3. Mixing water content = 3.5 percent by weight of dry aggregate, and
4. Optimal water content at compaction = 2.0 percent by weight of dry aggregate.

CONCLUSIONS

This paper describes the selection of various criteria for the EAM design procedure developed at the University of Illinois. A given mixture should meet the following selected criteria: (a) adequate stability when tested in a soaked condition, (b) no excessive loss of stability when tested soaked as opposed to dry, (c) limited moisture absorption into the mixture, and (d) adequate coating. The basic design philosophy is that a residual asphalt content should be selected that meets these criteria and maximizes soaked stability. Field and laboratory tests were conducted to establish a test series and procedures and tentative limiting criteria for mix design for low-volume bases. Much additional field verification is needed before the procedures and criteria can be used with confidence.

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The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Laboratory Evaluation of Asphalt Emulsion Mixtures by Use of the Marshall and Indirect Tensile Tests

MICHAEL S. MAMLOUK, LEONARD E. WOOD, AND AHMED A. GADALLAH

A laboratory procedure for specimen preparation, developed to characterize the asphalt emulsion mixtures used in base courses, is described. The main factors considered in the technique are aggregate coating, workability of the mix, and rate of moisture loss from the mix before and after compaction. The Marshall test was performed at room temperature to evaluate the performance of the mixture. The mixture was further characterized by conducting the indirect tensile test at various temperatures. Both types of tests were conducted for different mix compositions and curing conditions. The specimens were vacuum saturated after different curing times to evaluate the resistance of the mixture to adverse moisture conditions. An evaluation system for asphalt emulsion mixtures is recommended based on the results of the investigation.

Asphalt emulsion (AE) mixes offer several advantages over hot-mixed asphaltic concrete. Asphalt emulsion can be mixed with damp aggregate at ambient temperatures. This is a major advantage in relation to energy saving and air pollution. Either plant mix or road mix can be produced by using this type of mixture. The main disadvantage of AE mixes, however, is the slow development of the strength, which is controlled by the loss of moisture from the mixture.

The performance of AE-treated bases has generally been successful. In recent years, however, some distress has been noted on some heavily traveled roads on which cold-mixed AE-treated bases were used (1). The improper use of AE mixes could be the reason for this distress. The current lack of sufficient data on the influence of different mix components and weather conditions on the behavior of AE mixtures has been instrumental in focusing on the need for a proper design procedure for such mixtures.

Several investigations have been conducted to establish design procedures for cold-mixed AE mixtures, but no standard method has yet been adopted (2). The purpose of this study was to establish a laboratory technique to be used in characterizing cold-mixed AE mixtures used in black bases. Both the Marshall test and the indirect tensile test were used to evaluate the mixture. The susceptibility of the mixture to adverse water conditions was also investigated.

MATERIALS

Aggregate

Two types of aggregate that meet Indiana State Highway Commission (ISHC) standard specifications were used in this study. The first type was a mixture of sand and gravel that consisted of approximately 50 percent calcareous and 50 percent siliceous pieces; 56 percent of gravel particles retained on the 4.75-mm (No. 4) sieve had crushed faces. The second type of aggregate used was crushed limestone. The one aggregate gradation used followed the midspecification of the ISHC #73B gradation band and had a maximum size of 19 mm (0.75 in), as shown in Figure 1.

The properties of these two types of aggregate are given below:

Property	Sand and Gravel	Limestone
Apparent specific gravity	2.71	2.74
Bulk specific gravity	2.61	2.70
Absorption (%)	1.20	1.28

The sand-and-gravel mixture was used in the development of the mix-design procedure and the Marshall test. Both the sand-and-gravel and limestone mixtures were used in the indirect tensile test.

Asphalt Emulsion

The high-float AE used was HFMS-2s (ASTM D977). The physical properties of the emulsion were as follows: (25°C = 45°F):

Property	Value
Saybolt Furol viscosity (s)	>50
Residue by distillation (%)	70
Penetration of residue after distillation, at 25°C, 5 s, 100 g	>200
Specific gravity of residue after distillation, at 25°C	0.986

The compatibility between aggregate and AE was examined according to the ability of the emulsion to coat the aggregate particles. The amount of AE in the mixture was chosen to fall within the ISHC recommended range. Values of 2.5, 3.25, and 4 percent of AE residue by dry weight of aggregate were used.

Figure 1. Aggregate gradation.

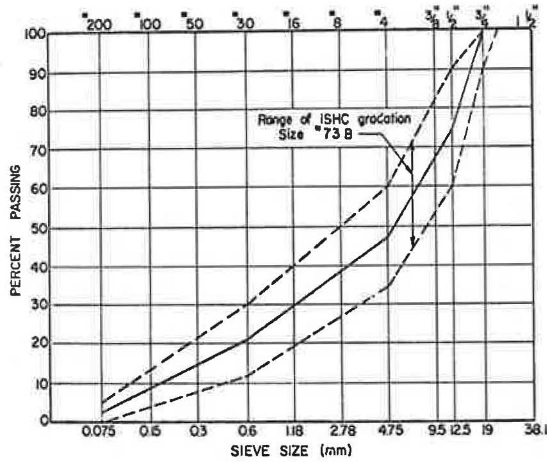
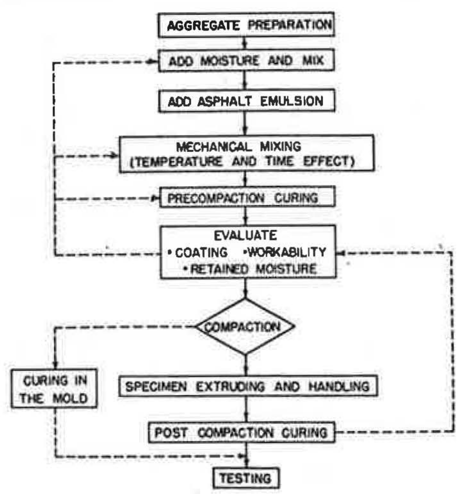


Figure 2. AE mixture preparation and testing procedure.



PROCEDURES FOR SPECIMEN PREPARATION

More effort needs to be expended in controlling and handling AE mixtures than in controlling the traditional hot mixes because more factors in the AE mixture system affect its performance during mixing and specimen preparation. The main factors evaluated to provide an adequate method for preparing and testing the AE mixture specimens were coating of the aggregate, workability of the mix, and the trend of the moisture retained in specimens before and after compaction (the curing rate). The different steps considered in this investigation are discussed below (see Figure 2).

The dry aggregate was blended into 1200-g (2.4-lb) batches by combining the different aggregate sizes to meet the desired gradation. The aggregate was used in the AE mixture at a room temperature of 22°C (72°F). The initial moisture content was added to the aggregate and mixed thoroughly by hand. The purpose of adding moisture to aggregate before mixing with AE is to prevent balling up of fine-grained particles and to provide a uniform AE coating of the aggregate particles. The amount of mixing water that will provide the best coating of aggregate with a certain amount of AE should be selected. A range of 0-4.5

Figure 3. Effect of precompaction curing condition on moisture retained in loose mixture (4 percent added moisture and 4 percent asphalt residue).

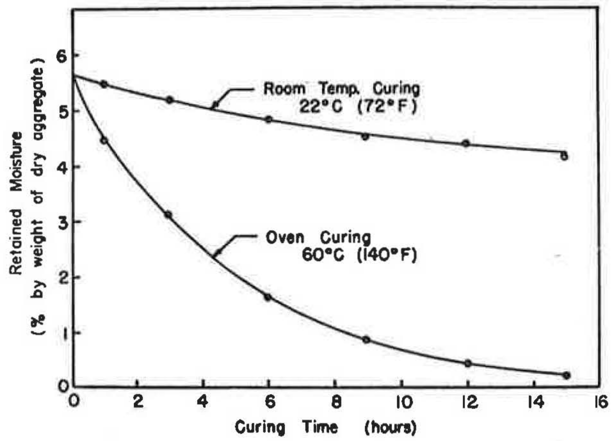
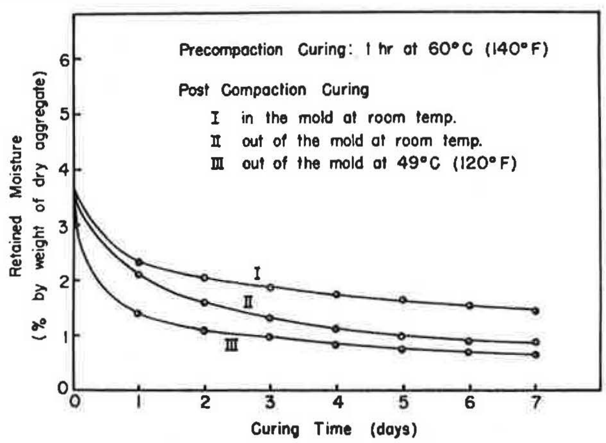


Figure 4. Effect of postcompaction curing condition on moisture retained in compacted specimen (4 percent moisture and 4 percent asphalt residue).



percent of initial added moisture by weight of dry aggregate was used.

The AE was added cold to the wet aggregate and mixed by using a mechanical mixer. Hand mixing was also used to overcome the segregation of fine and coarse aggregates during the mechanical mixing.

Precompaction Curing

The effect of curing on the amount of moisture retained in the mixture before compaction (mix in the loose condition) was investigated. Two conditions of precompaction curing were evaluated: (a) a complete curing of the loose mixture at a room temperature of 22°C (72°F) and (b) curing at 60°C (140°F). The effect of the precompaction curing condition on the moisture retained in the loose mixture is shown in Figure 3.

According to criteria used in Indiana for AE mix preparation, the amount of moisture in the mix should not exceed 4.5 percent by weight of dry aggregate prior to compaction. It was found that this moisture content was obtained after approximately 1 h of curing at 60°C (140°F) when 4 percent initial added moisture was used. The same moisture content was reached after 10 h of curing at room temperature. Since the initial added-moisture content does not exceed this value in most cases, it is recommended that the mixture should be cured for 1 h at 60°C and then remixed for 30 s before compaction.

The precompaction curing process is necessary not only to remove some of the excess water but also to compensate for the high energy provided in the field during mixture preparation. It was also found that precompaction curing provided better coating of the aggregate and easier handling of the mixture than a complete cold process. Precompaction curing produced a mix temperature of about 43°-49°C (110°-120°F) after 1 h at 60°C, which is considered reasonable for cold and intermediate AE mixtures.

Compaction

Marshall specimens 102 mm (4 in) in diameter and about 64 mm (2.5 in) in height were prepared by using 50 blows of the standard Marshall compaction hammer on each side of the specimen. This compacting effort was selected to duplicate the conditions of the pavement in the field under medium traffic. Specimens used in the indirect tensile test, however, were compacted by using a fixed-roller gyratory compaction machine. Twenty revolutions of the gyratory machine at 1.38 MPa (200 lbf/in^2) and a 1° gyration angle were used. Both methods of compaction were found to give similar specimen unit weights.

Postcompaction Curing

Three conditions of postcompaction curing of the compacted specimens were evaluated. The first two conditions were curing in the mold and out of the mold at room temperature. The amount of moisture retained in the compacted specimens was determined for these two cases (see Figure 4). It was found that curing the specimens out of the mold was beneficial in relation to the rate of moisture loss. Out-of-the-mold curing provides more surface area for the moisture to leave the specimen than does curing in the mold.

To expedite the curing process, a third condition was considered: curing the specimen out of the mold at 49°C (120°F). In this case, the amount of retained moisture dropped markedly at the beginning of the curing time and leveled off thereafter (Figure 4). After three days at 49°C, the amount of retained moisture did not exceed 1 percent by weight of dry aggregate. It was concluded, therefore, that curing the specimens out of the mold for three days at 49°C would approximate the long-term curing process in the field.

The levels of postcompaction curing that were considered in the mixture characterization are as follows:

1. One-day air curing at a room temperature of 22°C (72°F),
2. Three-day air curing at a room temperature of 22°C, and
3. Three-day oven curing at 49°C.

These postcompaction curings represented the initial (after construction), intermediate, and long-term curing conditions in the field, respectively.

The problems involved in extruding the specimens from the molds were evaluated at different curing times after compaction in conjunction with the precompaction curing conditions. For the selected precompaction curing condition [1 h at 60°C (140°F) and then remix before compaction], it was found that the specimens could be extruded from the molds without any damage about 30 min after compaction. However, care must be taken in handling specimens of some mix combinations, such as those that have a low amount of AE and/or high water content.

Recommended Method of Specimen Preparation for Marshall Test

Based on the evaluation study, the following procedure is recommended for preparing AE mixture specimens for Marshall testing (3):

1. The aggregate is prepared in approximately 1200-g (2.4-lb) batches, based on the aggregate gradation required.
2. The required amount of initial moisture is added to the cold aggregate and mixed thoroughly by hand.
3. The aggregate-water mixture is allowed to stand for 10-15 min before the AE is added to allow the mixing water to fill the surface voids of the aggregate and to obtain a uniform coating of moisture over the aggregate.
4. The amount of AE that is required to provide a certain AE residue content in the mix is added cold to the wet aggregate and mixed with a mechanical mixer for about 2 min and by hand with a spoon for 30 s.
5. The mix is cured for 1 h in a forced-draft oven at 60°C (140°F) and then remixed for 30 s with the mechanical mixer.
6. The mix is compacted with the mechanical Marshall compaction hammer by using 50 blows on each side of the specimen.
7. The compacted specimens are left in the mold for about 30 min before they are extruded.
8. The specimens are then left to cure for the required curing time and temperature before testing.

CHARACTERIZATION OF AE MIXTURE

Marshall Test

The Marshall test was performed at a room temperature of 22°C (72°F). A continuous chart recording of load versus deformation was obtained from the test (see Figure 5). Modified Marshall stability and Marshall flow were determined. Two new parameters—Marshall stiffness and Marshall index—were also obtained. Marshall stiffness is defined as the ratio between Marshall stability and flow, whereas the Marshall index is the slope of the linear portion of the load-versus-deformation trace. Specimens were tested in both before and after vacuum saturation.

A modified vacuum-saturation method developed by the Asphalt Institute was used in this study (4). According to this method, specimens were subjected to a vacuum of 30 mm Hg for 1 h and then submerged in water for 24 h at room temperature before being tested. A comparative analysis between the dry and vacuum-saturated specimens was performed.

The initial added moisture and its interaction with the AE content proved to have a considerable effect on the modified Marshall stability of the mixture. In addition, the effect of AE content on the stability of the mix was not apparent at early stages of curing, mainly because of the nature of the AE present in the mix at that time. However, the significant effect of AE content became increasingly important during the curing process, at which time the AE residue started to gradually affect the mix properties.

Figure 6 shows the Marshall stability values as a function of AE content and percentage of added moisture. The highest stability values were obtained for samples that had no added moisture (it should be noted that about 0.2 percent moisture content was present in the aggregate). At 1.5 percent added moisture, the highest stability values were obtained for samples that had 3.25 percent AE residue, but the difference in stability was small. When added- moisture content was increased, the samples with the low AE content (2.5 percent) displayed higher stability values.

Total liquid content, which is the sum of the AE residue content and the retained-moisture content, is an important factor in the response of an AE mixture. There exists an optimal liquid content that provides a mix with a maximum Marshall stability value. At a high AE content, a small percentage of initial added moisture is adequate. However, for low AE contents, increasing the amount of added moisture up to a certain limit improves the properties of the mix, as Figure 7 shows. The optimal liquid content at time of testing, after the samples with no added moisture were excluded, was in the range of 4.0-4.5 percent by weight of dry aggregate.

The Marshall stability values for dry and soaked conditions at the three curing periods are shown in Figure 8. A significant result of this test shows that at any curing level the percentage of retained stability increases with increasing AE content in the mix. In addition, the relations between stability and AE content for the soaked samples follow a curvilinear pattern, and an optimal AE content

Figure 5. Relation among Marshall stability, flow, stiffness, and index.

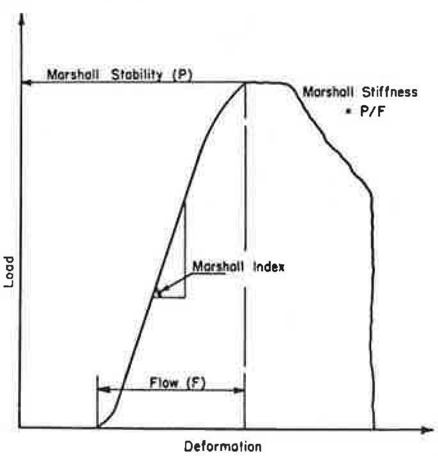


Figure 6. Marshall stability as a function of asphalt emulsion and added-moisture contents.

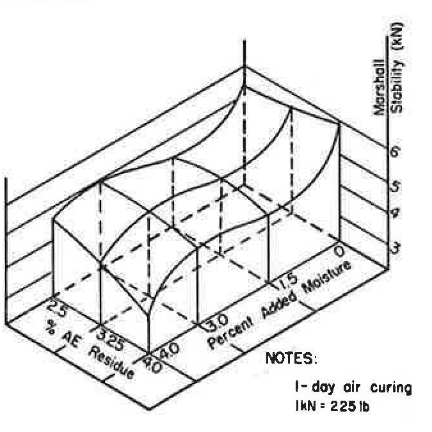
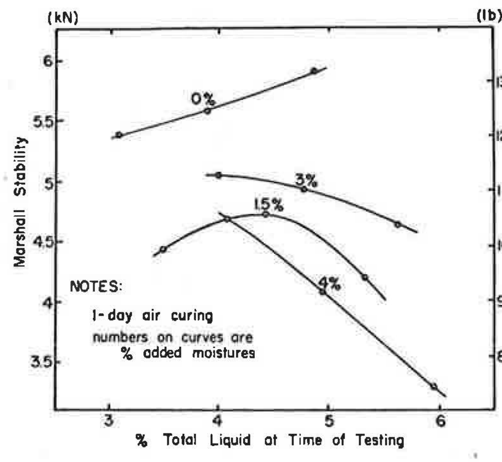


Figure 7. Marshall stability versus percentage total liquid for different added-moisture contents.



value corresponds to a maximum stability value. In contrast, the dry test results showed a decreasing trend with increasing AE content. Longer curing periods for the dry specimens resulted in greater changes in stability as AE content was increased.

The Marshall flow values ranged from 6 to 11 [in 0.25-mm (0.01-in) units]. The flow values increased with increasing AE or added-moisture content. However, mixes with no added moisture exhibited higher flow values than those with 1.5 percent added moisture.

Marshall stiffness and index were both markedly affected by AE content and added-moisture content. Decreasing the AE content resulted in a mix that was less plastic. The slope of the load-deformation curve became steeper, and both Marshall stiffness and index increased (see Figure 9). The same trend held for the effect of percentage added moisture.

Indirect Tensile Test

The indirect tensile test was performed by using the Material Testing System electrohydraulic machine at temperatures of 10°, 24°, and 38°C (50°, 75°, and 100°F). The load was applied at a rate of loading of 51 mm/min (2 in/min) by using two curved, stainless-steel, 12.7-mm (0.5-in) wide loading strips. Continuous recordings of load versus horizontal deformation and vertical deformation versus horizontal deformation during the load application were obtained. Tensile strength, Poisson's ratio, tensile stiffness, and tensile strain at failure were also determined (5,6). The equations used in calculating the above expressions are given elsewhere (7).

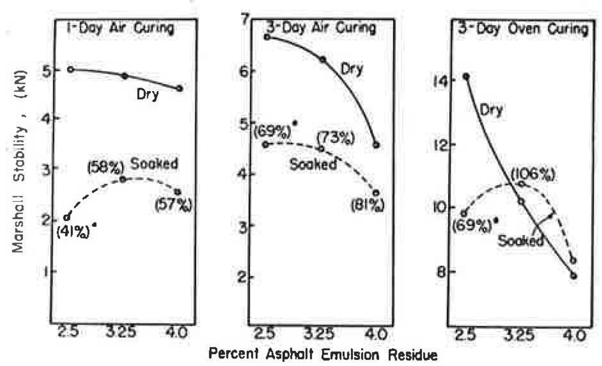
In this part of the study, both sand-and-gravel and limestone mixtures were used. Two initial added-moisture contents (3 and 4.5 percent) and two AE residue contents (3.25 and 4 percent) were evaluated. Both one-day air curing and three-day oven curing were investigated.

The tensile strengths, which ranged between 25 and 596 kPa (3.6 and 86.4 lbf/in^2), were largely affected by test temperature, aggregate type, curing, and initial added-moisture content. High tensile-strength values were obtained at low test temperatures with limestone mixtures, three-day oven curing, and small initial amounts of added moisture. The interaction effect of aggregate type, curing, and test temperature on tensile strength is shown in Figure 10.

Poisson's ratio was very sensitive to test temperature. When the test temperature increased, Poisson's ratio increased. At a test temperature of 38°C (100°F), the specimens began to develop hairline cracks before total failure. Thus, values of Poisson's ratio greater than 0.5 were obtained. In addition to test temperature, high values of Poisson's ratio were obtained at one-day air curing in comparison with three-day oven curing. In the rest of the analysis, Poisson's ratio was assumed to be 0.3, 0.35, and 0.4 at temperatures of 10°, 24°, and 38°C (50°, 75°, and 100°F), respectively.

The effect of test temperature, aggregate type, and AE content on tensile stiffness is shown in Figure 11. The test

Figure 8. Marshall stability for dry and soaked specimens after different curing periods.



NOTES: 3% added moisture
* - percent retained stability
1 kN = 225 lb

Figure 9. Asphalt emulsion content versus Marshall stiffness and index.

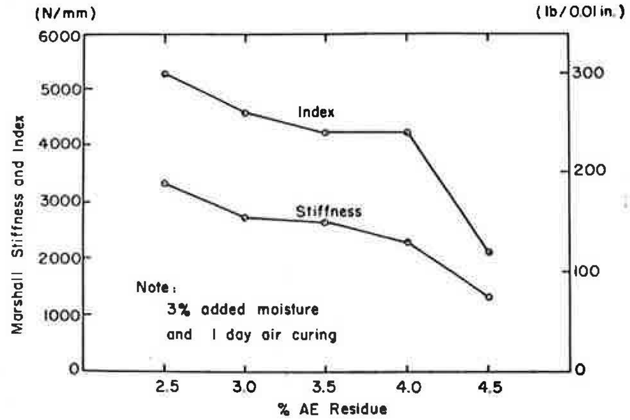


Figure 10. Effect of aggregate type, curing, and test temperature on tensile strength.

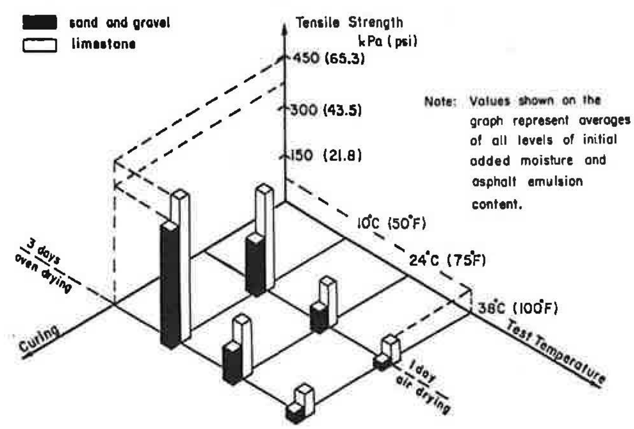
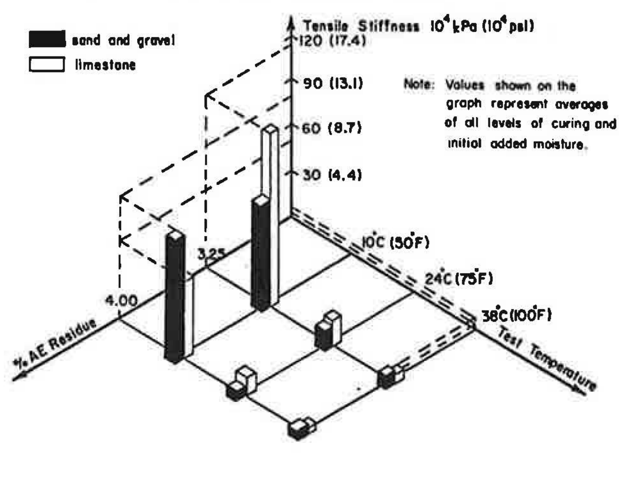


Figure 11. Tensile stiffness as a function of asphalt emulsion content, test temperature, and aggregate type.



temperature had an inverse effect on the stiffness value of the mixture. It may also be noted that AE content and aggregate type had a marked effect on tensile stiffness at a test temperature of 10°C (50°F).

Tensile strain at failure was affected by AE content and curing. Large tensile strains at failure were obtained for air-cured mixtures with 4 percent AE residue in comparison with oven-cured mixtures with 3.25 percent AE residue.

SUMMARY AND CONCLUSIONS

A laboratory technique for preparation of specimens to be used in the characterization of AE mixtures has been established. The technique was developed based on the coating of the aggregate, the workability of the mix, and the curing rate of the mixture before and after compaction. The mixture was characterized by using a modification of the Marshall method and the indirect tensile test. A modified water-sensitivity test developed by the Asphalt Institute was used to evaluate the resistance of an AE mixture to moisture.

The optimal initial added-moisture and AE contents should be selected to provide the best AE coating of aggregate particles. Two levels of added-moisture content and three levels of AE content would be adequate for the design of the mixture. Evaluating the mixture at two curing periods that represent the initial and long-term curing conditions would provide good understanding and control of mix performance.

The interaction of initial added-moisture and AE contents had a marked effect on the modified Marshall stability as well as Marshall stiffness and index of the mixture. There is an optimal liquid content that provides a mix with a maximum Marshall stability value. This liquid content was found to be in the range of 4-4.5 percent by weight of dry aggregate (for the materials and mixing procedures used in this study).

Test temperature and curing both had a substantial effect on the tensile properties of the AE mixtures. Moreover, the tensile strength of the mixture was markedly affected by aggregate type and initial added-moisture content. The AE content has a significant effect on tensile stiffness and tensile strain at failure.

The water-sensitivity test should play a major role in the evaluation of AE mixtures. Characterization of mixture specimens both before and after vacuum saturation would be beneficial in providing more realistic results, and this would in turn make it possible to establish better control over mixture properties.

ACKNOWLEDGMENT

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented.

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Use of the Hveem Stabilometer Test in Design Procedure for Emulsified-Asphalt Mix

LLOYD D. COYNE

The selection, proportioning, testing, and criteria recommended for the various uses of emulsified-asphalt mixes are discussed. Mix design incorporates the use of Hveem equipment to measure mix stability and cohesion. New testing techniques include the use of vacuum curing and vacuum saturation. The reasons for each test are reviewed. The mix-design procedure appears suitable for predicting the performance of emulsified-asphalt mixes. The intended use of the mix dictates the procedure and criteria to be used.

In the design of emulsified-asphalt mixes (EAMs), the intended use of the material determines the mix-design procedure and criteria. This paper discusses the design of such mixes according to their intended use.

CONSTRUCTION AID

Small percentages of emulsified asphalt (2-3 percent) may be added to sands and granular bases as part of the normal mixing water during the construction operation. The emulsified asphalt imparts cohesion to otherwise noncohesive materials, minimizing segregation during placement. It also aids in compaction and allows these materials to be used as a base and working table. The use of primes can frequently be eliminated. No testing of the EAM is required, provided the untreated aggregate meets the specifying agencies' requirements.