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Evaluation of Recycled Mixtures Using Foamed Asphalt

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ABSTRACT

The economic pressure from higher fuel, asphalt, and material prices, along with the growing use of milling equipment for smoothing pavement profiles and the problems of bridge clearances, have worked together to provide an abundance of salvaged roadway materials that are available for recycling. This material availability and the appearance of some performance problems with recycled materials on heavily traveled roadways have led to the consideration of using these salvaged roadway materials on low-volume roads. The laboratory study reported in this paper evaluated the feasibility of using foamed asphalt to recycle asphalt mixtures and compared the properties of foamed mixtures with those of conventional cold mixtures. The study involved an initial evaluation of the foamed process using two field sands. Additional tests were conducted by using salvaged pavement materials mixed with a foamed asphalt cement (AC-5) and with a cutback (MC-800) and two emulsions (EA-11M and AES-300). Specimens were prepared, cured, and tested under both dry and wet conditions. The wet strengths were less than approximately one-half the dry strengths, but in almost all cases the foamed AC-5 produced strength values equal to or higher than those using either the cutback or emulsions. In addition, the asphalt content for the foamed asphalt specimens was lower than for the cutback or emulsions. Overall, the foamed asphalt materials appear to offer a possible option for use in cold recycled asphalt mixtures for low-volume roadways.

Because of the continued price escalation for both energy and asphalt cement there is a continuing interest in producing asphalt mixtures by using cold mixing techniques, especially for lower volume roads. In addition, substantial volumes of surface material from the growing use of cold milling as well as the use of salvaged materials from existing roadways represent high-quality materials that can be recycled with the proper technology. Because there have been conflicting reports on the performance of foamed asphalt mixtures, a laboratory evaluation was conducted to determine the properties of foamed asphalt mixtures and to compare these properties with those of cutback and emulsion mixtures. Properties evaluated were indirect tensile strengths, static moduli of elasticity, and Hveem stabilities.

FOAMED ASPHALT PROCESS

In 1957 Csanyi (1) of Iowa State University demonstrated the effectiveness of preparing low-cost mixes by stabilizing ungraded local aggregates such as gravel, sand, and loess with foamed asphalt. Controlled foam was produced by introducing saturated steam into heated asphalt through a specially designed nozzle. The reduced viscosity, increased volume (±2,000 percent), and reduced surface energy in the foamed asphalt allowed intimate coating when mixed with the cold, wet aggregates. Foamed asphalt allowed materials normally considered unsuitable for hot plant-mixed applications to be used in stabilized bases and surface mixtures for low-volume roads.

In 1968 the patent rights for the Csanyi process were acquired by Mobil of Australia (1). Mobil modified the steam production process by blending 1 to 2 percent cold water with the hot asphalt before mixing with cold, mineral aggregate.

MATERIALS SUITABLE FOR USE

Aggregates

Bowering and Martin (2) tested foamed asphalt mixtures comprised of materials ranging from a sandy clay to a well-graded gravel. Test results indicated that the low-plasticity materials with a relatively large percentage of fines (-200 sieve) were best because the asphalt tends to coat the fines and partly coat the larger particles (3). Acott (4) suggested adding fines to increase low stabilities of foamed asphalt mixtures made with both clean and dirty sands. Fine material must be present to enhance the ability of the foam to produce uniform, thin coatings on a large surface area. Soils that benefit the most from the addition of foamed asphalt also show significant strength loss when tested wet.

In addition to using natural aggregates, foamed asphalt mixtures have been prepared with salvaged asphalt materials. Lee (5) prepared foamed asphalt mixtures by using two recycled materials. The reclaimed materials were blended with virgin aggregates of the type and amount normally specified in Iowa for hot recycled mixtures.

Brennan et al. (6) produced a foamed recycled asphalt mixture by using salvaged material from a state road near Wabash, Indiana, that had an asphalt content of 5.4 percent and a penetration of 20. The material was crushed, graded, separated into four sizes, and recombined to produce a 100 percent recycled mixture.

These studies (5,6) demonstrate the feasibility of using salvaged material to produce a foamed, recycled mixture with or without virgin material. Generally, the mixture properties were reported to have improved when fines were added to the salvaged material.

Asphalt

The percent asphalt included in a foamed asphalt mixture is a function of the soil type and moisture content and the desired mixture properties. Generally, foamed asphalt mixtures can be prepared at lower asphalt contents and can obtain about the same properties as conventional cold mixtures at higher asphalt contents (1,3). Typical asphalt contents for foamed mixtures range from 3 to 6 percent. When the films are too thick, the asphalt simply lubricates the aggregate particles. When the films are too thin, there may not be enough asphalt for coating, with a resulting decrease in mixture stability and high strength loss when tested wet.

Brennan et al. (6) reported excellent Marshall stabilities by adding 0.5 and 1.0 percent asphalt by total weight to salvaged material with stabilities peaking at 1 percent asphalt. The amount of water absorption and the effect of water on stability decreased with increasing asphalt content.

Most asphalt cement (7) can be foamed, but Abel (3) reported that the lower viscosity asphalts foamed better than higher viscosity asphalts, but the higher viscosity asphalts produce better aggregate coating.

Shackel et al. (8) reported that mixtures made from higher penetration asphalt (lower viscosity) experienced lower strains under repeated loading, but also had lower resilient moduli.

CONSTRUCTION CONSIDERATIONS

Prewetting Aggregate

Brennan et al. (6) reported that it is necessary to add a small amount of water to the aggregate before mixing so that the foamed asphalt would thoroughly coat and adhere to the particles. Best mixing occurred at the fluff point; that is, the point at which the loose material occupies the maximum volume.

The amount of moisture was reported to be fairly critical because the proper amount of water aids in the distribution of the asphalt, whereas insufficient water results in a mixture that cannot be laid (9). Too much water increases curing times and reduces both density and strength of the compacted mixtures.

Anderson et al. (7) reported different optimum water contents for strength, density, minimum moisture absorption, and minimum expansion. Anderson et al. concluded that because mixing generally controls the construction process, the selected optimum moisture content should be controlled by that value. Lee (5) recommended that 65 to 85 percent of the AASHTO optimum moisture content be used for mixing and stressed that the moisture content before mixing was the most important design factor that affected the construction of foamed asphalt mixtures.

Construction and Curing

Most foamed asphalt mixtures have been mixed in a conventional pugmill, fitted with a special spray bar for mixing the water and asphalt to produce foam (10). After mixing, the material can be placed and compacted with conventional equipment and traffic may be allowed on the pavement shortly after compaction. Brennan et al. (6) indicated that most of the mixing water had to evaporate before best compaction could be achieved. Curing of foamed asphalt mixtures occurs as the water evaporates (3,7) and is considerably longer than that for emulsion mixtures. During the curing period the mixture can be reworked and relaid with no apparent detrimental effects (9). Laboratory test results indicate that the method of curing and length of the curing period significantly affect the properties of the foamed mixture. Bowering (11) stressed the importance of curing and reported that laboratory specimens developed full strength only after a large percentage of the mixing water was lost.

LABORATORY STUDIES

A preliminary laboratory study was conducted first to evaluate the effects on tensile strength and Hveem stability produced by curing methods, moisture content, and asphalt content. Subsequently, the main laboratory study to evaluate the characteristics of foamed recycled mixtures was conducted.

Specimens were prepared with both the field sands and the salvaged asphalt material by using a cutback and two emulsions in order to compare properties of foamed specimens with those prepared by using traditional cold-mixed procedures. The asphalts used in the laboratory study are given in Table 1, along with the properties of the recycled asphalt.

All mixtures were tested to obtain indirect tensile strengths and moduli of elasticity and Hveem stabilities.

TABLE 1 Asphalt Used in Laboratory Study

Asphalt Used	Value
Tests on residual asphalt	
Recycled project	
Penetration (77°F)	37
Ductility (cm)	141
Viscosity at 140°F (Stokes)	5,592; 5,549
Tests on new asphalt	
No. 399, cutback MC-800 (producer: Cosden Oil & Chemical Co.)	
Penetration (77°F)	208
Kinematic viscosity (140°F)	1,266
No. 395, AES-300 (producer: Texas Emulsions, Inc.)	
Furol viscosity (77°F)	180
Penetration (77°F)	300
No. 398, EA-11M (producer: Texas Emulsions, Inc.)	
Furol viscosity (sec @ 77°F)	74
Penetration (77°F)	134
No. 274, AC-5 (producer: Dorchester)	
Penetration (77°F)	208

Preliminary Laboratory Study

The sand consisted of a fine white sand and a coarser sand that were blended in equal parts to produce a gradation with 100 percent passing the No. 10 sieve, 73 percent passing the No. 40 sieve, 31 percent passing the No. 80 sieve, and 10 percent passing the No. 200 sieve.

The curing cycle consisted of oven curing for 4 days at 140°F followed by either the wet or dry 3-day cure at 75°F. The wet cure consisted of 2 hr of 26-in. vacuum saturation followed by 3 days of soaking at 75°F. Bowering (11) previously concluded that the moisture content of the specimen reaches equilibrium after 3 days of curing at 140°F.

Specimens prepared at different asphalt and initial water contents and tested in the Hveem stabilimeter at 140°F and indirect tensile test at 75°F (10) gave the following results.

1. There was a significant increase in tensile strengths as curing temperatures increased from 75° to 140°F.
2. Specimens tested after wet curing had less than 50 percent of the strength of those tested after dry curing.
3. Stabilities of all specimens were low, which is typical of sand-asphalt mixtures, and the stability decreased with increased asphalt content.
4. Stabilities of foamed asphalt-sand specimens were higher than those of sand mixtures mixed with MC-800 cutback and AES-300 and EA-11M emulsions.
5. Tensile strengths for the foamed sand asphalt were substantially higher than those for either the cutback or the emulsions.

Details of this preliminary analysis can be found in Roberts et al. (12).

Laboratory Study of Salvaged Pavement Material

A laboratory study was conducted to evaluate the characteristics of salvaged materials recycled using foamed asphalt. The purposes of the study were to evaluate the properties of foamed recycled materials and to compare those properties with the properties of more traditional cold mixtures prepared with the same salvaged material using the two emulsions and a cutback.

Specimen Preparation

The salvaged material was sieved into two sizes and recombined with 40 percent of material passing the No. 4 sieve and with 60 percent material retained on the No. 4 sieve; material larger than 3/4 in. was discarded. This gradation is shown in Figure 1. In preparing the foamed asphalt materials, the mixing water varied from zero to approximately 2 percent by weight of aggregate.

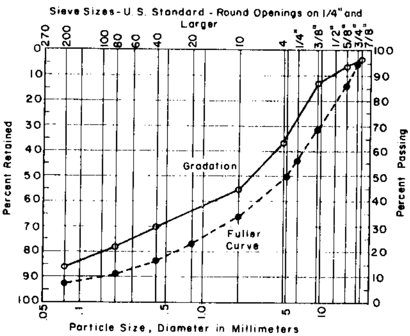

FIGURE 1 Gradation of salvaged pavement materials from TSDHPT District 13.

Experimental Program

The first series of tests was performed on specimens prepared from salvaged materials that had no water added before mixing. These specimens were cured for 7 days, including 4 days at 140°F with 3 additional days at 75°F either dry or submerged in water (wet).

A second series of tests was conducted to evaluate the effect of mixing water content and curing temperature on the strengths of the foamed, recycled asphalt mixtures. The water content before mixing varied from zero to 2 percent. The curing temperatures ranged from 140° to 75°F for the initial 4-day cure and the final 3 days of curing was at 75°F either dry or submerged in water (wet).

A third series of tests involved using the salvaged material to prepare specimens with two emulsified asphalts and one cutback asphalt. Test results from these specimens were used to compare the properties of foamed, recycled specimens with those of specimens prepared by using traditional cold-mixed processes. To ensure accurate comparisons, curing conditions for all specimens were kept constant.

Specimens were tested by using the indirect tensile and Hveem stability tests. In addition to engineering properties, various other standard tests were conducted on specimens to determine specific gravity, density, air void content, asphalt content, and gradations to evaluate the characteristics of foamed, recycled asphalt specimens and to compare those results with specimens prepared by using other techniques or materials.

Series 1: Test Results- No Mixing Water

Specimens were prepared at asphalt contents varying from zero to 2 percent and tested at 75°F after the dry and wet curing periods. Because of the foaming process, the amount of water in the mix varied from about 0.5 to 1.0 percent, averaging about 0.8 percent at the time of compaction.

Figure 2 shows tensile strength results for dry- and wet-cured specimens. The dry-cured specimens show a definite optimum at 0.5 percent foamed asphalt, whereas the wet-cured specimens achieved a maximum tensile strength at about 1 percent. In general, the strengths of the wet-cured specimens were less than 50 percent of the strengths of the dry-cured specimens. Strength losses of this magnitude are fairly typical for specimens of foamed asphalt mixtures tested wet (6,11).

Hveem stabilities for dry-cured specimens are shown in Figure 3 along with the stabilities for specimens of salvaged material heated and compacted at 320°F without the addition of new asphalt.

These data indicate that only specimens with around 0.5 percent foamed asphalt would meet the Texas State Department of Highways and Public Trans-

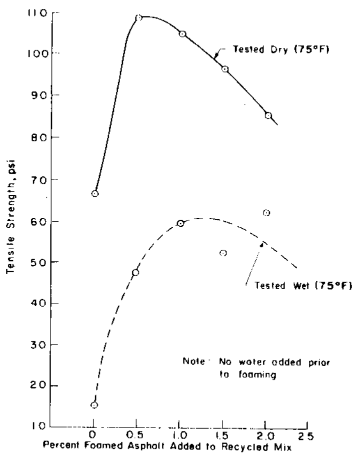

FIGURE 2 Comparison of tensile strength at various percentages of foamed asphalt with no water in mix before foaming.

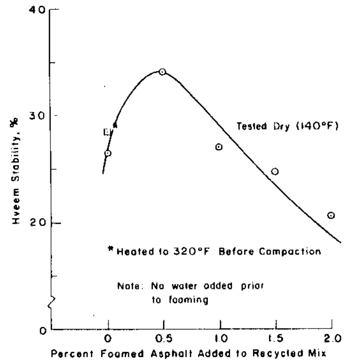

FIGURE 3 Comparison of Hveem stability to percentages of foamed asphalt with no water added before foaming.

portation (TSDHPT) Type B stability requirement of 30. However, it should be noted that the stabilities of the foamed specimens compare favorably with those of the salvaged material that was only heated and compacted. Because stability tests are performed immediately after curing and because no soaking is prescribed in the procedure, stability tests were performed only on the dry-cured foamed asphalt specimens.

The static moduli of elasticity of both dry- and wet-cured foamed, recycled asphalt specimens and of recycled mixtures that were heated to 320°F before compaction and testing are shown in Figure 4. The static moduli were fairly constant for both dry- and wet-cured foamed asphalt specimens for asphalt contents between 0.5 and 1.5 percent. The static moduli decreased significantly at values greater than and less than this range. In the asphalt content range between 0.5 and 1.5 percent the static moduli for the dry-cured specimens were at least 3 times the moduli for the wet-cured specimens, indicating again the significant effect of moisture on the engineering properties of foamed asphalt mixtures. The static moduli for the recycled mixtures that were only heated before compaction and testing were higher than those for the foamed asphalt specimens and the strength loss was much less for the wet specimens.

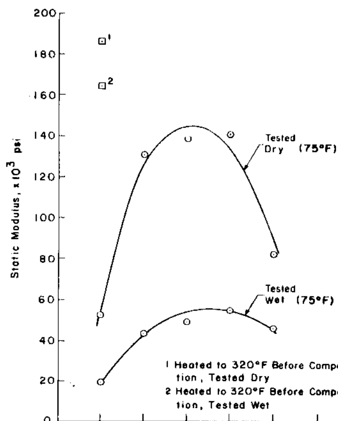

FIGURE 4 Comparison of modulus values to percentage of foamed asphalt with no water added before foaming.

Figure 5 shows the relationship between foamed asphalt content and density for both the wet- and dry-cured specimens. The optimum asphalt content for both sets of data indicates that about the same density was achieved between 0.5 and 1.5 percent asphalt. The percentages of theoretical maximum density achieved for the dry-cured specimens ranged from about 93 to 95 percent for added asphalt contents ranging from 0.5 to 1.5 percent. The density for the recycled mixtures that were only heated before compaction and testing was significantly higher than that for the foamed, dry-cured specimens.

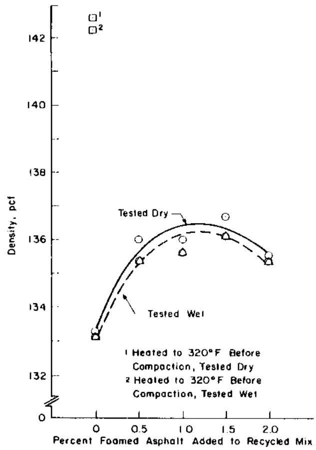

FIGURE 5 Relationship between density and percentage of foamed asphalt with no water added before foaming.

Series 2: Test Results - Effect of Mixing Water on Properties

Specimens were prepared at 0.5 and 1.0 percent asphalt with the water content at compaction varying from zero to slightly greater than 2 percent. Both the foaming process and the premixing water contributed to the total water in the material at compaction; therefore, water contents were determined from the weights of specimens immediately after compaction and after curing 4 days at ±40°F.

The effect of mixing water content and asphalt content on tensile strength is shown in Figure 6. For both those specimens tested wet and those tested dry the total liquids at optimum were about the same (i.e., the percent water in the specimens with 1.0 percent asphalt is about 0.5 percent less than for the specimens with 0.5 percent asphalt). In addition, the loss of tensile strength between the dry and wet specimens is consistent with that previously shown in Figure 2 and in the preliminary testing.

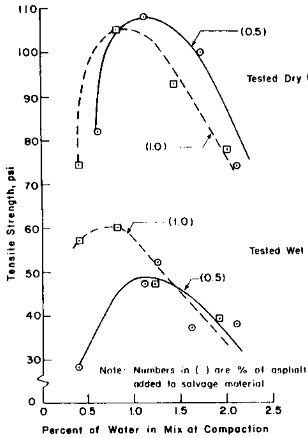

FIGURE 6 Comparison of results of foamed specimens at different mixing water and asphalt contents.

There was no significant difference in density for the wet specimens at either 1.0 or 0.5 percent asphalt. The increased wet tensile strength at 1.0 percent asphalt is probably caused by the protection provided by the extra asphalt.

Figure 7 shows the effect of both asphalt content and moisture content at compaction on Hveem stability. As expected, the stabilities are lower for specimens prepared with 1.0 percent foamed asphalt because at the same water content the total volume of liquids is larger than for 0.5 percent asphalt, producing additional lubrication and hence lower stability. The optimum moisture content appears to be slightly lower for the 1.0 percent asphalt curve than for the 0.5 percent asphalt, although the latter is not well defined. The optimum stability for both curves may well occur at about the same total liquids content.

The effect of temperature during the initial 4-day curing period on the tensile strength of specimens tested dry and wet is shown in Figure 8. These specimens were compacted from a different mixture. Because of variations in asphalt concrete (AC) content of the salvaged material, the results are different from those obtained in series 1 (Figure 2). The foamed asphalt content varied from zero to 1.0 percent. For the specimens tested dry, the optimum foamed asphalt content was 0.5 percent. However, for the specimens tested wet, the tensile strength continued to increase as the asphalt content increased.

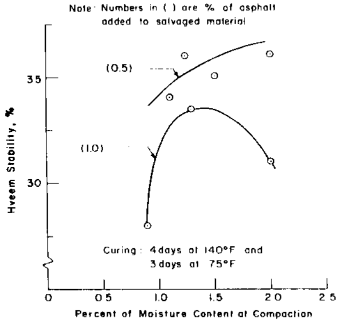

FIGURE 7 Effect of moisture content at compaction on the Hveem stability of foamed specimens.

For the specimens tested wet, however, the effect of curing temperature was much more significant than the effect of asphalt content, indicating the tremendous impact of curing conditions on the properties of this type of pavement material. These results indicate that the higher the initial curing temperature, the less the effect of moisture for the wet tests and the lower the strength loss due to wetting. For the specimens tested dry, the effect of asphalt content was much less than for those tested wet; however, a well-defined optimum asphalt content occurred at 0.5 percent.

The effects of temperature and length of the curing period on tensile strengths were also investigated and the results from specimens tested wet after curing are shown in Figure 9. These specimens were prepared from a different mixture. Because of

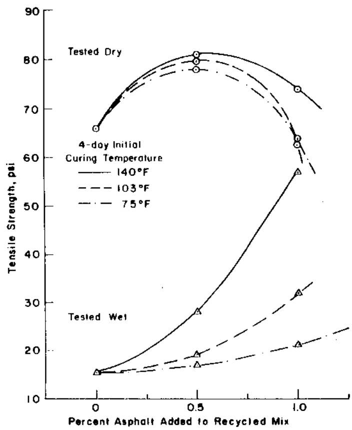

FIGURE 8 Effect of curing on tensile strength with dry mixing of foamed specimens.

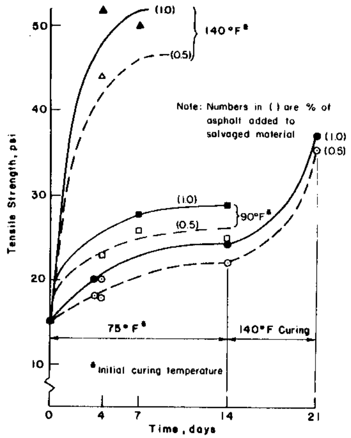

FIGURE 9 Effect of curing temperature and length of curing period on tensile strength of specimens tested after soaking.

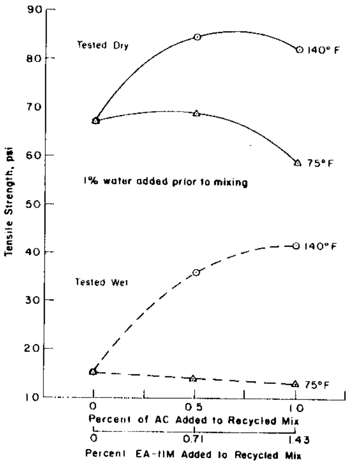

FIGURE 10 Comparison of tensile strengths at various percentages of emulsion EA-11M (70/30).

variability of AC content of salvaged material, results are somewhat different from those of Figure 8. These results indicate that the higher the temperature during curing, the higher the tensile strength, but that about 75 percent of the strength was developed after 4 days of curing for all curing temperatures. After curing begins, if the curing temperature is increased to 140°F, the tensile strength also increased, but at a lower rate than for specimens that began curing at 140°F.

Series 3: Test Results--Comparison with Emulsions and Cutbacks

To evaluate the engineering properties of foamed asphalt specimens, a series of comparison tests was conducted on cold-mixed specimens prepared by using selected emulsions and a cutback asphalt. The foaming process caused a moisture content of ±1 percent at compaction. Premixing water of 1 percent was added to the emulsion mixes for consistency. Specimens were prepared and cured in the same manner as for the foamed asphalt specimens: one set at 140°F for 4 days followed by 3 days of either wet or dry curing at 75°F, and a second set at 75°F for 4 days and then either wet or dry cured for 3 days at 75°F. The specimens were then tested immediately after curing at 75°F; those that were tested after dry curing were designated as tested dry, whereas those tested after wet curing were designated as tested wet.

Test results for the specimens prepared with EA-11M and AES-300 emulsions are shown in Figures 10 and 11, and the results for specimens prepared with the MC-800 cutback are shown in Figure 12. The same basic trends as for the foamed, recycled asphalt are evident in these relationships. The tensile strength of the dry specimens cured at 140°F for 4 days exhibited a fairly well-defined optimum asphalt content of 0.5 percent for both the dry-tested specimens and the wet-tested specimens cured at 140°F. Generally, the strengths of the specimens prepared with emulsions and cutbacks compared favorably with those of similar specimens prepared with foamed asphalt. However, as shown in Figure 13, the tensile strengths for the specimens prepared with foamed asphalt were consistently higher than those for specimens prepared with either of the other asphalt materials; the differences were as significant for the specimens cured at 75°F for 4 days, wet cured (soaked) at 75°F for 3 days, and then tested.

Hveem stabilities from specimens prepared with

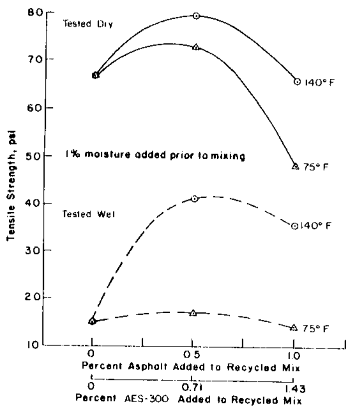

FIGURE 11 Comparison of tensile strength at various percentages of emulsion AC and curing effects AES-300 (70/30).

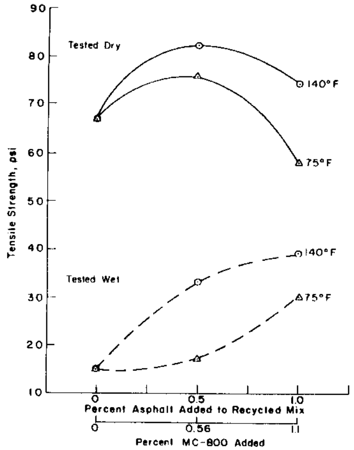

FIGURE 12 Comparison of tensile strengths at various percentages of cutback MC-800.

foamed AC-5, EA-11M, AES-300, and MC-800 and then dry cured are shown in Figure 14. Specimens prepared by using the foamed AC-5 and EA-11M asphalts showed higher stabilities than those prepared by using AES-300 and MC-800. Except for the MC-800 specimens, the optimum asphalt content for stability occurred at 0.5 percent. Stabilities were low at both zero and 1.0 percent added asphalt. When no new asphalt was

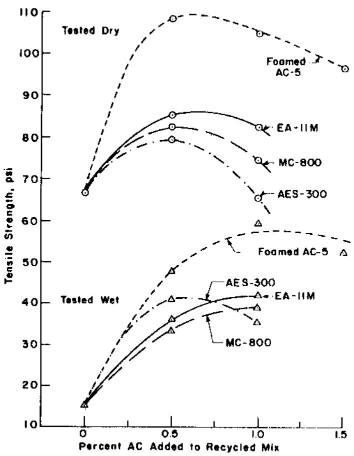

FIGURE 13 Comparison of tensile strength results for foamed, emulsions, and cutback specimens.

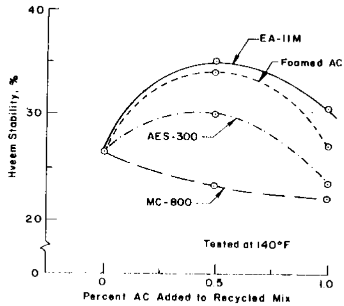

FIGURE 14 Hveem stability in relation to emulsions, cutbacks, and foamed specimens at various percentages of asphalt.

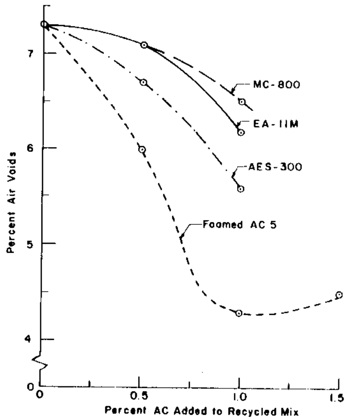

FIGURE 15 Air void contents for mixture prepared by using different asphalts.

added, the air void content was around 7 percent; at an asphalt content of 1.0 percent, the voids ranged from about 4.3 to 6.5 percent, as shown in Figure 15. It is obvious that the foamed asphalt specimens were compacted to a higher density than were specimens prepared with either the emulsions or the cutback. This ease of compaction could have resulted from better distribution of the asphalt because of the thinner films produced by the foaming process and from the lubricating effects of extra water introduced into the foamed materials from the cold water that produced the foaming of the asphalt.

CONCLUSIONS AND RECOMMENDATIONS

Based on the data collected in this limited laboratory study using one salvaged pavement material, one blend of field sands, an AC-5 asphalt cement, two emulsions, and one cutback, the following tentative conclusions and recommendations were prepared.

Conclusions

1. Curing temperature, length, and moisture conditions dramatically affected the strength of foamed asphalt mixtures prepared by using both the sand and the salvaged pavement materials.

2. The stabilities of dry-cured foamed asphalt and sand mixtures were equivalent to that of a hot sand-asphalt prepared by using the same sand and asphalt cement. However, when the foamed asphalt-sand mixtures were tested wet, the strengths were reduced to less than 50 percent; however, all specimens lost at least 50 percent of their strength when tested wet as compared with the strengths when tested dry.

3. The foamed asphalt specimens prepared from both the salvaged pavement materials and the sand exhibited equivalent or superior engineering properties to specimens prepared by using either the emulsions or the cutback.

4. The engineering properties of the foamed salvaged asphalt specimens were substantially less than the properties of mixtures prepared by heating the salvaged materials before compaction; however, specimens prepared from the heated materials were compacted to much higher densities than were achieved for any of the cold-mixed materials.

5. Within the range of values investigated, increases in asphalt content for specimens of foamed asphalt-recycled materials increased the strength of the specimens tested wet but decreased the strength of the specimens tested dry.

6. Hveem stabilities were significantly affected by the total volume of liquids added to the salvaged materials, with these changes being more pronounced at higher asphalt contents.

Recommendations

1. In those situations where cold-mixed materials are being considered for use in bases or subbases, foamed asphalt may be a feasible alternative, especially if available materials include silty sands and gravels that are otherwise considered marginal.

2. The foamed asphalt process probably can be used with salvaged pavement materials to produce base courses and paved shoulder surfaces. However, at this time the use of these materials as a permanent surface on any road is not recommended.

3. Field experience should be well documented because, to date, reports on the performance of foamed asphalt mixtures have been conflicting.

ACKNOWLEDGMENT

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