Information Series 139

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

High RAP Asphalt Pavements

Japan Practice — Lessons Learned

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High RAP Asphalt Pavements: Japan Practice — Lessons Learned

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16. Abstract This document is the final report of the U.S. industry scanning tour of Japan conducted in December 2014 to learn about Japan's use of asphalt pavements with high reclaimed asphalt pavement content. The scanning tour also focused on construction operations and practices used in Japan, including porous friction courses. The scan tour readily illustrated the potential for asphalt mixtures with higher RAP content (>25%) that maintain equivalent or better quality and performance. Recommendations based on Japanese practices are offered to further the implementation of higher RAP content asphalt mixtures in the United States.			
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CONTENTS

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
DOT	Department of Transportation
DAP	Drainage Asphalt Pavements
FHWA	Federal Highway Administration
GAPA	Global Asphalt Pavement Alliance
HMA	Hot-Mix Asphalt
IDOT	Illinois Department of Transportation
JAMA	Japan Asphalt Mixture Association
JARA	Japan Road Association
JRCA	Japan Road Contractors Association
LA DOTD	Louisiana Department of Transportation and Development
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MOE	Ministry of the Environment
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NEXCO	Nippon Expressway Co.
NILIM	National Institute for Land and Infrastructure Management
PFC	Porous Friction Course
POSMAC	Porous Surface Mastic Asphalt Course
PWRI	Public Works Research Institute
RAP	Reclaimed Asphalt Pavement
SAPA	State Asphalt Pavement Association
SBS	Styrene-Butadiene-Styrene
SHRP	Strategic Highway Research Program
SMA	Stone-Matrix Asphalt
TDOT	Tennessee Department of Transportation
WisDOT	Wisconsin Department of Transportation
WMA	Warm-Mix Asphalt

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The authors would like to thank the entire high RAP tour delegation for their contributions of takeaways from the tour, input, and review of this report. NAPA and the delegation are grateful for the time and effort spent planning and hosting the tour by the Japan Road Contractors Association (JRCA) and especially, Takeo Miyoshi, Chairman of the JRCA, and Hitoshi Fujita of Nippon Road Co. Ltd., who led the international committee working group that planned the tour. The delegation is also grateful to Yuki Tsukimoto and Haruna Kogusuri from Sakai Corp., Masahiko Iwama of Nippo Corp., Nagato Abe of Toa Road Corp., and Hiroji Koseki of Obayashi Road Corp. for their hospitality and assistance while traveling. Acknowledgement of all persons the delegation met with is included in Appendix A.

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Notice

Quality Assurance Statement

Executive Summary

In Japan, on average, 47 percent reclaimed asphalt pavement (RAP) is used in asphalt pavements. In the United States, the average amount of RAP used in asphalt mixtures is slightly more than 20 percent. The National Asphalt Pavement Association (NAPA) and Federal Highway Administration (FHWA) promote the increased use of RAP in asphalt pavements and were interested in learning how Japan has achieved a national average of 47 percent RAP in asphalt mixtures, the quality achieved, and best practices applied. An industry scan tour of Japan was planned to learn about Japan's use of high RAP. The scan trip also focused on construction operations, practices, and other pavement technologies used in Japan.

The delegation included 19 representatives from NAPA producer and associate member companies; the director of the National Center for Asphalt Technology (NCAT); officials from state departments of transportation in Tennessee, Wisconsin, Illinois, and Louisiana; and the 2014 chairman of the State Asphalt Pavement Associations (SAPAs). Tour members met with representatives from more than 15 organizations in Japan, including contractors, public work officials, suppliers, and industry associations. The delegation toured two asphalt plants, four construction or completed asphalt pavement sites, a government laboratory and a contractor laboratory, and participated in three different knowledge exchanges.

There are about 1,150 asphalt plants in Japan, serving more than 90% of the country and producing about 55 million tons of hot-mix asphalt (HMA) annually. Of those 55 million tons, about 41.9 million tons (nearly 38 million metric tonnes) contain recycled HMA. The vast majority of asphalt plants in Japan are batch-type plants that use and produce smaller quantities of materials and have slower production rates than the drum plants common in the U.S. Approximately 15% of asphalt mixtures in Japan use polymer-modified asphalt binder. Because Japan's highway network is fairly mature and most paving is now for system maintenance, the majority of asphalt mixture production is for surface courses. Recycling HMA is considered routine in Japan, and the main focus for innovation centers on porous asphalt pavements (drainage pavements), water-retaining pavement structures, and heat-insulating pavements.

The average RAP content in Japan asphalt mixtures increased from 33% on average in 2000 to 47% on average in 2013. About 99% of RAP in Japan, similar to in the U.S., is recycled into new asphalt pavement mixtures, but some RAP is reused as base course. The average RAP contents are similar in colder northern and warmer southern regions and vary from 20%–60% on average.

The Japanese attribute their successful use of high levels of RAP in HMA to three key points:

1. A focus on quality (reducing variability), including processing RAP (i.e., fractionating) and covering stockpiles.
2. Heating the RAP to drive out moisture and soften the RAP binder.
3. Using a softening agent (and other mixing best practices) to achieve desired mix characteristics.

Japanese mix producers take great care in minimizing moisture in the raw materials by utilizing as little water as possible in crushing operations and keeping the stockpiles and bins covered. Most Japanese plants use a separate drum for drying and heating RAP, the so-called parallel heating method. Afterburner technology is used to eliminate hydrocarbon odor. The hot gasses are ducted to the virgin aggregate dryer to recover some of the heat energy. The use of rejuvenators (also referred to as softening agents) is common for high RAP content mixes in Japan. The rejuvenators are used to restore some physical characteristics of the RAP binder. Rejuvenators are mixed directly with the heated RAP in a small pugmill. The merit of this approach is that it allows the rejuvenator to quickly diffuse into the softened aged RAP binder.

The quality of Japan's pavements and roadways is due to an attention to detail and a focus on quality. Japanese contractors and road owners follow a simple mix design and materials testing process with a focus on performance. The scan tour readily illustrated the potential for asphalt mixtures with higher RAP content (>25%) that maintain equivalent or better quality and performance. Based on the delegation's observations and experiences while in Japan, there are no barriers to the potential for asphalt mixtures with higher RAP content (>25%) that maintain equivalent or better quality and performance in the United States. The consensus among the delegation is that the use of high RAP in asphalt pavements should continue to be pursued through a partnership between industry, including asphalt mixture producers, contractors, and suppliers, and government, including federal, state, and local agencies.

As part of this partnership, the following recommendations should be implemented:

- The high RAP tour delegation should provide knowledge transfer of the information gained through a report, presentations, and articles.
- Agency specifications should allow the use of RAP in asphalt pavement layers at the contractor's discretion and provide simple and clear criteria for ensuring pavement performance, including considering a simple lab mix stiffness test and criteria for determining mixture suitability. In addition, it is recommended that agencies explore reducing the number of mix designs as the cost of developing and updating many (in some cases upwards of 100) job-mix formulas is high.
- Best practices should be implemented and used for RAP processing, storage, mixture production, and paving, including minimizing moisture in RAP, fractionation for high RAP use, and stockpile storage. Probably most beneficial on the material side for production is keeping the RAP dry (which means a very low moisture content), reducing the superheating of the virgin aggregate needed for indirect heating of the RAP and allowing for an increased production rate. The implementation of well-known best practices in order to increase RAP content is critical.
- The U.S. asphalt pavement industry should consider potential benefits in the U.S. production process and how continuous plants are designed and manufactured, which will result in better drying of the aggregate and RAP materials and mixing with the virgin asphalt binder and additives. Production changes may include longer virgin aggregate and RAP mix times, high shear mixing, and storage time, which may facilitate the softening and blending of the RAP binder.
- The asphalt industry should also consider rejuvenators, softening binders, or another agent to facilitate high RAP amounts in asphalt mixtures. Currently (2015), NCHRP Project 9-58 is exploring the Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios; however, industry should also play an active role in determining the optimal use of recycling agents.

Another area of interest for the U.S. tour group was Japan's innovations with porous friction course mixtures. Porous friction courses (PFC), also referred to as "drainage" asphalt pavements or DAP, are widely used in Japan primarily for the safety benefits of reducing hydroplaning and splash/spray, as well as reducing roadway noise (Fujita, 2012). Japan considers PFC to have the same structural value as dense-graded mixtures for thickness design and the service life of PFC layers is similar to that of dense-graded surface layers. The Japanese asphalt industry and highway agencies have worked to improve the performance of PFCs and address many of the common issues with these layers. Key innovations for PFCs in Japan are:

1. Thick PFC layers (4–5 cm) to better suppress tire–pavement noise and to improve drainage. The economic justification of thicker layers is aided by the fact that PFCs are given the same structural layer coefficient as dense-graded mixes.
2. Use of highly modified asphalt binders (4%–8% SBS polymer) to improve resistance to raveling and eliminate the need for fibers.
3. Use of edge drains with PFCs placed in curb and gutter sections (i.e., urban areas).
4. Use of spray-pavers to apply a thick asphalt emulsion layer just before the PFC mix. The residual asphalt from the emulsion creates an impermeable layer at the bottom of the PFC to protect underlying asphalt layers.
5. Routine cleaning of the PFC with specialized equipment that flushes the PFC voids to help maintain permeability for a much longer period of time.

Currently, most of Japan's PFC mixes use all virgin materials. However, some trial projects have been constructed using 20%–50% RAP in the PFC mixes. Preliminary results indicate that up to 30% RAP can be satisfactorily used in porous mixes (Kanou et al., 2010).

An aspect of Japan's asphalt industry that has likely aided rapid implementation of new technologies is the small number of producers and contractors. These large companies have not only invested heavily in state-of-the-art plants and equipment, they also have built and staffed advanced central laboratories to explore innovations and to develop proprietary products. The technical expertise of these Japanese companies is impressive and the level of trust between the highway agencies and the contractors appears to be much better than is generally seen in the United States. Productivity and competition are much less of an emphasis compared to the U.S. road building industry. Safety, quality, and care for the environment are hallmarks of Japanese culture and are clearly the top priorities for the road construction industry.

A large focus of the high RAP Japan tour effort is knowledge and technology transfer. In addition to this report, NAPA has organized several industry educational sessions, including a session at the NAPA 2015 Annual Meeting, a presentation at the NAPA 2015 Asphalt Sustainability West Conference in partnership with FHWA, and a presentation at the NAPA 2015 Young Leaders Conference. A follow-up educational session was held at NAPA's 2016 Annual Meeting focusing on plant production practices for using more RAP. Several of the delegates have also presented at government and industry meetings, including the AASHTO Standing Committee on Highways and at SAPA meetings in Alabama, Indiana, Kansas, Kentucky, and Virginia.

1 Introduction

On average, 47 percent reclaimed asphalt pavement (RAP) is used in Japan's asphalt pavements. In the United States, the average amount of RAP used in asphalt mixtures is about 20 percent. Since 2007, the U.S. pavement industry has made a concerted effort to increase the amount of RAP used in asphalt pavements due to increased cost of virgin materials and a desire to emphasize sustainable, environmentally friendly practices. Based on annual industry and highway agency surveys, there appears to be an upper limit on the average amount of RAP in asphalt mixtures of about 20%; however, these same surveys have identified that the majority of state department of transportation (DOT) specifications and standards will allow up to 30% RAP on average (Copeland, 2011; Hansen & Copeland, 2015).

The National Asphalt Pavement Association (NAPA) and Federal Highway Administration (FHWA) promote the increased use of RAP in asphalt pavements and were interested in learning how Japan has achieved a national average of 47 percent RAP in asphalt mixtures, the quality achieved, and the best practices applied. Therefore, an industry scanning tour of Japan was arranged to learn about Japan's use of high RAP. The scan trip also focused on construction operations and practices used in Japan.

An Overview of Japan and Its Asphalt Industry

The land area of Japan is 145,932 square miles and the mainland lies between the 32° and 47° North lines of latitude. The climate of Japan is predominately temperate, but varies from north to south with hot temperatures and winter weather, including snow. The population of Japan is 128,057,000 persons and the population of Tokyo metropolitan area is 35,618,000 persons (Statistics Bureau, 2015). In comparison to the United States, Japan has less than half the population and less than 4% the land area of the United States (Pollack, 1997).

More than 80.6 million vehicles travel on Japan's roads (AIRIA, 2015), and Japan has approximately 791,189 miles (1,273,295 km) of roads composed of:

- 656,110 miles (1,055,906 km) of city, town and village roads,
- 88,501 miles (142,429 km) of prefectural roads,
- 40,883 miles (65,796 km) of general national highways and
- 5,695 miles (9,165 km) of national expressways (MLIT, 2014).

Funding for the road network is primarily through tolls on the national expressways and through general fund appropriations. Prior to fiscal year 2009, Japan used dedicated fuel and vehicle taxes to support road construction; however, following a review begun in 2005, the government shifted those tax moneys to the general fund in 2009 (Umeda, 2014).

Contractors (i.e., asphalt mixture producers) in Japan are privately held. The expressway projects are joint private and government ventures. Four privately held companies are the primary contractors in Japan, owning 60% of the asphalt plants, and about 10 companies in total construct roads.

There are about 1,150 asphalt plants in Japan, serving more than 90% of the country and producing about 55 million tons of hot-mix asphalt (HMA) annually. Of those 55 million tons, about 41.9 million tons (nearly 38 million metric tonnes) contain recycled HMA. In the United States, there are more than 3,000 plants producing a total of about 350 million tons of asphalt mixture annually (Hansen & Copeland, 2015). The vast majority of asphalt plants in Japan are batch-type plants that use and produce smaller quantities of materials and have slower production rates than the drum plants common in the U.S. Approximately 15% of asphalt mixtures in Japan use polymer-modified asphalt binder. Since Japan's highway network is fairly mature and most paving is now for system maintenance, the majority of asphalt mixture production is for surface courses. Recycling HMA is considered routine in Japan, and the main focus for innovation centers on porous asphalt pavements (drainage pavements), water-retaining pavement structures, and heat-insulating pavements.

The Japanese contractors place the utmost importance on safety and the country, as a whole, has a commitment to sustainability and recycling/reuse is expected by the general population. There are two national laws that promote recycling of pavements and the use of RAP in new pavements: the Waste Management and Public Cleansing Law (Law No. 137 of 1970) and the Act on Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities (Law No. 100 of 2000) (MOE, 2010). Given the relatively small land area of the Japanese islands, with limited raw materials and even less space for waste disposal, conservation of natural resources and minimizing waste are ingrained in the culture and society and designated in legislation; Japanese laws mandate recycling across society, including construction and demolition (C&D) waste materials. The Basic Environment Law (Law No. 91 of 1993) includes a number of environmental conservation measures (Iwama, 2014). An early piece of legislation, the Waste Management and Public Cleansing Act (Law No. 137 of 1970), requires that pavement waste be tracked using a manifest system from the point of removal through processing and finally to the point of recycling. The Act on Promotion and Procurement of Eco-Friendly Goods and Services (Law No. 100 of 2000) promotes the use of recycled materials, and the Law on Recycling Construction-Related Materials (Law No. 104 of 2000) specifically covers the handling of C&D waste. Presently, 99% of all asphalt pavement material removed from use in Japan is recycled into new pavements, a similar rate of recycling as in the United States.

The average RAP content in Japan asphalt mixtures increased from 33% on average in 2000 to 47% on average in 2013. The average RAP contents are similar in colder northern and warmer southern regions and vary from 20%–60% on average (Figure 2-2). Japan has reached its current high percentage of RAP utilization over several decades of research and field performance evalu-

Figure 1-1. Delegation members (left to right) Dan Gallagher, Randy West, Vince Hafeli, Nagato Abe (host), John Bartoszek, Michael Cote, Greg Renegar, Chris Abadie, Aaron Price, Don Chambers, Ron Sines, Audrey Copeland, Rebecca Burkel, Jay Winford, Kevin Kelly, Paul Degges, Andy Welch, Pete Capon, Abdul Dahhan, Brian Wood, and Yuki Tsukimoto (host).

Table 1-1. Tour Itinerary and Sites Visited

Date	Sites Visited & Hosts
December 3	Taisei Rotec Co. Ltd. asphalt plant; Expressway asphalt pavement construction site, including mobile asphalt plant
December 4	Recycling meeting and knowledge-transfer seminar (see agenda in Appendix D)
December 5	Bus tour of Shin-Tōmei Expressway and double-layer porous asphalt sites visits
December 8	Maeda Road Construction Co. Ltd. asphalt plant; Public Works Research Institute (PWRI)
December 9	Nippo Corp. technical laboratory; Pavement technology in Japan knowledge exchange seminar

ations. Through analysis of pavement performance on hundreds of projects and experimentation in the lab and field, the country has developed standards and practices that have proven to provide equal performance for high RAP content mixes and virgin mixes.

It should be noted that axle loads on Japan's highways are much lower than in the United States. This likely has a significant effect on strain levels experienced by Japan's pavements and therefore also impacts their performance.

Except for expressways, Japanese maximum legal truck loads are less than those in the United States. In the U.S., maximum vehicle loads can vary by state, but are typically around 80,000 pounds (36.3 metric tonnes) with a maximum single-axle load of 20,000 pounds (9.1 metric tonnes). In Japan, maximum legal truck loads vary by type of facility, with general roads set at 44,000 pounds (20 metric tonnes) and freeways at 79,366 pounds (36 metric tonnes). The maximum single-axle load for all facilities is set at about 11,000 pounds (4.99 metric tonnes) (MLIT 2015).

Delegation Members

The delegation included 19 representatives from NAPA producer and associate member companies; the director of the National Center for Asphalt Technology (NCAT); officials from state departments of transportation in Tennessee, Wisconsin, Illinois, and Louisiana; and the 2014 chairman of the State Asphalt Pavement Associations (SAPAs). The full list of delegates and their affiliations is provided as Appendix B.

Itinerary and Host Organizations

The scanning tour took place over 10 days in December 2014. The tour included visits to three asphalt plants, an expressway construction project, two porous pavement urban roadways, a technical tour at the Public Works Research Institute (PWRI) of the National Institute for Land and Infrastructure Management (NILIM), the research laboratories of contractor Nippo Corp., and three different knowledge exchange meetings. Due to the short duration of the tour, the itinerary focused on sites near Tokyo. During the trip, tour members met with representatives from more than 15 organizations in Japan, including contractors, public work officials, suppliers, and industry associations. The itinerary is provided in Table 1-1.

Report Organization and Scope

This report summarizes the scan tour findings and recommendations for the asphalt industry in the U.S. Chapter 2 discusses high RAP content asphalt mixtures, including mix types, materials, mix design, and production. Chapter 3 discusses construction and paving practices. Chapter 4 focuses on innovations in porous asphalt mixtures. Finally, Chapter 5 concludes the report with a summary of key innovations for high RAP use and opportunities for the U.S. asphalt industry.

2 High RAP Content Asphalt Mixtures

Background

The primary objective of the U.S. tour of the asphalt industry in Japan was to learn about the use of high RAP content mixtures. In 2013, Japan used an average of 47% RAP in its dense-graded asphalt mixtures. The RAP content varies from region to region, plant to plant, and mix to mix. The Kantō region, where the U.S. tour group spent the greatest amount of time, has the highest average RAP content in Japan, averaging 51% across the region. Within the region, Kanagawa Prefecture, along the southwestern side of Tokyo Bay, averages 73% RAP (Hirama, 2014).

Asphalt recycling in Japan began in the 1970s. Japan's Ministry of Construction began investigations on the performance of recycled mixes in the early 1980s, and the Japan Road Association issued the first of its publications covering RAP use, *Handbook of Recycling Technology of Pavement Waste*, in 1984. By 1992, field performance studies confirmed that the performance of mixes containing RAP was

Figure 2-2. Regions of Japan and their average RAP contents. (Hirama, 2014)

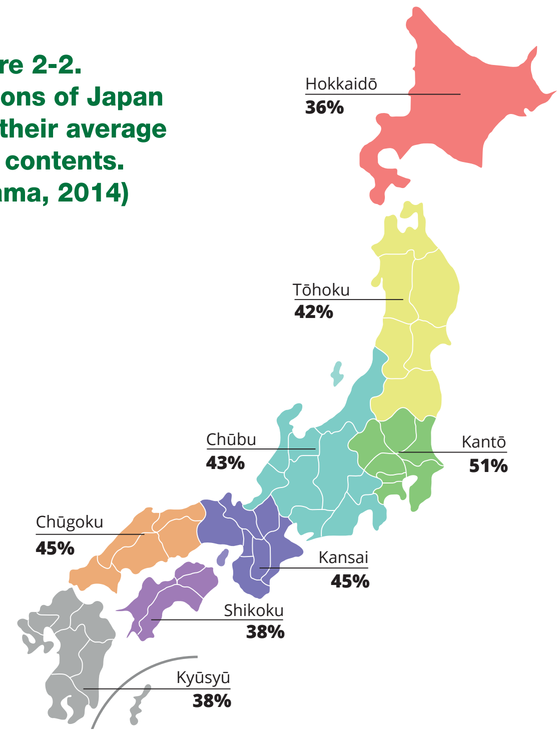
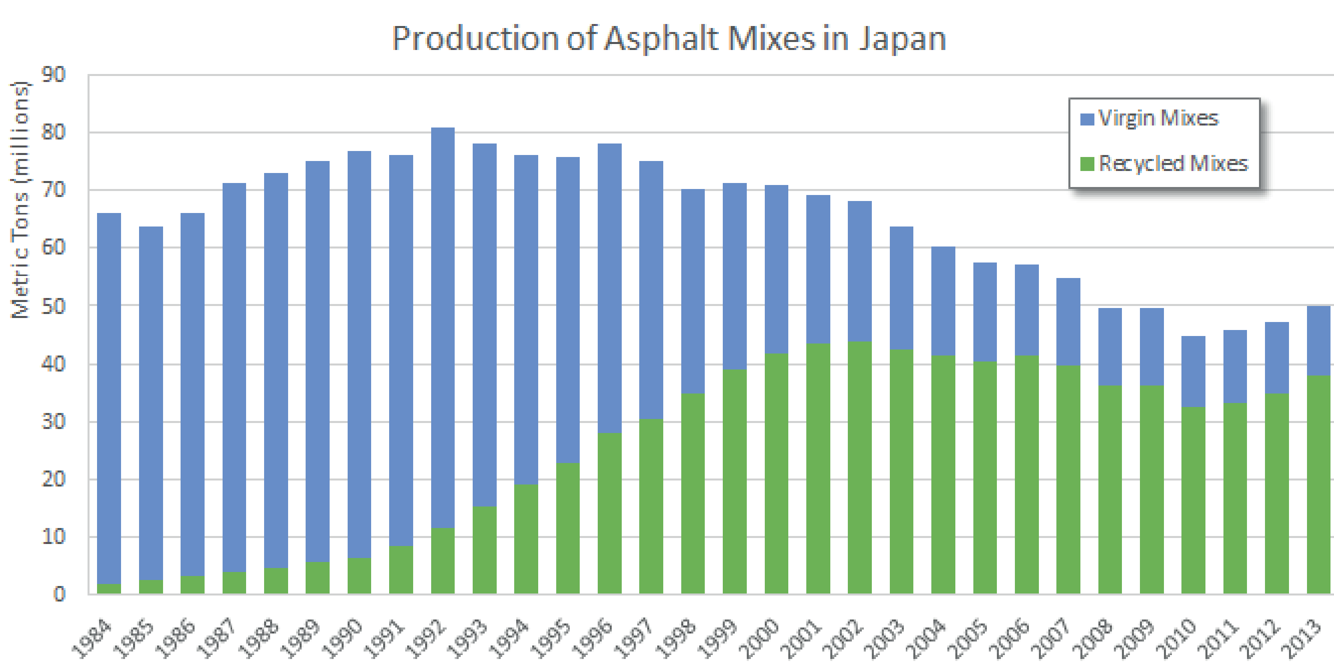


Figure 2-1. Production of virgin and recycled asphalt mixes in Japan. (Hirama, 2014)



equivalent to that of virgin mixes (Monden, 2014). Of the 213 pavement sites with RAP contents ranging from 30%–100%, only five sites had cracking ratios greater than 10%. Those sites were all on very high traffic roadways. The factors considered to be the causes of higher cracking ratios led to the establishment of standards for RAP quality and plant operations. In 1992, the Japan Road Association issued the *Handbook of Plant Recycling of Pavement*, the first technical guide for hot-mix asphalt recycling. The *Handbook of Pavement Recycling* followed in 2004 and was revised in 2010. The Japan Asphalt Mixture Association (JAMA) issued a guidebook on the use and handling of RAP for asphalt plants in 2013.

Production of mixes containing RAP increased from approximately 2 million metric tonnes (2.2 million tons) in 1984 to approximately 42 million metric tonnes (46 million tons) in 2000. Overall mix asphalt mixture production has declined since the early 1990s due to the economic recession in Japan, but the average RAP content steadily increased from 32.5% in 2000 to 47% in 2013.

Japan's asphalt recycling efforts are based on five motives:

1. Minimizing the amount of asphalt paving material waste;
2. Saving natural resources (raw materials, primarily asphalt and aggregate);
3. Conservation of energy (energy to extract, process, and transport raw materials);
4. Reduction of carbon dioxide by conserving energy; and
5. Reduction of asphalt paving costs.

Mix Types

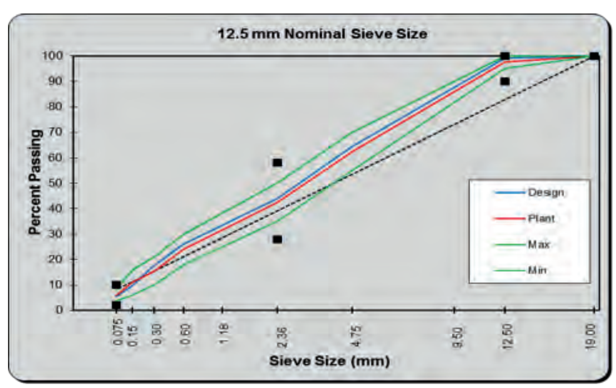
In 2013, Japan produced approximately 50 million metric tonnes (55 million tons) of asphalt mixtures. Nearly 38 million metric tonnes (41.9 million tons) of asphalt mix contained RAP. Most of the remainder was porous friction course mixtures, which are discussed in greater detail in Chapter 4. Of the 38 million metric tonnes containing RAP, 76% was for surface layers (Hirama, 2014).

The most common mix in Japan is a 13 mm dense-graded surface mix, which is similar to a ½-inch nominal maximum aggregate size (NMAS) mixture in the U.S. Table 2-1 shows a typical gradation for a surface mixture with a plot of the design gradation, expected plant gradation, and the 13 mm specification range shown on a Superpave 12.5 mm NMAS chart. Note that the plant gradation curve does not cross the maximum density line. This results in a mix that is "forgiving" with respect to segregation, and it helps explain the total lack of segregation observed on Japan's roadways. In Chapter 3, the lack of segregation is discussed along with how ensuring quality paving began with the mix design.

Other mix types include 13 mm gap-graded mixes for surface layers, 20 mm top size mixes used pri-

Table 2-1. Typical Japanese Dense-Graded Surface Mix Gradation

Sieve Size	Design Gradation	Expected Plant Gradation	Specification Gradation Range
19 mm	100	100	100
13.2 mm	99.2	97.5	95–100
4.75 mm	64.4	62.5	55–70
2.36 mm	44.1	42.5	35–50
0.60 mm	26.0	24.0	18–30
0.30 mm	17.7	15.5	10–21
0.15 mm	9.7	11.0	6–16
0.075 mm	5.5	6.0	4–8



marily for binder course layers, and the open-graded (porous mixes) used for improved skid resistance and tire–pavement noise reduction.

Collection and Processing of RAP

Many Japanese asphalt plants have affiliated RAP processing facilities on the same site. Waste asphalt pavement materials are received by the processing facilities from numerous sources and processed into usable RAP stockpiles. The majority of waste asphalt received at facilities observed by the U.S. tour group was small quantities of pavement chunks and slabs rather than the millings common in the U.S. Milled pavement material and rubble from small-scale pavement demolition must be tracked from the project site through processing and recycling back into new asphalt pavements.

RAP processing operations were enclosed in buildings. This minimized fugitive dust and helped keep the RAP relatively dry. A very light mist was used over the crushers to minimize dust. However, moisture contents of the RAP materials were kept very low compared to U.S. operations. Notes from the tour group indicated that typical RAP moisture contents were 1.5%–2% in the stockpile (i.e., before going through the asphalt plant).

RAP processing operations generally include multiple stages of crushing and screening. As is typical, one of the sites visited by the U.S. tour group fractionated the RAP into two sizes: –13 to 5 mm, and –5 mm. RAP stockpiles were maintained in large, covered bins at each location visited by the U.S. tour group.

RAP Testing and Specifications

Japan's standard for RAP permitted as a component in new asphalt mixtures is summarized in Table 2-2. RAP must have a minimum asphalt content of 3.8 percent, the asphalt extracted and recovered from the RAP must have a penetration grade of 20 or more, and the fine dust content (P_{200}) of the processed RAP (not the RAP aggregate) cannot exceed 5%. Although the amount of RAP that fails to meet these requirements is typically very low, failing material may still be recycled for other purposes, such as in unbound base layers.

Figure 2-3. Photos from the Taisei Rotec Tokyo Aomi Asphalt Mixing Plant and Tokyo Rinkai Recycling Center. (A) Receiving recyclable pavement waste; (B) Enclosed recycling facility; (C) Primary roller crusher; (D) Indoor processing equipment; (E) Fractionated RAP, –13 to 5 mm on left, –5 mm on right; (F) Samples of coarse and fine fractionated RAP.

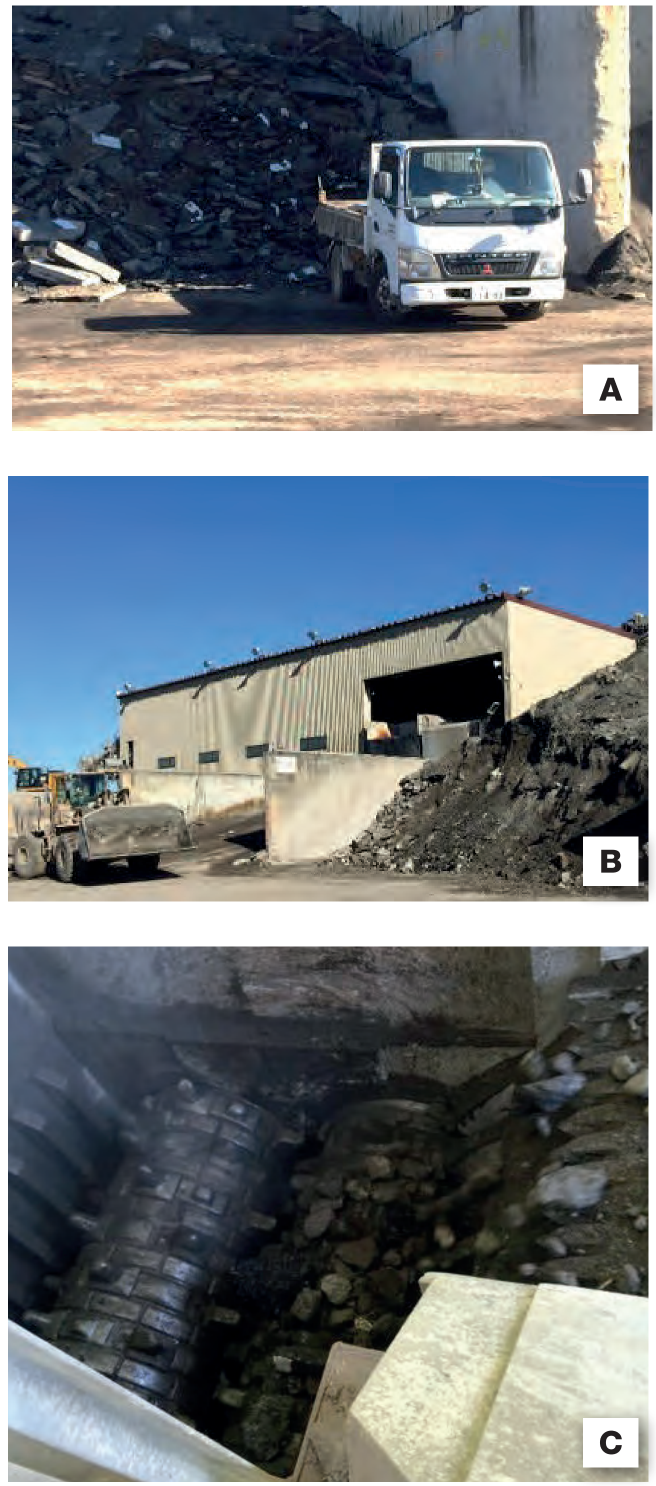
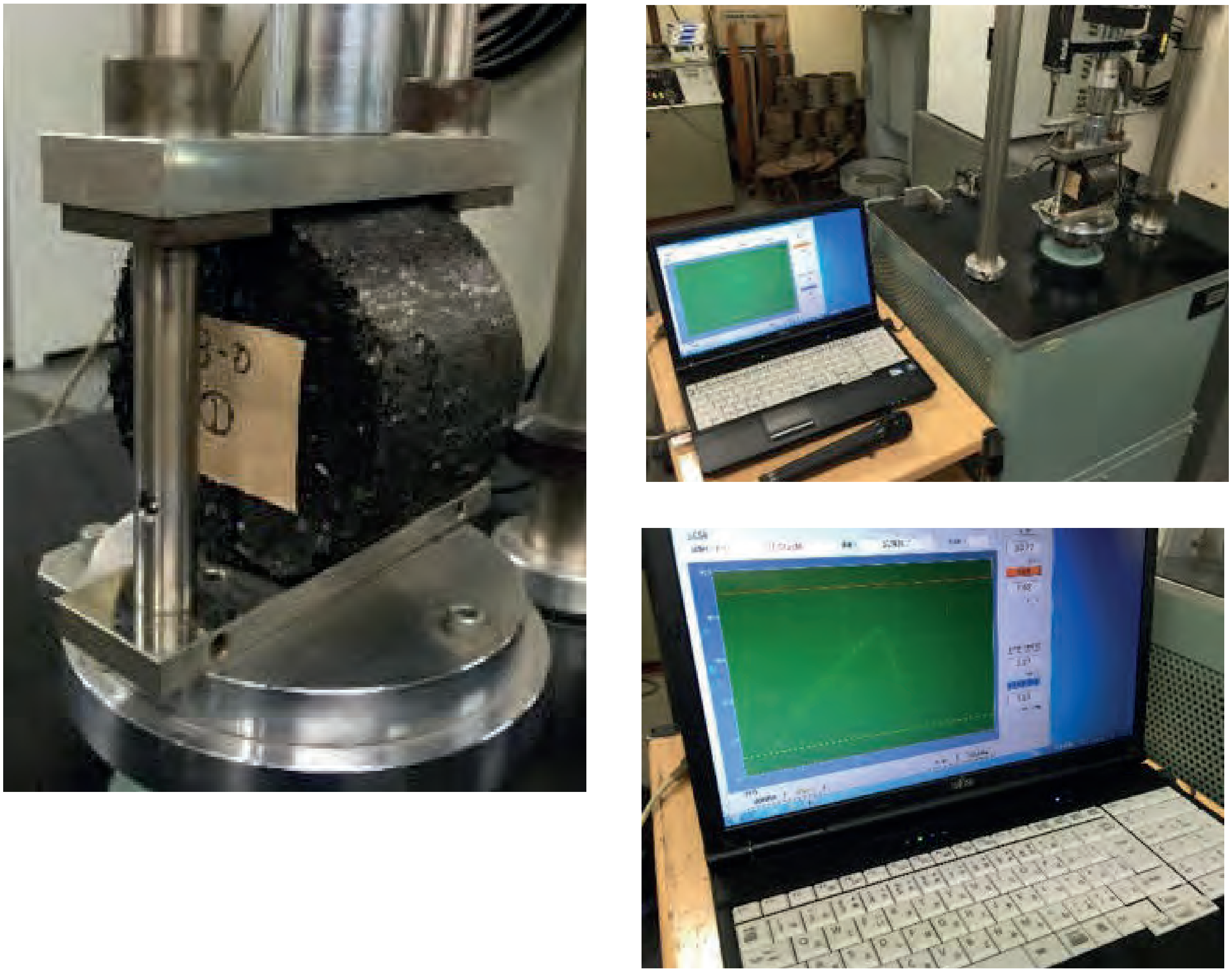


Table 2-2.
RAP Quality Specifications (Monden, 2014)

Characteristic	Spec. Requirement
Asphalt Content	Min. 3.8%
Notes: Solvent (trichloroethylene) extraction method similar to AASHTO T 164/ASTM D2172	
Penetration of recovered asphalt	Min. 20 pen
Notes: Penetration grading test standard similar to AASHTO T 49/ASTM D5	
Percent Passing the 75 µm sieve (P_{200})	Max. 5.0%
Notes: Conducted on processed RAP, not RAP aggregate	

Recently, an alternative to the minimum penetration grade of the RAP binder was developed to address concerns about an increasing quantity of RAP binders failing to meet the specification limit due to the increased use of polymer-modified asphalt, as well as repeated recycling of pavements. Much of the asphalt pavement being recycled now in Japan contains polymer-modified asphalts (Suzuki et al., 2010). In lieu of the penetration test on recovered RAP asphalt, specimens of 100% RAP are compacted and tested using an indirect tensile strength test at 20°C (Figure 2-4). From this test, an indirect tensile coefficient (referred to as the "IDT modulus" in Japan) is determined. If the IDT coefficient of the compacted RAP samples exceeds 1.70 MPa/mm, it may not be used in new asphalt mixes (Hirato, 2014).

Figure 2-4. Indirect tensile strength test used for evaluating RAP and mixes containing RAP.



Virgin aggregates used for asphalt mixtures in Japan include domestically produced sandstone, granite, and less frequently limestone. Limestone is not used in surface courses due to polishing. Specifications for crushed stone are shown in Table 2-3 and Table 2-4.

Table 2-3. Japanese Specifications for Crushed Stone Aggregate

Property	Surface and Binder Layers	Base Course Layers
Bulk Specific Gravity (SSD)	≥2.45	—
Water Absorption (%)	≤3.0	—
Abrasion Loss	≤30	≤50

Table 2-4. Japanese Grading Requirements for Crushed Stone Percent Passing (by weight %)

Designation	Nominal Size	Percent Passing (by weight %)										
		106 mm	75 mm	63 mm	53 mm	37.5 mm	31.5 mm	26.5 mm	19 mm	13.2 mm	4.75 mm	2.36 mm
S-80 (Grade 1)	80–60	100	85–100	0–15								
S-60 (Grade 2)	60–40		100	85–100	—	0–15						
S-40 (Grade 3)	40–30				100	85–100	0–15					
S-30 (Grade 4)	30–20					100	85–100	—	0–15			
S-20 (Grade 5)	20–13							100	85–100	0–15		
S-13 (Grade 6)	13–5								100	85–100	0–15	
S-5 (Grade 7)	5–2.5								100	85–100	0–25	0–5

Mix Design

Japan uses the Marshall Method of mix design with 75- and 50-blow compaction efforts — 50 blows per side are used for pavements with design traffic volumes less than 1,000 vehicles per day (vpd); 75 blows per side are used for pavements with design traffic volumes greater than or equal to 1,000 vpd. Mix design criteria are shown in Table 2-5.

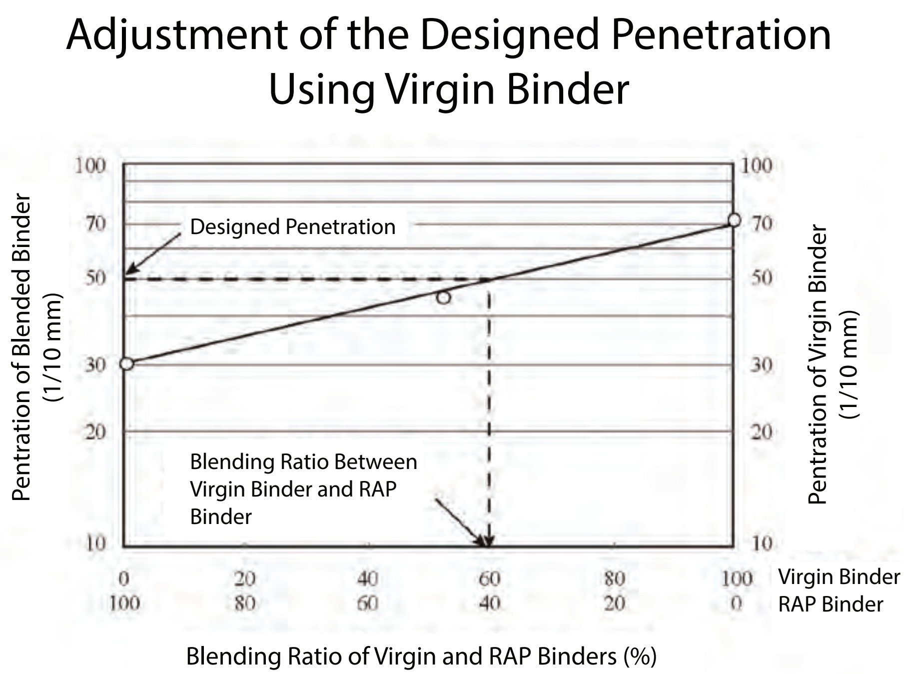
Table 2-5. Marshall Method mix design criteria (Monden, 2014)

Mix Design Parameter		Criteria
Air Voids (%)		3–6
Voids Filled with Asphalt (%)		70–85
Stability (kN)	Traffic ≥1000 vpd	≥7.35
	Traffic <1000 vpd	≥4.90
Flow (1/100 cm)		20–40

Asphalt binders are penetration graded with additional requirements on softening point, ductility, flash point, mass loss and penetration ratio after the thin film oven test. The most common grades used for virgin asphalts are 40/60 and 60/80 pen grades. Polymer-modified asphalt binders are typically used in porous friction course mixtures and dense-graded mixtures used on trunk roads and often on other heavy traffic roadways. Crude oil imported primarily from the Middle East is refined in Japan and is the primary source for asphalt binders.

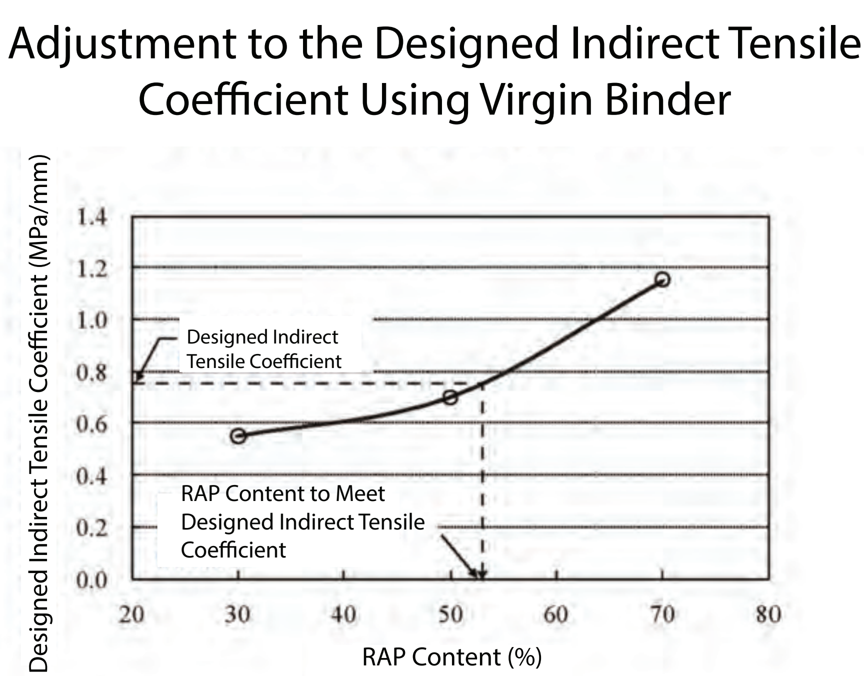
Blending charts are used to determine the appropriate blending ratio of virgin to recycled binders. In Japan, the blending charts are based on penetration grade values. These charts follow the same concept as the PG blending charts and viscosity-based blending charts used in the United States. Figure 2-5 shows an example penetration blending chart where the target penetration is 50 pen, which is obtained through a 60:40 blend of the particular virgin and RAP binders.

Figure 2-5. Penetration-based blending chart.



Alternatively, for RAP containing polymer-modified asphalt, the RAP content can be based on the IDT coefficient, as shown in Figure 2-6. Using this approach, the "general use" target IDT coefficient is 0.75 MPa/mm.

Figure 2-6. Chart for determining RAP content based on IDT coefficient data. (Monden, 2014)



The IDT coefficient test is conducted on standard Marshall specimens cured for a minimum of 5 hours. The test is conducted at 20°C using a loading rate of 50 mm/min. The IDT coefficient is calculated as shown in Figure 2-7.

Figure 2-7. Illustration of IDT coefficient data and calculation. (Monden, 2014)

Indirect Tensile Coefficient

$$\text{Indirect tensile coefficient (MPa/mm)} = \frac{\sigma_t}{x}$$

$$\text{Indirect tensile strength} = \sigma_t \text{ (MPa)} = \frac{2 \times P}{\pi \times d \times L}$$

Where:
x = Amount of displacement
P = Maximum load at break
d = Thickness of the specimen
L = Specimen's diameter

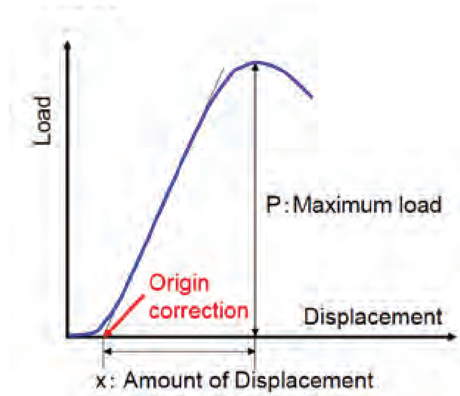


Table 2-6 shows the design ranges for the blended (composite) binder penetration grade and mixture IDT coefficient for different climates in Japan.

Table 2-6. Design Ranges for Mixes Containing RAP (Monden, 2014)

Area	Penetration Grade (1/10 mm)	IDT Coefficient (MPa/mm)
General use	40/60	0.60–0.90
Cold and snowy regions	60/80	0.40–0.60

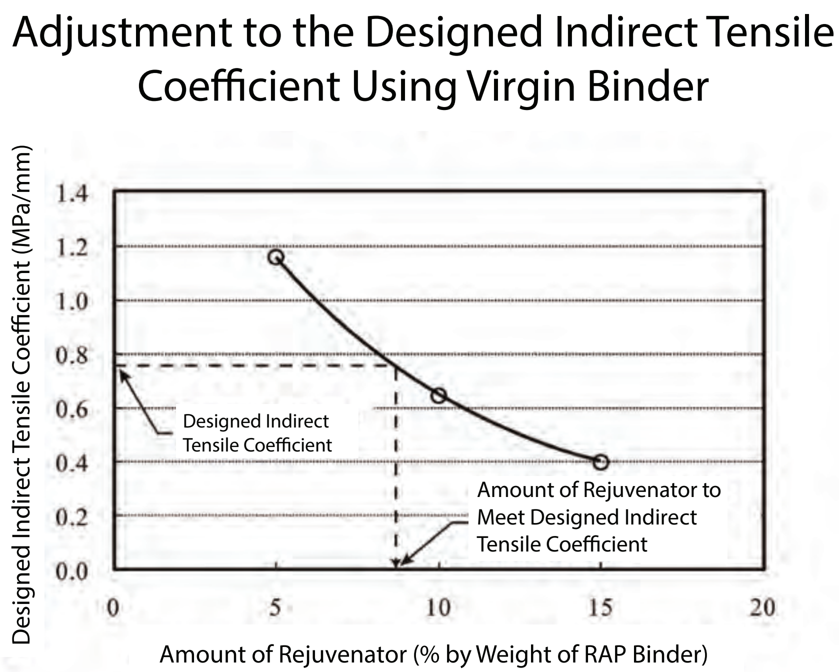
The use of rejuvenators (also referred to as softening agents) is common for high RAP content mixes in Japan. The rejuvenators are used to restore some physical characteristics of the RAP binder. Details about the chemical nature or formulations of the rejuvenators were not shared with the U.S. tour group. It was understood that the rejuvenators are closely held trade secrets specific to each of the major asphalt producers. In the literature, Kanou et al. (2010) reported on experiments with paraffin-rich rejuvenators (similar to lubricants). Japan's specifications for rejuvenators are shown in Table 2-7 (Monden, 2014). It was reported that the cost of using rejuvenators was about the same as the cost of using softer grades of asphalt.

Table 2-7. Standard for Rejuvenators (Monden, 2014)

Test	Criteria
Kinematic viscosity at 60°C	80–1,000 cSt
Flash point, minimum	250°C
Viscosity ratio after TFOT, maximum	2.0
Mass change after TFOT, maximum	3%
Density at 15°C	report
Composition, JPI-5S-70-10	report

Dosage rates for rejuvenators were typically about 5%–10% by weight of the RAP binder, which will usually work out to approximately 0.25%–0.30% by weight of the total mix. Figure 2-8 shows an example chart for selecting the dosage rates for a rejuvenator.

Figure 2-8. Example chart showing selection of the rejuvenator dosage. (Monden, 2014)



An example Japanese mix design (annotated in English) using 60% RAP and a rejuvenator is provided in Appendix E.

Further research is being conducted in Japan on using high penetration asphalts (i.e., softer grades) rather than rejuvenators (Hirato, 2014). A recent laboratory study indicates that repeated recycling using a paraffin-rich rejuvenator may cause the composite binder to become stiff and more brittle (Kanou et al., 2010).

Mix Production

Japan currently has 1,150 asphalt plants. All but 176 plants are capable of producing mixes with RAP. Of the Japanese plants with recycling capability, 17.7% utilize an indirect heating system, 68.8% use a parallel heating system, and 15.5% use a drum mix process. As shown in Figure 2-9, the indirect heating system is a batch plant operation where the RAP is heated by contact with superheated virgin aggregate in the weigh hopper and pugmill. The parallel heating system is also a batch-type operation that uses a separate (parallel) RAP dryer to dry and heat the RAP. An illustration of a parallel heating system batch plant is shown in Figure 2-10. The U.S. tour group visited two plants that use the parallel heating method.

The drum mix process, illustrated in Figure 2-11, is similar to many U.S. continuous-mix plant operations where the RAP is heated and dried in the same dryer as the virgin aggregate. Asphalt and additives are mixed with the hot aggregates and RAP in a separate continuous mixer to achieve a well-coated product.

The “parallel” heating method for recycled mix production is further illustrated in the photographs in Figures 2-12 and 2-13. This approach to production of high RAP content mixes differs from most U.S. plants in five significant ways. The first major difference between Japanese and U.S. mix production is the stockpile moisture content of the RAP and virgin aggregates. Japanese mix producers take great care in minimizing moisture in the raw materials by utilizing as little water as possible in crushing operations and keeping the stockpiles and bins covered.

Five Major Differences Between U.S. and Japanese Mix Production

1) Stockpile moisture content of the RAP and virgin aggregates is minimized
2) Use of batch plants instead of continuous mix plants
3) Use of a separate drum for drying and heating RAP (parallel heating method)
4) Use of the afterburner technology to burn off any hydrocarbons in RAP dryer exhaust
5) Rejuvenators mixed directly with heated RAP in a small pugmill

Figure 2-9. "Indirect" heating method for recycled mix production. (Hirama, 2014)

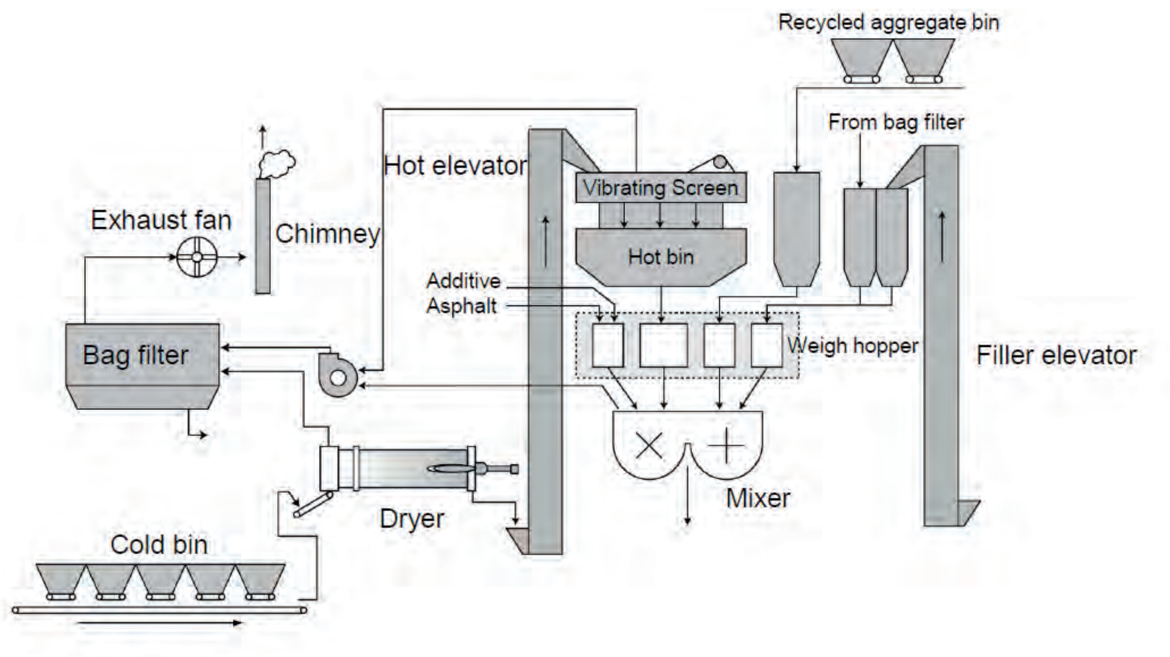


Figure 2-10. "Parallel" heating method for recycled mix production. (Hirama, 2014)

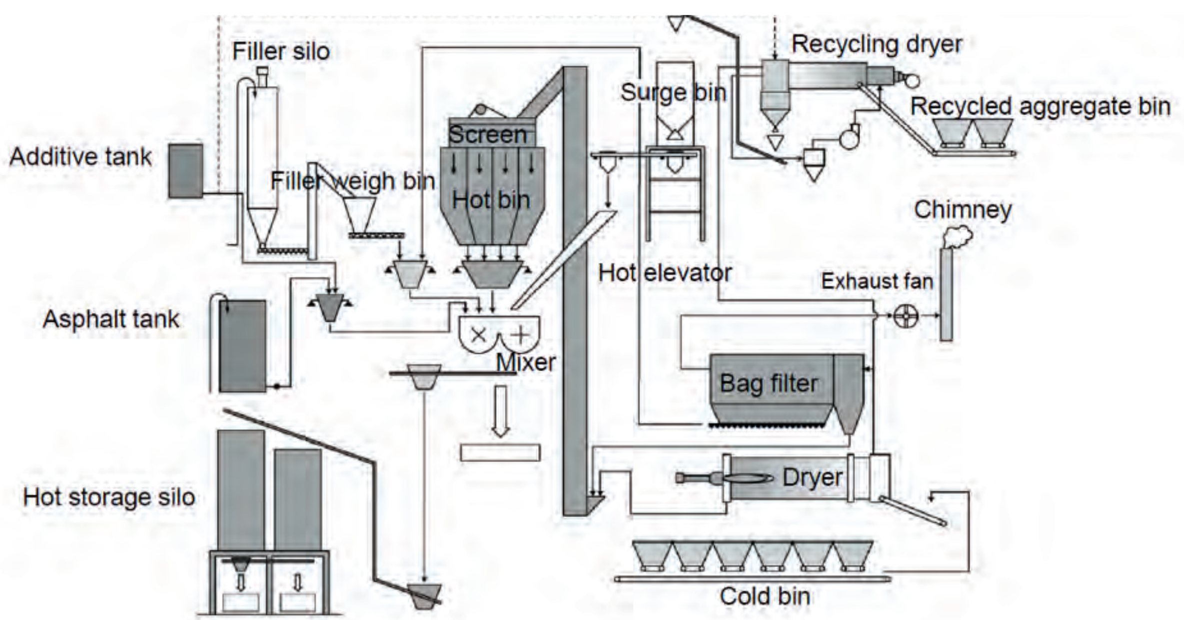


Figure 2-11. Illustration of drum/continuous process for recycled mix production. (Hirama, 2014)

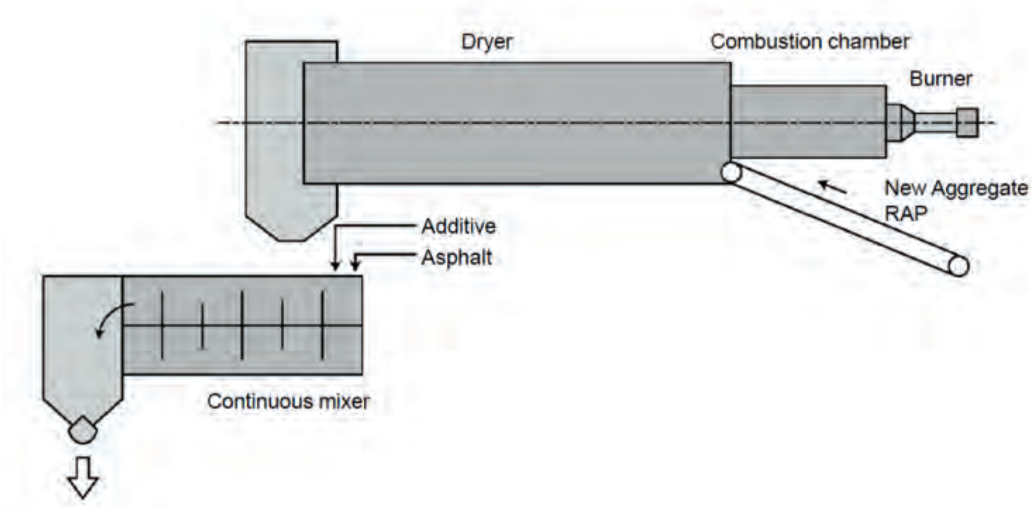
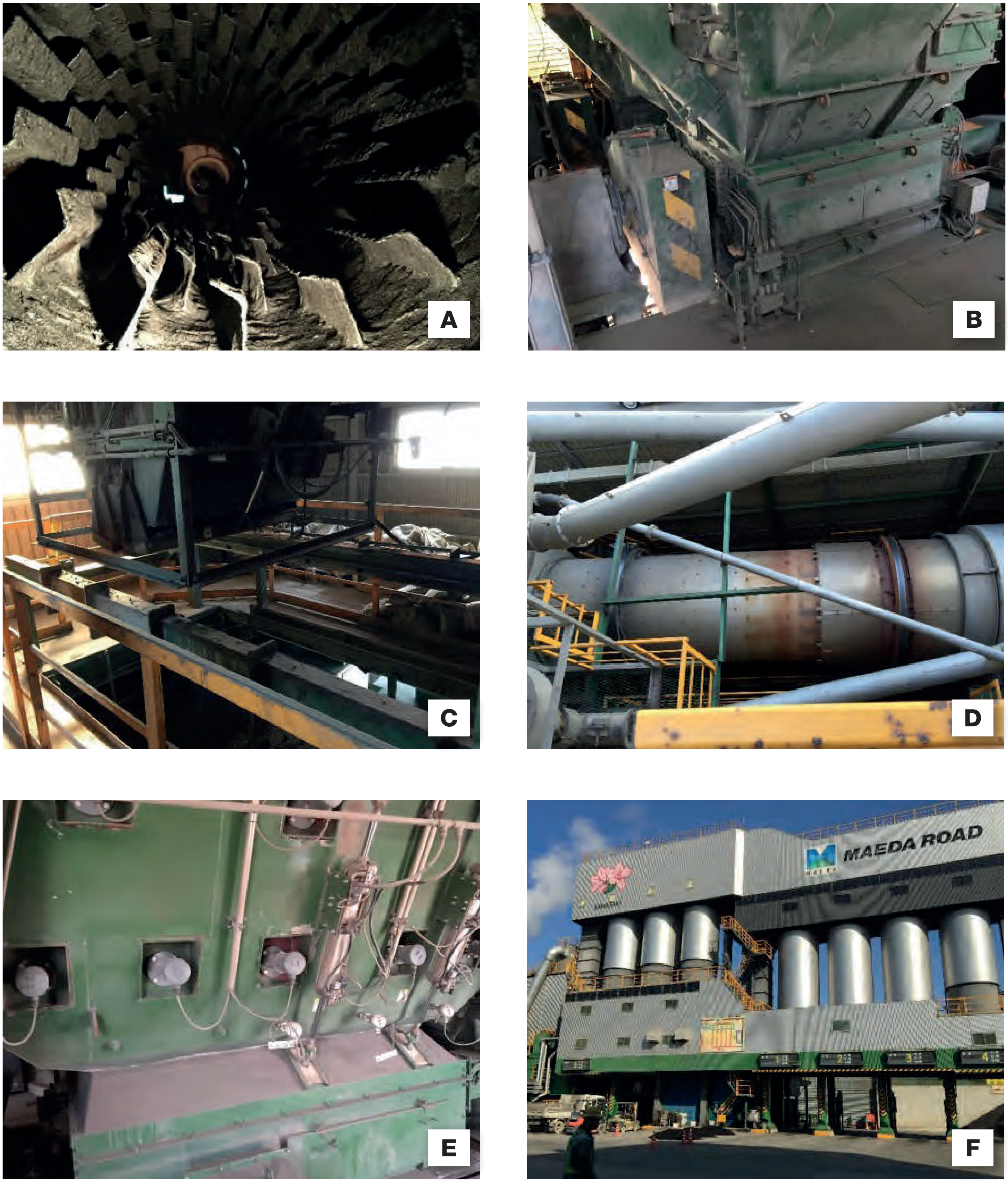


Figure 2-12. Photos from the Maeda Road Construction Co. Ltd. asphalt plant in Kawasaki, Kanagawa Prefecture. (A) Aggregate storage bins; (B) Aggregate cold feed binds; (C) RAP cold feed bins for two size fractions; and (D) Parallel-flow RAP dryer with natural gas burner in foreground.

Figure 2-13. (A) Inside of RAP dryer; (B) Pugmill for mixing hot RAP with rejuvenator; (C) Batch hopper conveyor to move rejuvenated hot RAP to surge bin; (D) Downward view of a counter-flow aggregate dryer; (E) Aggregate hot bins above weigh hopper; and (F) Plant view of three RAP surge bins on the left and four hot-mix silos on the right.



The second significant difference between Japan and U.S. plant operations is the use of batch plants instead of continuous mix plants. Over the past 30 years, the majority of asphalt mix production in the United States has shifted from batch plants to continuous mix plants due to higher production rates (tons per hour) and lower operating costs for continuous mix plants. The dominance of batch plants in Japan partly explains why there are many more plants per land area in Japan compared to the U.S. Also, Japanese plants are designed and operated at relatively low mix production rates (up to 180 metric tonnes per hour) whereas U.S. plants are typically double that range. However, it was interesting to note that one of the plants visited by the U.S. tour group operated nearly 24 hours per day, seven days a week. The facility included a dormitory for the plant crew and the only time the plant stopped operations was on Sunday afternoons.

The third significant difference in recycled mix production is that most Japanese plants use a separate drum for drying and heating RAP, the so-called parallel heating method. The RAP dryer at the Taisei Rotec Tokyo Aomi asphalt mixing plant in the southern part of Tokyo was a 2.5 m diameter by 10 m long dryer with a 100 metric tonnes per hour capacity. This parallel RAP heating approach is also used in Europe and other parts of Asia. For most batch plants still in operation in the U.S., the indirect heating method is more commonly used. However, indirect heating is generally limited to a maximum RAP content of about 20% due to the "steam explosion" that occurs when wet RAP is added to the hot aggregate in the weigh hopper or pugmill. The parallel heating approach avoids that issue and allows for much higher RAP contents.

The direct heating of RAP to approximately 165°C (329°F) in a parallel-flow dryer likely further oxidizes

Figure 2-14. Small piles of dense-graded mixes to demonstrate qualities. V indicates a virgin mix, R45 a 45% RAP mix, and R60 a 60% RAP mix.

the RAP binder and creates significant smoking of the RAP binder. However, the Japanese plants duct the RAP dryer exhaust through an afterburner (also referred to as a thermal oxidizer and "deodorizer") that raises the gas temperature to above 700°C (1,292°F) to burn off any hydrocarbons. Afterburner exhaust is ducted to the virgin aggregate dryer to recover some of the heat energy. The use of the afterburner technology is the fourth major difference with the U.S. approach to recycled mix production.

The fifth significant difference in recycled mix production in Japan is the mixing of rejuvenators directly with the heated RAP in a small pugmill. The merit of this approach is that it allows the rejuvenator to quickly diffuse into the softened aged RAP binder. The hot rejuvenated RAP is then transferred to a surge bin to give additional conditioning time (2–3 hours). It was observed that the rejuvenated/conditioned RAP had the appearance of fresh HMA before mixing with the virgin aggregate and new asphalt. The finished mix is very well coated and uniform even before it is transferred to the silo. Temperature of the final mix is typically about 160°C (320°F).

Figure 2-14 shows three small piles of mixes from one plant. In the foreground is a virgin mix (V). The middle pile (R45) is a mix containing 45% RAP and the far pile (R60) is a mix with 60% RAP. Visually, there was no difference in the mixes and they had the same workability.

The use of warm-mix technologies has not become commonplace in Japan yet. However, many of the Japanese asphalt industry stakeholders who met with the U.S. tour group expressed interest in learning more about WMA technologies and practices in the U.S. The Maeda Road Construction Co. Ltd. has used a water-injection foaming technology in at least one plant and presented a research paper on this subject (Koshi et al, 2014).

Given the relatively small volume of virgin asphalt in Japanese high RAP content mixtures, the effectiveness of the common foaming approach was considered inadequate. Foaming was improved with a "foaming enhancer" to result smaller bubbles, greater expansion ratio and longer half-life, which improved mix workability and compactability. No details were provided with regard to the nature of the "foaming enhancer" (Koshi et al., 2014). In the U.S., foaming technology has been used successfully with high RAP contents varying from 25% up to 50%.

A very noticeable characteristic of Japanese asphalt plants and recycling plants was that they were neat and well organized. The plant yards were completely paved and swept, truck traffic flows were organized, labs were clean and orderly, and plant components were clearly signed for safety and maintenance requirements. A culture of safety was also evident with all employees wearing safety vests, dust masks, hard hats, and other necessary personal protective equipment at all times around the plants and paving sites.

3 Paving Operations in Japan

The U.S. tour group visited one working paving site. It was the construction of part of the Satte section of the Ken-Ō Expressway/Metropolitan Inter-City Expressway, the outermost expressway loop around Tokyo. The Satte section is located approximately 50 km north of Tokyo. Most of the Satte section is an elevated viaduct. The asphalt pavement on the viaduct consisted of a 40 mm thick layer of a dense-graded Type A leveling course and a 40 mm surface layer using a "hybrid" mix. The hybrid mix had a porous upper part and a SMA-like bottom part. Details of the hybrid mix design were not provided. The U.S. tour group observed paving of the dense-graded leveling course. Weather conditions at the site were clear skies with temperatures near 10°C (50°F) and very little wind. The dense-graded mix was placed on a thin, hard bituminous waterproofing membrane that was gritted to provide traction for the paver. Unique aspects of the paving operation observed by the U.S. tour group included:

- a slow speed of paving
- no signs of segregation
- vertical longitudinal joint construction
- slow compaction process

A general, notable aspect of the construction process was the attention to detail, cleanliness, and quality that resulted from these practices. Each truck bed was cleaned on site after dumping materials and caution was taken when working on and around the newly paved mat.

Slow Paving Speed

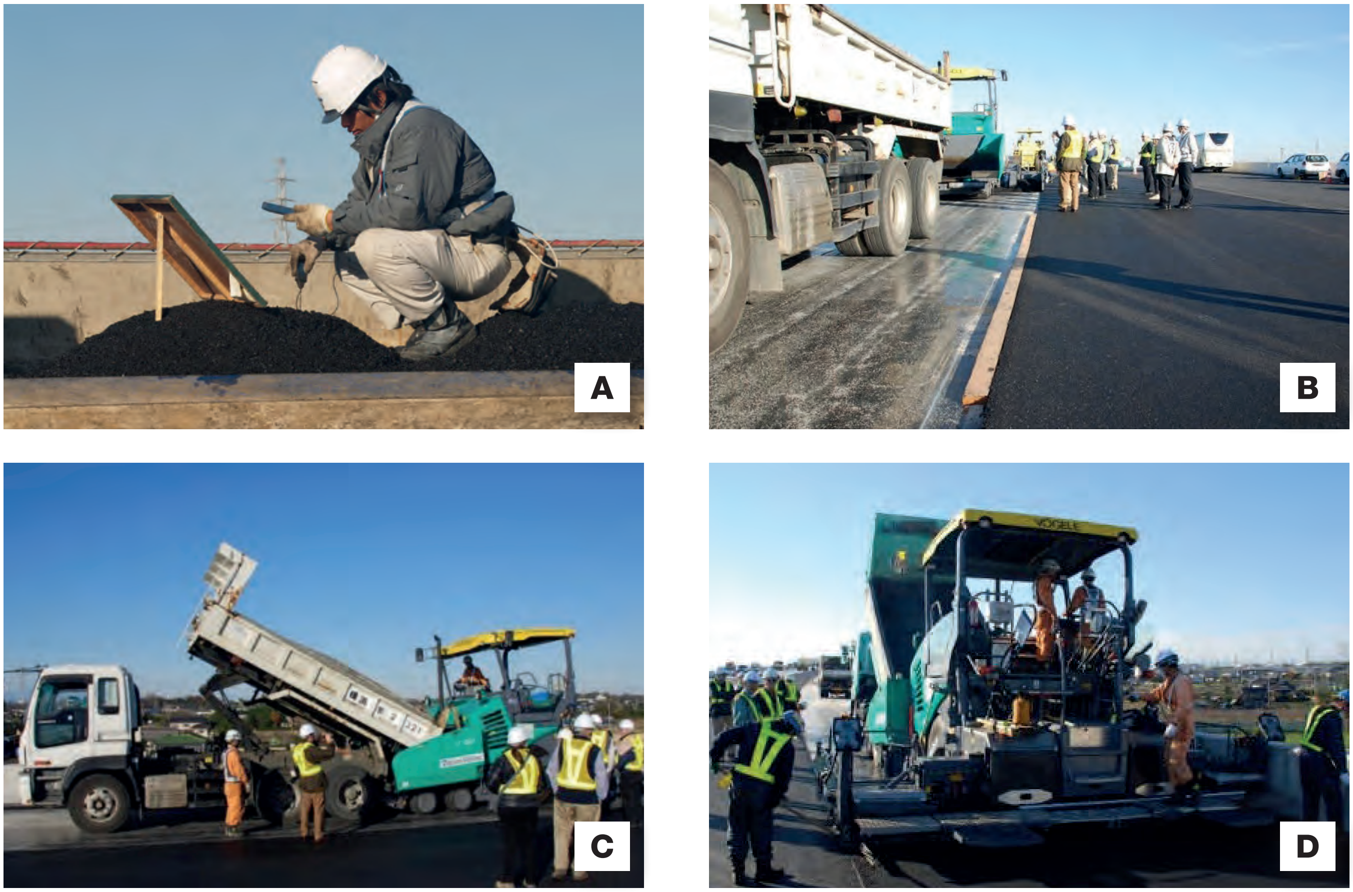
The speed of paving was approximately 2–3 m/min (6.5–10 ft/min) which is much slower than the 30–45 ft/min (9–14 m/min) typically used in the U.S. One factor that likely contributes to the slower pace is the use of small haul trucks (Figure 3-1). The capacity of the Japanese haul trucks is 9 metric tonnes, which is approximately half the typical capacity in the U.S. The slow paving speed seemed to follow the Japanese cultural value of quality over quantity. The paving machine was a Vögle Super 1803-3i paver with a tamping-bar screed (Figure 3-2 D).

No Signs of Segregation

The finished mat had no signs of mix segregation despite the fact that the haul trucks dumped straight into the paver hopper without the aid of

Figure 3-1. Small haul trucks that carry approximately 9 metric tonnes (9.9 tons).

Figure 3-2. A) Technician checking mix temperature of every truck load before dumping into the paver; B) Lumber used along previously placed mat to protect the vertical edge as haul trucks move in and out of paving lane; C) Mix is transferred from the haul truck directly into the paver hopper; and D) Paver screed and mat.



any type of remixing equipment. The rear-dump haul trucks emptied directly into the rear part of the paver hopper. After each load of mix, the hopper wings were folded and the paver hopper was completely emptied to avoid the collection of cooled polymer-modified mix in the wings. This differs from what is considered best practice in the U.S. Fixed screed extensions (approximately 0.85 m) were added to the main screed, but auger extensions were not added, which would potentially allow mix to segregate as it rolled out to the screed extension. However, the mat behind the screed appeared uniform across the entire paved width. The lack of segregation could be partly attributed to a high asphalt content mixture, which would tend to increase cohesion within the mix.

Vertical Longitudinal Joints

One of the most unique aspects of the paving operation was how the contractor built the longitudinal joints. As can be seen in Figure 3-3, the longitudinal joints were vertical butt-joints. Edges of the first lane were essentially "formed" using wooden boards (similar in size to 2×4 lumber) held in place below the string-line with heavy weights (Figure 3-4). This results in a vertical face against which the second lane is butted against. Prior to placing the second lane, a light tack coat was manually applied to the vertical edge of the first lane. To avoid destruction of the vertical edge by haul trucks traversing across the lanes, a few lumber forms were moved along ahead of the paver to protect the joint.

The U.S. tour group only observed this one paving operation. However, at each of the other places the group stopped, whether it was a newly paved road or older road as the group traveled by bus from stop to stop, there were no signs of segregation and the longitudinal joints were well made.

Figure 3-3. Left: The vertical longitudinal joint in the dense-graded layer formed using 2×4 lumber along the outer edge of the lane. Right: The straight joint after paving the adjoining lane.

Figure 3-4. Left: Paving on the Satte viaduct. Wooden forms are set for the unconfined edge. Right: After paving the wooden forms are still in place.

Slow Compaction Operation

Compaction of the mat was achieved with three rollers: a three-wheel breakdown roller, and two pneumatic-tire rollers (Figure 3-5). The breakdown roller was a 10 tonne Sakai three-wheel roller (Model R2), the intermediate roller was a 25 tonne Sakai pneumatic-tired roller (Model TS650C), and the finish roller was a 9.5 tonne Sakai vibratory pneumatic-tired roller (Model GW750). With the slow pace of the paver, all of the rollers were operated within approximately 100 m of the paver.

As is common for paving projects in Japan, the roller patterns were established on the first day of paving for each mix. Cores were taken from the mat to verify the desired level of density. Field compaction was monitored by counting passes for each roller.

Figure 3-5. Left: A three-wheel roller was used for breakdown compaction. A pneumatic-tire roller is seen in the distance. Right: Pneumatic-tire roller used for intermediate compaction.

Figure 3-6. Compaction of the asphalt mix along the barrier wall with a vibratory plate compactor.

4 Porous Mixtures

Figure 4-1. Recently constructed porous friction course in Kyōto

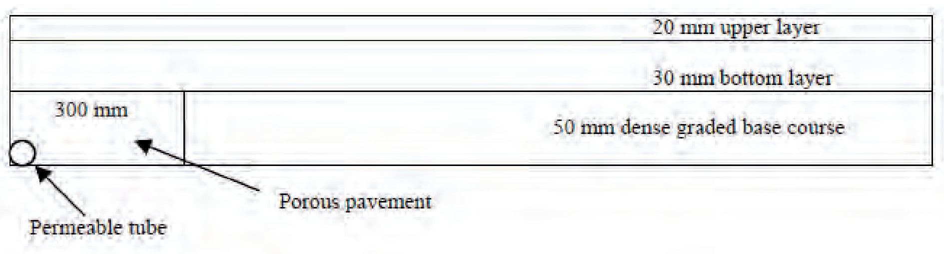
Porous friction courses (PFC), also referred to as "drainage" asphalt pavements or DAP, are now widely used in Japan primarily for the improved safety benefits of reducing hydroplaning and splash/spray, as well as reducing roadway noise (Fujita, 2012). Japan has established noise pollution standards at 70 dB during daytime hours and 65 dB at nighttime (Nielsen et al., 2005). In 2003, the Ministry of Land, Infrastructure, and Transport reported that noise pollution from arterial roads had not met the environmental standards. The primary source of noise problems were urban roads with a maximum speed of 40–60 km/h (25–38 mph).

The use of PFC layers in Japan began in the early 1990s and has increased steadily since. According to JAMA, approximately 2 million metric tonnes of PFC are placed each year covering more than 20 million square meters (3,400 lane miles). Currently, more than 70% of expressways in Japan are surfaced with a PFC. PFC mixes are not used in colder parts of Japan that get snow. In those areas, vehicles use tire chains, which are extremely harsh on PFC surfaces. SMA mixes are used for the surface layer in those colder regions to provide high macrotexture for skid resistance.

Japan considers PFC to have the same structural value as dense-graded mixtures for thickness design. The service life of PFC layers is similar to that of dense-graded surface layers. The PFC layers are generally constructed 4–5 cm thick. In the U.S., PFC mixes are generally not considered as part of the structural design. Recent research at the NCAT Test Track has recommended adopting a conservative structural layer coefficient of 0.18 for PFC layers, which is approximately one-third the value for dense-graded mixtures (West et al., 2012).

In urban areas with curb and gutters, the surface of the PFC layers is paved flush with the gutter. As shown in Figure 4-2, water drains from the PFC into an edge drain system consisting of a 50 mm thick layer of 13 mm porous asphalt with a drain tube that carries the water to drainage inlets along the edge of the road.

Figure 4-2. Top: Illustration of edge drain below a double-layer PFC; Bottom: Photo of drainage inlet with edge drain tubes.



Japan's mix design criteria for PFC mixes are summarized in Table 4-1. One source also states that PFC mix designs must pass the Cantabro test (ASTM D7064M) at 20°C with less than 15% loss (Kanou et al., 2010). The target binder content for PFC mixes is set by the asphalt binder drain-off test (Japan Road Association Drainage Pavement Specification, 排水性舗装技術指針(案)). Japan's specifications for PFC have evolved over time. Initially, PFCs used modified binders with low to moderate polymer contents and cellulose fibers, but those mixes had problems with raveling. Now PFC binders are highly modified with 4%–8% SBS polymers to enhance durability. The highly modified PFC binders are referred to as "high-viscosity binders" in Japan. Criteria for the high-viscosity binders are summarized in Table 4-2. Fibers are no longer used in PFC or SMA mixes in Japan. During production, gradations, binder contents, and mix temperatures are controlled very closely. Pneumatic/rubber-tire rollers are not used on PFC mixes to avoid their sealing affect and a loss of the PFC's permeability.

Table 4-1. PFC Mix Design Criteria (Fujita, 2012)

Gradation	Percent Passing		Marshall Compactive Effort	
Sieve	Max.	Min.	Traffic Classification C or Higher	75 blows
19.0	100	—	Traffic Classification B or Lighter	50 blows
13.2	100	95	Air Voids	20 ±1%
4.75	23	45	Marshall Stability	Min. 350 kgf
2.36	15	30	Marshall Flow	20–40 (1/100 cm)
0.6	8	20	Permeability	10–2 cm/sec
0.3	4	15	Dynamic Stability (Wheel Tracking at 60°C)	
0.15	4	10	Heavy Traffic	Min. 1,500 passes/mm
0.075	2	7	Very Heavy Traffic	Min. 3,000 passes/mm

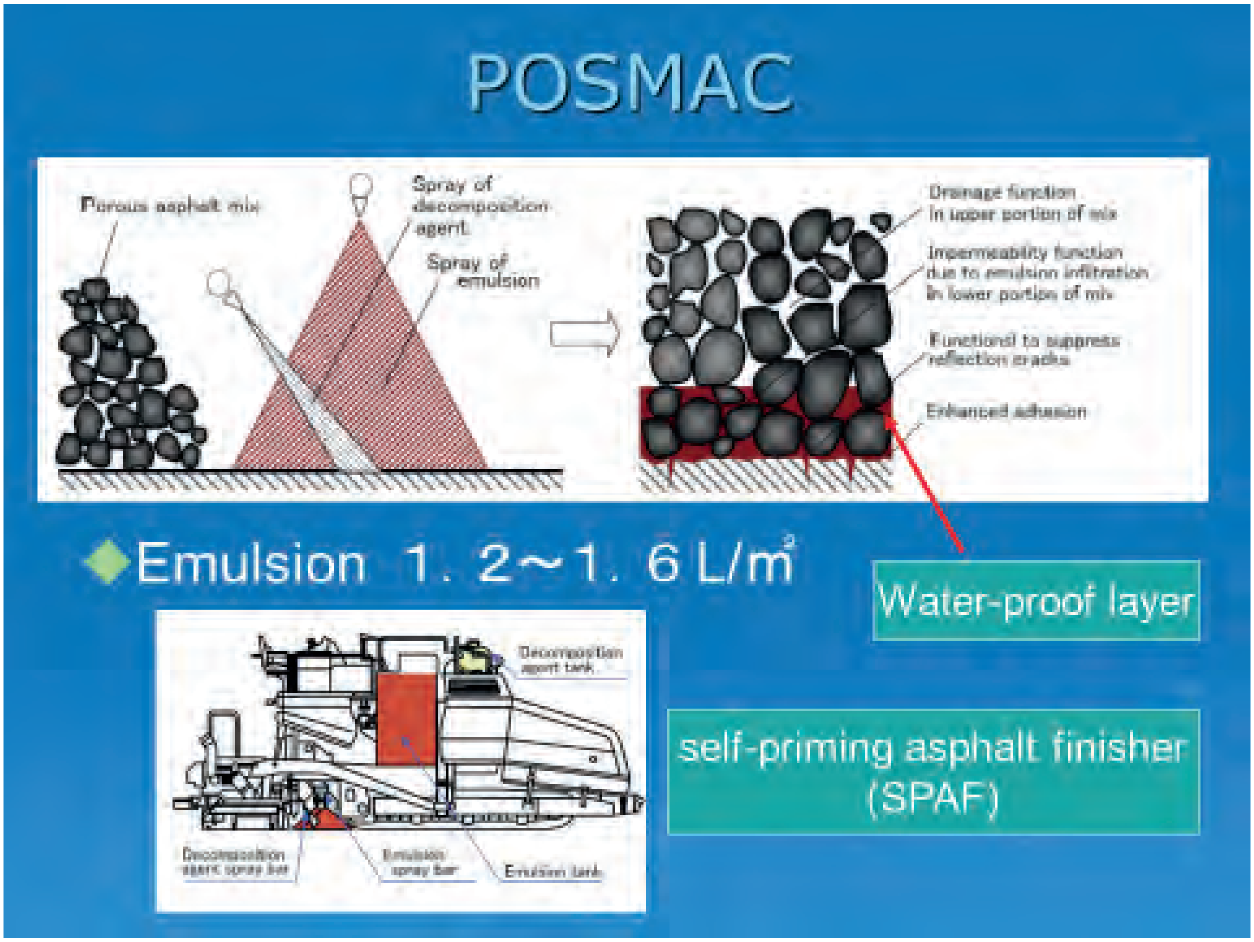
Table 4-2. Criteria for PFC binders (Fujita, 2012)

Test	Criteria
Penetration (25°C, 100 g, 5 sec.)	Min. 40
Ring and Ball Softening Point	Min. 80°C
Ductility (15°C)	Min. 50 cm
Toughness (25°C)	Min. 20 N·m
Tenacity (25°C)	Min. 15 N·m
Viscosity (60°C)	Min. 20 kPa

Japan has developed several innovations in porous surface layers. One area of research involves using RAP in PFC mixes. Currently, most of Japan's PFC mixes use all virgin materials. However, some trial projects have been constructed using 20%–50% RAP in the PFC mixes. Preliminary results indicate that up to 30% RAP can be satisfactorily used in porous mixes (Kanou et al., 2010).

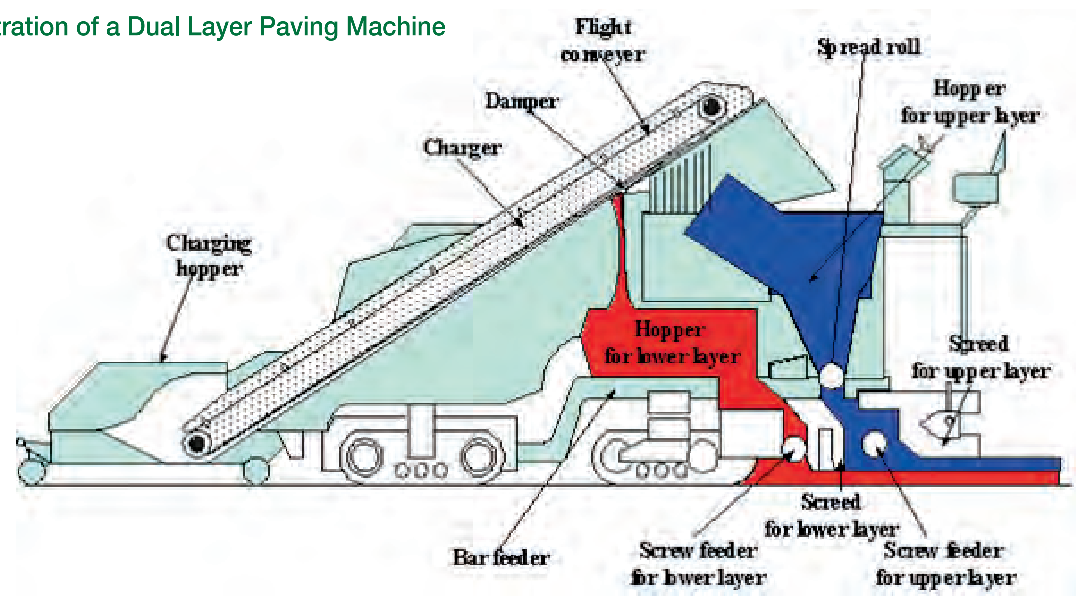
Another PFC innovation is the Porous Surface Mastic Asphalt Course (POSMAC) which was developed as a countermeasure to stripping of the binder course below the PFC (Fujita, 2012). POSMAC is similar to an ultrathin bonded wearing course (i.e., NovaChip) except the POSMAC layer is much thicker, typically 4–5 cm. The POSMAC requires a self-priming asphalt finisher (i.e., a spray-paver), which applies an asphalt emulsion and a breaking agent just ahead of placing the porous mixture. The emulsion is applied at a rate of 1.2–1.6 L/m^2, which seals the underlying layer and saturates approximately 5 mm of the bottom of the PFC. Figure 4-3 illustrates placement of a POSMAC layer.

Figure 4-3. Illustration of placement of a Porous Surface Mastic Asphalt Course (POSMAC) (Fujita, 2012)



Another pavement innovation used in Japan is the double-layer porous asphalt, also referred to as "Twin-lay" (Tsukamoto et al., 2003). As shown in Figure 4-4, double-layer porous asphalt is built in a single process with a special "hot-on-hot" or "twin-layer" paver designed to receive two mixes and simultaneously pave two layers with separate screeds. This technology is believed to have been developed in Germany and has

Figure 4-4. Illustration of a Dual Layer Paving Machine



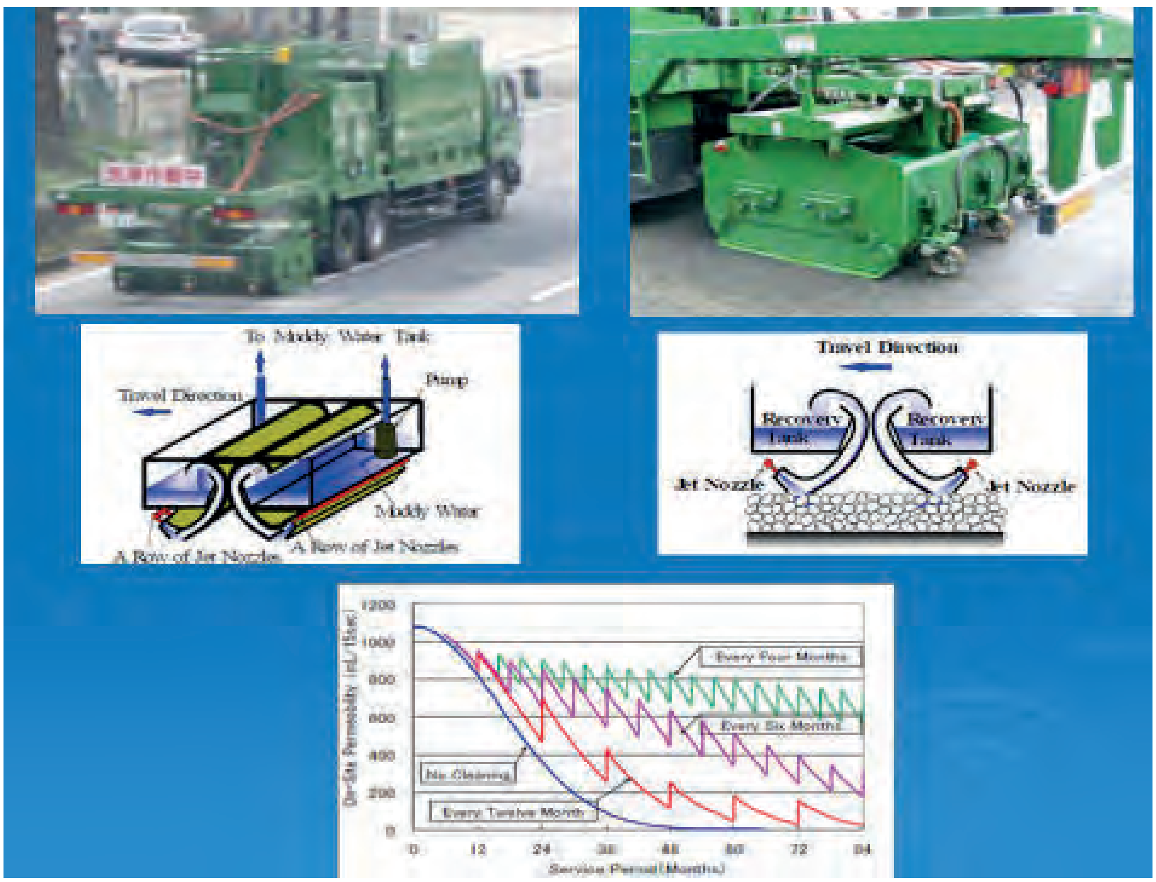
been used in several European countries and China. In some cases, dual-layer pavers are used for simultaneously placing two dense-graded layers. A successful demonstration of double-layer porous asphalt was also conducted on the NCAT Test Track from 2006 to 2012 (Willis et al., 2009).

The advantages of the double-layer porous surface are excellent noise-reduction and less clogging (permeability loss) compared to conventional porous friction course layers. The Japanese double-layer porous asphalt uses a 5–13 mm NMAS upper layer and a 13–20 mm NMAS lower layer. The upper layer is 20–30 mm thick and the lower layer is typically 30–70 mm thick.

Maintenance of Porous Friction Courses

Nippo Corp. has developed a special vacuum truck to help recover loss of permeability from normal road wear. Figure 4-5 shows the PFC cleaning vehicle, which operates at speeds between 6 and 10 km/h (4 and 6 mph). It is recommended to clean PFCs every four months to maintain permeability.

Figure 4-5. Specialized vehicle for flushing PFC layers to maintain permeability. (Fujita, 2014)



5 Summary of High RAP Use in Japan and Recommendations

The primary area of interest for the U.S. tour group was to understand how Japan was able to accomplish very high percentages of asphalt recycling. Japan's average RAP content — approximately 47% — is more than double the current average percentage in the United States. The tour group learned that several factors have enabled Japanese contractors to achieve such high RAP contents. Some factors are technical and some are political or cultural.

Political and cultural factors include a strong emphasis on the need to preserve raw materials, to avoid generating waste, and to recycle. Japan has a number of environmental laws that require the responsible reuse of waste pavement materials. Therefore, the primary motivation for recycling appears to be for conservation and economic reasons. Japanese contractors are willing to invest heavily in state-of-the-art RAP processing plants and sophisticated asphalt mix plants to effectively utilize RAP at high percentages. However, the Japanese specifications for mixes containing RAP are not complex. Rather, their specifications seem designed to encourage the use of high RAP contents. Japanese contractors and road owners follow a simple mix design and materials testing process with a focus on performance.

Key aspects of the Japanese asphalt recycling specification include:

1. RAP is processed from multiple sources. No restrictions are made as to the origin of the RAP.
2. RAP quality is judged by three criteria:
   a) It must have a minimum asphalt content of 3.8%.
   b) The recovered RAP binder must have a penetration greater than 20 or samples of the compacted RAP must have an IDT coefficient of less than 1.70 MPa/mm.
   c) The processed RAP material may not contain more than 5% P_{200} fines.
3. Fractionation of RAP is a contractor's choice, not a requirement. Most contractors choose to fractionate the RAP.
4. Blending charts are used to determine ratios of virgin and recycled binders or dosage rates for recycling agents. Mix designers may use soft virgin asphalts or recycling agents to meet a target penetration value for the composite binder or a desired indirect tensile coefficient for the mixture.
5. Mix designs use the Marshall Method and criteria with a simple supplemental performance test, the indirect tensile coefficient which limits mixes with very high stiffness (and low cracking resistance).

In several regards, Japanese contractors follow best practices for RAP management that have been recognized for years in the U.S., but are not necessarily widely used by many U.S. asphalt mix producers. Following are some of the standard practices used in Japan:

1. Stockpiles are covered and on a paved surface
2. Moisture and dust contents of the RAP are minimized during crushing, processing, and storage
3. RAP binders are recovered and tested to evaluate their stiffness
4. RAP is fractionated and the plants are equipped with multiple RAP feed bins

Production of high RAP content mixes in Japan was quite different than in the U.S. Perhaps the most obvious contrast in mix production between the United States and Japan is the prevalence of batch plants in Japan compared to continuous mix plants in the U.S. However, the most significant paradigm shifts were the method of heating RAP in a separate dryer followed by mixing and conditioning the dry and hot RAP with a rejuvenator for several hours prior to mixing with hot virgin aggregate and asphalt.

Key aspects of the Japanese method for high RAP mix production include:

1. Drying and heating of RAP in a separate parallel dryer

2. Use of thermal oxidizers to handle emissions from the RAP dryer
3. Mixing a rejuvenator with the hot RAP and giving the material time to “activate and condition” the aged RAP binder.
4. Low production rates, typically 100–180 metric tonnes per hour. The conditioning step noted above is likely the controlling process.

The tour of asphalt pavement innovations in Japan was enlightening in many ways. The U.S. tour group took away an appreciation of the Japanese attention to quality, simplicity, and trust between highway agencies and contractors. The quality of Japan’s pavements and roadways is due to attention to details and a focus on quality. There were, however, some aspects of Japanese practices that are unlikely to take hold in the U.S., such as the widespread use of batch plants and low production rates.

Recommendations

Over the past decade, the U.S. has increased the amount of RAP used in asphalt pavements from an average around 10% to an average of almost 20% through dedicated efforts by NAPA, NCAT, and FHWA’s RAP Expert Task Group including best practices education, technology transfer, and publications. However, the increased use of RAP seems to have plateaued around 20% on average even though the majority of state DOT specifications may allow up to 30% RAP. The average amount of RAP used in the U.S. is a balance between urban areas with an abundance of RAP and rural areas with a shortage of RAP, which slows the growth of the overall average RAP use. Successfully continuing to increase the amount of RAP used in asphalt mixtures while improving performance can further minimize the impact of material price variability.

Based on the delegates’ observations and experiences while in Japan, there are no barriers to the potential for asphalt mixtures with higher RAP content (>25%) that maintain equivalent or better quality and performance in the United States. The consensus among the delegation is that the use of high RAP in asphalt pavements should continue to be pursued through a partnership of industry, including asphalt mixture producers, contractors, and suppliers, and government, including federal, state, and local agencies, and that the following recommendations be considered:

- The high RAP tour delegation should provide knowledge transfer of the information gained through a report, presentations, and articles.
  - » NAPA has organized several industry educational sessions including a session at the NAPA 2015 Annual Meeting, a presentation at the NAPA 2015 Sustainability West Conference in partnership with FHWA, and a presentation at the NAPA 2015 Young Leaders Conference. A follow-up educational session was held at NAPA’s 2016 Annual Meeting focusing on plant production practices for using more RAP. Several of the delegates have also presented at government and industry meetings, such as the AASHTO Standing Committee on Highways, and at SAPA meetings in Indiana, Kansas, Kentucky, Alabama, and Virginia.
- Agency specifications should allow the use of RAP in asphalt pavement layers at the contractor’s discretion and provide simple and clear criteria for ensuring pavement performance, including considering a simple lab mix stiffness test and criteria used to determine mixture suitability. By using a performance-based test system, contractors have flexibility to innovate in using RAP and other materials. In addition, it is recommended that agencies explore reducing the number of mix designs as the cost of developing and updating many (in some cases upwards of 100) job-mix formulas is high.
  - » The FHWA Asphalt Mix ETG RAP Task Group can lead the development of national criteria for RAP use and specification development guidance.
- Best practices should be implemented and used for RAP processing, storage, mixture production and paving, including minimizing moisture in RAP, fractionation for high RAP use, covered RAP stockpiles and processing, and longer mixing times during production. Probably most beneficial on the material side for production is keeping the RAP dry (very low moisture content), which reduces the superheating of the virgin aggregate (i.e., cost) necessary for indirect heating of the RAP and allows for increased production rates. The implementation of well-known best practices in order to increase RAP content is

critical.

- The U.S. industry should consider the potential benefits in the production process and how continuous plants are designed and manufactured that will result in better drying of the aggregate and RAP materials and mixing with the virgin asphalt binder and additives. Production changes may include longer virgin aggregate and RAP mix times, high shear mixing, and storage time, which may facilitate the softening and blending of the RAP binder.
- The asphalt industry should also consider rejuvenators, softening binders, or another agent to facilitate high RAP amounts in asphalt mixtures. Currently, NCHRP Project 9-58 is exploring the Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios; however, industry should also play an active role in determining the optimal use of recycling agents.

Figure 5-1. Mount Fuji, as seen from the Tōmei Expressway

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Appendix A — Further Acknowledgements

The authors and tour delegates sincerely thank the following individuals (arranged alphabetically) and companies for accommodating the group and sharing technical knowledge while in Japan:

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Appendix B — Delegation Members and Biographical Information

Industry High RAP Tour of Japan 2014
United States Delegates

Name	Title	Organization
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Pete Capon	Corporate Quality Control Director	Rieth-Riley Construction Co. Inc.
Don Chambers	President	LoJac Enterprises Inc.
Audrey Copeland	Vice President Engineering, Research and Technology	National Asphalt Pavement Association
Mike Cote	Executive Vice President & Chief Development Officer	The Lane Construction Corp.
Abdul Dahhan	Bureau Chief of Materials	Illinois Department of Transportation
Paul Degges	Chief Engineer and Deputy Commissioner	Tennessee Department of Transportation
Dan Gallagher	Vice President and CFO	Gallagher Asphalt Corp.
Vince Hafeli	Vice President of Plants and Materials	Ajax Paving Industries of Florida LLC
Kevin Kelly	President and CEO	Walsh & Kelly Inc.
Aaron Price	Vice President/General Manager	Cadillac Asphalt LLC (An Oldcastle and Levy JV)
Greg Renegar	Vice President of Engineering	Astec Inc.
Ron Sines	Vice President — Asphalt Performance	Oldcastle Materials Inc.
Andy Welch	Project Manager	Maxam Equipment Inc.
Randy West	Director	National Center for Asphalt Technology (NCAT)
Jay Winford	President	Prairie Contractors Inc.
Brian Wood	Executive Director	Plantmix Asphalt Industry of Kentucky (PAIKY)

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As Materials Engineer Administrator, Chris is responsible for quality assurance, testing, and environmental compliance for the Louisiana Department of Transportation and Development. He coordinates the sampling and testing program for LA DOTD, insuring sufficient laboratory expertise and equipment is available to provide quality testing. He also reviews specifications and research proposals for all materials, and he serves on several state and national committees concerned with asphalt materials and pavements.

John Bartoszek, P.E.
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John is in charge of the General Contracting and Engineering Division of Payne & Dolan Inc. He is also in charge of research and development for Payne & Dolan with an emphasis on asphalt plant automation and recycled materials utilization. He serves on various boards for the NCHRP and NCAT.

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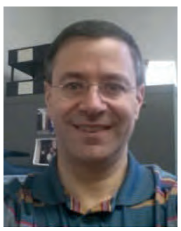
Rebecca is responsible for management and oversight of the bureau's technical services that oversee real estate, utilities, environmental, access, materials, pavements, geotechnical, survey, and mapping and plats functions related to the state's highway system.



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Pete has more than 25 years' experience in quality control/material sciences with Rieth-Riley Construction Co. Inc., serving in roles ranging from field technician to corporate quality control director. His responsibilities at Rieth-Riley include: administration of the quality control program for the company's 30+ asphalt/concrete/aggregate plant and construction operations (FAA, DOT, municipal and commercial construction), environmental plant permitting/compliance, statistical analysis of materials and construction process control, and materials and operations research for Rieth-Riley.

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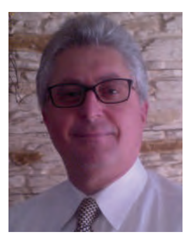

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Dan is a third-generation Gallagher and began his career at Gallagher Asphalt Corp. as a plant supervisor in 1987; he is currently the company's Vice President and CFO. Dan is actively involved in the industry and serves on the Illinois Asphalt Pavement Association (IAPA) Board of Directors and is the Second Vice Chairman (2015) for the National Asphalt Pavement Association (NAPA).

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Vince is Vice President of Plants and Materials for Ajax Paving Industries of Florida LLC where he oversees the operation of seven asphalt plants, along with all quality control activities at the company's production facilities and its roadway projects.

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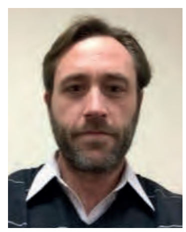
Kevin is President and CEO of Walsh & Kelly Inc., a highway construction company with offices in Griffith, South Bend, and Goshen, Indiana, and five hot-mix plants in Indiana. Walsh & Kelly is jointly owned by and is part of The Heritage Group of companies, headquartered in Indianapolis, Indiana. He serves as the First Vice Chairman (2015) of the National Asphalt Pavement Association and on NAPA's Executive Committee. He also serves on the Build Indiana Council, where he is immediate Past Chairman.



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Greg joined Astec Inc. in 1985 and he has worked in the United States, Canada, China, Australia, and across Europe as a project engineer, field engineer, and design engineer. With Astec, Greg previously held positions as Director of Thermal Systems, Chief Engineer, and in 2013 he was promoted to Vice President of Engineering.

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Ron has been employed by Oldcastle Materials for the past 15 years, and is currently the Vice President for Asphalt Performance, where he is responsible for asphalt initiatives ongoing across all of Oldcastle Materials. Oldcastle Materials is a vertically integrated company producing 130 million tons of aggregate and 43 million tons asphalt that is supplied to its paving and construction operations across the United States.

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Jay is president of Prairie Contractors Inc., a hot-mix asphalt producer and contractor with operations in southcentral and southwestern Louisiana. Jay has been associated with engineering research and construction delegations to China, Eastern Europe, the Soviet Union, and the Middle East. He is very active with the National Academies of Science.

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Brian joined PAIKY in 2000 and currently serves as Executive Director of the association. He is actively involved in advocating for and educating stakeholders on behalf of the asphalt paving industry. He is the primary liaison to the Kentucky Transportation Cabinet on technical issues and is a lobbyist to the Kentucky General Assembly, promoting increased and sustainable highway funding.

Appendix C — Questions and Answers from Tour

Questions and Comments on Japan RAP Scan Tour from various audiences

Last updated 6/24/15

1. **What is the average age of asphalt plants in Japan?**
The plants are of various ages. The life expectancy of an asphalt plant is 20–25 years. At that point, the plant is replaced because it has reached the end of its useful life or the technology needs to be upgraded to current standards.

2. **Is whole pavement taken up for RAP?**
Companies will mill and take up the entire roadway, depending on the existing road condition. If milling is an option, 5–10 cm (2–4 inches) is milled.

3. **How much mill and fill does Japan do (on average)?**
No data available.

4. **What is the Japanese mix design approach? Since a combination of Marshall and performance testing is used, could it be considered a balanced mix design?**
The Japan mix design approach could be considered a balanced approach, but they do not use that term. Japan uses traditional Marshall Method criteria and supplement it with a simple IDT cracking test and determines a parameter called the "IDT modulus" (IDT coefficient), which is an indicator of stiffness. A rutting test (dynamic stability) is used only for porous friction course (PFC) mixes.

5. **How does Japan construct joints?**
The approach delegates observed on the Satte viaduct field project, which was being paved with hybrid PFC/SMA mix using squared joints, is common practice in Japan and is used on all large-volume roads. On smaller, low-traffic roads, the squared joints are not typically used.

6. **What are binder grades? How many binder grades does Japan use?**
A source indicated that 40/60 and 60/80 penetration grades were the most used and 60/80 pen binder is the most common with polymer-modified asphalt used in all high traffic areas and for porous pavements. According to documentation provided to the delegation, about seven penetration grades in total are used.

7. **Where does RAP go that does not meet specifications?**
This is said to be very uncommon. They are typically able to make it work by adjusting the rejuvenator. If not, it is used for base fill.

8. **Do they design for volumetrics?**
In Japan, they use the Marshall Method like we used in most of the U.S. until the mid-1990s. They look at peak density, stability air voids, saturation (VFA), and flow.

9. **Any information on airport pavements?**
Design varies and is currently going through design evaluation based on projects recently completed at Tokyo International Haneda Airport.

10. **What are the typical mix temperatures?**
Typical is 150–170°C (302–338°F) for hot mixes and 130–135°C (266–275°F) for the warm mixes now being trialled in Japan.

11. **Provide more details on drying RAP, handling fumes, and deodorizer.**
There are many versions used in Japan, but most have a few common themes. The RAP is dried in a parallel flow drier and heated to around 140–150°C (284–302°F). The heated RAP is mixed with a rejuvenator and either stored for a period of time for rejuvenator activation or used directly in the mix. The exhaust gases from the RAP heating

and drying process are ducted through an oxidizer to burn the hydrocarbons, then the remaining heat (or a portion of it) is used in the virgin drying process.

12. **Does Japan use asphalt roofing shingles (RAS) in pavement mixes?**
 No. Some shingle use was tried several years ago, but it didn't catch on because the chemicals used in the shingle manufacturing process were considered dangerous.

13. **What is typical air void content?**
 Typical dense grade mixes have a target of 3%–4% air voids. According to an example mix design from Maeda Road Construction Co. Ltd. (Appendix E), the mix design range is 3%–6% with other criteria also used to select the optimum asphalt content.

14. **How often is the RAP pile tested?**
 Once per week after testing shows the RAP stockpile to be consistent.

15. **Is production slowed down so that the rejuvenator has time to work?**
 No. Some plants are equipped with RAP dwell time storage (300–400 metric tonnes) and some have just small (40–50 metric tonne) surge-type hoppers for the RAP. The overall mix out of a plant with dwell time storage is considered a "better mix" than those without.

16. **What motivates contractors to do blending?**
 Most plants are equipped with systems to do online binder blending. This is to achieve the correct grade for the final mix, depending on the tested penetration grade of the recycled material being used.

17. **How fast is paving per minute?**
 Typically 2–3 m/min. The actual paver speed is dependent on the depth of the mat.

18. **Can you provide traffic control details for projects?**
 It varies greatly based on the traffic level of the roadway being paved. Night paving is becoming more popular in Japan.

19. **What is the cost per ton of asphalt mixture?**
 U.S. dollars per ton placed is about $180–$200/tonne. The difference between virgin and RAP mixtures can be as much as $50 per tonne, depending on the type of AC and the percentage of RAP.

20. **When is polymer-modified AC used and how is it specified?**
 Typically polymer-modified AC is used on all high volume roadways and on gap-graded mixes.

21. **Are aggregates produced in Japan or imported? What are the most common geologic types (e.g., granite, limestone, traprock, etc.)?**
 The typically aggregates are domestic sandstone and granite.

22. **For RAP that fails the quality tests (e.g., pen <20) for use in HMA, is that RAP used in other pavement applications? What percentage of RAP fails the quality standards?**
 Very little typically fails. The failed RAP is used for base fill.

23. **What is a typical range of production rates (tons per hour) for plants in Japan?**
 90 to 160 metric tonnes per hour.

23. **Is performance testing used on asphalt mixtures during production in Japan?**
 No. There is no performance testing performed on asphalt mixtures during production. Performance testing is only conducted during mix design.

Answers for questions were provided by Hirochika Moriyasu, P.E., Kentaro Koshi, P.E., and Dr. Toshifumi Emukai of Maeda Road Construction Co. Ltd. and Kazuyuki Kubo of the Public Works Research Institute (of Japan).

Appendix D — Agenda for Seminar on Pavement Technology Exchange

NATIONAL ASPHALT PAVEMENT ASSOCIATION

公益社団法人 日本道路協会 JARA JAPAN ROAD ASSOCIATION

一般社団法人 日本道路建設業協会 JAPAN ROAD CONTRACTORS ASSOCIATION

一般社団法人 日本アスファルト合材協会 JAPAN ASPHALT MIXTURE ASSOCIATION

SEMINAR ON PAVEMENT TECHNOLOGY EXCHANGE BETWEEN U.S.A. AND JAPAN

*Date: **4th December 2014*** *Venue: Main Hall, Seiryo-Kaikan, Tokyo*

Chairman: Hidenori Yoshikane (Chairman, JARA Pavement Committee, JARA)

TIME	CONTENT
13:20–14:00	**Registration**
14:00–14:05	**Welcome and Opening Remarks** Takeo Miyoshi (Chairman, Japan Road Contractors Association)
14:05–14:30	**1st Presentation** Tennessee DOT's Asset Management Approach Paul Degges (Chief Engineer & Deputy Commissioner, Tennessee DOT)
14:30–14:55	**2nd Presentation** Louisiana DOTD's Data Collection for Pavement Management Christopher Abadie (Materials Engineer Administrator, Louisiana DOTD)
14:55–15:20	**3rd Presentation** Use of SMA by Illinois DOT in an Urban Environment Abdul Dahhan (Bureau Chief of Materials, Illinois DOT)
15:20–15:40	**Break Time**
15:40–16:05	**4th Presentation** Road System Investment and Maintenance Financing in Japan Shigeru Kikukawa (Chairman International Committee, Japan Road Association)
16:05–16:30	**5th Presentation** Pavement Management & Technologies in Japan Masahide Ito (Director for Road Engineering Analysis, MLIT)
16:30–16:55	**6th Presentation** Japanese Technology in Japan Hitoshi Fujita (Japan Road Contractors Association)
16:55–17:00	**Closing Speech** Audrey Copeland (Vice President for Engineering, Research, & Technology, NAPA)

Appendix E — Mix Design

An example of a 60% RAP Mix Design from Maeda Road Construction Co. Ltd., annotated in English.

アスファルト混合物配合設計報告書

Mix Design Test Report

混合物：再生密粒度アスファルト混合物（１３）［５０］ｂ

Mix · Dense graded Recycled mix (13) [50] b

２０１３年１１月

京浜リサイクルセンター

前田道路㈱　川崎合材工場

Maeda Road Kawasaki Plant

Aggregate Test Report

骨材試験成績表

目的 配合試験 Objection : design test　　報告年月日 2013年11月 日

混合物の種類 再生密粒度アスファルト混合物(13)[50]b

type of mix : Recycled dense graded mix (13) [50] b

試験項目 (test item)		砕石6号 (Crushed Rock 6)	砕石7号 (Crushed Rock 7)	砕砂 (Crushed Stone)	粗砂 (Coarse Sand)	細砂 (Fine Sand)	再生骨材 13-0 (Recycle aggregate)	石粉 (Stone powder)	
密度 (density)	① 表乾	2.673	2.662	2.626	2.591	2.666	———	———	
	② かさ	2.655	2.636	2.592	2.563	2.613	———	———	
	③ 見掛	2.703	2.705	2.681	2.637	2.759	———	2.721	
④ 吸水率 %		0.67	0.97	1.28	1.11	2.03	———	———	
⑤ すりへり減量 %		13.3	———	———	———	———	———	———	
⑥ 安定性 %		3.6	3.5	2.6	2.8	2.7	———	———	
⑦ 微粒分量試験 %		———	———	———	———	———	2.04	———	
⑧ 軟石含有量 %		2.9	———	———	———	———	———	———	
⑨ 偏平細長石片 %		2.8	———	———	———	———	———	———	
⑩ 単位容積質量		———	———	———	———	———	———	———	
⑪ 粘土塊量 %		0.03	———	———	———	———	———	———	

	ふるい目の開き (Sieve opening)	砕石6号	砕石7号	砕砂	粗砂	細砂	再生骨材 13-0	石粉	
通過質量百分率 % (Percentage passing)	53 mm								
	37.5								
	31.5								
	26.5								
	19	100.0					100.0		
	13.2	96.1	100.0	100.0	100.0		99.8		
	9.5								
	4.75	3.2	87.5	99.9	99.0	100.0	72.9		
	2.36	0.8	5.9	87.1	80.5	99.2	52.7		
	1.18								
	600 μm		1.0	32.1	37.7	91.1	31.8		
	300			18.5	19.1	48.1	22.7	100.0	
	150			8.5	6.7	6.3	13.2	92.5	
	75			2.8	1.3	0.6	7.5	80.7	

① surface dry
② bulk
③ apparent
④ water absorption
⑤ abrasion loss
⑥ soundness
⑦ Content of materials finer than 75 μm sieve test
⑧ freestone content
⑨ flatness
⑩ mass of unit volume
⑪ Content of clay lumps

(Grade of aggregate Design)

骨　材　粒　度　設　計

目　的　配合試験　　　　報告年月日　2013年11月　日

混合物の種類　再生密粒度アスファルト混合物(13)[50]b

3．使用予定骨材の合成粒度 (3. Combined grading of aggregate)

骨材 (aggregate)		砕石6号	砕石7号	砕砂	粗砂	細砂	再生骨材 13-0	石粉	
配合率A% (Design %)		19.0	7.5	5.0	5.0	2.5	60.0	1.0	
通過質量百分率B% (Percentage Passing)	53 mm								
	37.5								
	31.5								
	26.5								
	19	100.0					100.0		
	13.2	96.1	100.0	100.0	100.0		99.8		
	9.5								
	4.75	3.2	87.5	99.9	99.0	100.0	72.9		
	2.36	0.8	5.9	87.1	80.5	99.2	52.7		
	1.18								
	600 μm		1.0	32.1	37.7	91.1	31.8		
	300			18.5	19.1	48.1	22.7	100.0	
	150			8.5	6.7	6.3	13.2	92.5	
	75			2.8	1.3	0.6	7.5	80.7	

	各骨材のふるい目の大きさ別配合率(A)×(B) (Design percentage of aggregate sieve opening)								合成 (Composition)	予定 (plan)
53 mm										
37.5										
31.5										
26.5										
19	19.0					60.0			100.0	100.0
13.2	18.3	7.5	5.0	5.0		59.9			99.2	97.5
9.5										
4.75	0.6	6.6	5.0	5.0	2.5	43.7			64.4	62.5
2.36	0.2	0.4	4.4	4.0	2.5	31.6			44.1	42.5
1.18										
600 μm		0.1	1.6	1.9	2.3	19.1			26.0	24.0
300			0.9	1.0	1.2	13.6	1.0		17.7	15.5
150			0.4	0.3	0.2	7.9	0.9		9.7	11.0
75			0.1	0.1	0.0	4.5	0.8		5.5	6.0

4．骨材の密度による配合率の補正

骨材									計
①配合比									
②密度									
③＝①×②									
補正配合率 ③／計×100									

Grain size accumlation curve of aggregate

骨材の粒径加積曲線図

目　的　配 合 試 験　　　　報告年月日　２０１３年１１月　　日

混合物の種類　再生密粒度アスファルト混合物（１３）［５０］b

5．合成粒度 total grading

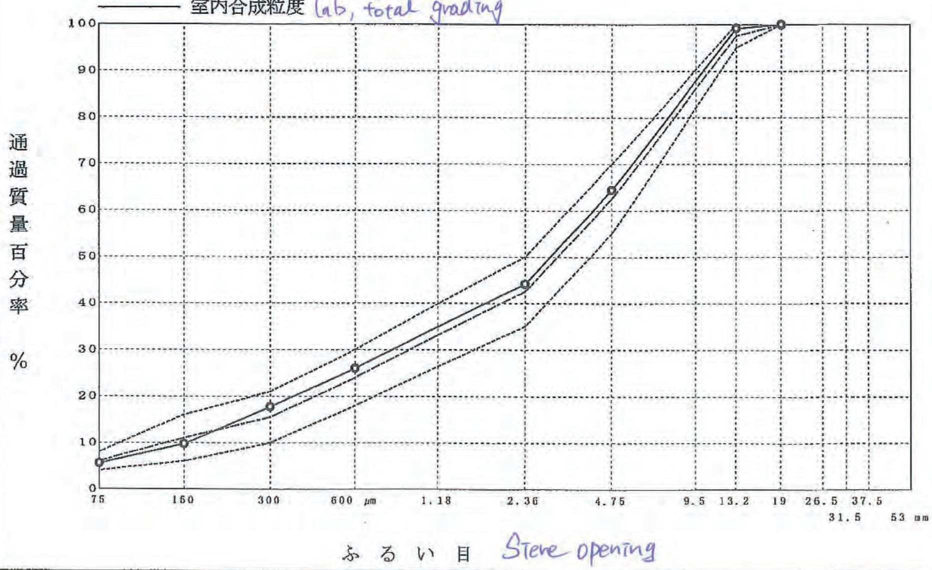
ふるい目 Sieve opening	合成粒度	室内合成粒度 lab total grading	予定粒度 planned grading	粒度範囲 grading range
５３　ｍｍ				
３７．５				
３１．５				
２６．５				
１９		１００．０	１００．０	１００
１３．２		９９．２	９７．５	９５　～１００
９．５				
４．７５		６４．４	６２．５	５５　～７０
２．３６		４４．１	４２．５	３５　～５０
１．１８				
６００　μｍ		２６．０	２４．０	１８　～３０
３００		１７．７	１５．５	１０　～２１
１５０		９．７	１１．０	６　～１６
７５		５．５	６．０	４　～８

6．粒径加積曲線図 Grain size accumlation curve

粒度範囲 Grading range

予定粒度 planned grading

室内合成粒度 lab, total grading



再生骨材の性状試験結果

目　的　配 合 試 験　　　報告年月日　2013年11月　日

混合物の種類　再生密粒度アスファルト混合物(13) [50] b

試験項目 Test Item / 材料名 material		再生骨材 13−0 Recycled aggregate 13-0				規格値 Value of Standard
通過質量百分率 % Percentage passing	53 mm					
	37.5					
	31.5					
	26.5					
	19	100.0				
	13.2	99.8				
	9.5					
	4.75	72.9				
	2.36	52.7				
	1.18					
	600 μm	31.8				
	300	22.7				
	150	13.2				
	75	7.5				
① 旧アスファルト含有率 %		5.00	① Content rate of recycled AC			3.8 以上
② 旧アスファルト針入度(25℃) 1/10mm		22	② penetration of recycled AC			20 以上
③ 微粒分量試験による損失量 %		2.04	③ loss from the content of materials finer than			5 以下
④ 最大密度		2.494	④ Maximum density		75 μm sieve test	

再生添加剤の性状 Property of Softening agent

項 Item 目	試験値	標準的性状
⑤ 動粘度 (60℃) cSt	260.0	80〜1000
⑥ 引火点 ℃	275	250以上
⑦ 薄膜加熱後の粘度比 (60℃)	1.23	2以下 below 2
⑧ 薄膜加熱質量変化率 %	0.87	±3%以内 below
⑨ 密度 (15℃) g/cm³	1.003	

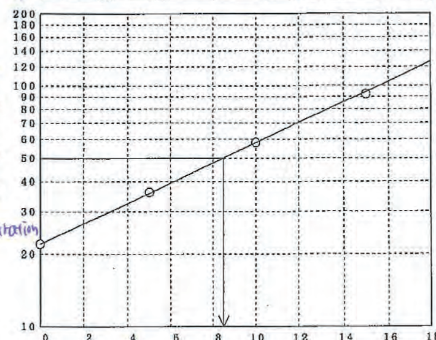
↑ tested value　↑ normal property

再生アスファルトの性状 Property of recycled asphalt

⑩ 針入度 (25℃) 1/10mm		50	
⑪ 軟化点 ℃		52.1	
⑫ 伸度 (15℃) cm		69	
⑬ トルエン可溶分 %		99.31	
⑭ 引火点 ℃		274	
⑮ 薄膜加熱質量変化率 %		0.05	
⑯ 薄膜加熱針入度残留率 %		63.3	
⑰ 蒸発後の針入度比 %		96	
⑱ 密度 (15℃) g/cm³		1.047	
⑲ 動粘度	(120℃)	1130.0	
	(150℃)	311.0	
	(180℃)	97.0	

⑳ 針入度と添加剤添加量の関係

㉑ 添加剤量 (%)	0	5	10	15
㉒ 針入度 (1/10mm)	22	36	58	92



㉑ 添加剤添加量(%)

right amount of Softening agent for planned penetration

目標針入度になる添加剤量	
対アスファルト (against AC)	対混合物 (against mix)
8.50	0.27

⑤ Kinematic viscosity
⑥ flash point
⑦ viscosity ratio of thin film heat
⑧ mass change ratio of thin film heat
⑨ density
⑩ penetration
⑪ flexibility point
⑫ extension percentage
⑬ toluene Soluble
⑭ flash point
⑮ mass change ratio of thin film heat
⑯ thin film heat penetration residual %
⑰ penetration ratio after evaporation
⑱ density
⑲ Kinematic viscosity
⑳ Relationship between penetration and the amount of Softening agent.
㉑ the amount of Softening agent
㉒ penetration

Maximum theoretical density calculating table of mix

混合物の理論最大密度計算表

目 的 配 合 試 験　　　　報告年月日 2013年11月 日

混合物の種類 再生密粒度アスファルト混合物(13)[50]b

骨材の種類 (Type of aggregate)	A 骨材のみ (Ⓐ only aggregate)	B(旧アスファルト含む) (Ⓑ With old AC, RAP)
砕石6号 Crushed Rock 6	19.0	19.00
砕石7号 Crushed Rock 7	7.5	7.50
砕砂 Crushed sand	5.0	5.00
粗砂 Coarse sand	5.0	5.00
細砂 fine sand	2.5	2.50
再生骨材 13−0 Recycle agg.	60.0	63.16
石粉 Stone powder	1.0	1.00
計 total	100.0	103.16
① 設計針入度		50
② 旧アスファルト量 (外割%)		3.16
③ 再生用添加剤量 (対アスファルト量) %		8.50
④ 再生用添加剤量 (対再生混合物) (外割%)		0.27

						OAC
⑤ 再生アスファルト量 (%)	4.5	5.0	5.5	6.0	6.5	5.5
⑥ 再生アスファルト量 (外割%)	4.71	5.26	5.82	6.38	6.95	5.82
⑦ 旧アスファルト量 (外割%)	3.16	3.16	3.16	3.16	3.16	3.16
⑧ 再生用添加剤量 (外割%)	0.27	0.27	0.27	0.27	0.27	0.27
⑨ 新アスファルト量 (外割%)	1.28	1.83	2.39	2.95	3.52	2.39

① 骨材の種類 (type of aggregate)	② 配合率(%) (design ratio)	③ 計算に用いる密度 (density used for calculation)	④ ②/③
Crushed 砕石6号 Rock 6	19.00	2.703	7.029
Crushed 砕石7号 Rock 7	7.50	2.705	2.773
Crushed 砕砂 sand	5.00	2.681	1.865
Coarse 粗砂 sand	5.00	2.637	1.896
fine 細砂 sand	2.50	2.759	0.906
再生骨材 13−0 recycled aggregate	63.16	2.494	25.325
石粉 Stone powder	1.00	2.721	0.368
SRラックス SR lax (softening agent)	0.27	1.003	0.269
Σ②=	103.43	Σ④=	40.431

⑤ 新アスファルト量 (%) (New AC amount)	⑥ アスファルトの密度 (density of AC)	⑦ ⑤/⑥	⑧ Σ④	⑨ ⑦+⑧	⑩ 理論最大密度 (Σ②+⑤)/⑨ (maximum theoretical density)
1.28	1.038	1.233	40.431	41.664	2.513
1.83		1.763		42.194	2.495
2.39		2.303		42.734	2.476
2.95		2.842		43.273	2.458
3.52		3.391		43.822	2.441
OAC 2.39		2.303		42.734	2.476

① designed penetration
② Recycled AC amount
③ Softening agent amount (against AC amount)
④ Softening agent (against recycled mix)
⑤ Recycled AC amount
⑥ Recycled AC amount
⑦ old AC amount
⑧ Softening agent amount
⑨ new AC amount

Marshall Stability Test

マーシャル安定度試験（ その１ ）

目　的　配 合 試 験　　　　報告年月日　２０１３年１１月　　日

混合物の種類　再生密粒度アスファルト混合物（１３）［５０］ｂ

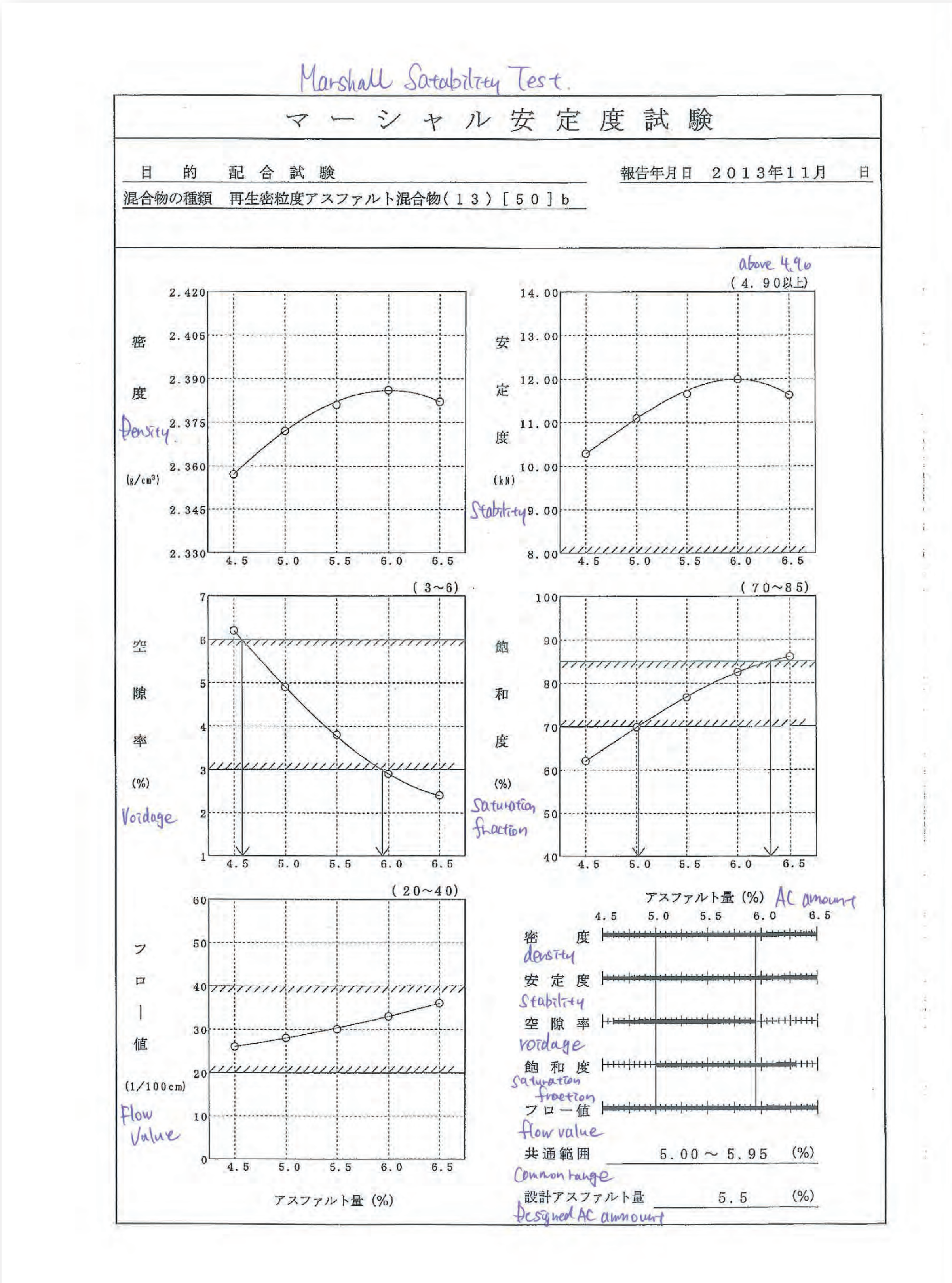
type of AC
アスファルトの種類 再生アス４０／６０ Recycled AC40/60　アスファルトの密度 (A) １．０４７　アスファルトの温度 １５３ ℃ AC temperature

骨材の温度 １８０ ℃ Agg temperature　突固め温度 １５２ ℃ temperature of blow　突固め回数 ５０ 回 number of blows　力計の係数 (B) ０．１４２７８ｋＮ dynamometer factor.

⑱ 試験条件	⑰ 供試体番号	① アスファルト量 (%)	② 供試体平均厚 (cm)	③ 空中質量 (g)	④ 水中質量 (g)	⑤ 表乾質量 (g)	⑥ 容積 (cc)	⑦ ⓐ密度 ⓑかさ (g/cm³)	⑧ 密度 理論 (g/cm³)	⑨ アスファルト容積 (%)	⑩ 空隙率 (%)	⑪ 骨材間隙率 (%)	⑫ 飽和度 (%)	⑬ ⓐ安定度 ⓑ力計の読み	⑭ 安定度 (kN)	⑮ フロー値 1/100 cm	⑯ 安定度／フロー (kN/m)
							⑤−④	③/⑥		①×⑦/(A)		⑨+⑩	⑨/⑪		(B)×⑬		
⑲ 標準	1	4.5		1187.4	685.4	1188.5	503.1	2.360						72	10.28	26	
	2			1188.6	684.8	1189.7	504.9	2.354						69	9.85	24	
	3			1190.1	686.4	1191.3	504.9	2.357						75	10.71	28	
	平均							2.357	2.513	10.1	6.2	16.3	62.0		10.28	26	3954
標準	4	5.0		1195.1	692.5	1195.7	503.2	2.375						80	11.42	29	
	5			1194.0	690.8	1194.8	504.0	2.369						75	10.71	26	
	6			1192.2	690.6	1193.0	502.4	2.373						78	11.14	28	
	平均							2.372	2.495	11.3	4.9	16.2	69.8		11.09	28	3961
標準	7	5.5		1198.3	694.6	1198.8	504.2	2.377						78	11.14	28	
	8			1200.2	697.0	1200.7	503.7	2.383						84	11.99	31	
	9			1196.1	695.0	1196.7	501.7	2.384						83	11.85	30	
	平均							2.381	2.476	12.5	3.8	16.3	76.7		11.66	30	3887
標準	10	6.0		1201.3	697.7	1201.8	504.1	2.383						80	11.42	31	
	11			1205.3	701.2	1205.7	504.5	2.389						87	12.42	35	
	12			1203.0	699.5	1203.5	504.0	2.387						85	12.14	34	
	平均							2.386	2.458	13.7	2.9	16.6	82.5		11.99	33	3633
標準	13	6.5		1210.3	703.5	1210.8	507.3	2.386						85	12.14	37	
	14			1207.3	700.3	1207.8	507.5	2.379						78	11.14	36	
	15			1208.4	701.6	1208.9	507.3	2.382						81	11.57	34	
	平均							2.382	2.441	14.8	2.4	17.2	86.0		11.62	36	3228

⑩= (1- ⑦/⑧) ×１００

① AC amount
② test piece average thickness
③ mass in the air
④ mass in the water
⑤ surface dry mass
⑥ volume
⑦ⓐ density
⑦ⓑ bulk
⑧ theory
⑨ asphalt volume
⑩ voidage
⑪ aggregate voidage
⑫ saturation fraction
⑬ⓐ stability
⑬ⓑ dynamometer
⑭ stability
⑮ flow value
⑯ stability / flow
⑰ test piece number
⑱ test condition
⑲ standard



Marshall Satability Test.

マーシャル安定度試験

目的　配合試験

報告年月日　２０１３年１１月　日

混合物の種類　再生密粒度アスファルト混合物（１３）［５０］ｂ

共通範囲 Common range　５.００～５.９５　(%)

設計アスファルト量 Designed AC amount　５.５　(%)

[Grade of aggregate design]

骨材粒度設計

目的　配合試験（現場）　　報告年月日　2013年11月　日

混合物の種類　再生密粒度アスファルト混合物(13)[50]b

3. 使用予定骨材の合成粒度　[3. Combined grading of aggregate]

骨材 [aggregate]		1ビン [bin 1]	2ビン [bin 2]	3ビン [bin 3]	再生骨材 [Recycled agg.]	回収ダスト [Recovery Dust]	石粉 [Stone powder]			
[Design %] 配合率A%		12.0	9.0	18.0	60.0	0.2	0.8			
通過質量百分率B %	53 mm									
	37.5									
	31.5									
	26.5									
	19			100.0	100.0					
	13.2		100.0	96.6	99.8					
	9.5									
	4.75	100.0	80.9	1.2	72.9					
	2.36	96.2	1.3	0.1	52.7					
	1.18									
	600 μm	50.3	0.2		31.8					
	300	27.9			22.7	100.0	100.0			
	150	8.6			13.2	92.5	92.5			
	75	2.3			7.5	80.7	80.7			

各骨材のふるい目の大きさ別配合率(A)×(B) [design percentage of aggregate sieve opening]									合成 [Composition plan]	予定
53 mm										
37.5										
31.5										
26.5										
19			18.0	60.0					100.0	100.0
13.2		9.0	17.4	59.9					99.3	99.2
9.5										
4.75	12.0	7.3	0.2	43.7					64.2	64.4
2.36	11.5	0.1	0.0	31.6					44.2	44.1
1.18										
600 μm	6.0	0.0		19.1					26.1	26.0
300	3.3			13.6	0.2	0.8			17.9	17.7
150	1.0			7.9	0.2	0.7			9.8	9.7
75	0.3			4.5	0.2	0.6			5.6	5.5

4. 骨材の密度による配合率の補正

骨材									計	
① 配合比										
② 密度										
③ = ① × ②										
補正配合率 ③／計×100										

Decision of job mix formula.

現場配合の決定

目　的　配 合 試 験　　　　　　　　報告年月日　２０１３年１１月　日

混合物の種類　再生密粒度アスファルト混合物（１３）［５０］ｂ

1 batch, 2,500KG

1バッチ　2500 kg

		① 骨材配合比(%)	② 外割配合比(%)	③ 内割配合比(%)	④ 1バッチ質量(kg)	⑤ 骨材累加質量(kg)
bin 1	1　ビン	12.0	12.00	11.34	285	285
bin 2	2　ビン	9.0	9.00	8.51	210	495
bin 3	3　ビン	18.0	18.00	17.00	425	920
Recycled agg.	再生骨材	60.0	63.16	59.68	1500	1500
Recovery dust	回収ダスト	0.2	0.20	0.19	5.0	5.0
Stone powder	石粉	0.8	0.80	0.76	18.0	18.0
Recycled AC	旧アスファルト		(3.16)	(2.98)		
Softening Agent	再生用添加剤		0.27	0.25		
New AC	新アスファルト		2.39	2.27	57.0	57.0
	合計	100.0	105.82	100.00	2500.0	2500.0

① aggregate ratio
② designed AC amount
③ plant ratio
④ mass per batch (KG)
⑤ aggregate culmative mass

※添加剤はアフターミキサー添加のため再生材の計量値に含まれます。

Softening Agent is calculated into the amount of Recycled aggregate.

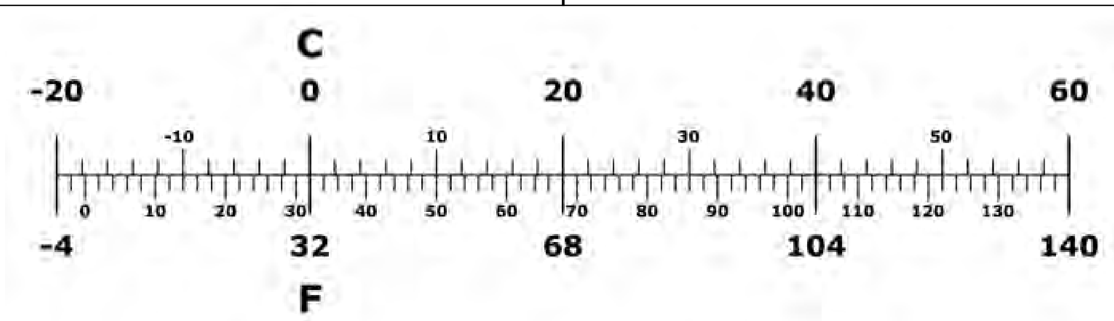
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSION TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	645.2	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L should be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lbs	pounds	0.454	kilograms	kg
T	short tons	0.907	megagrams	Mg
T	short tons	0.907	metric tonnes	t
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°F	Fahrenheit	$\frac{5(F-32)}{9}$	Celsius	°C

APPROXIMATE CONVERSION FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lbs
Mg	megagrams	1.102	short tons	T
t	metric tonnes	1.102	short tons	T
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°C	Celsius	(1.8×C)+32	Fahrenheit	°F



*SI is the symbol for the International System of Units

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