COMPACTION OF NOISE-REDUCING ASPHALT MIXTURES IN THE LABORATORY

Qing Lu, Ph.D., P.E. (corresponding author)
University of California Pavement Research Center
1353 S. 46th St., Bldg. 480
University of California, Berkeley
Richmond, CA 94804, USA
Tel: (510) 665-3596, Fax: (510) 665-3562
Email: qlu@ucdavis.edu

Sang Luo
Graduate Student Researcher
Intelligent Transportation System Research Center
Southeast University
Nanjing, 210096, China
Email: luosang@seu.edu.cn

John T. Harvey
Professor
Department of Civil and Environmental Engineering
University of California, Davis
Engineering III, Room 3153
One Shields Avenue
Davis, CA 95616, USA
Tel: (530) 754-6409
Fax: (530) 752-1228
Email: jtharvey@ucdavis.edu


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ABSTRACT
In recent years, significant amount of research effort has been spent by engineers worldwide to develop alternative asphalt surface mixtures that are quieter, safe, and durable. These mixtures typically have very high air-void contents, placed in thin layers, and compacted in a way different from conventional dense-graded asphalt mixtures. Different compaction methods have been applied to fabricate specimens in laboratory studies. The effect of compaction on mix performance has not been sufficiently studied. This paper investigates the impact of compaction methods on the performance of quiet (porous) asphalt mixtures. Four different compaction methods are included: Marshall impact, Hveem kneading, Superpave gyratory, and rolling wheel compaction. The rolling wheel compaction is selected as a surrogate for field compaction. Specimens of four different porous mixtures with nominal maximum aggregate sizes varying from 4.75 mm to 19.0 mm are compacted by the four methods, and are tested for various performance indices, including permeability, sound absorption, moisture sensitivity, and resistance to raveling. It is found that each compaction method has its own advantages and disadvantages. The effect of compaction methods also varies with the aggregate gradation. Mix performance indices also have different sensitivities to the compaction method.
INTRODUCTION

With the continuing increase of traffic volume, traffic noise pollution has become a growing problem, particularly for residents in urban areas (1). Use of noise barriers is currently a common way to mitigate noise, but it comes with high cost, block of sight, and other drawbacks. In recent years, alternative solutions have been proposed and developed around the world — ones that can reduce tire/pavement noise at the source by using “quiet” pavement surfaces. For asphalt pavements, typically a thin asphalt surface layer is placed, which has very high air-void contents to absorb tire/pavement noise and good riding smoothness to reduce vehicle vibration related noise. Previous studies and field experience have revealed that open-graded asphalt friction course (OGFC), which is primarily designed to increase roadway safety during wet weather, can also significantly reduce tire/pavement noise (2, 3). The majority research effort spent worldwide on quiet asphalt pavements has been on the noise performance and design improvement of open-graded (or porous) asphalt mixes.

Open-graded asphalt mixes are compacted in a way different from conventional dense-graded or gap-graded asphalt mixes. Regular asphalt mix compaction is achieved by specifying the number of coverages of rollers or relative density of the mix, and involves both static/vibratory steel wheel rollers and pneumatic-tired rollers. Open-graded mixes, on the other hand, are typically compacted by an 8- to 10-ton static steel wheel roller with a few (one to four) coverages over the surface, and vibratory or pneumatic-tired rollers are not used. Vibratory rollers degrade the aggregate and pneumatic-tired rollers tend to pick up asphalt and close the voids in the mix (2, 4).

In the past, porous asphalt mixes have been mainly evaluated in the field for their surface characteristics including friction, permeability, and texture. In the United States, laboratory evaluation of their durability to environmental and traffic attack has been limited. In some states, like California, no OGFC specimens are fabricated in the laboratory for performance evaluation. With the development of new generation of OGFC (5), new performance requirements have been added into the mix design procedure, including moisture susceptibility, resistance to raveling, permeability, and others. Specimens of open-graded (porous) asphalt mixtures then have to be fabricated in the laboratory to evaluate these performances. Along with the application of Superpave design procedure for dense- and gap-graded mixes, Superpave gyratory compaction has become the dominant laboratory compaction method for asphalt mixtures in the United States. It is then also adopted to fabricate OGFC specimens with either 100 mm or 150 mm diameter (6). In Europe, East Asia, and many other countries where research on quiet pavement started earlier, Marshall impact compaction is the main method for making porous asphalt mixture specimens in the laboratory. In California, Hveem kneading compactor has been used to prepare dense- or gap-graded asphalt mixture specimens in the laboratory for mix design, but has not been used for open-graded asphalt mixtures.

The effect of compaction methods on performances of dense- or gap-graded asphalt mixes have been studied by many researchers (7, 8), and there has been some research effort on the compaction effect on performance of open-graded (or porous) asphalt mixtures. For example, Watson et al. compared the Cantabro test results of 100-mm Marshall hammer compacted samples and 150-mm Superpave gyratory compactor (SGC)-compacted samples and found no significant difference (6). In general, however, the compaction effect on open-graded (porous) asphalt mixture performance, and the similarity between laboratory compaction and field compaction, have not been sufficiently studied.
OBJECTIVE

This paper investigates the impact of compaction methods on the performance of quiet (porous) asphalt mixes. The effect of aggregate gradation, particularly nominal maximum aggregate size (NMAS), is also studied.

EXPERIMENTAL DESIGN

Materials and Mix Designs

One basaltic-volcanic nature aggregate and one Superpave performance-graded (PG) asphalt binder, PG64-16, were used for all mixes. A total of four mix designs, with various nominal maximum aggregate sizes (4.75-mm, 9.5-mm, 12.5-mm, and 19-mm) were included in the experiment. The aggregate gradations, as shown in Table 1, were determined from one European fine (4.75-mm) OGFC gradation, California Department of Transportation (Caltrans) 9.5-mm and 12.5-mm OGFC gradation specifications, and Indiana DOT 19-mm OGFC gradation specifications. The optimum binder contents, also shown in Table 1, were determined following Caltrans test method 368, which is based upon draindown of asphalt at production temperatures.

<table>
<thead>
<tr>
<th>NMAS</th>
<th>19-mm</th>
<th>12.5-mm</th>
<th>9.5-mm</th>
<th>4.75-mm</th>
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<td>25.4</td>
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<td>100</td>
<td>100</td>
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<tr>
<td>19.05</td>
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<td>100</td>
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<td>12</td>
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</tr>
<tr>
<td>0.075</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>6</td>
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</table>

Binder Content (%) 5.0 5.9 5.9 7.9

Compaction Methods

Four compaction methods were selected and compared in the study: Hveem kneading compaction, Superpave gyratory compaction, Marshall impact compaction, and rolling wheel compaction.

Hveem kneading compaction consolidates a mix by a series of roving impressions made by a ram with a face shaped as a circle sector. This compaction method has been adopted by Caltrans for a long time for fabricating laboratory specimens for asphalt mix design. In this study, the compaction procedure generally follows California Test 304 “Method of Preparation of Bituminous Mixtures for Testing” with a few modifications. Specifically, weighted loose mix was distributed into a compaction mold in one lift, and then rodded 10 times in the middle and...
10 times around the edge with a bullet-nosed steel rod. The mix was then compacted at a tamper foot pressure of 1.7 MPa for 25 tamping blows, and then leveled under a compression load at a speed of 6.35 mm/min to a height of 63.5 mm.

Superpave gyratory compaction was conducted following the procedure in AASHTO T 312, with 50 gyrations for each specimen, as specified in ASTM D 7064 “Standard Practice for Open-Graded Friction Course Mix Design”.

Marshall impact compaction follows the procedure that has been widely used by other researchers, particularly in European countries, for OGFC specimen fabrication (5, 10). Specifically, 50 blows of a Marshall hammer were applied on each side of the specimens.

Rolling wheel compaction simulates the field compaction on a smaller scale. Pre-weighed loose mix was distributed in a steel mold of 635 mm length and 560 mm width, and then compacted by a BOMAG 90 AD ride-on tandem roller (with an approximate weight of 2000 kg). The compaction was done in the static mode and generally 30 passes were applied to make the slab surface flush with the mold edge. Cores were then taken from the slab specimen for further testing.

Before being compacted in either method, all the loose mixes were short-term aged in accordance with AASHTO PP2, i.e., aged in a force draft oven at 135°C for four hours. All specimens have the same diameter of 100 mm and a nominal height of 63.5 mm.

Test Methods
The mix properties that are critical to pavement surface performance were evaluated in the study, including permeability, acoustic absorption, moisture sensitivity, and resistance to raveling.

Air-void Content
The air-void content of specimens was calculated from the theoretical maximum specific gravity measured in accordance with AASHTO T 209 and the bulk specific gravity measured using the CoreLok method following AASHTO T 331.

Permeability
Permeability was measured by a flexible-wall falling-head permeameter on the 100-mm diameter specimens, following the procedure specified in ASTM PS 129.

Acoustic Absorption
The acoustic (sound) absorption coefficient of a material represents the proportion of acoustic energy not reflected by the surface of the material for a normal incidence plane wave. In an earlier study (12), it has been found that the sound absorption value is correlated with the California On-Board Sound Intensity (OBSI) value (a measure of the tire/pavement noise level) at high frequencies for open-graded asphalt mixes, and at all frequencies for dense- or gap-graded mixes. In the study, acoustical absorption was measured in accordance with ASTM E 1050, using a Brul & Kjaer Type 4206A impedance tube.

Moisture Susceptibility
Moisture susceptibility of the mixtures was determined using the AASHTO T 283 test method with some modifications specified in ASTM D 7064. For moisture conditioned specimens, they were first saturated at a vacuum of 87.8 kPa for 10 minutes, and then submerged in water during the 16 hrs freeze cycle. In the 24 hrs thaw cycle, specimens were wrapped with plastic tube walls
to prevent breakdown of the porous mixture in the 60°C water bath. Instead of five freeze/thaw
cycles as specified in ASTM D 7064, only one cycle was applied. An earlier study by Watson et
al. found that no significant difference in tensile strength when one, three, and five freeze/thaw
cycles are used in the moisture conditioning of open-graded asphalt mixtures, and suggested only
one freeze-thaw cycle is needed (4).

Resistance to Raveling
Resistance to raveling was evaluated using the Cantabro test on both unaged and aged specimens,
following the procedure described in the report by Kandhal et al. (5). Specifically, compacted
specimens were put inside a Los Angeles Abrasion machine drum without steel balls, and the
drum was turned for 300 revolutions in 10 minutes. The percentage of mass loss during this
process is used to evaluate the resistance of asphalt mixtures to raveling. A custom
environmental chamber was made to enclose the machine to keep the test temperature at 25±1°C.
Aging was accomplished by placing specimens in a forced draft oven set at 60°C for 168 hrs. To
prevent breakdown of the highly porous mixtures, specimen side was retained by a plastic tube
wall during the whole process.

Test Matrix
For each of the four mixtures, cylindrical specimens were fabricated with each of the four
compaction methods, which lead to a total of 16 different types of specimens. Each of the test
methods described in the previous section was conducted on each type of specimens. Three
replicates were used in each test, and the same specimens tested for permeability were used later
in the impedance tube test for sound absorption. A total of 240 specimens were fabricated and
tested in this study.

RESULTS AND DISCUSSION
Air-void Content
The nominal air-void content of all specimens was selected at 20 percent. Based on this value
and the nominal specimen sizes (100 mm in diameter and 63.5 mm in thickness), the amount of
loose mix was weighed and compacted by different methods. In the Hveem kneading and the
rolling wheel compactions, specimens were compacted to a predefined volume, so the obtained
air-void contents should be near 20 percent. In the Marshall and Superpave gyratory compactions,
however, only the number of blows or gyrations was specified. The obtained air-void content,
therefore, may vary from 20 percent significantly, depending on the structure of aggregates in a
mixture and the amount of compaction energy provided by the specific compaction procedure.

The average thickness of each type of specimen is shown in Figure 1. As expected,
specimens compacted by the Hveem kneading and rolling wheel methods have an average
thickness close to 63.5 mm (in the range of 62 mm to 64 mm). The Marshall compacted
specimens also have an average thickness close to the nominal value (63.5 mm). On the other
hand, the Superpave gyratory compacted specimens are generally thicker than 63.5 mm. This
indicates that the 50 blows (on each side) Marshall compaction provides similar compaction
action to the rolling wheel and Hveem kneading compactions, while the 50 gyrations gyratory
compaction is less efficient than the other three compaction methods, particularly for the 9.5-mm
and 12.5-mm mixes.

Figure 2 shows the average air-void content of the 16 types of specimens. Specimens
with a NMAS of 19 mm generally have smaller measured air-void contents than specimens with
a NMAS of 4.75 mm, 9.5 mm, or 12.5 mm. This is due to the very rough surface of the 19-mm mixture, which is comparable to the specimen sizes. The large surface voids are mostly not included in the measured air-void contents in the CoreLok method due to the penetration of the bag film into the voids under vacuum. Excluding the 19-mm specimens, it can be seen that the Hveem kneading compacted specimens have an average air-void content close to 20 percent, which is expected. For the Marshall compacted specimens, the air-void contents are close to 20 percent, except for the 4.75-mm specimens, which are slightly lower. For the gyratory compacted specimens, the air-void contents are close to 20 percent for the 4.75-mm mixture, but higher than 20 percent for the 9.5-mm and 12.5-mm mixtures. For the rolling wheel compacted specimens, the air-void contents are slightly less than 20 percent for the 9.5-mm and 12.5-mm mixtures and about 2.5 percent less for the 4.75-mm mixture. This is likely due to slight over compaction in the center of the slab, from which the cylindrical specimens were cored, when 30 wheel passes were applied.

![Graph showing average thicknesses of specimens versus NMAS and compaction methods.](chart.png)

**FIGURE 1** Average thicknesses of specimens versus NMAS and compaction methods.
Permeability

Specimens of similar air-void contents were selected in the permeability test. The measured permeability was corrected to a value corresponding to a standard water temperature 20°C, using the correction factors specified in ASTM PS 129.

The average permeability of each type of specimen is shown in Figure 3. The figure shows that the permeability measured from the 19-mm NMAS specimens is smaller than the values measured from the 9.5-mm and 12.5-mm NMAS specimens. Generally a mixture with coarser gradation should have more connected voids, so that higher permeability. The permeability measured on the slab specimens before coring using a Gilson AP-1B permeameter (an on-site falling head permeameter used in the field) verified this trend, as shown in Figure 4. The low values measured from the 19-mm NMAS, 100-mm diameter specimens were likely due to the relatively small sizes of the specimen compared to the maximum aggregate size, which made the side effect (e.g., penetration of confining membrane into voids) non-negligible.

Excluding the 19-mm NMAS specimens, it can be seen that there is no significant difference of permeability among specimens compacted by the four compaction methods for the 9.5-mm and 12.5-mm NMAS mixtures. For the 4.75-mm NMAS mixture, the rolling wheel compaction produced less permeable specimens than the other three compaction methods. Because specimens of similar air-void contents were used in the permeability test, this difference indicates that the rolling wheel compaction creates less interconnected voids in the 4.75-mm NMAS mix than the other three compaction methods.

FIGURE 2 Average air-void contents of specimens versus NMAS and compaction methods.
FIGURE 3 Average permeability versus NMAS and compaction methods.

FIGURE 4 Permeability measured from cores and slabs.

Acoustic Absorption
The result of a sound absorption test is a vector containing the absorption coefficient in the one-third octave frequency bands from 100 to 2000 Hz. Each absorption coefficient value ranges from 0 to 1 depending on the fraction of the sound energy that at any given frequency is reflected back ($\alpha = 0$) or absorbed ($\alpha = 1$). The frequency at which the maximum absorption occurs is
known as the resonant frequency \((J2)\). In this study, there are generally two peaks in every absorption curve measured from every mixture, as shown in Figure 5.

Figure 5 presents the average absorption curve in the one third octave frequency bands for each of the 16 different types of specimens. As can be seen, the resonant frequencies are generally similar for specimens of the same NMAS but compacted by different methods, except that the Marshall compacted specimens showed slightly higher resonant frequency than the specimens compacted by the other three methods for the 4.75-mm and 12.5-mm NMAS mixtures, and that the rolling wheel compacted specimens showed slightly higher resonant frequency than the specimens compacted by the other three methods for the 9.5-mm and 19-mm NMAS mixtures. The maximum absorption coefficients are similar among the four compaction methods for the 9.5-mm and 12.5-mm NMAS mixtures, but significantly lower for the 4.75-mm and 19-mm NMAS specimens compacted by the rolling wheel compactor than specimens compacted by the other three compaction methods.

In a summary, from the acoustic absorption consideration, specimens compacted by the gyratory, Marshall, and kneading methods are similar to the rolling wheel compacted specimens for mixtures with NMAS no larger than 12.5 mm, except that for small aggregate size (4.75-mm NMAS) mixtures, the Marshall compaction may lead to higher absorption than the rolling wheel compaction. For the mixture with large size aggregates (19-mm NMAS), the rolling wheel compacted specimens have significantly different acoustic absorption characteristics from specimens compacted by the other three methods.

![Absorption coefficients at 1/3 octave frequency bands for mixtures with various aggregate sizes.](image-url)
To compare the sound absorption of mixtures with different NMAS, the measured absorption coefficients between 200 and 1700 Hz are averaged to cover the absorption effects at all available frequencies. Absorption at frequencies below 200 Hz and above 1700 Hz are not included because leakage through the annulus around the specimen, or blow-by, may affect some of the test results at low frequencies, while the absorption above 1700 Hz may not be accurate either due to the geometry of the impedance tube used.

Figure 6 shows the averaged average absorption of each type of specimen. Generally there is no significant difference between gyratory, Marshall, and kneading compaction methods for mixtures with NMAS no larger than 12.5 mm, except that Marshall compaction leads to higher absorption for the 4.75-mm NMAS mixture. For the four mixtures, the 9.5-mm and 12.5-mm NMAS specimens show higher absorption than the 4.75-mm and 19-mm NMAS specimens. This ranking is similar to the ranking based on permeability (Figure 3), which indicates the existence of correlation between sound absorption and permeability.

**FIGURE 6 Average absorption coefficient versus NMAS and compaction methods.**

**Moisture Susceptibility**  
Specimens of similar air-void contents were selected in the moisture susceptibility test. The average indirect tensile strengths of the 16 types of specimens with and without moisture conditioning are shown in Figure 7. It can be seen that for the unconditioned specimens, the indirect tensile strength (“dry strength”) is generally higher for specimens from gyratory and Marshall compaction than those from the rolling wheel compaction. The kneading compaction is similar to the rolling wheel compaction in terms of dry strength for mixtures with 4.75-mm or
19-mm NMAS, but produces higher strength for mixtures with 9.5-mm and 12.5-mm NMAS. One potential reason for the relatively lower strength of the rolling wheel compacted specimens is that they were cored from slabs so that their sides have cut aggregate faces. Specimens compacted by other methods, on the other hand, have intact molded surfaces.

For the moisture-conditioned specimens, the indirect tensile strength ("wet strength") is generally still higher for specimens from gyratory and Marshall compactions than those from the rolling wheel compaction, but generally lower for specimens from the kneading compaction.

The tensile strength ratio (TSR) is shown in Figure 8. Specimens compacted by the rolling wheel compactor generally show higher TSR values than specimens compacted by other methods. Gyratory compacted and Marshall compacted specimens have similar TSR values for all sizes of aggregate gradations. The kneading compacted specimens showed similar TSR values to the gyratory and Marshall compacted specimens for the 4.75-mm and 19-mm NMAS mixtures, but showed lower TSR values than other compaction methods for the 9.5-mm and 12.5-mm NMAS mixtures.

The TSR values show that mixtures with 4.75-mm and 19-mm NMAS seem to have better resistance to moisture damage than mixtures with 9.5-mm and 12.5-mm NMAS. None of the four mixtures, however, can retain tensile strength over 80%, as recommended in ASTM D 7064. Visual examination of the broken faces of conditioned specimens did not reveal any stripping in the mix. The reduction in strength after moisture conditioning, therefore, may be attributed to the possible weakening of binder by moisture and/or change of aggregate skeleton structure due to the freeze-thaw cycle. The 24-hour conditioning at 60°C may introduce significant creep deformation in the porous mix even without water. This is verified by a small scale experiment in the laboratory, in which additional rolling wheel compacted 12.5-mm NMAS specimens were conditioned at 60°C for 24 hours without water and then tested for the indirect tensile strength. It was found that the strength was about 75% of that of unconditioned specimens. The validity of current test procedure for moisture susceptibility, therefore, needs further investigation.

**FIGURE 7** Average indirect tensile strength of unconditioned and conditioned specimens.
Resistance to Raveling
Resistance to raveling was evaluated by the Cantabro test. The average Cantabro loss values of unaged specimens are shown in Figure 9. The average air-void content of each type of specimen used in the test is very similar to the value shown in Figure 2. As can be seen from Figure 9, the amount of mass loss in the Cantabro test is highly correlated to aggregate size. The general trend is that larger NMAS leads to more material loss in the test. The Cantabro loss of mixture with 19-mm NMAS is high for all compaction methods, with the rolling wheel compaction producing specimens with the highest mass loss. For mixtures with 9.5-mm and 12.5-mm NMAS, gyratory compacted specimens showed the highest mass loss among four compaction methods. This is likely due to the relatively higher air-void contents in these specimens, as shown in Figure 2. This again verifies that less compaction energy is provided for the 9.5-mm and 12.5-mm mixtures in the Superpave gyratory compaction than in other compaction methods, as pointed out in the earlier section. There is no statistically significant difference among the other three compaction methods. For the mixture with 4.75-mm NMAS, there is no statistically significant difference among all four compaction methods.

Figure 10 shows the average Cantabro loss values of aged specimens. Generally aging makes asphalt binder more brittle, and therefore leads to more material loss in the Cantabro test. This can be observed by comparing the data in Figure 9 and Figure 10. Statistical analysis shows that after 7-day aging at 60°C, Superpave gyratory compacted specimens have more material...
loss than the rolling wheel compacted specimens, while specimens compacted by kneading and
Marshall compaction methods have statistically similar material loss to the rolling wheel
compacted specimens.

![Diagram showing average Cantabro loss from unaged specimens versus NMAS and compaction
methods.](image)

**FIGURE 9** Average Cantabro loss from unaged specimens versus NMAS and compaction
methods.

**Discussion**

Results of the study show that compaction effect varies with aggregate gradation and the
performance being evaluated. Depending on the type of mixture and the performance index to be
evaluated, different compaction methods may be chosen in the laboratory to better represent the
mixture placed in the field. Other considerations may also need to be taken when selecting the
compaction method in the laboratory. For example, unlike dense-graded mixes, the porous mixes
cannot be extruded from a mold shortly after compaction, otherwise the compacted specimen
will collapse under gravity. When multiple specimens need to be fabricated in a batch, which is a
typical case, it is better to have multiple molds to prevent long waiting period. The high cost of
gyratory compaction molds may then prevent the use of this compaction method in a laboratory
with limited budget. As another example, the Hveem kneading compactor compacts the mix by a
ram foot with a small bottom area, which may create stress concentration in aggregate particles
high enough to break the aggregate. This is particularly true for porous mixes because their
gradations contain mainly large aggregate particles. In fact, breaking and crushing of surface
aggregate have been frequently observed in the Hveem kneading compaction in this study.
CONCLUSIONS

This paper presents the results of a laboratory study on the effect of compaction methods on performance of porous asphalt mixes. Four compaction methods were compared on four porous asphalt mixes with NMAS varying from 4.75 mm to 19.0 mm. The following conclusions can be obtained from the study:

- Difference exists among performances of a porous asphalt mixture compacted by different methods. The compaction effect varies with aggregate gradation and the performance being evaluated.
- For porous mixes with 9.5-mm and 12.5-mm NMAS, gyratory compaction with 50 gyrations is less efficient in compaction than the Marshall compaction (50 blows on each side), Hveem kneading compaction, and rolling wheel compaction, and produces a specimen with higher air-void content and less resistance to raveling. For porous mixtures with 4.75-mm or 19-mm NMAS, gyratory compaction produces specimens with similar air-void contents to specimens compacted by the other three methods.
- For specimens with similar air-void contents, gyratory, Marshall, Hveem kneading, and rolling wheel compactions create similar void structure (in terms of permeability and sound absorption) for the 9.5-mm and 12.5-mm NMAS mixtures. For the 4.75-mm mixture, Marshall compaction produces the most open (i.e., most permeable and sound absorptive) void structure while the rolling wheel compaction produces the least open void structure.
• For moisture susceptibility evaluated by the indirect tensile strength ratio method, rolling wheel compacted specimens have lower dry and wet strengths, but higher TSR values than the specimens compacted by the gyratory or Marshall method.
• Mixtures with 4.75-mm and 19-mm NMAS seem to have better resistance to moisture damage than mixtures with 9.5-mm and 12.5-mm NMAS. The validity of current test procedure for moisture susceptibility of porous asphalt mixtures, however, is questionable. The 24-hour conditioning at 60°C alone may lead to creep deformation large enough to change the specimen structure.
• Resistance to raveling, as evaluated by the Cantabro test, is highly correlated to aggregate size. Generally larger NMAS leads to more material loss.
• Hveem kneading compaction may crush surface aggregates for porous asphalt mixtures with NMAS larger than 9.5 mm due to stress concentration.

Based on the above findings, it is recommended to select a compaction method for porous mixes based on the nominal maximum aggregate size. For mixes with small aggregates (4.75 mm or less), gyratory or Hveem kneading compaction can be used. For mixes with medium or large aggregates (9.5 mm or more), Marshall or gyratory compaction can be considered, while Hveem compaction should be avoided due to aggregate breakage.
For gyratory compaction on mixes with medium size (9.5 mm and 12.5 mm) aggregates, a fixed specimen height might be specified instead of a fixed number of gyrations. This needs further investigation.

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REFERENCES


