Characterization of Rutting Potential of Large-Stone Asphalt Mixes in Kentucky

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Large-stone mixes are becoming a popular means for reducing rutting in flexible pavements. Heavy concentration of aggregate interlock in large-stone mixes allows for efficient dissipation of compressive and shear stresses that are otherwise known to be responsible for rutting and shoving in flexible pavements. Mix design procedures and laboratory testing for characterization of rutting potential of large-stone asphalt mixes (LSAMs) in Kentucky are documented. A series of large-stone aggregate gradations was studied. In cooperation with the Kentucky Department of Highways and representatives of the asphalt industry, a promising aggregate gradation was selected. On the basis of the findings of this study, several test sections were constructed on coal-haul corridors throughout Kentucky. At this time, these LSAM sections have been in service for less than 1 year; therefore, any conclusion on the performance is premature. However, performance-oriented laboratory test results indicate that higher levels of structural capacity and rutting resistance, as compared with conventional hot mix asphalt, can be achieved by using LSAMs in flexible pavements.

In recent decades, pavement engineers have been challenged to use conventional methods to design cost-effective pavements that are expected to withstand unconventional wheel loads and tire pressures. In addition, the emphasis by many state agencies on postconstruction ride quality, as a check on quality control, has contributed to contractors' high regard for mixture handling and workability rather than long-term mixture performance. One can ask the following question: Are we designing asphalt mixtures that are easy to handle so we can mold them in the laboratory by using the available equipment, or are we designing our mixtures for performance while maintaining an open attitude for progress with regard to some of our conventional design methods? Unfortunately, most highway agencies are rigidly adhering to traditional mix design methods that are incapable of addressing current severe pavement-loading conditions. However, this is understandable, since performance-oriented standardized tests are not available.

As a possible solution to the problem of rutting on coal-haul roads in Kentucky, a series of large-stone aggregate gradations was studied. In cooperation with the Kentucky Transportation Cabinet, a promising aggregate gradation was selected. An in-depth research study was conducted to determine an optimum mixture design and to determine the rutting behavior of the optimum design.

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AGGREGATE GRADATION ANALYSES

The coarse aggregates used in this study were from Plum Run, Ohio. All were crushed limestone from the same quarry. The average gradations for these aggregates were supplied by the quarry and are given in Table 1. Unless otherwise noted, the aggregate gradation data are based on dry-sieve analyses. Two sand fractions were used in these analyses. The first was a natural washed sand from Plum Run, Ohio. The second was a crushed limestone sand from Kenmore, Kentucky.

Initially, 11 gradations were considered for laboratory testing. Each gradation was made by blending two or three coarse aggregates and one sand fraction. The blends were made within the Kentucky Class K specification limits. Figure 1 illustrates the Kentucky specification limits (*1*) for Class K large-stone mix.

After a thorough review of the literature and the state-of-the-art on LSAMs (*2–8*) and several discussions with representatives of the asphalt industry and the personnel of the Kentucky Department of Highways (DOH), it was decided to test only Blends 1, 1a, 2a, and 5a. The gradation distributions of these blends are depicted in Figure 2. These aggregate blends were selected to represent two groups: aggregate blends containing all crushed sand (Blends 1a, 2a, and 5a) and the aggregate blend containing all natural sand (Blend 1). The following sections present the results of a detailed mixture study that was conducted on the Louisa Bypass project.

MARSHALL MIX DESIGN

To accommodate the LSAM's aggregate size, 6-in. diameter modified Marshall specimens were compacted in the laboratory by using a 22.5-lb hammer. This was done partially on the basis of earlier work conducted by the Pennsylvania Department of Transportation (*9*), using 3.75 in. as the target height. On the basis of the ratio of volume to compactive effort, 112 blows of a 22.5-lb hammer on a 6-in. diameter specimen is equivalent to 75 blows of a 10-lb hammer on a 4-in. diameter specimen, and this was used as an interim guide for laboratory compaction of LSAMs by the Kentucky DOH.

TABLE 1 GRADATION OF AGGREGATE SOURCES

	PERCENT PASSING				
SOURCE	No. 4	No. 56	No. 78	Plum Run Sand	Kenmore Sand (1)
SIEVE					
2"	100				
1 1/2"	95	100			
1"	26	87			
3/4"	9	61	100		
1/2"	2	25	94		
3/8"	1	7	70		
4		3	11	100	92
8			3	88	72
16				58	52
30				34	44
50				19	36
100				8	25
200				4	16

(1) Wet Sieve Analysis.

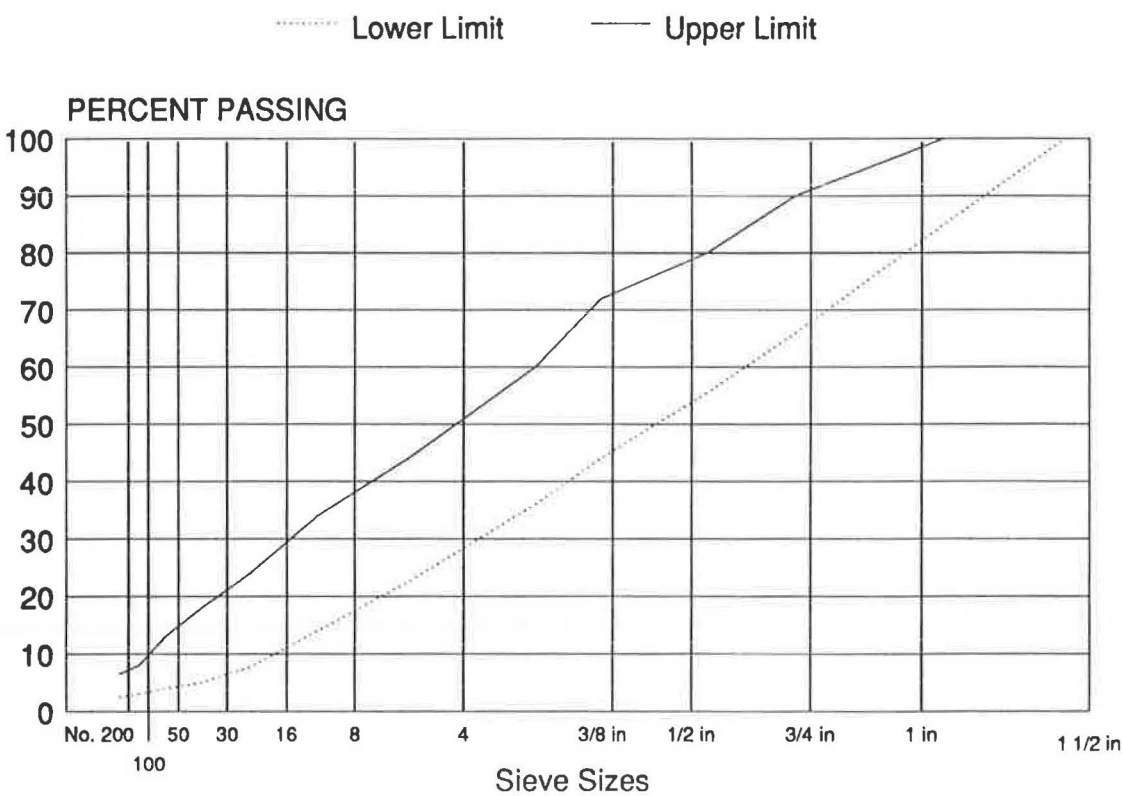

FIGURE 1 Gradation specification limits for Kentucky Class K (sieve sizes raised to 0.45 power).

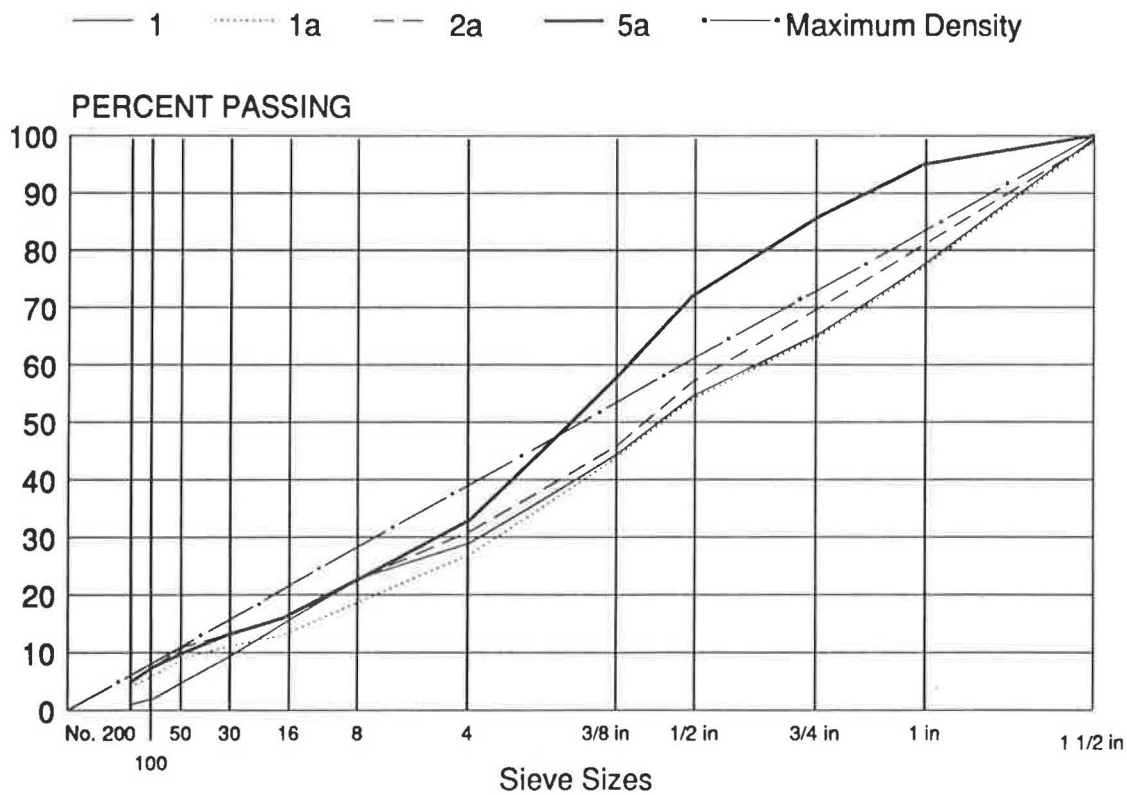

FIGURE 2 Trial large-stone gradations (sieve sizes raised to 0.45 power).

A comparison of density and air voids data obtained from LSAM cores (6-in. diameter by 12-in. height) and the laboratory-compacted specimens (6-in. diameter by 3.75-in. height and 6-in. diameter by 12-in. height) was conducted to verify the compaction efficiency of the modified 6-in. Marshall method. The 6-in.-diameter by 12-in.-high LSAM specimens were compacted in three 4-in. lifts based on weight/volume relationships and enough 22.5-lb blows to yield densities similar to the 6-in. diameter by 3.75-in.-high specimens. Results are presented in Figures 3 and 4, which demonstrate that target densities and air voids may be readily achieved by using the modified 6-in. Marshall method. As expected, the laboratory compaction procedures produced higher densities and lower air voids. The 6-in.-diameter by 12-in.-high pavement cores and laboratory-manufactured specimens were later tested for creep and permanent deformation.

In an effort to obtain high stability, the first trial specimen was compacted at 135 blows per side. This compaction was equivalent to 88 blows per side on a 4-in.-diameter standard Marshall specimen. It resulted in a high density (approximately 150 lb/ft^3) and a low void content. However, considerable particle crushing occurred. As a result, all remaining 6-in.-diameter specimens were compacted at 112 blows per side. Marshall mix design data are summarized in Table 2. From the mixture stability point of view, Blend 1a was recommended as the gradation of choice for large-stone construction in Kentucky (*10*).

Purely on the basis of similitude of the standard 4-in. Marshall specimen that may contain top-size aggregate of 0.75 in., the 6-in. Marshall should not include particles that are larger than 1.125 in. This may appear to be a point for concern regarding the type of LSAM that was used in Kentucky (Class K top size 1.5 in.). However, this is a minor concern because at least 95 percent of Class K particles pass the 1.5-in. sieve.

Realizing that not all bituminous laboratories have 6-in. diameter Marshall molds and testing capabilities, the U.S. Army Corps of Engineers (*11*) has recommended a procedure by which particles larger than 1 in. in diameter are removed from the gradation and replaced with particles ranging from 0.75 in. to 1 in. This procedure was conducted on both 4-in. and 6-in. diameter specimens, and the results are presented in Table 3. These data suggest that mix variables, such as density, air voids, voids in the mineral aggregate (VMA), and flow, were only slightly affected by this procedure. The mixture stability, however, exhibited a pronounced sensitivity to the large aggregate replacement procedure of the U.S. Army Corps of Engineers. It is therefore recommended that the gradation of LSAM not be altered to satisfy the requirements of the 4-in. diameter Marshall test unless verifiable stability correlations are available for the Corps of Engineers gradation adjustment procedure.

COMPRESSIVE STRENGTH

In addition to the conventional stability and flow tests, it was decided to conduct a series of mechanistic tests to better understand fundamental mechanical deformation characteristics of LSAM. These tests included compressive strength, creep and permanent deformation, and resilient modulus.

Because there was a lack of sufficient data on the effectiveness of the modified Marshall mix design procedure, as compared with other mix design procedures, it was decided to conduct a limited sensitivity study. The objective of this

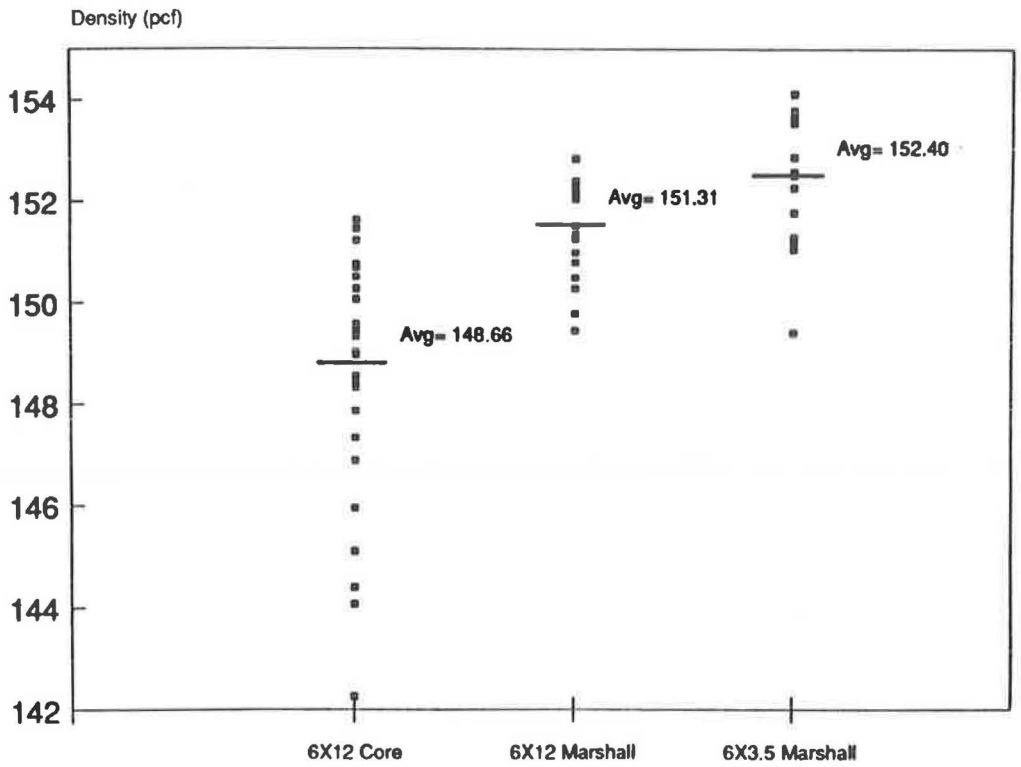

FIGURE 3 Laboratory and field density data for large-stone mixes.

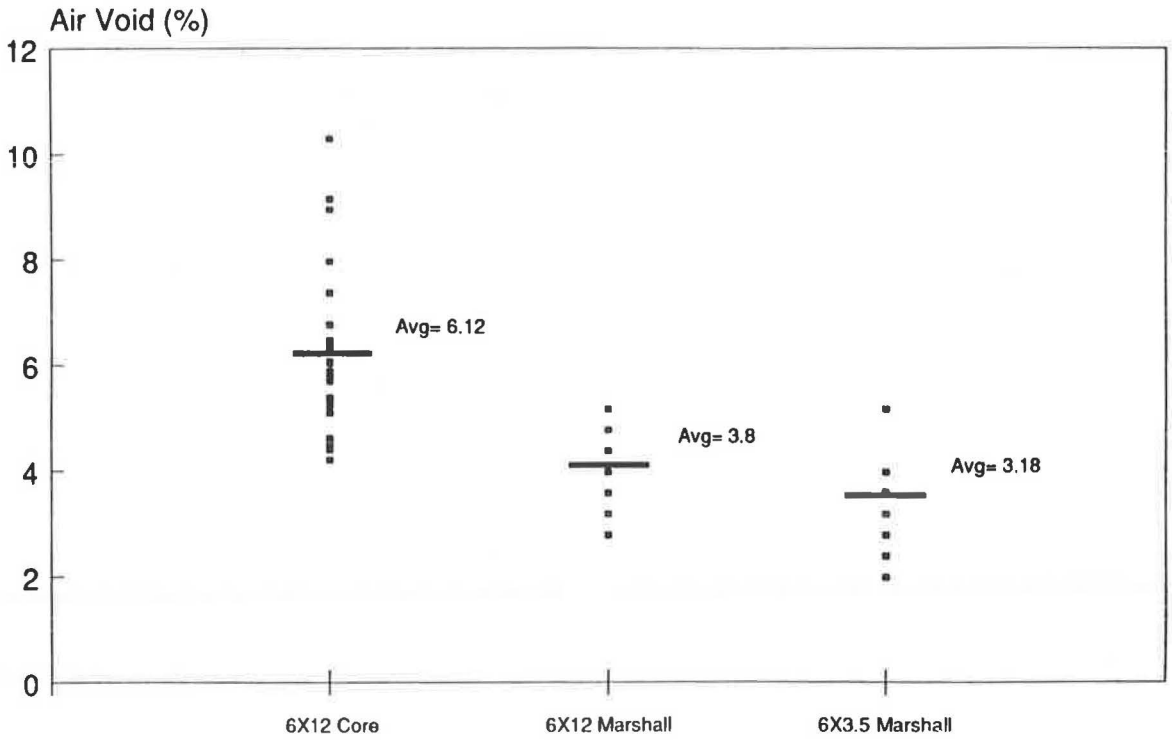

FIGURE 4 Laboratory and field air voids data for large-stone mixes.

TABLE 2 MIX DESIGN PARAMETERS FOR TWO KENTUCKY LSAM PROJECTS: LOUISA BYPASS AND MOUNTAIN PARKWAY

Mix Parameter (1)	Louisa Bypass	Mountain Parkway	Criteria
Stability, lb.	5,300	5,900	3,000 (min)
Flow, 0.01 in.	16	19	28 (max)
Air Voids, %	3.6	4.4	3.5 - 5.5
VMA, %	13.1	13.0	11.5 (min)
Retained Tensile Strength, %	Pass	Pass	70

(1) Data is based upon 6 inch diameter by 3.75 inch thick modified Marshall, specimens were compacted at 112 blows per side using a 22.5-lb. hammer.

TABLE 3 SUMMARY OF MARSHALL MIX DESIGN DATA

Mix Parameter (1)	Aggregate Blends					
	1	1a	2a	5a	1a (2)	1a (3)
Stability, lb.	5,100	5,000	5,200	4,500	4,100	2,850
Flow, 0.01 in.	22	20.5	26.5	23	20	14
Air Voids, %	5	4.7	4.3	4	4.3	4.5
VMA, %	12.6	11.5	12.2	14.5	12.4	13.2

(1) Data is based on 6-inch diameter by 3.75-inch thick modified Marshall specimens compacted at 112 blows per side using a 22.5-lb. hammer, unless otherwise indicated.

(2) U.S. Army Corps of Engineers, Method 103 (11), 6-inch mold 112 blows.

(3) U.S. Army Corps of Engineers, Method 103 (11), 4-inch mold, 112 blows

limited study was to quantify the sensitivity of the strength and deformation characteristics of the Kentucky Class K LSAM to variations in the asphalt content and method of compaction. Three different methods of compaction were used: 6-in. modified Marshall, vibratory, and kneading.

Unconfined compression tests are often used as index tests for determining the resistance of an asphaltic mixture to shear flow and permanent deformation (i.e., rutting and shoving). In this study, the compressive strength tests were conducted by researchers at the Asphalt Institute. Specimens were 6 in. in diameter and 6 in. in height. Unconfined compressive tests were conducted at 77°F and 0.05 in./min rate of loading. These data are presented in Figure 5, and they suggest that the method of laboratory compaction significantly influences the compressive strength of LSAMs. It is clear that the modified Marshall compacted specimens were sensitive to variations in the asphalt content, and this is desirable for mix design purposes. That is, a moderate peak in the LSAM compressive strength characteristics occurs in the neighborhood of the optimum asphalt content.

RESILIENT MODULUS

Elastic modulus is a measure of a material's response to load and deformation. The modulus of elasticity relates the forces

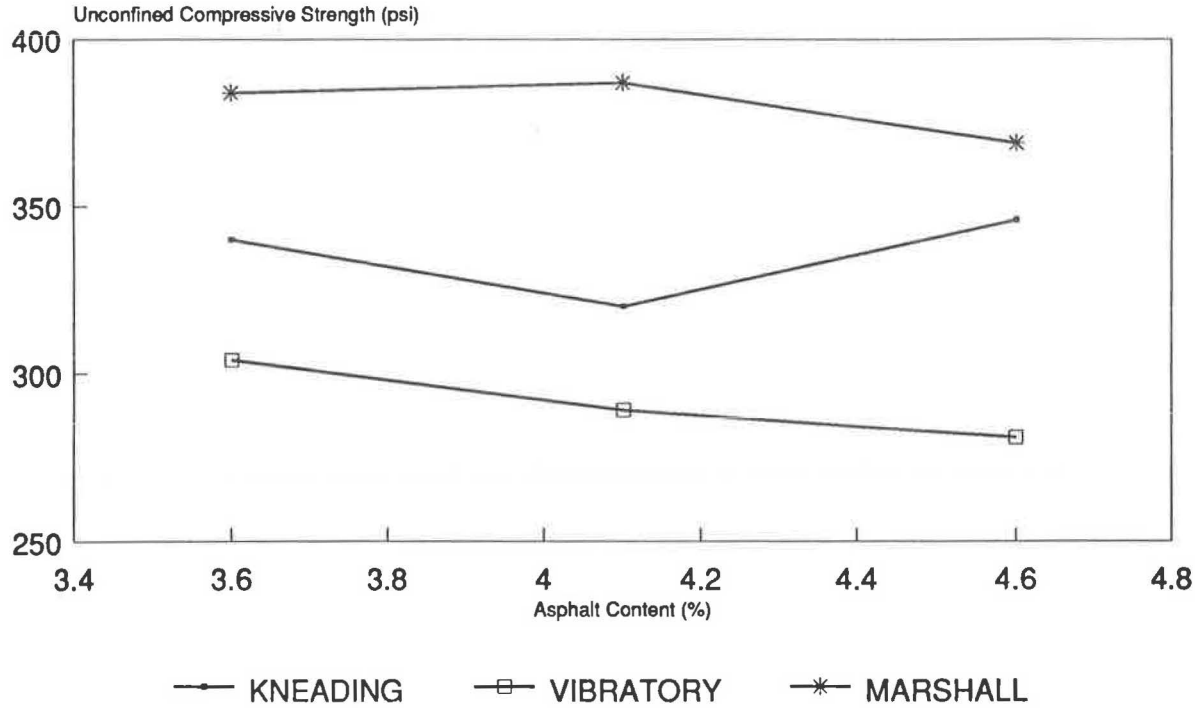

FIGURE 5 Compressive strength as a function of asphalt content and method of compaction for large-stone asphalt mixes.

causing deformation to the actual deformation. In pavement technology, the resilient modulus has long been used as a surrogate parameter for the elastic modulus because it lends itself to relatively simple testing procedures. For pavement design and analysis purposes, generally, higher moduli indicate more resistance to deformation and deflection and longer pavement life. A high modulus surface or base layer, or both, will also protect the subgrade from being overstressed, and, therefore, will reduce the probability of subgrade failure.

Characterization of the LSAM from a structural point of view was of great interest to the Kentucky DOH. In this regard, a series of resilient modulus tests was conducted at different temperatures to better understand the potential structural benefits of the LSAM. Chevron USA, Inc., at Richmond, California, participated in the resilient modulus testing program. The resilient modulus data over a range of temperatures are summarized in Figure 6. The data indicate that an LSAM pavement layer offers a higher level of structural capacity when compared with a conventional hot mix asphalt (HMA) layer of the same thickness. Therefore, large-stone mixes can be cost competitive in terms of their added structural capacity combined with their lower optimum asphalt content.

STATIC AND DYNAMIC CREEP

The Kentucky Transportation Center, University of Kentucky, conducted several creep tests on 6-in.-diameter by 12-in.-high pavement cores and on laboratory-compacted specimens of the same dimensions at 104°F. This mechanistic methodology is often used for characterizing permanent deformation. Both static and dynamic (cyclic repeated-load) creep tests were conducted at 29 psi. The static creep test consisted of monitoring the creep strain for 1 hr under a constant load of 29 psi. The dynamic creep test, however, was conducted under square-shaped, repeated-load pulses at 1 Hz. The resilient and permanent components of deformation were recorded. The data from both static and dynamic tests were merged to study permanent deformation characteristics of LSAMs under static and dynamic modes. This was possible under the assumption of linear viscoelasticity. For example, the cumulative creep deformation caused by a set of ten 1-Hz load pulses was assumed to be equivalent to the creep deformation caused by 10 sec of static creep load. The merged data are presented in Figure 7. The trends in Figure 7 indicate that the laboratory specimens, compacted by using the modified Marshall hammer, are less prone to permanent deformation than the LSAM pavement cores. This is because the higher densities are more readily achievable under laboratory conditions. The Class K LSAM was less susceptible to permanent deformation than the conventional Class I mix.

The stone-to-stone contact of aggregate particles in the LSAM reduces the probability of plastic flow owing to low air voids and/or high densities. Therefore, all mix design criteria that are commonly applied to conventional HMAs should be reexamined before extrapolating to LSAMs. The observation that the method of laboratory compaction significantly influences the mechanical behavior of the LSAM is consistent with the compressive strength data presented in Figure 5.

CONCLUSIONS AND RECOMMENDATIONS

Large-stone asphalt mixes offer a number of desirable properties for heavy-duty asphalt pavements. The LSAM prop-

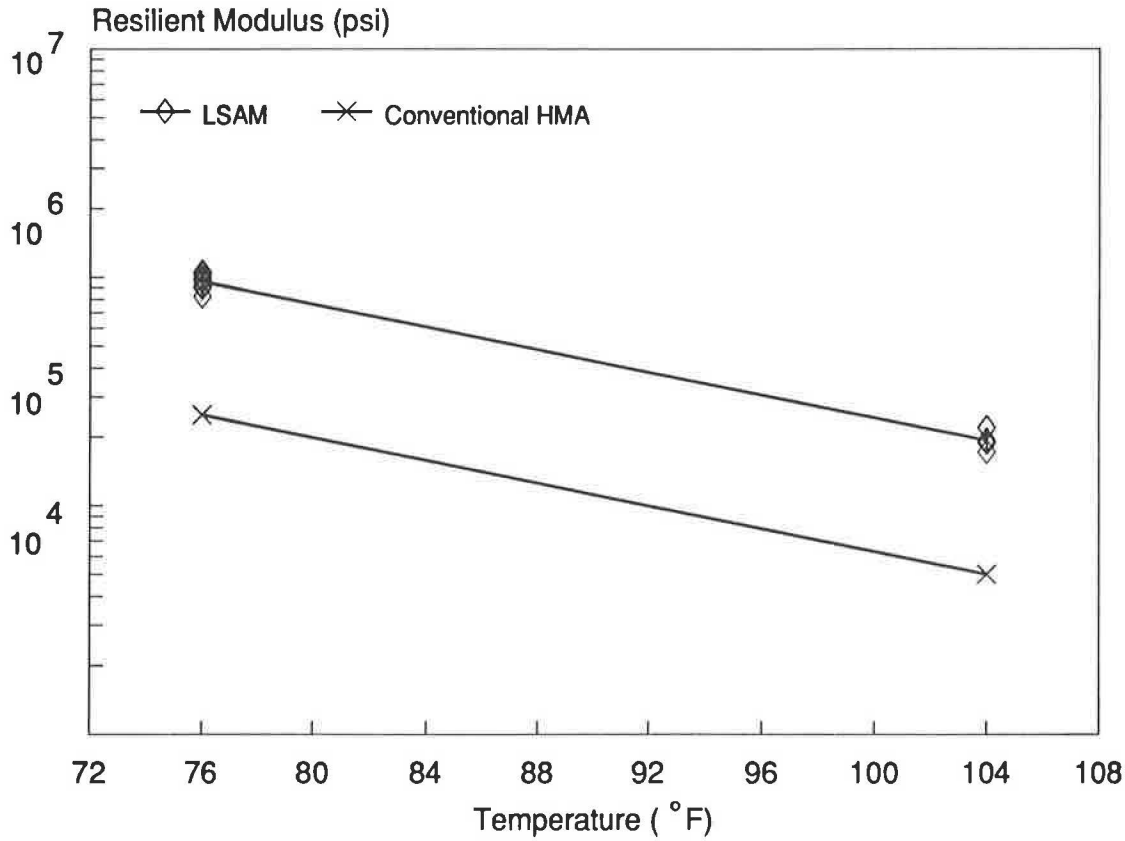

FIGURE 6 Resilient modulus as a function of temperature.

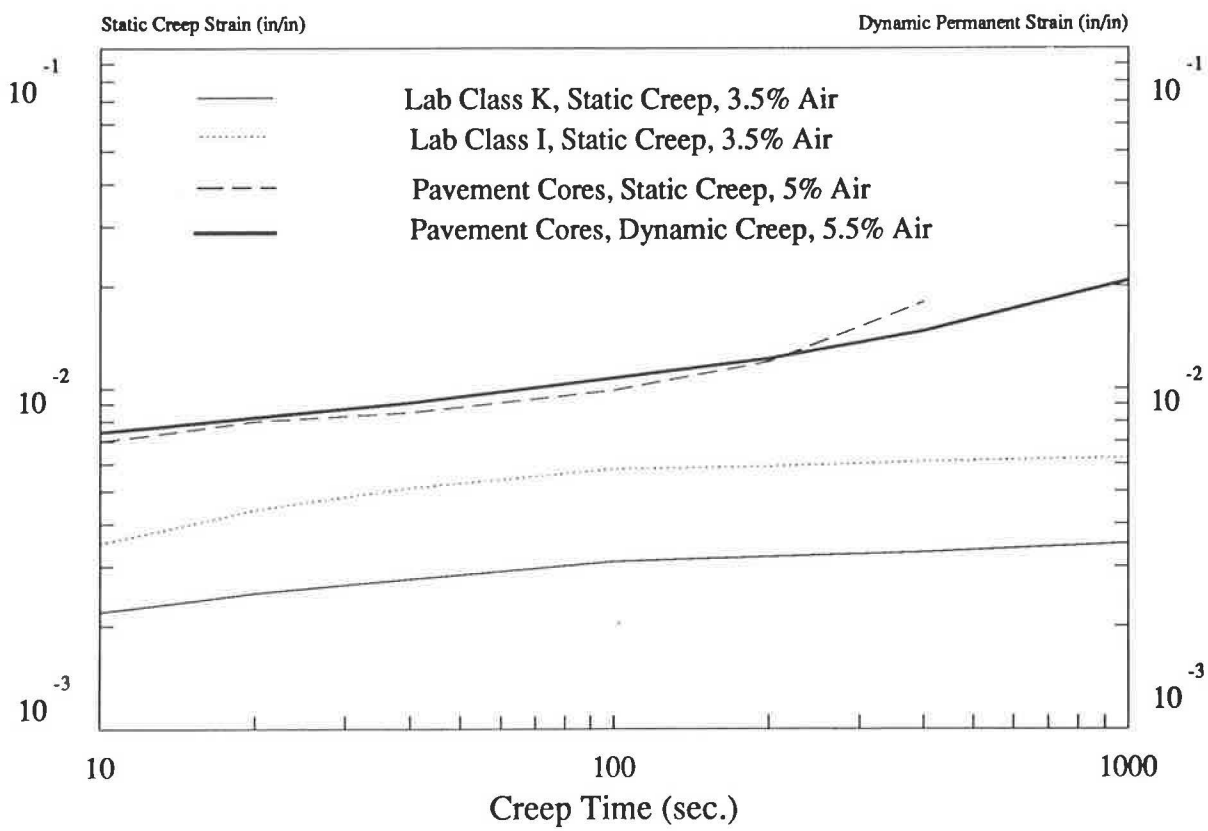

FIGURE 7 Creep and permanent deformation data for laboratory and field specimens at 104°F.

erties that receive high marks include stability, compressive strength, resilient modulus, and creep, all of which contribute to a more rutting-resistant mix. Large-stone mixes offer higher structural capacity at lower optimum asphalt content when compared with conventional mixes that makes them cost competitive. It was demonstrated that desirable densities and air voids can be readily achieved by using a modified Marshall compaction procedure.

It is recommended that large-stone gradations, such as Kentucky Class K, be used in heavy-duty HMA construction (*12*). The laboratory method of compaction has a significant influence on the mechanical properties of HMA. A standard method of laboratory compaction that would simulate the field compaction is needed.

Mix design and construction procedures for LSAMs are not fully developed. Further work based on the 6-in. diameter modified Marshall procedure is needed to standardize laboratory procedures for specimen preparation and testing.

ACKNOWLEDGMENT

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