Sensitivity of Strategic Highway Research Program A-003A Testing Equipment to Mix Design Parameters for Permanent Deformation and Fatigue

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A new comprehensive mix design methodology using compaction and mix evaluation procedures developed as part of the Strategic Highway Research Program A-003A research endeavor is presented. The methodology can be used within the framework of an analysis system to estimate the likely performance of the selected mix in service. Descriptions of specimen preparation using rolling wheel compaction, mix evaluation in fatigue using a third-point loading controlled-strain flexural fatigue test, and rutting (permanent deformation) evaluation using a newly developed simple shear test capable of testing specimens 0.15 m (6 in.) in diameter and 0.05 m (2 in.) high or 0.20 m (8 in.) in diameter and 0.076 m (3 in.) high in repetitive loading are included. The mix design framework is presented as a matrix that allows the effects of asphalt content and air void content to be evaluated separately. The results of an example mix design within this framework demonstrate the sensitivity of the new tests to these variables.

The scope of Strategic Highway Research Program (SHRP) Project A-003A, Performance-Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures, included the development of laboratory tests for asphalt-aggregate mixes. The tests permit the estimation of mix performance in situ. This paper presents some of the recommended procedures and equipment for specimen fabrication and evaluation of rutting and fatigue characteristics of an asphalt-aggregate mixture. It proposes that the effects of asphalt content and void content be individually evaluated and presents a mix design matrix for this purpose.

BACKGROUND

Specimen Preparation

For test results to be meaningful, specimens prepared in the laboratory must resemble as closely as possible in-service mixtures (i.e., those produced by mixing, placement, and compaction in the field and subsequently conditioned by traffic loads and aged by environmental influences).

The compaction method has been found to significantly affect the permanent deformation properties of dense-graded mixtures (*1,2*). Among the three compaction methods examined (California kneading, Texas gyratory, and rolling wheel), kneading specimens were generally most sensitive to aggregate characteristics and least sensitive to asphalt characteristics. Gyratory specimens were least sensitive to aggregate characteristics and only slightly more sensitive than rolling wheel specimens to asphalt characteristics.

The rolling wheel compactor has been recommended for use by the SHRP Project A-003A team, since it generally produces specimens whose permanent deformation characteristics lie between those of specimens produced by gyratory and kneading compaction and are within the range of those produced by field compaction. Moreover, specimens have homogeneous aggregate and air void structures and have all cut surfaces, and air void contents of compacted mixes can be reasonably controlled.

Rolling wheel compaction is a comparatively easy procedure to accomplish and enables rapid fabrication of a large number of specimens and a wide range of shapes and dimensions. Specimens for fatigue and permanent deformation can be cut or cored from the same slab. The procedure is also appealing because of its intuitive similarity to field compaction.

Fatigue

Fatigue resistance of an asphalt mixture is the ability to withstand repeated bending without fracture. Fatigue is one of the common forms of distress in asphalt concrete pavements and manifests itself in the form of cracking under repeated traffic loading. Cracking may initiate at either the top or bottom of an asphalt concrete layer, depending on the relative stiffness of the layers, tire pressure distribution and magnitude, pavement temperature profile, and so forth. In all cases fatigue has been directly associated with repeated application of tensile stresses or strains at a particular point in the asphalt-aggregate mixture.

Whereas there have been attempts to develop simplified representations of fatigue response (e.g., representative fatigue relationships, surrogate methods based on measurements of stiffness or dissipated energy, etc.), it is generally accepted that the fatigue resistance of a mix can be reasonably defined by the third-point bending beam fatigue test. In this

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test an imposed strain or stress is applied repetitively until failure occurs, either by complete fracture or by a significant reduction in stiffness. The fatigue behavior of a specific mixture can then be characterized by the relationship between level of stress or strain and the number of load repetitions to failure.

In the third-point bending beam repetitive flexure test used herein, a sinusoidally varying strain level is imposed in such a way that permanent deformation cannot occur. Variation of the magnitude of the stress is monitored, and failure occurs when an arbitrary but predefined reduction of stiffness occurs.

This test has been selected for the following reasons:

1. Specimen geometry: Beams 0.05 m (2 in.) by 0.063 m (2.5 in.) by 0.38 m (15 in.) can be readily obtained either from slabs sawed from existing pavements or from slabs prepared by rolling wheel compaction. With this geometry a relatively large section of the beam is subjected to a uniform flexural bending moment. The beam section is sufficiently large to accommodate maximum particle sizes used in actual mixes. The contribution to the deformation by shear stresses is negligible.
2. Repetitively applied loads: Although considerable progress has been made in fracture mechanics, given the relative magnitude of particle size and specimen size for the mixes used herein, a phenomenological approach is believed to produce more reliable results. Accordingly, application of repetitive strains (at different levels) has been used to define the fatigue mechanism experienced by pavements under traffic.
3. Mode of loading: Much discussion has been directed to the relative performance of mixtures in controlled-stress versus the controlled-strain mode of loading, with controlled-stress loading conditions applicable to comparatively thick and stiff asphalt-bound layers and the controlled-strain mode of loading applicable to thinner and more flexible asphalt-bound layers. Tayebali et al. suggest that the relative ranking of the mixtures in both modes of loading is the same when comparisons are made of the performance of various mixes in representative pavement structures (*3*). The controlled-strain mode of loading was selected for use in this investigation since the testing is easier to control in the laboratory (i.e., fatigue tests can easily be programmed and executed without accumulation of permanent deformation). (It is necessary to use a shift factor to translate the laboratory results to estimate field performance regardless of the mode of loading selected. The magnitude of this factor therefore can be defined according to the specific mode used.)

It was therefore necessary to develop a testing device that could be used in laboratories for routine fatigue testing. Such a device needed to provide for easier positioning and removal of specimens than existing equipment to minimize overall testing time, as well as provide more reliable results than have been obtained thus far (i.e., a lower coefficient of variation).

Rutting

Rutting (permanent deformation) in an asphalt-concrete layer is caused by a combination of densification (volume change) and shear deformations, both resulting from repetitive application of traffic loads. For properly compacted pavements, shear deformations caused primarily by large shear stresses in the upper portions of the asphalt-aggregate layers and below the edges of the passing tire are dominant. Repetitive loading in shear is considered essential to properly measure, in the laboratory, the influence of mixture composition on resistance to permanent deformation. Because the rate of permanent deformation accumulation increases rapidly at higher temperatures, laboratory testing should be conducted at the higher temperatures.

To predict permanent deformation, laboratory tests must be capable of measuring properties under states of stress that are encountered within the entire rutting zone, particularly near the pavement surface. Since there are an infinite number of states of stress, it is impossible to simulate all of them with a single test. Moreover, the nonlinear behavior of the material makes the estimation of stress conditions more difficult. Accordingly, several tests have been proposed to determine a constitutive law for asphalt concrete, which are necessary to determine these stresses for a range in traffic conditions (see paper by Sousa, Weissman et al. in this Record). To rapidly screen and evaluate the resistance of various mixtures to permanent deformation, it appears desirable to use a single test rather than the battery of tests noted above, with the requirement that it be sensitive to the most important aspects of mix behavior.

A test that appears to meet this requirement is the constant height repetitive simple shear test on cylindrical specimens, for the following reasons:

1. Specimen geometry: A specimen 0.15 m (6 in.) in diameter by 0.05 m (2 in.) high can be obtained readily from a pavement section by coring or can be produced by compaction methods proposed by SHRP (i.e., gyratory or rolling wheel compaction). The state of stress is relatively uniform for the loads applied. The magnitude of loads required to test specimens of this size is easily attained by servohydraulic loading equipment.
2. Rotation of principal axes: It is the simplest test that permits controlled rotation of principal axes of strain and stress, which are important in studying rutting.
3. Repetitively applied loads: Studies have suggested that repetitive rather than creep loading is required to define the propensity of mixes to permanent deformation. The difference has, in part, been attributed to the viscoelastic characteristics of different asphaltic binders.
4. Dilation: An important factor controlling the resistance of a mix to permanent deformation is dilation. Under shear strains, densely compacted mixes tend to dilate (as to dense sands). If dilation is constrained (as it is to some degree by the adjacent material in the pavement), confining stresses are generated. It is in part due to the development of these confining stresses that a mix derives its resistance to shear strains, and mixes with little tendency to dilate will have a higher propensity for rutting. In the constant height simple shear test the development of axial stresses is dependent on the dilatancy characteristics of the mix, with the amount of axial stress depending on the aggregate type, structure, texture, and void level. The two primary mechanisms that resist permanent deformation of a mix during the test are the stiffness of the asphalt binder and the increased stability in the aggregate

structure imparted by axial stress generated by dilation. (It is possible that mixes containing some modified binders can have additional dilation forces caused by modifier dilatancy resulting from shear strain rates.)

A well-compacted mix with a good granular aggregate will develop a high axial stress at very small shear strain levels. Poorly compacted mixes can generate similar levels of axial stresses but require much higher shear strains to do so.

Stiff binders assist in resisting permanent deformation, since the magnitude of the shear strain is less for each load application compared with mixes containing low stiffness binders, and the rate of permanent deformation accumulation is directly related to the magnitude of the shear strain.

Because both of these mechanisms contribute to the resistance of a mix to permanent deformation in the constant height simple shear test as well as in the field, evaluation of the permanent deformation resistance of an asphalt-aggregate mix is believed to be a suitable test.

The execution of a constant height repetitive simple shear test required the design and fabrication of totally new equipment. Taking into consideration that this test would be performed on a routine basis, considerable effort was made to ensure the easiest possible interface with the user.

EQUIPMENT AND TEST DESCRIPTIONS

Compaction Equipment

Two types of compaction equipment have been proposed for inclusion in the SHRP mix design specimen preparation procedure: (*a*) gyratory compaction for the majority of mix evaluations and (*b*) rolling wheel compaction for situations in which prismatic (fatigue specimens) might be required. Two slightly differing methods have evolved from the SHRP A-003A research program, one at the University of California at Berkeley (UCB) and the other at Oregon State University (*4*). The UCB rolling wheel compaction method was used to prepare all specimens for the investigation reported herein.

The UCB rolling wheel compactor, shown in Figure 1, is a commercially available single steel wheel roller weighing approximately 550 kg (1,200 lb). The roller is operable as a vibratory compactor but is only used in the static mode in the UCB method.

The compaction mold used at UCB is made of layers of plywood covered with ¼-in. steel plates for durability. The height of the one lift is .075 m (3 in.), with the length and width being adjustable. The sides of the mold have a 4:1 slope to prevent material being trapped uncompacted in the bottom corners of the slab. For compaction as a part of the mix design process a steel plate insert is used to divide the mold into three cells 0.15 by 0.60 m (6 by 24 in.).

All aggregates are assembled in 7-kg (14.5-lb) batches and mixed using a commercially available mixer. The mixed materials are placed in steel pans until heated for compaction. Each cell or "ingot" weighs approximately 20 kg (45 lb) and provides two fatigue beams and one permanent deformation specimen, or three permanent deformation specimens.

After the compacted mix has cooled overnight, specimens are obtained by coring or cutting (see Figure 2). Commercially available coring machines and saws are used to obtain the cores and make the first cut on the fatigue beams. A double-blade saw developed at UCB, shown in Figure 3, is used to cut the cores and fatigue beams to their final dimensions. The use of two simultaneously operating blades results in greater precision in making the faces of the cores and beams parallel, a requirement to ensure good test results. (However, acceptable precision has been obtained using a conventional single-blade saw.)

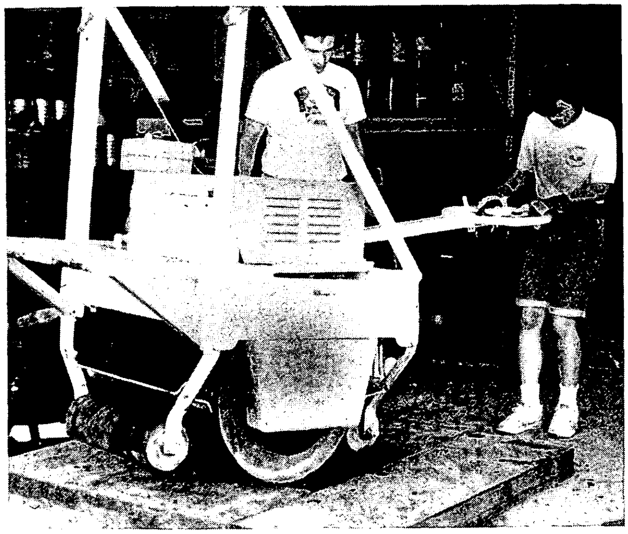

FIGURE 1 View of the mold and rolling wheel as part of the UCB compaction procedure.

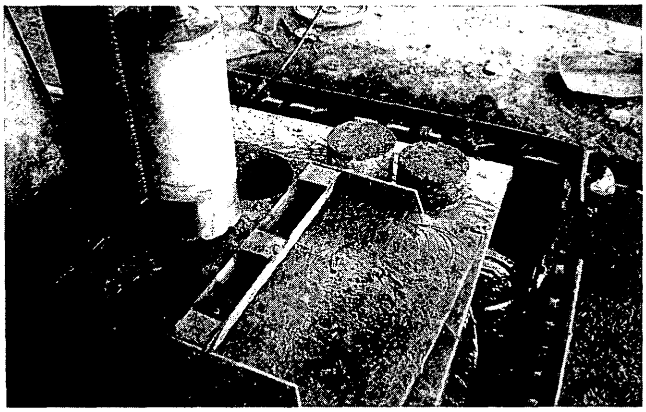

FIGURE 2 View of a small asphalt-aggregate mixture slab "ingot" being cored.

Compaction Procedure

Rolling wheel compaction involves calculation of the mass of material to be compacted within a mold of known volume. First, the maximum specific gravity of the mixture is determined by the Rice method (ASTM D 2041). Second, the volume of the compaction mold is measured. These two values are then used with the desired air void content to determine

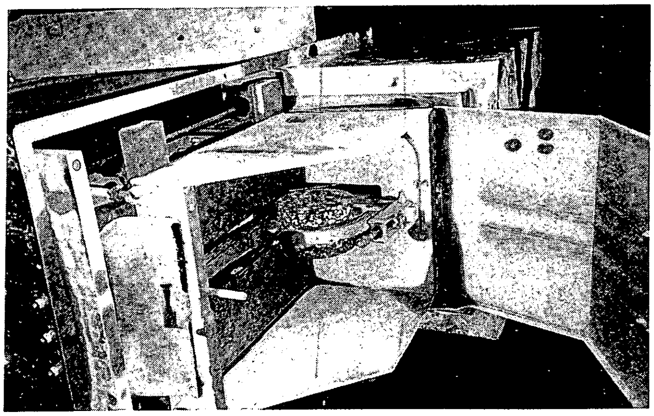

FIGURE 3 Two-blade saw used in the fabrication of cylindrical and beam specimens.

FIGURE 4 General view of the UTM constructed by James Cox and Sons, Inc.

the mass of material to be placed in the mold, rodded, and compacted to the measured volume. The compactor is passed repeatedly over the mixture until it is compacted level with the top of the mold. Several mixtures of different air void contents or different asphalt contents can be compacted simultaneously in the three cells of the mold.

Alternatives

If no fatigue beams were required for the mix design analysis, the amount of material required to produce 36 permanent deformation specimens using rolling wheel compaction would be approximately 250 kg (550 lb), with 3 days of preparation time. Approximately 2 additional days of preparation time would be required to produce the 16 fatigue beams.

In comparison, and assuming that each specimen had the correct measured air void content, approximately 200 kg (440 lb) of material would be required to produce the same 36 specimens using a gyratory compactor. The compaction time for the gyratory compactor would depend on the number of compaction molds available. The mixing, coring, cutting and air void content measurement time would be approximately the same as for rolling wheel compaction.

Testing Equipment

SHRP Project A-003A has developed and installed a newly designed materials testing system termed the Universal Testing Machine (UTM) because of its comprehensive testing capabilities and accommodation of add-on testing modules (see Figure 4). The equipment, manufactured by James Cox and Sons, Inc., Colfax, California, accommodates testing modules for permanent deformation, fatigue, and stiffness testing. A microcomputer using the ATS software (*5*) provides feedback closed-loop control to the servohydraulic system, confining pressure, test temperature, and data acquisition.

Fatigue

The beam testing module can be hydraulically clamped in the UTM for testing beam fatigue specimens, which are placed in the device and secured by electric geared motors. The fatigue module allows testing of beams with maximum dimensions of 0.05 by 0.063 by 0.38 m (2 by 2.5 by 15 in.), as shown in Figure 5.

The fatigue beam device can also be used as a stand-alone system using the same hydraulic pump and control console. This approach frees the UTM for stiffness testing (frequency and strain sweeps) and permanent deformation testing.

Specimen temperature is maintained by circulating air directly around the specimens, minimizing the time required to reach equilibrium temperature. The environmental chamber unit, an integral part of the stand-alone equipment, can provide accurate temperature control over a wide range of temperatures, −20°C to 70°C (−4°F to 158°F), with an accuracy of 0.5°C (0.9°F), as does the UTM. [Fatigue testing would normally be done at temperatures less than 30°C (85°F).]

The fatigue beam device allows the fatigue characteristics of mixes to be defined over a wide range of temperatures and loading conditions. The loading conditions include both the controlled-load and controlled-deformation modes under step, haversine, sinusoidal, or other predefined loading patterns at frequencies up to 20 Hz. In addition, this equipment can be used to define the frequency response of a material over a wide range of temperatures, frequencies, and strains in flexure.

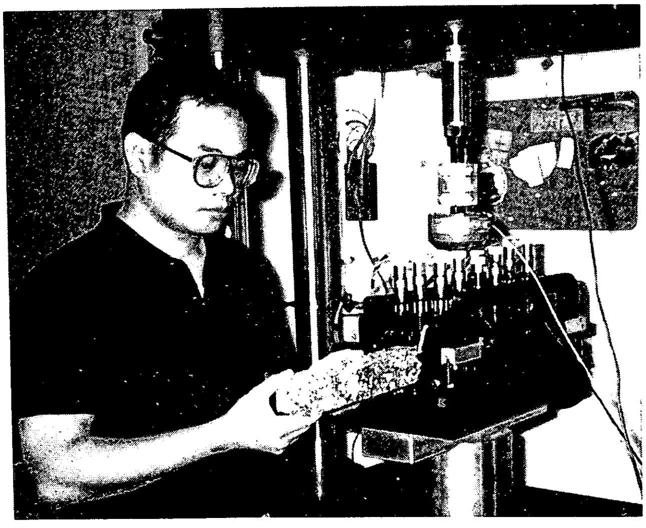

FIGURE 5 Four-point bending beam fatigue test module for the UTM.

Results from SHRP Project A-003A associated with characterization of fatigue behavior of mixtures suggest that use of the new equipment has considerably improved the reliability of results compared with those obtained with earlier devices. For example, the coefficient of variation in the fatigue data has improved from about 70 percent using the old equipment to 40 percent using this new device. Good reliability can be obtained with as few as 4 specimens, compared with the 21 to 26 reported in the literature.

Permanent Deformation

One of the developments resulting from SHRP Project A-003A is the capability of determining properties of an asphalt-concrete mixture in the simple shear mode. The device is capable of determining stiffness and permanent deformation characteristics in shear over temperatures from 0°C to 60°C (32°F to 140°F), a range in which stiffness moduli vary by three orders of magnitude.

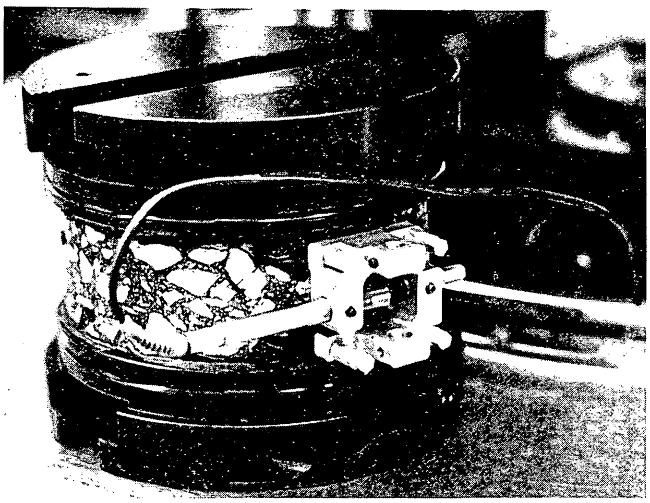

FIGURE 6 Shear specimen (6 in. in diameter by 2 in. high) with caps glued.

The testing system consists of two orthogonal tables mounted on bearings. The tables are connected to two hydraulic actuators, which are controlled using servovalves under feedback closed-loop digital algorithms. To ensure that the shear and axial forces are transmitted to the specimen, aluminum caps are glued to the parallel faces of the specimen. A gluing device developed by James Cox and Sons, Inc., is used to ensure that the faces of the caps are glued parallel. Hydraulic clamps ensure an easy interface with the user by eliminating the need to use tools to fasten the specimens to the loading tables (Figure 6).

To execute a repetitive simple shear test at constant height, the vertical actuator maintains the height of the specimen using as feedback the output of an LVDT, which measures the relative displacement between the specimen caps. The horizontal actuator applies haversine loads under control by the shear load cell. For this study a loading time of 0.1 sec and a rest period of 0.6 sec were used with a shear stress level of 69 kPa (10 psi). For this study a temperature of 60°C (140°F) was used.

EXPERIMENT DESIGN

In the Marshall and Hveem mix design methods, a fixed compaction effort is applied to mixtures with varying asphalt contents, resulting in a test program involving combinations of asphalt content and air void content, as indicated in Table 1. The two variables cannot be evaluated individually because they are dependent on each other. The disadvantage of this

TABLE 1 Typical Values of Asphalt Content and Void Content Obtained from a Mix with Watsonville Aggregate and Valley Asphalt Using the Hveem or Marshall Method of Compaction

	asphalt content %						
	A	B	C	D	E	F	G
void content %	4.00	4.25	4.75	5.25	5.75	6.25	6.50
0 (0%-3%)						Marshall 2.6	
1 (3%-4%)				Marshall 3.6	Marshall 3.2		
2 (4%-5%)							
3 (5%-6%)			Marshall 5.5				
4 (6%-8%)		Marshall 7.7					

TABLE 2 Matrix of Asphalt Content and Void Level Used in the New Mix Design Framework

void content %	asphalt content % A 3.1	B 4.2	C 4.5	D 4.9	E 5.3	F 5.5	G 6.0
0 (0%-2.5%)							
1 (2.5%-4%)			M1C 2.9	M1D 2.9		M1F 3.0	M1G 2.6
2 (5%-6%)			M2C 5.0	M2D 4.9		M2F 5.3	M2G 5.0
3 (6%-7%)							
4 (7%-9%)			M4C 7.8	M4D 7.6		M4F 8.1	M4G 8.9

type of approach is that the standard compaction method used for specimen preparation may be less or more than can be achieved by the contractor under the circumstances of the individual project. The effects on pavement performance of higher or lower degrees of compaction, and to some extent the effects of the variations in asphalt content, cannot be evaluated from the mix design. To overcome these problems a new mix design procedure is proposed in which both the asphalt content and air void content are varied, resulting in a rectangular matrix, as indicated in Table 2. This framework allows the effects of asphalt content and air void content to be evaluated individually and allows for a range of possible combinations. In this approach the compaction effort is varied for each cell (asphalt content–void content combination).

An example experiment design was carried out for this paper for two reasons: to determine (*a*) whether SHRP Project A-003A testing equipment and test procedures were sensitive to variation in mix parameters and (*b*) whether significant changes in fatigue and permanent deformation performance could be detected using the new mix design procedure when air void content and asphalt content are varied independently.

SPECIMEN FABRICATION

Materials

Aggregate RB (Watsonville granite) and an AR-4000 asphalt (asphalt AAG-1) were the materials selected for this example. The RB aggregate is completely crushed, has an angular shape, and is composed mostly of medium-grained quartz with dark areas of feldspar. It has been used in a large number of SHRP experiments.

The asphalt contents included in the design for this paper were 4.5, 4.9, 5.5, and 6.0 percent (by weight of aggregate), and the air void contents were 2 to 4.5 percent, 5 to 7 percent, and 8 to 10 percent [measured using parafilm (*6*)] (see Table 2). The materials were mixed at 137°C (280°F) and compacted at 116°C (240°F).

Three shear specimens 0.10 m in diameter by 0.05 m high (4 in. by 2 in.) were prepared for each cell using the UCB rolling wheel compaction method. Three or four fatigue beams were prepared for four of the cells around the perimeter of the matrix. [Shear specimens 0.10 m (4 in.) in diameter were used because the permanent deformation testing machine was still being fabricated for the proposed standard specimens 0.15 m (6 in.) in diameter.]

Material Quantities

Assuming that all of the specimens compacted for each of the 12 cells of the design matrix had the target air void content, approximately 420 kg (900 lb) of mix would be required to provide the 36 permanent deformation specimens [0.15 m (6 in.) in diameter] and 16 fatigue beams. In practice, some small adjustments may be required in the weight-volume calculations to achieve the desired air void content of some cells. The amount of adjustment required is reduced as experience is gained with a given aggregate.

Duration

For this investigation specimens were prepared in only two of the three cells in the compaction mold to prevent material passing from one cell to another (a slightly greater distance between cells in the mold will eliminate this problem). Thus, using two molds and allowing for overnight cooling, all specimens could be compacted in 5 days, assuming no adjustments were required. Coring and cutting require approximately 1 hr, and air void content measurement using parafilm requires approximately 30 min for each cell.

TEST RESULTS

Air Void Content

The air void contents for the specimens used in this study measured using parafilm and the maximum effective specific gravity (ASTM D 2041) are given in Table 2. The use of parafilm, or some other suitable method, is required for the high air void content specimens included in the design matrix. Otherwise, with water entry and the interconnection of pores in these specimens, the weight-in-water measurement for bulk specific gravity would be meaningless.

Fatigue

The fatigue characteristics of asphalt mixtures are usually expressed as relationships between the initial stress or strain and number of load repetitions to failure. An energy approach—based on a relationship between the cumulative dissipated energy and the number of cycles to failure—has also been used to characterize fatigue behavior of asphalt mixtures. Conventionally, in order to establish these relationships repeated flexure, direct tension or diametral tests are performed at several stress or strain levels requiring up to 36 specimens and 3 to 4 weeks of testing time.

The new fatigue device enables characterization of any given mix within a relatively short time and requires fewer specimens without sacrificing the reliability of the results. With this short procedure, fatigue tests would be performed at a given temperature and at relatively higher frequency (10 Hz) over a range of strain levels (strain levels that will give a fatigue life varying between 5,000 and 500,000 cycles), permitting fatigue response to be developed. Interpretation of the results can be established by either the conventional method (i.e., log-strain versus log-cycles to failure relationship) or by use of dissipated energy expressed in terms of log-initial dissipated versus log-cycles to failure or log-cumulative dissipated energy versus log-cycles to failure.

For typical mixtures containing conventional asphalt binders, this procedure requires approximately 24 hr to ascertain whether a mix is suitable for the intended pavement application. It is conducted by testing a minimum of four beam specimens in the controlled-strain mode of loading at 10 Hz. For atypical mixtures (e.g., mixtures with gap-graded aggregates) or mixtures containing modified binders, full fatigue testing with more than four specimens is recommended.

The short test procedure is as follows:

1. Conduct a test at a fairly high strain level such that the specimen will last for 5,000 to 10,000 cycles. For example, one could start a test at a strain level in the range 800×10^{-6} to 1000×10^{-6} in./in. and determine the life. If the life is higher than 10,000 cycles, increase the strain level for the second specimen. If it is lower, reduce the strain level. Two tests at these strains will take about 2 hr.
2. From the first two tests a crude estimate of the slope of the log-strain versus log-cycles relation can be determined. Use this relationship to estimate the strain level that will provide a fatigue life around 100,000 cycles. This test will take about 4 hr.
3. Reestablish the log-strain versus log-cycles relationship from Step 2 and estimate the strain required for the test to fail at 400,000 to 500,000 cycles. This test will take 13 to 15 hr. However, this long test can be done at the end of the day (about 5 p.m. or earlier if the other three tests have been completed) and be left to run overnight. The specimen will have reached its fatigue life by the next morning.

Figures 7 to 9 show the results of the fatigue tests for mixes containing 4.5 and 6.0 percent asphalt content (by weight of aggregate) and different air void contents. Figure 7 shows the plot of strain versus number of cycles, Figure 8 shows the initial dissipated energy per cycle versus the number of cycles, and Figure 9 shows the cumulative dissipated energy (*7*) versus the number of cycles. Table 3 compares fatigue life for these mixtures at the 400×10^{-6} in./in. strain level. It can be seen that by increasing the asphalt content from 4.5 to 6.0 percent, the fatigue life increased by about 70 percent. Increasing the air void content from the range of 4 to 5 percent to 7 to 9 percent resulted in a reduction of fatigue life of about 40 percent.

The fatigue test results illustrate that the fatigue performance of mixes can be evaluated in a relatively short time period using the improved fatigue equipment and procedure without compromising the reliability of the test results.

Permanent Deformation

Simple shear repetitive load tests wherein specimen height was maintained constant were performed, and for each of the tests the number of load repetitions to reach 3 percent permanent shear strain was computed. A plot of the accumulation of permanent deformation with load repetitions is shown in Figure 10 for some of the cells of the new mix design matrix. The slopes and intercepts of the lines vary with air void content and asphalt content. The best performance was obtained between cells M1D and M1F, indicating an optimum asphalt content between 4.9 and 5.5 percent by weight of aggregate. Interestingly, 4.9 percent was the asphalt content previously obtained from the Hveem mix design method for this aggregate and asphalt, and 5.5 percent was the asphalt content obtained from the Marshall method.

A three-dimensional plot of the variation of repetitions to reach 3 percent permanent shear strain with air void content and asphalt content is shown in Figure 11. The air void content is an important mix variable in the design process. Asphalt content plays a role in optimizing that performance not only by the viscosity level at a given test temperature and rate of loading, but also during specimen fabrication (*2*). These results show that the constant height repetitive simple shear test is sensitive to mixture variables and that asphalt content and air void content influence the results in accordance with experience. It is particularly interesting to note the sharp decease in resistance to permanent deformation for mixes with very low void contents.

Recognizing that the results of the constant height repetitive simple shear test suggest an optimum asphalt content similar to that which would be obtained from the Hveem method in this instance, one could ask, Why use this more comprehensive procedure? There are cases in which the Hveem stabi-

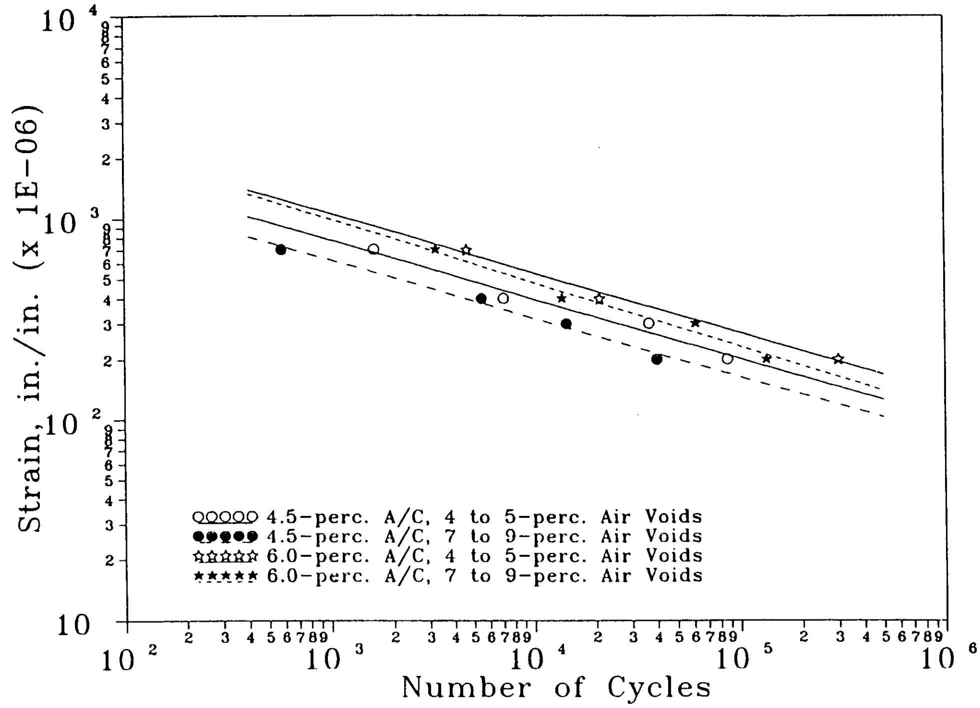

FIGURE 7 Comparison of fatigue life in terms of strain level versus the number of cycles to failure for four asphalt-aggregate mixtures.

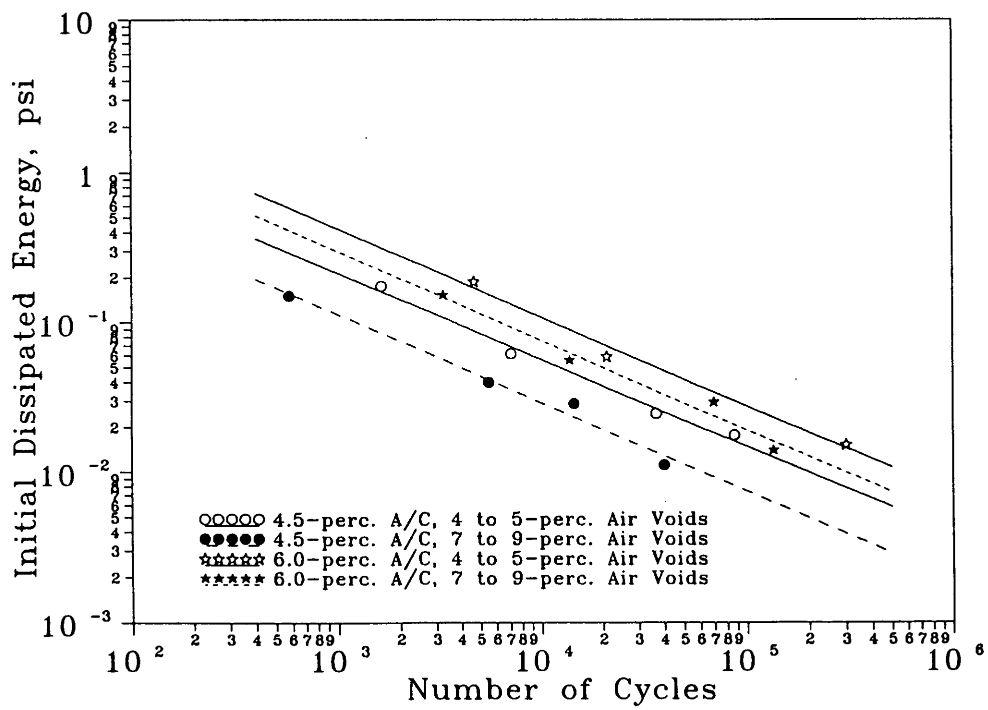

FIGURE 8 Comparison of fatigue life in terms of initial dissipated energy versus the number of cycles for four asphalt-aggregate mixtures.

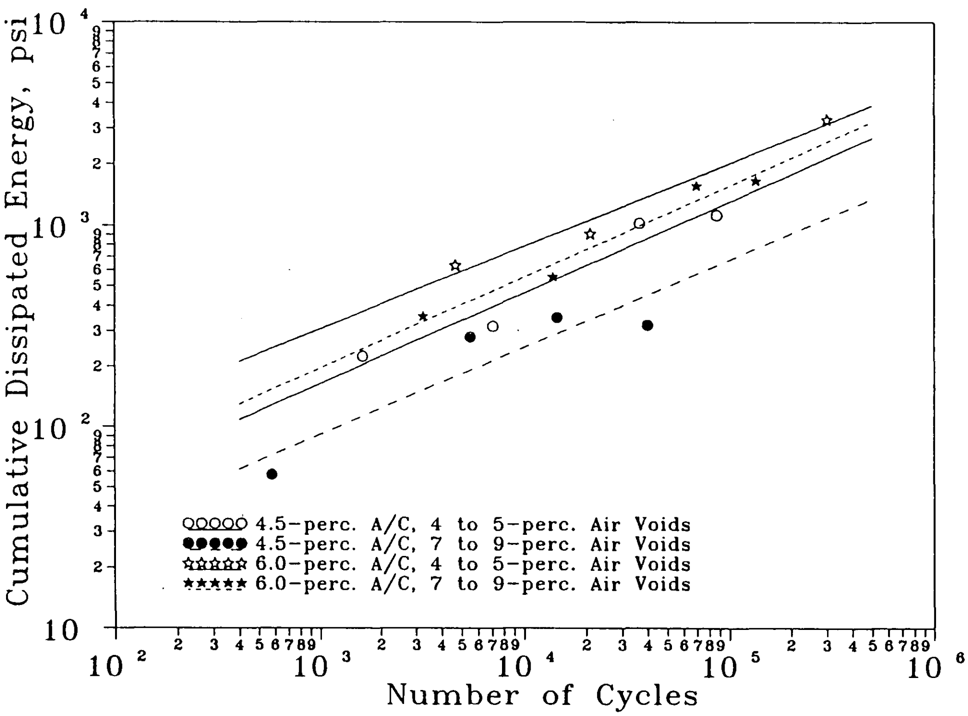

FIGURE 9 Comparison of fatigue life in terms of cumulative dissipated energy versus the number of cycles for four asphalt-aggregate mixtures.

TABLE 3 Fatigue Life (Number of Cycles to Failure) at 400 μin./in. Strain Level

		Air Voids (%)		Percentage Diff.
		4-5	7-9	
Asphalt Content (% by wt. of mix)	4.5	9700	4500	54
	6.0	26500	18100	32
Percentage Diff.		63	75	

Note: percentage difference is the difference expressed as a percentage of larger value

lometer test has shown no difference in performance when modifiers have been used, while the constant height repetitive simple shear test produces results that follow engineering expectations (*2,8,9*). This test can also be used for evaluating large stone mixtures, since specimens 0.20 m (8 in.) in diameter by 0.076 m (3 in.) high can be accommodated. Another major advantage of the new procedure is the capability of obtaining properties in engineering units, which can in turn be used in performance prediction models.

INTEGRATION OF MIX DESIGN PARAMETERS INTO STRUCTURAL DESIGN AND PERFORMANCE ESTIMATION

Figure 12 shows a framework for a mix design and analysis system that has been suggested by SHRP researchers (*10*). Essentially the procedure requires that the specific distress mode under consideration—fatigue, rutting, or thermal cracking—be evaluated using the results of the accelerated performance test within the context of a specific pavement section, environment, and anticipated traffic loading.

To examine the propensity for fatigue cracking, data like those shown in Figures 7 through 9 can be used in a performance prediction model (such as those being developed as part of SHRP Project A-005) that is analytically based. If the results of the computations show that the mix exhibits cracking before the expected performance life is obtained, either the thickness of the layer can be increased or the mix can be redesigned.

In the case of rutting, results of the accelerated performance test (e.g., constant height repetitive simple shear test) would initially be used within the framework of an abridged analysis system to ensure that the estimated rut depth does not exceed

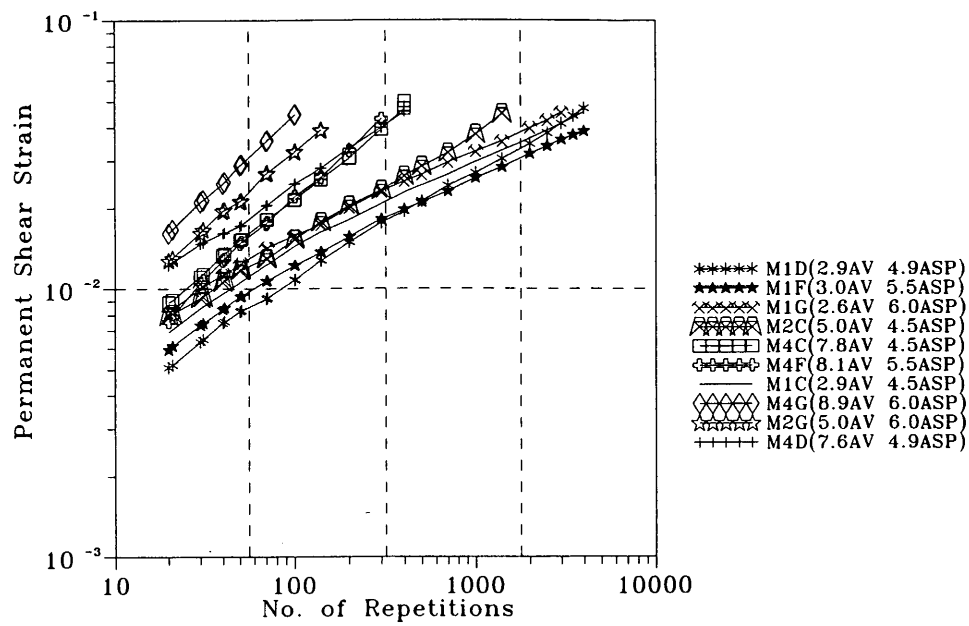

FIGURE 10 Variation of permanent shear strain with the number of load applications for some of the cells in the new mix design framework.

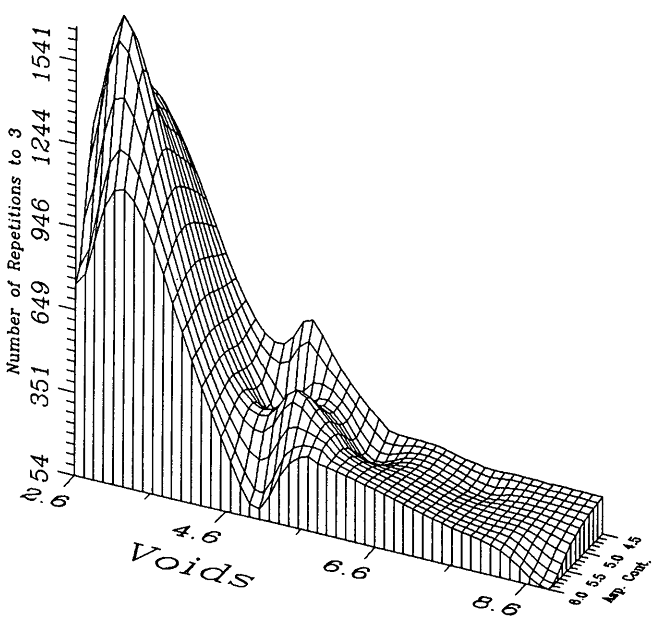

FIGURE 11 Variation of the number of repetitions to reach 3 percent permanent shear strain with asphalt and void content (maximum at 3.0 void content and 4.9 asphalt content).

some level of rutting associated with the specific pavement conditions. [A more comprehensive rutting prediction procedure has also been proposed that includes the simple shear test (see paper by Sousa, Weissman et al. in this Record). This requires a more detailed test program and analysis procedure.] If the rut depth is larger than allowed, the mix must be redesigned.

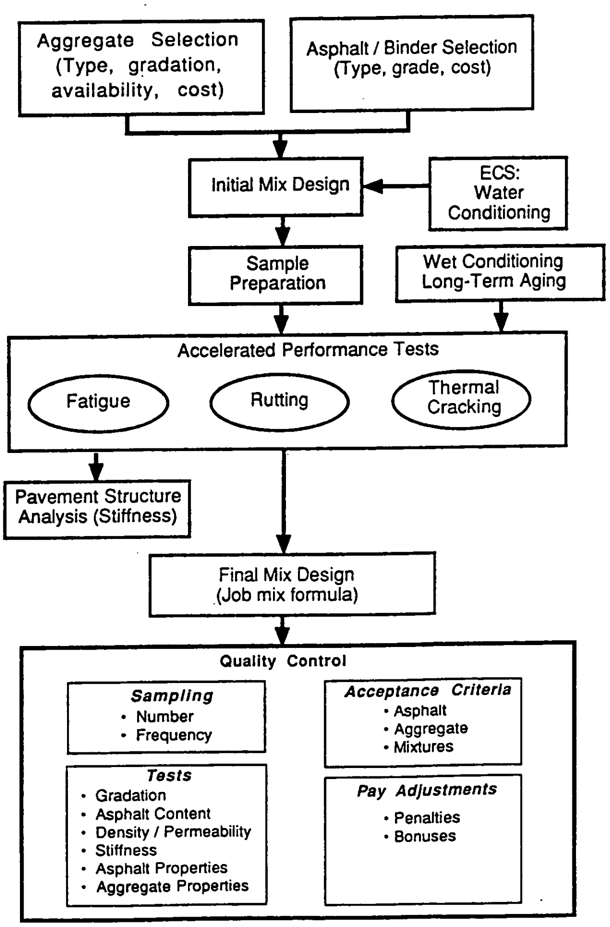

FIGURE 12 Framework for mixture design and analysis system.

In general, the mix design approach described herein emphasizes not only the comprehensive evaluation of mix properties using the accelerated performance tests developed as part of the SHRP research efforts but also the importance of being able to use these results within a suitable analysis framework to estimate performance.

SUMMARY

This paper presents some of the equipment and procedures recommended by the SHRP A-003A contractor for mix evaluation. As part of this research effort, the rolling wheel compactor is recommended for fabrication of asphalt concrete mixes in the laboratory, since beams and cylinders can be produced with the same equipment and at the same time in an efficient manner in terms of time and material quantities.

To characterize the fatigue behavior of asphalt concrete mixtures, a third-point bending fatigue test operating in the controlled-strain mode is recommended. New equipment developed to perform this test, together with a shortened procedure, facilitates the determination of a fatigue relationship at a given temperature in about 24 hr.

To characterize the permanent deformation characteristics of mixes, several tests have been developed. The test selected for an abridged procedure for mix evaluation is the constant height repetitive simple shear test. This test permits the determination of mix characteristics to assess both the relative performance of various candidate mixes and the development of permanent shear deformation in situ.

A new mix design procedure is presented in which air void content and asphalt content are varied independently. To evaluate the sensitivity of the new equipment and procedures to the mix design variables, a 12-cell mix evaluation was undertaken. The proposed design procedure provides more detailed information compared with conventional mix design methodologies. The tests presented discriminated among the different test variables. Moreover, it provides sufficient data so that the influence of expected field compaction conditions, as well as subsequent permanent shear deformation caused by traffic, can be assessed. Finally, the methodology provides information that can be used in prediction models, from which decisions regarding in situ performance can be made.

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