size per the FAA classification, maximum gross aircraft weight (GAW), and LTPP climatic zone (Schwartz, et al., 2015; FAA, 2021; FAA, 2022; Airport-Data.com, 2022).



Source: University of Nevada, Reno

Figure 1. Geographical Location of Airports on the LTPP Climate Zone Map

Table 1. Characteristics of Airports Used in the Evaluation

Airport	State	Airport Code	Classification/Hub (FAA, 2021)	GAW (lb) (FAA, 2022; Airport-Data.com, 2022)	LTPP Climatic Zone
Buffalo Niagara International Airport	NY	BUF	Primary/Small	>100,000	Wet-Freeze
Hollywood Burbank/Bob Hope Airport	CA	BUR	Primary/Medium	>100,000	Dry-Nonfreeze
Ronald Reagan Washington National Airport	VA	DCA	Primary/Large	>100,000	Wet-Freeze
Detroit Metropolitan Airport	MI	DTW	Primary/Large	>100,000	Wet-Freeze
Key West International Airport	FL	EYW	Primary/Small	>100,000	Wet-Nonfreeze
Blue Grass Airport	KY	LEX	Primary/Small	>100,000	Wet-Freeze
Beaufort Marine Corps Air Station (Merritt Field) Airport	SC	NBC	GA/Nonprimary hub	—	Wet-Nonfreeze
Newark Liberty International Airport	NJ	EWR	Primary/Large	>100,000	Wet-Freeze
Philadelphia International Airport	PA	PHL	Primary/Large	>100,000	Wet-Freeze
Sacramento International Airport	CA	SMF	Primary/Medium	>100,000	Dry-Nonfreeze
Teterboro Airport	NJ	TEB	GA/Nonprimary hub	≤100,000	Wet-Freeze

GA = General aviation.

Table 2 summarizes the 12 airfield AC pavement projects along with their respective construction dates and pavement sections. The asphalt mixture type, binder performance grade (PG), gradation, nominal maximum aggregate size (NMAS), and reclaimed asphalt pavement (RAP) content are also included in Table 2. While asphalt mixtures are identified as either P-401 or P-403, the following modifications from the FAA Standard Specifications are noted (FAA, 2018):

- The Beaufort Marine Corps Air Station Airport (NBC) is designed at 4.0 percent AV per the Naval Facilities Engineering Command Specification Section 32 12 15.13. However, the NBC mixtures still met the main P-401 specifications, including gradation, number of gyrations, voids in mineral aggregates, tensile strength ratio, and binder content.
- The Newark Liberty International Airport (EWR) and Teterboro Airport (TEB) mixtures are designed per the Port Authority of New York and New Jersey (PANYNJ) Specification Section 321218, which includes the requirements of FAA AC 150/5370 Item P-401 with FAA-approved modifications.

The field acceptance data for the evaluated asphalt mixtures (Table 2) were acquired and analyzed as shown in the following sections.

Table 2. Characteristics of Airfield Asphalt Mixtures Used in the Evaluation

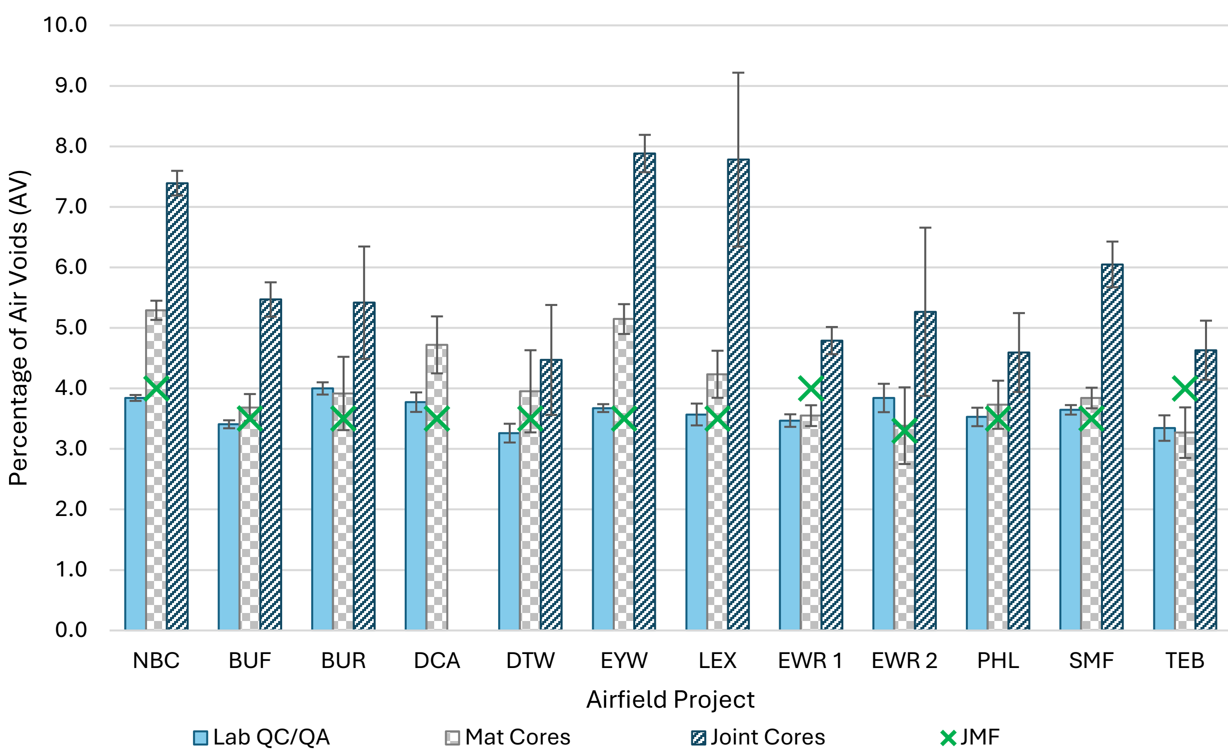
Airfield Project	Construction Date	Section	Mixture Type	Mix Design	Binder PG	Gradation	NMAS (inch)	RAP (%)
BUF	May–Aug 2017	Runway	P-401 (surface)	Marshall	64E-22	Grad 2 (401-3.3)	1/2	0
		Runway	P-401 (base)	Marshall	64S-22	Grad 1 (401-3.3)	3/4	0
BUR	Feb 2021	Taxiway	P-401 (surface)	Superpave	76-22	Grad 1 (401-3.3)	3/4	0
		Taxiway	P-401 (base)	Superpave	70-10	Grad 1 (401-3.3)	3/4	0
DCA	Apr–May 2010	Runway/ Taxiway	P-401 (surface)	Marshall	76-22	Grad 1 (401-3.3)	3/4	0
DTW	July–Oct 2020	Apron	P-401 (surface)	Marshall	76-22P	Grad 2 (401-3.3)	1/2	0
		Deicing Facility	P-403 (surface)	Marshall	64-22	Grad 2 (403-3.3)	1/2	30
EYW	Jan 2018	Runway	P-401 (surface)	Superpave	76-22 (PMA)	Grad 2 (401-3.3)	1/2	0
	June 2020–Sept 2021	Taxiway	P-401 (surface)	Superpave	76-22 (PMA)	Grad 2 (401-3.3)	1/2	0
LEX	Sept 2020	Runway/ Taxiway	P-401 (surface)	Superpave	76-22 (SBS)	Grad 1 (401-3.3)	3/4	0
NBC	Mar–Oct 2020	Runway	P-401 (surface)	Superpave	76-22 (PMA)	Grad 2 (401-3.3)	1/2	0
		Runway	P-401 (intermediate)	Superpave	76-22 (PMA)	Grad 2 (401-3.3)	1/2	20
		Shoulder	P-401 (surface)	Superpave	76-22 (PMA)	Grad 2 (401-3.3)	1/2	20
EWR 1	May–Sept 2021	Runway	Modified P-401 (surface)	Marshall	76-22	Mix 3[1]	1/2	0
		Runway	Modified P-401 (surface)	Marshall	76-22	Mix 3[1]	3/4	0
EWR 2	Aug–Sept 2022	Taxiway	Modified P-401 (surface)	Marshall	82-22	Mix 2[1]	3/4	0
PHL	Dec 2017–May 2018	Runway	P-401 (surface)	Marshall	82-22	Grad 1 (401-3.3)	3/4	0
		Runway	P-401 (base)	Marshall	70-22	Grad 1 (401-3.3)	3/4	20
SMF	Dec 2016–Mar 2017	Taxiway	P-401 (surface)	Marshall	64-28PM	Grad 1 (401-3.3)	3/4	0
TEB	July–Aug 2022	Runway	Modified P-401 (surface)	Marshall	64-22	Mix 3[1]	3/4	0

[1]PANYNJ Specification Section 321218.

Chapter 3. Airfield Pavements Acceptance Data

For each airfield AC pavement project, job mix formula (JMF), laboratory quality control/quality assurance (QC/QA), field report format, and joint core density data were obtained and analyzed to determine the percentage of AV in the asphalt mixtures. All evaluated airfield projects were designed in accordance with FAA specifications at 3.5 percent AV, except for NBC, EWR, and TEB, which were designed at 4 percent AV.

Figure 2 shows the calculated percentage of AV in the asphalt mixtures using PMLC samples (i.e., laboratory QC/QA), in-place asphalt mat density (i.e., mat cores), and in-place asphalt joint density (i.e., joint cores). The average percentage of AV ranged from 3.3 to 4.0 percent, 3.3 to 5.3 percent, and 4.5 to 7.9 percent for laboratory QC/QA, mat cores, and joint cores, respectively. For laboratory QC/QA data, the average percentage of AV in asphalt mixtures was within 0.7 percent of the design AV (i.e., JMFs). Joint cores consistently showed a higher percentage of AV than mat cores and laboratory QC/QA. Moreover, the 95 percent confidence intervals (CI) suggest higher variability in the percentage of AV from the joint cores compared to those from the mat cores, while the least variability was observed in the PMLC samples (i.e., laboratory QC/QA).



Source: University of Nevada, Reno

Figure 2. Summary of Percentage of AV in Asphalt Mixtures (Error bars represent the mean plus or minus the 95 percent CI.)

Chapter 4. Combined Data Analysis

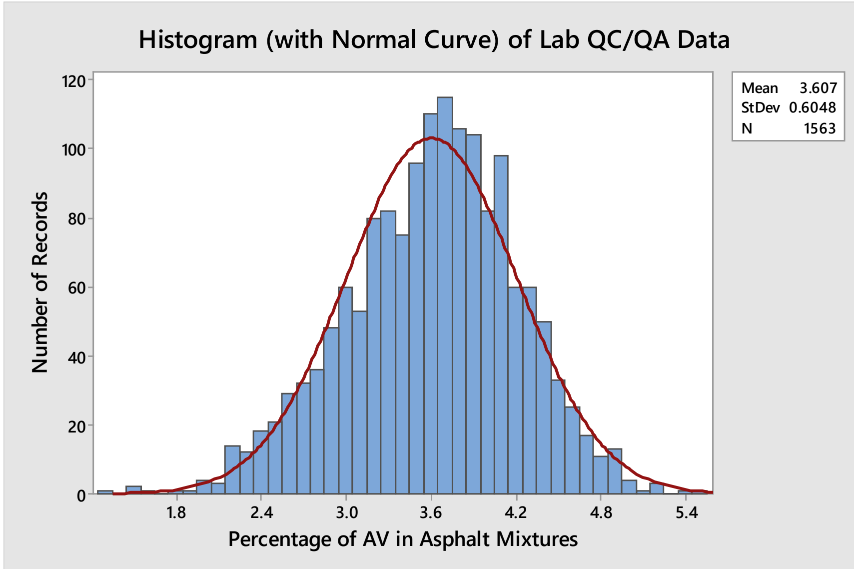
The percentage of AV in asphalt mixtures data from the 12 airfield AC pavement projects have been categorized into the following three datasets:

- Dataset 1: Laboratory QC/QA data with a total of 1,563 data points.
- Dataset 2: Mat cores with a total of 858 data points.
- Dataset 3: Joint cores with a total of 760 data points.

An additional dataset that combines mat and joint core data from all 12 airfield AC pavement projects could have been included in the analysis. However, grouping the mat and joint core data into one dataset should be based on pavement area (i.e., weighted by mat and joint pavement surface area).

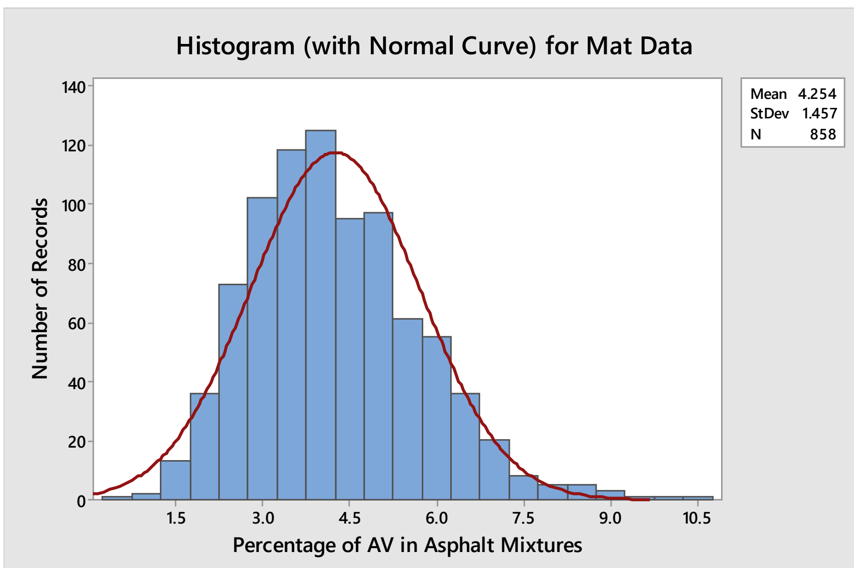
Each of the three datasets was analyzed using Minitab Statistical Software (Minitab® 17.1.0) to generate descriptive statistical parameters (e.g., mean, median, mode, standard deviation, skewness, and kurtosis) (Minitab, 2024). Subsequently, three histograms, along with fitted normal curves, were developed for each dataset (i.e., laboratory QC/QA, mat cores, and joint cores) and are presented in Figure 3 through Figure 5.

Each dataset was subjected to the Anderson-Darling normality test, which compares the empirical cumulative distribution function of the sample data with the expected distribution in case of normal data. The null hypothesis of population normality is rejected if the observed difference is adequately large at 95 percent CI. (Minitab, 2022) To pass the Anderson-Darling normality test at 95 percent confidence level, the values in datasets 1 and 2 had to be mathematically transformed by raising the percentage of AV in asphalt mixtures to the power of 1.5 and applying a square root, respectively. Whereas, for dataset 3, the quality tools analysis using Minitab software with individual distribution identification indicated that none of the mathematical transformations could fit the percentage of AV in asphalt mixtures for joint cores into a normal distribution with a p-value ≥ 0.05. This result was expected based on the bimodal distribution of the original joint core data shown in Figure 5, which delineates two different peaks in the respective histogram. Although the transformed dataset 3 did not pass the normality test (p-value < 0.05), Figure 6 shows that most of the transformed data (i.e., after square root transformation) falls within the 95 percent confidence band of the normal probability plot.



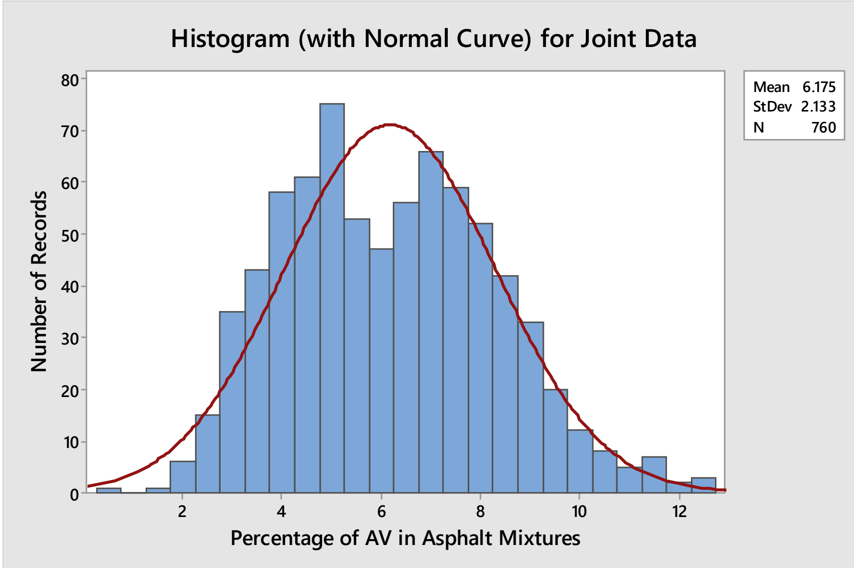
Source: University of Nevada, Reno

Figure 3. Histogram of Percentage of AV in Asphalt Mixtures for Dataset 1 (Combined Laboratory QC/QA Data)



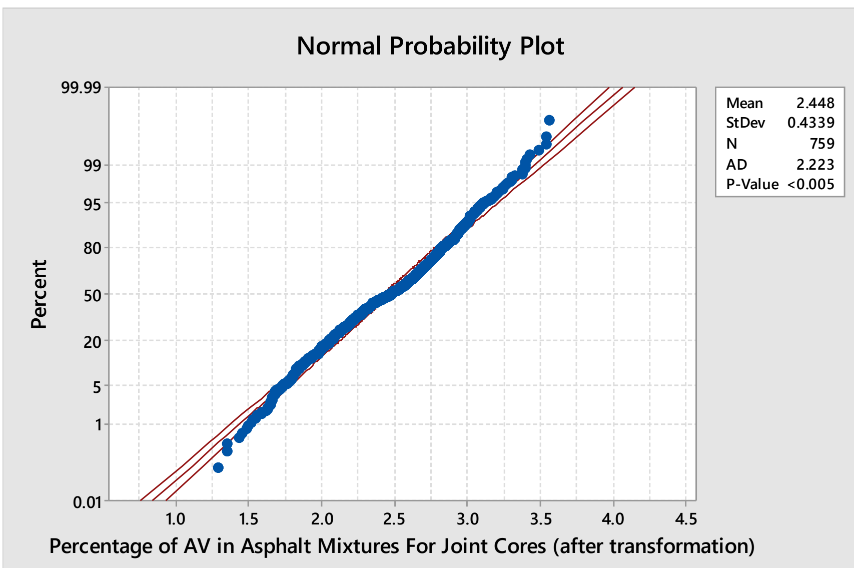
Source: University of Nevada, Reno

Figure 4. Histogram of Percentage of AV in Asphalt Mixtures for Dataset 2 (Combined Mat Core Data)



Source: University of Nevada, Reno

Figure 5. Histogram of Percentage of AV in Asphalt Mixtures for Dataset 3 (Combined Joint Core Data)



Source: University of Nevada, Reno

Figure 6. Normal Probability Plot for the Square Root of Percentage of AV in Asphalt Mixtures for Dataset 3 (Combined Joint Core Data)

Table 3 shows the average percentage of AV for each of the three datasets before and after transformation to better fit for normal distribution. The average percentage of AV in asphalt mixtures is 3.6, 4.3, and 6.2 for laboratory QC/QA, mat cores, and joint cores, respectively. A decrease of 0.2 percent in the average percentage of AV in asphalt mixtures was observed for the mat and joint cores after transformation of the respective data.

Table 3. Average Percentage of AV in Asphalt Mixtures

Dataset	Before Transformation to Better Fit for Normal Distribution	After Transformation to Better Fit for Normal Distribution
1 (Laboratory QC/QA)	3.6%	3.6%
2 (Mat Cores)	4.3%	4.1%
3 (Joint Cores)	6.2%	6.0%

A useful characterization of the evaluated datasets is to calculate the percentiles of each distribution for the percentage of AV. Table 4 shows the results for the 25th, 50th (i.e., median), 75th, and 99th percentiles. The median for each of the datasets is comparable to the average value before and after transformation. The 75th percentile of the percentage of AV in asphalt mixtures was calculated to be 4.0, 5.2, and 7.7 percent for laboratory QC/QA, mat core, and joint core data, respectively. The 99th percentile covering most of the data points was determined to be 4.9, 8.7, and 11.5 percent for laboratory QC/QA, mat core, and joint core data, respectively.

Table 4. Percentiles of Percentage of AV in Asphalt Mixtures

Percentile	Percentage of AV		
	Dataset 1 (Laboratory QC/QA)	Dataset 2 (Mat Cores)	Dataset 3 (Joint Cores)
25th	3.2%	3.2%	4.5%
50th (Median)	3.7%	4.1%	6.1%
75th	4.0%	5.2%	7.7%
99th	4.9%	8.7%	11.5%

Chapter 5. FAA Specifications

Acceptance Limits

Percentage of AV in asphalt mixtures for PMLC samples (laboratory QC/QA), mat cores, and joint cores are used for acceptance in the current FAA AC 150/5370-10H, *Standard Specifications for Construction of Airports* (FAA, 2018). While the target percentage of AV for mix design is set at 3.5 percent for Items P-401 and P-403, the acceptance limits during production and after construction differ slightly between the two mixture types.

Item P-401 is intended to be used for the surface course of airfield flexible pavements subjected to aircraft loadings of gross weights greater than 30,000 lb, and the acceptance of each lot of plant-produced material is defined based on the percentage of material within specification limits (PWL). Item P-403 is intended to be used as a base or leveling course, shoulder surface, or surface for pavements designed to accommodate aircraft of gross weights less than or equal to 30,000 lb.

Table 5 summarizes the specification tolerance limits for Item P-401 and Item P-403 mixes (FAA, 2018). Table 6 shows the percentage of the combined AV data within the set acceptance limits for each of three datasets (FAA, 2018). The percentage of AV in asphalt mixtures data that are within the specification limits ranges from 87.5 to 100 percent. For the P-403 mat cores, 12.5 percent (that is, 100 minus 87.5 percent) of the analyzed combined AV data exceeded 6.0 percent.

Table 5. Acceptance Limits for Percentage of AV in Asphalt Mixtures

Mix Item	Percentage of AV				Notes
	PMLC Samples	Mat Cores (Surface Course)	Mat Cores (Base Course)	Joint Cores	
P-401 (401-6.3)	2–5%	≤7.2%	≤8.0%	≤9.5%	PWL
P-403 (403-6.2)	2–5%	—	≤6.0%	≤8.0%	—

Table 6. Summary of Percentage of Data Meeting the FAA Acceptance Specifications[1]

Mix Item	PMLC Samples	Mat Cores (Surface Course)	Mat Cores (Base Course)	Joint Cores
P-401 (401-6.3)	99.1%	97.1%	100.0%	93.8%
P-403 (403-6.2)	100.0%	—	87.5%	94.1%

[1]Percentages were calculated based on the combined data of the evaluated airfield projects and should not be confused with the PWL that is determined on a lot basis for each airfield project.

Airfield Pavements

Current FAA specifications for Item P-401 require each sublot to be evaluated with three PMLC samples, one mat core, and one core centered over the longitudinal joint. The acceptance criteria and PWL limits for Item P-401 mixtures are presented in Table 7 followed by the payment adjustment factors in Table 8. The lot PWL has to be equal or greater than 90 percent for the lot to be accepted without a pay deduction. The lot is rejected if the corresponding PWL for PMLC samples or mat cores is less than 55 percent.

The lot pay factor for both PMLC samples and mat cores is calculated as shown in Table 8 . The higher lot pay factor from the PMLC and mat cores is used when calculations for both PMLC and mat cores are 100 percent or higher. In case only one of the calculations for either PMLC or mat cores is 100 percent or higher, the lot pay factor is the product of the two values. Finally, when calculations for both PMLC and mat cores are less than 100 percent, the lot pay factor is the lower of the two calculated values. For joint cores, the lot pay factor is reduced by 5 percent but may not exceed 95 percent if the PWL is less than 71 percent.

Table 7. Item P-401 Acceptance Criteria and Corrective Actions

Sample Type	Lot PWL Acceptance Criteria	Corrective Action
PMLC and Mat Cores	≥90	Accept (Refer to Table 8).
	55–90	Pay deduction (Refer to Table 8).
	<55	Reject.
Joint Cores	≥90	Accept.
	80–90	Contractor shall evaluate the reason and act accordingly.
	<80	Contractor shall cease operations until the reason for poor compaction has been determined.
	<71	Lot pay factor reduced by 5% points (Refer to Table 8).

Table 8. Item P-401 Adjustment Schedule[1]

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96–100	106
90–95	PWL+10
75–89	0.5 PWL+55
55–74	1.4 PWL−12
<55	Reject[2]

[1]Although it is theoretically possible to achieve a pay factor of 106% for each lot, actual payments above 100% shall be subject to the total project payment limitation specified in paragraph 401-8.1a.

[2]The lot shall be removed and replaced. However, the Resident Project Representative (RPR) may decide to allow the rejected lot to remain. In that case, if the RPR and Contractor agree in writing that the lot shall not be removed, it shall be paid for at 50% of the contract unit price and the total project payment shall be reduced by the amount withheld for the rejected lot.

On the other hand, the acceptance criteria and corrective actions for Item P-403 mixes are based on the average percentage of AV for each lot (Table 9). Current FAA specifications require each sublot to be evaluated with three PMLC samples, one mat core, and one core centered over the longitudinal joint. The average of all investigated sublots is used for further acceptance of each lot, as shown in Table 9.

Table 9. Item P-403 Acceptance Criteria and Corrective Actions

Sample Type	Acceptance Criteria (Percentage of AV)	Corrective Action
PMLC	2%≤Avg. lot AV≤5%	Accept.
	Avg. Lot AV<2% or Avg. lot AV>5%	Remove and replace at the Contractor's expense.
Mat Cores	Avg. lot AV≤6%	Accept.
	Avg. lot AV>6%	Remove and replace at the Contractor's expense.
Joint Cores	Avg. lot AV≤8%	Accept.
	Avg. lot AV>8%	Stop production until the Contractor takes appropriate measures for proper compaction.

Avg. = average.

Chapter 6. Test Method Precision

The precision of the ASTM D3203 test method depends on the precision of test methods for bulk specific gravity and theoretical maximum density. It is computed by a procedure described in ASTM D4460 (ASTM, 2022a). Consequently, the precision limits for percent AV have been established in AASHTO T 269 "Standard Method of Test for Percent Air Voids in Compacted Dense and Open Asphalt Mixtures" (AASHTO, 2022a). Table 10 summarizes the one-sigma limit (1s) and the difference two-sigma limit (d2s) determined for single- and multi-operator conditions. The 1s is the standard deviation of the population of AV data, indicating the variability of a large group of individual AV values obtained under similar conditions (Hand & Epps, 2000). The d2s provides a maximum acceptable difference between two AV results on test portions of the same material. The d2s index equals the difference between two individual AV values that would be equaled or exceeded in the long run only 5 percent of the time under normal and correct operation of the test method. The d2s index is determined by multiplying the 1s by a factor of $2\sqrt{2}$, which represents the 95 percent confidence interval (Hand & Epps, 2000).

The AV precision limits in Table 10 should be considered to minimize the likelihood of two sets of samples being compacted to different target AV levels but yielding statistically similar AV values. In other words, when d2s criteria are considered, the difference in AV between the two datasets must exceed the specified limits to indicate that the AV values on the two datasets are statistically different at the 95 percent confidence level. This ensures the selection of two distinct target AV levels for performance testing of compacted asphalt mixtures.

Table 10. Precision Limits for Percentage of AV (AASHTO T 269)

Precision	Standard Deviation, 1s (%)	Acceptable Range of Two Results, d2s (%)
Single Operator (repeatability)	0.21	0.59
Multi Operator (reproducibility)	0.40	1.13

Chapter 7. Recommendations

Based on the analyzed airfield project data, the following AV levels for laboratory performance testing were identified for further evaluation:

- **Based on in-place mat density:**
    - AV level matching the observed median of mat core data for the percentage of AV in the asphalt mixtures (i.e., 4.1 percent): an AV level of 4.0±0.5 percent is selected; or
    - AV level matching the 75th percentile of mat core data for percentage of AV in the asphalt mixtures (i.e., 5.2 percent): an AV level of 5.0±0.5 percent is selected.
- **Based on in-place joint density:**
    - AV level matching the 75th percentile of joint core data for percentage of AV in the asphalt mixtures (i.e., 7.7 percent): an AV level of 7.0±0.5 percent is selected to maintain consistency with the AV level specified in current standard test methods, for example, AASHTO T 324, AASHTO T 340, and ASTM D8360 (AASHTO, 2022b; AASHTO, 2020; ASTM, 2022b).

While 7.0 percent AV is recommended to represent in-place joint density, either 4.0 or 5.0 percent AV is to be selected to represent in-place mat density. A percentage of AV tolerance of ±0.5 percent is recommended on the samples used for performance tests. This tolerance may be increased (e.g., ±1.0 percent) for performance test samples (e.g., field cores) used for acceptance during production.

The difference between the AV levels identified to represent in-place mat density (i.e., 4.0±0.5 or 5.0±0.5 percent) and that representing in-place joint density (i.e., 7.0±0.5 percent) exceeds the single-operator d2s precision limit for percentage of AV (see Table 10). In other words, two samples compacted by a single operator to 4.0 percent (or 5.0 percent) and 7.0 percent AV are considered to have statistically different AV values, even when accounting for the 0.5 percent tolerance. However, in the case of multi-operator variability, it is possible that two samples compacted to 5.0±0.5 and 7.0±0.5 percent may have statistically similar AVs. This is demonstrated by the difference between 5.5 percent (i.e., 5.0+0.5 percent) and 6.5 percent (i.e., 7.0−0.5 percent) being within the multi-operator d2s precision limit for percentage of AV (that is, 6.5 percent minus 5.5 percent = 1.0 percent, which is less than the multi-operator d2s precision limit of 1.13 percent).

The three AV levels identified for laboratory performance testing (two from in-place mat density and one from joint density) are assessed in Table 11 by using the empirical cumulative distribution function to determine the percentage of data covered within each AV range. Table 12 summarizes the advantages and disadvantages of implementing each of the identified AV levels. While evaluating the data, one should keep in mind that the ultimate aim is to implement performance tests as part of the BMD framework for asphalt mixture design, verification, and acceptance during production.

Based on the potential advantages and disadvantages identified in Table 12, a mini experiment to study the feasibility of using the identified AV levels should be conducted using select performance tests. The objective of the mini experiment is to verify whether target AV levels can be achieved within a reasonable number of gyrations without damaging the aggregate particles or structure. In particular, the study should assess the effort needed in the Superpave gyratory compactor (i.e., number of gyrations) to reach the target AV levels for asphalt mixtures having an NMAS of 0.5 inch and 0.75 inch. The selection of the performance tests for inclusion in the mini experiment should consider the specified thickness of the test specimen relative to the NMAS of the asphalt mixture. The findings from this study can be used to finalize recommendations for the AV levels to be used in performance testing.

Table 11. Selected AV Levels for Laboratory Performance Testing[1]

AV Level[2]	Dataset	AV_{LL} ≤ Percent of Data ≤ AV_{UL}	Percent of Data ≤ AV_{UL}
4.0±0.5%	Laboratory QC/QA	53.4	93.5
	Mat Cores	27.6	60.0
5.0±0.5%	Laboratory QC/QA	6.5	99.9
	Mat Cores	17.6	77.6
7.0±0.5%	Mat Cores	4.8	97.7
	Joint Cores	16.7	71.8

[1] AV_{LL} = AV lower limit; AV_{UL} = AV upper limit.

[2] The ±0.5% tolerance may be increased (e.g., ±1.0%) for performance test samples used for acceptance during production.

Table 12. Potential Advantages and Disadvantages for Identified AV Levels

Identified AVs	Advantages	Disadvantages/Challenges
4.0±0.5%	• Performance testing is done at an AV level consistent with the asphalt mix design. • Performance testing is implemented during production for acceptance and/or consistency of the asphalt mixture. • Laboratory QC/QA: PMLC samples are used for both volumetrics and performance testing (if Superpave mix design method is used). • Cores: mat cores are used for both in-place density and performance testing.	• Target AV level may not be achieved within a reasonable number of gyrations. • Damage to the aggregate particles or structure when compacting asphalt mixtures with a large NMAS to the target AV level in relatively thin compacted samples. • Core thickness is less than the recommended sample thickness for the performance test.
5.0±0.5%	• Percent of in-place mat AV data below the upper limit of 5.5% is 77.6%. • Target AV level is likely to be achieved within a reasonable number of gyrations, thereby reducing the potential for damage to aggregate particles or structure.	• AV level different than the mix design target AV level. • Trial and error are needed to achieve target AV level. • Potential to have statistically similar AV values between a sample compacted to 5.0±0.5% AV and another sample compacted to 7.0±0.5% AV.
7.0±0.5%	• AV level is consistent with several standard test methods for performance testing. • Industry has the experience and knowledge in fabricating samples to target AV level. • Findings and data are leveraged from past and existing research studies. • Percent of in-place mat and joint AV data below the upper limit of 7.5% is 97.7% and 71.8%, respectively. • Performance testing is implemented during production for acceptance and/or consistency of the asphalt mixture. • Cores: joint cores are used for both in-place density and performance testing.	• AV level different than the mix design target AV level. • Trial and error are needed to achieve target AV level.

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