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Laboratory Investigation of the Use of Foamed Asphalt for Recycled Bituminous Pavements

M. BRENNEN, M. TIA, A. ALTSCHAEFFL, AND L.E. WOOD

Recent advances in foamed-asphalt technology have created new interest in the subject. A series of studies of foamed asphalt was conducted in Indiana. The results of one of these studies are described. The study had three objectives. The first was to determine the foaming characteristics of a selection of asphalts commonly used in construction in Indiana. Foaming characteristics in terms of expansion ratio and half-life were recorded. The second objective was to evaluate the performance of three of these asphalts as binders for a recycled bituminous paving mixture using (a) the gyratory and the Marshall compactive methods and (b) the Marshall stability testing procedure. The third objective was to evaluate the effect of curing time and moisture on the stability of a recycled mix. Three asphalts were chosen for the study based on their foaming characteristics. A foaming temperature of 325°F (160°C) and an added water content of 2 percent were selected as the best conditions for optimum foam volume and half-life. Excellent Marshall stability values were obtained with 0.5 and 1.0 percent foamed asphalt added to the recycled mixtures. Curing time had a marked effect on the lower additions of foamed asphalt. The effect of water decreases with increased amounts of foamed asphalt.

The ability of foamed asphalt to coat and adhere to wet aggregate has been known for more than 20 years. Bituminous road construction using foamed asphalt has been successfully tried and tested in projects in Australia, Canada, South Africa, and the United States (1-5).

Recent advances in foamed-asphalt technology have created new interest in the subject. In Indiana relatively little experience is available on the production and use of foamed asphalt containing locally available materials. For this reason, it was decided to conduct a series of studies on foamed-asphalt production. The results of one of these studies are described in this paper.

OBJECTIVES

This study had three objectives. The first was to determine the foaming characteristics of a selection of asphalts commonly used in construction in Indiana. Foaming characteristics in terms of expansion ratio and half-life were recorded. The second objective was to evaluate the performance of three of these asphalts as binders for a recycled bituminous paving mixture by using (a) the gyratory and Marshall compactive methods and (b) the Marshall stability testing procedure. The three asphalts selected for this part of the study were those deemed to be most suitable on the basis of their foaming characteristics. The third objective was to evaluate the effect of curing time and moisture on the stability of a recycled mix.

FOAMING CHARACTERISTICS OF ASPHALTS

Asphalts

Eight asphalts were selected for the study. They consisted of four AC-20 grades from different sources, two AC-2.5 grades from different sources, one AP-4 grade, and one RC-SC base. The AP-4 grade is an Indiana Department of Highways designation that is close to an AC-10. The RC-SC base is a special residue used in the laboratory to produce our cutbacks. The sources and viscosities of the asphalts are given below (1 cSt = 0.01 cm²/sec):

Grade	Source	Penetration (0.1 mm)	Kinematic Viscosity at 135°C (cSt)
AC-20	A	42	443
AC-20	C	55	390
AC-20	B	68	437
AC-20	D	74	425
AC-2.5	A	185	160
AC-2.5	B	>200	195
AP-4	C	69	261
RC-SC base	A	78	285

Analysis Procedure

Foamed asphalt was produced by using a laboratory Foamix asphalt dispenser. The foam was produced by injecting air and cold water into hot asphalt as it passed under pressure through the nozzle of the dispenser. The foam expanded rapidly and reached its maximum volume in a matter of 2 or 3 sec. The ratio of maximum volume of foamed asphalt to the volume of liquid asphalt used was termed the expansion ratio. After reaching its maximum volume, the foam gradually dissipated until the foamed asphalt returned to the liquid phase. The time that elapsed between the moment that the foam was at its maximum volume and the time that it reached half of this volume was termed the half-life of the foam. Accordingly, expansion ratios and half-lives were used to compare the foaming characteristics of the asphalt.

Expansion ratio and half-life are affected by (a) the amount of foam produced, (b) the amount of water in the foam, and (c) the foaming temperature of the asphalt (6). The availability of 1-gal (3.7-L) cans was convenient for the production of foam in 200-g batches. Expansion ratios up to 19 could be measured. The water content of the foam was expressed as a percentage by weight of the asphalt. The results of trial mixes (6) indicated that it would be desirable to compare the foaming characteristics at foaming temperatures of 300°, 325°, and 350°F (149°, 163°, and 177°C) and at water contents of 1.5, 2, and 2.5 percent. Therefore, the expansion ratios and half-lives were measured for each combination of these parameters.

The volume of foam corresponding to each integer expansion ratio was computed from the densities of the asphalts. Equal volumes of water were poured into an empty can, and a meter stick was graduated to show the height to which the foam should rise in the can for each expansion ratio. During the experiment, the meter stick was held vertically against the outside of the can and the expansion ratio was estimated to the nearest half-division to which the foam expanded. A new can was used for each sample of foam produced.

The profile of the surface of the foam was irregular. It was generally humped in the center of the can during expansion and dipped during dissipation. Therefore, it was necessary to estimate the average level of the surface in measuring the expansion ratio and the half-life.

Three samples of foam were produced at each of the nine combinations of foaming temperature and water content for each asphalt. The average expan-

Figure 1. Expansion ratios and half-lives at various temperatures and water contents.

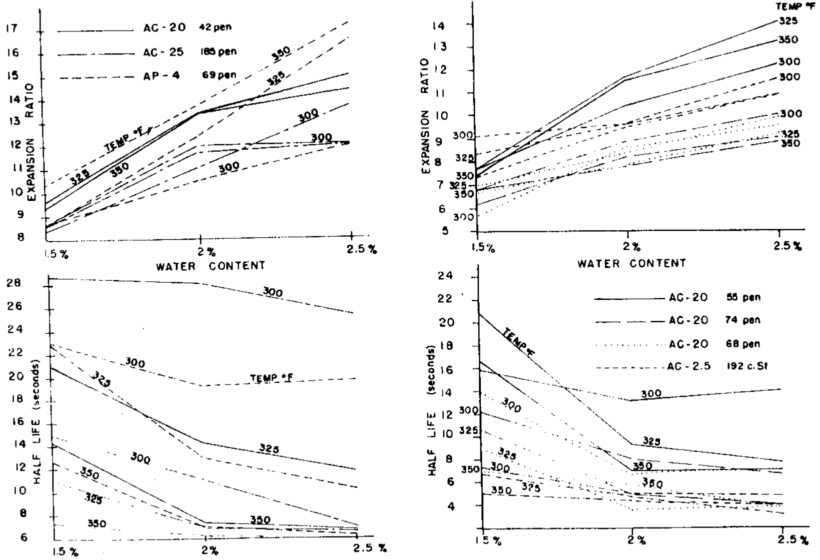


Table 1. Expansion ratios and half-lives for RC-SC base.

Water Content (%)	300°F, 161 cSt Expansion Ratio	300°F, 161 cSt Half-Life (sec)	325°F Expansion Ratio	325°F Half-Life (sec)	350°F, 59 cSt Expansion Ratio	350°F, 59 cSt Half-Life (sec)
1.5	7.5	45.0	9.3	30.3	13.2	17.7
2	9.8	44.3	12.7	26.3	14.3	19.3
2.5	12.3	37.3	15.0	19.3	19.0	17.7

Note: °F = (°C ÷ 055) + 32; 1 cSt = 0.01 cm^2/sec.

sion ratio and half-life were used in making comparisons among the asphalts. The kinematic viscosities of the asphalts were measured at 300° and 350°F (149° and 177°C) to compare expansion ratios, half-lives, and viscosities at these foaming temperatures.

RESULTS

The expansion ratios and half-lives for the regular grades of asphalt are shown in Figure 1. Because the RC-SC base is not commonly available, its performance is given separately in Table 1. Surprisingly, the RC-SC base had good foaming characteristics: it had the highest expansion ratio, 19, and the longest half-life, 45 sec.

The effects of foaming temperature and water content on expansion ratio and half-life are shown in Figure 1. In general, increasing the foaming temperature had the effect of increasing the expansion ratio and decreasing the half-life. Increasing the water content also had the effect of increasing the expansion ratio but of decreasing the half-life. Therefore, a trade-off of half-life for expansion ratio or vice versa was implicit in the selection of a particular set of values for foaming temperature and water content.

A foaming temperature of 325°F (163°C) and a water content of 2 percent were chosen for making comparisons between the asphalts. The AC-20 (42 penetration) and AP-4 (69 penetration) had the best characteristics, i.e., expansion ratios greater than 12 and half-lives greater than 13 sec. The selection of the third asphalt was not straightforward because the decision between the AC-2.5 (185 penetration) and the AC-20 (55 penetration) involved a trade-off between expansion ratio and half-life. The AC-2.5 (185 penetration) was chosen so that a soft grade of asphalt would be included in the second stage of the study. The AC-2.5 had an expansion ratio of 12 and a half-life of 7 sec.

The relations between the viscosities of the asphalts at the foaming temperature of 325°F, the expansion ratios, and the half-lives for the three water contents are shown in Figures 2 and 3. The results indicate that viscosity alone is not sufficient to explain the variations in expansion ratio and half-life.

Figure 2. Expansion ratio versus viscosity.

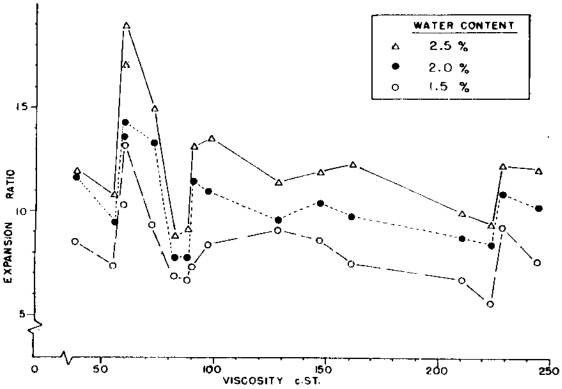
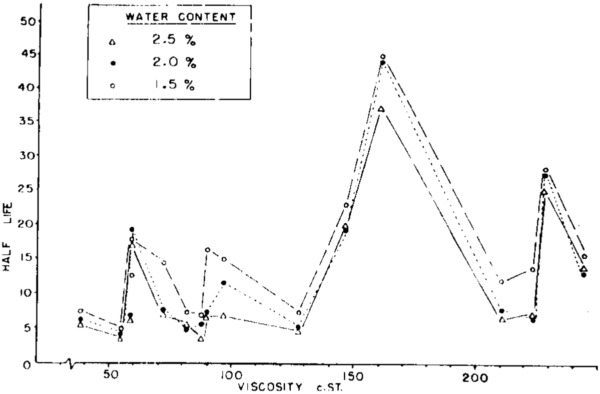


Figure 3. Half-life versus viscosity.



FOAMED ASPHALT AS BINDER FOR A RECYCLED MIX

Recycled Pavement Material

The pavement material to be recycled was obtained from a state road near Wabash, Indiana. The asphalt content was 5.4 percent by weight of the total mix. The penetration of the recovered asphalt was approximately 20. The gradation of the recovered aggregate is shown in Figure 4. The material to be recycled was crushed before delivery to the laboratory. Its gradation was established by using the 0.375-in, No. 4, and No. 16 (9.5-, 4.75-, and 1.18-mm) ASTM sieves (Figure 4). The material was separated into four sizes and recombined in the same proportions to ensure homogeneity in each recycled mix. The four sizes were >0.375 in., 0.375 in. to No. 4, No. 4 to No. 16, and <No. 16.

Asphalts

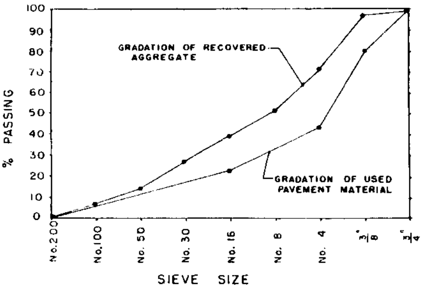
New supplies of the three asphalts selected in the first part of the study (AC-20, AP-4, and AC-2.5) were obtained. Their sources and viscosities are given below (1 cSt = 0.01 cm²/sec):

Grade	Source	Penetration (0.1 mm)	Kinematic Viscosity at 135°C (cSt)
AC-20	A	42	443
AP-4	C	69	261
AC-2.5	A	185	160

Analysis Procedure

At the outset, a cold-mix analysis procedure was required to simulate the cold-mix production of a recycled mix. The recycled mix was intended for use

Figure 4. Gradations of used pavement material and recovered aggregate.



primarily as a base course (7). Csanyi (8) had shown that cold mixes could be prepared with cold, wet aggregates and hot asphalt.

The recycled mixes were prepared by adding foamed asphalt to the cold, wet pavement material. The objective was to determine the optimum foamed-asphalt content for the three grades of asphalt and to compare the strengths of the mixes at different asphalt contents.

Compaction Methods

Trial mixes compacted by the Marshall hammer and the gyratory machine indicated that gyratory compaction was more suitable for compacting the mixes at room temperature. It was decided to compare the mixes by using a standard compactive effort that would simulate initial compaction after construction. A ram pressure of 200 psi (1.38 MPa) and 20 revolutions of the gyratory compactor were believed to produce satisfactory compaction; densities of about 140 lb/ft^3 (2.25 g/cm^3) were achieved by using this compactive effort.

Seventy-five blows of the Marshall compaction hammer are equivalent to a ram pressure of 200 psi and 30 revolutions of the gyratory compactor at a test temperature of 140°F (60°C) (9, Part 15). Comparisons of these compactive efforts on the recycled mix showed that this equivalence of the gyratory and Marshall compactive efforts did not hold true at room temperature. A maximum density of 125 lb/ft^3 (2 g/cm^3) was achieved by 75 blows of the Marshall hammer at room temperature. However, it was decided to compare the strengths of the mixes by using two compactive efforts:

1. Gyratory compaction at room temperature [72° to 75°F (22° to 24°C)] with a ram pressure of 200 psi and 20 revolutions; and
2. Marshall compaction at room temperature (72° to 75°F) using 75 blows of the hammer.

Testing Procedure

The strengths of the mixes were compared by testing Marshall size specimens in the Marshall stability apparatus. The specimens were 4 in. (10.26 cm) in diameter and approximately 2.5 in. (6.0 cm) high when compacted in the gyratory compactor. They were approximately 2.7 in. (6.8 cm) high when compacted by the Marshall hammer. Three response variables were obtained for each specimen: Marshall stability (lb), Marshall flow (0.01-in. units), and Marshall stiffness (lb/in.).

The stability correction factors published by the Asphalt Institute (10) were applied to correct the stability values for variations in the heights of the specimens. The specimens were tested at room temperature, which varied, as stated above, from 72° to 75°F. Therefore, it was necessary to assume that any variations in strength due to fluctuations in room temperature were small so that comparisons between the specimens could be made. For this reason, it was also necessary to establish a strict experimental procedure for preparing the specimens.

Design of Experiment

Details of the numbers of Marshall size specimens produced are shown in Figure 5. The foamed-asphalt content was expressed as a percentage by weight of the aggregate in the mix. Three specimens were produced at each foamed-asphalt content for the three grades of asphalt and the two compactive efforts. The average results of three specimens were used for making comparisons for the recycled mixes.

Specimen Preparation

Before preparation and mixing, 3300 g of the recycled material was weighted out according to its gradation into four batches, as follows: (a) three batches of coarse material containing 616 g retained on the No. 4 sieve and (b) one batch of fine material containing 1452 g passing the No. 4 sieve.

The fine material was mixed with a small quantity of water. The water acted as a vehicle for the foamed asphalt to thoroughly wet the mix (11). The amount of water to be added was established by the fluff point of the fine material. The fluff point is the water content at which the material has its maximum loose volume. The method used to determine the fluff point of the used pavement material was as follows:

1. A total of 200 g of material was loosely poured into a graduated cylinder. The height of the material in the cylinder was noted.
2. The material was put into a basin and thoroughly mixed with 1 percent (2 g) of water.
3. Then the wet material was loosely poured back into the graduated cylinder and the new increased height was noted.
4. This procedure was repeated for 2 percent, 3 percent, etc. of water and the heights of the material in the cylinder were noted.
5. The water content at which the material reached its maximum height was recorded as the fluff point.

At water contents above the fluff point the volume of the used pavement material remained the same;

Figure 5. Experimental design for evaluation of foamed asphalt as binder for a recycled mix.

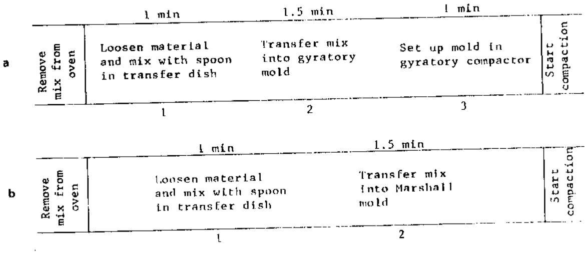
Gyratory Compaction
1.38 MPa, 20 revs.

	0.5%	1%	2%	3%
AC-20	3	3	3	3
AP-4	3	3	3	3
AC-2.5	3	3	3	3

Marshall Compaction
75 blows

	0.5%	1%	2%	3%
AC-20	3	3	3	3
AP-4	3	3	3	3
AC-2.5	3	3	3	3

Figure 6. Procedures for transferring recycled mix from oven to (a) gyratory compactor and (b) Marshall compactor.



the volumes decreased when the same procedure was used on virgin aggregates.

The fluff point was found to be 5 percent of water by weight of the fine material. Therefore, 72.6 g (5 percent x 1452 g) of water was mixed with the fine material for 1 min with a Hobart kitchen mixer.

The foamed asphalt was mixed with the recycled pavement material in two stages. First, the foamed asphalt and the cold, wet fine material was mixed for 2 min with a Hobart kitchen mixer and then mixed by hand for 1 min. Second, the mixed fine material was divided equally into three parts and each part was thoroughly mixed by hand for 1 min with a batch of coarse material.

Trial mixes and the results of cold-mix designs using asphalt emulsion (12) indicated that it was necessary to evaporate most of the water added to the mixes in order to achieve the needed compacted densities. Therefore, the recycled mixes were placed in transfer dishes in a forced-draft oven at 140°F (60°C) for between 1 and 1.25 hr before compaction began. As much as 75 percent of the water added to the mixes evaporated during this process. Later research has indicated that the amount of water initially needed for distributing the foamed asphalt could be reduced for recycled mixes so as to avoid the moisture loss in the oven before compaction.

The procedures for transferring the recycled mixes from the oven to the gyratory compactor and to the Marshall compactor are shown in Figure 6.

The compacted specimens after extrusion from the molds were left at room temperature (72° to 75°F) for 24 hr. Their weights and volumes were then recorded. The specimens were tested at room temperature in the Marshall stability testing apparatus. Their weights were recorded again to account for small losses of material that occurred during testing. The failed specimens were next placed in an oven at 220°F (104°C) for 24 hr. After drying, the specimens were weighed to determine the loss in weight due to water content. The following calculations were made:

Let W_1 = weight of specimen just before testing, W_2 = weight after testing, W_3 = weight after drying, and V = volume of specimen just before testing.

Density = W_1/V, and water content during test = $[(W_2 - W_3)/W_3] \times 100$.

Results

The compacted densities of the mixes are shown in Figure 7. Densities obtained with 75 blows of the Marshall hammer were about 90 percent of the densities obtained by using 200-psi ram pressure and 20 revolutions of the gyratory compactor. The variations in density obtained by varying the foamed-asphalt content were small.

The stability values of the various mixes are shown in Figure 8. The values obtained by using gyratory compaction were two to three times greater than the values obtained with Marshall compaction. The maximum stability values obtained with the two compaction methods do not coincide. Because variations in stability with foamed-asphalt content were greater for gyratory compaction, the maximum stability value obtained for this type of compaction was more clearly defined. With gyratory compaction, the trend was for maximum stability to occur at low foamed-asphalt contents (from 0.5 to 1 percent). The highest stability value recorded was 2720 kg (6,000 lb) with 0.5 percent of the AP-4 grade asphalt.

Figure 9 shows the Marshall flow values. The range in flow values (0.01-in. units) varied from 10 to 17 for gyratory compaction. The range for Marshall compaction was from 16 to 34. The flow values for gyratory compaction were consistent with

Figure 7. Density versus foamed-asphalt content.

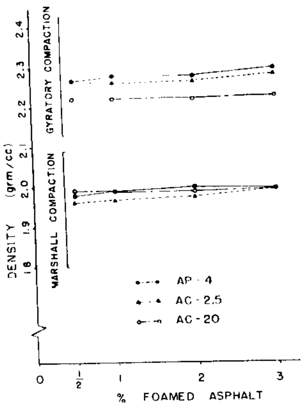


Figure 8. Stability versus foamed-asphalt content.

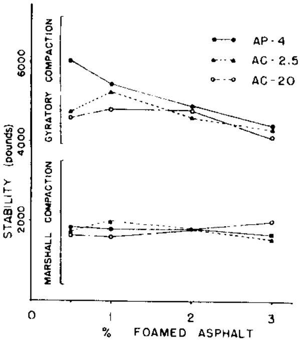
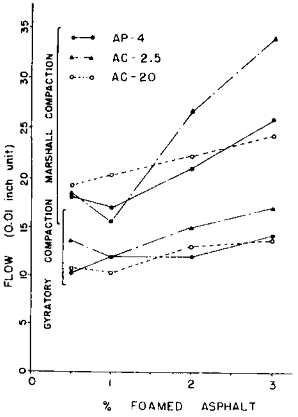


Figure 9. Flow versus foamed-asphalt content.



the stability results insofar as maximum stability occurred at lowest flow for the three grades of asphalt. The flow values for Marshall compaction were not consistent in this respect.

The Marshall stiffness values that represent the slope of the stability-versus-flow curve obtained from the autographic trace recorded during the stability test are shown in Figure 10. The values are 1-1/3 to 2-1/3 times greater for gyratory compaction. Maximum stiffness corresponded with maximum stability except for the AP-4 Marshall compacted mix. The maximum stiffness obtained was 102,000 lb/in. (18.1 Mg/cm) with 0.5 percent of the AP-4 foamed asphalt in the recycled mix.

The average water content of the recycled mixes at the time of testing was 0.55 percent, and the standard deviation was 0.15 percent.

Figure 10. Stiffness versus foamed-asphalt content.

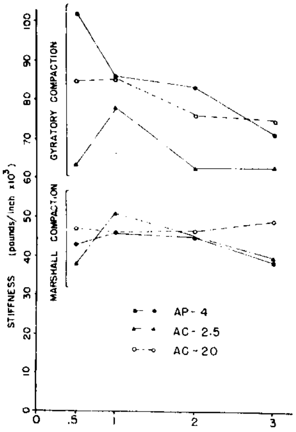


Figure 11. Experimental design for study of effect of curing time and water on recycled mixtures.

% Foamed asphalt added / Curing time	one day	seven days
1/2	×	⊗
1	×	⊗
2	×	⊗
3	×	⊗

Note: × 3 samples per cell tested dry
○ Water sensitivity test, 2 samples per cell

EFFECT OF CURING TIME AND WATER

Design of Experiment

In this set of experiments, the effects of curing time and water on the properties of mixes that were recycled with foamed asphalt were studied. An AP-4 was used as the foamed asphalt to be added to the recycled mix. Figure 11 shows the experimental design for this study. A water sensitivity test was used to evaluate the resistance of the recycled mix to water. Two curing times (1 day and 7 days) were studied. Water sensitivity tests were run after the 7-day curing period.

Experimental Procedures

Mixes were prepared by using the same procedure as described in the earlier part of this paper. Specimens were compacted with the gyratory compactor for 20 revolutions at 200 psi. Curing took place at room temperature. Cured samples were tested in the Marshall testing apparatus as described earlier.

The water sensitivity test as recommended by the Asphalt Institute was modified and used. The procedures are briefly described below:

1. Specimens are to be subjected to 1 hr of vacuum of 30 mm Hg.
2. After a 1-hr period, water at room temperature of 72°F is drawn into the vacuum chamber, submerging the specimens and vacuum-saturating them.
3. The vacuum is released and the specimens are then left in the water for 24 hr.
4. Before testing in the Marshall apparatus, the saturated surface dry weight of the specimen is determined to calculate the percentage of water absorption.

Response Variables

The response variables measured and analyzed in this study are Marshall stability, Marshall stiffness, Marshall flow, bulk specific gravity, and percentage of water absorbed (in water sensitivity test). The first four variables have been described previously. The percentage of water absorbed is the percentage of water by weight of the dry specimen absorbed during the 24-hr soaking period.

Results

Figure 12 shows Marshall stabilities versus percentage of asphalt added for the recycled mix at 1 day and 7 days of curing and the water sensitivity test. It is noted that for the "as is" test (1 day and 7 days), the optimum stability occurs when 0.5 percent asphalt is added. For the water sensitivity test, optimum stability occurs when 1 percent asphalt is added.

The effect of curing is appreciable for 0.5 and 1 percent asphalt added; at 2 and 3 percent asphalt added, it is not. The effect of water decreases with increasing percentage of asphalt added. At 3 percent asphalt added, the water sensitivity test does not have any effect on the stability of the recycled mix.

Figure 13 shows Marshall stiffness versus percentage of asphalt added. Trends similar to those for Marshall stability are noted. The effect of curing time and water decreases with increasing percentage of asphalt added. Average Marshall flow values vary from 12 to 15, showing no general pattern.

Figure 14 shows the percentage of water absorbed in the water sensitivity test. The percentage of water absorbed decreases with increasing percentage of asphalt added. Thus, it can be concluded that the more porous the specimens are, the more they will be affected by the action of water.

Figure 12. Marshall stabilities of recycled mixtures with AP-4 asphalt added.

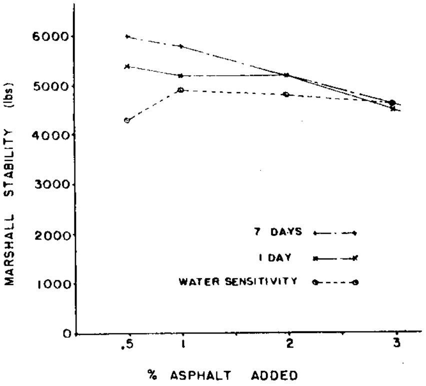


Figure 13. Marshall stiffness for recycled mixtures with AP-4 asphalt added.

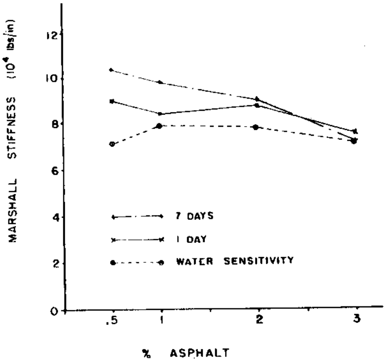
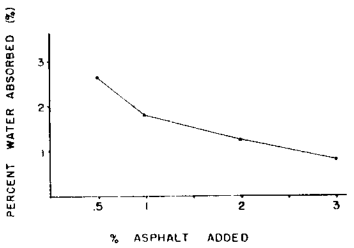


Figure 14. Percentage of water absorbed in water sensitivity test.



DISCUSSION OF RESULTS

Satisfactory laboratory procedures for comparing the foaming characteristics of asphalts and their uses in a recycled mix were established. Researchers had shown that it would be necessary to add a small amount of water to the pavement material so that the foamed asphalt would thoroughly coat and adhere to it. The water content that gave the material its maximum loose volume--i.e., its fluff point--proved to be an ideal water content for mixing purposes. The mixing process was a relatively clean operation because the moisture in the mix prevented the foamed asphalt from adhering to the blade and mixing bowl of the mixer. To achieve useful compacted densities, it was necessary to evaporate most of the water that aided in the mixing. Gyratory compaction with a ram pressure of 200 psi and 20 revolutions provided a degree of compaction that simulated initial compacted densities obtainable by using construction equipment. The highest Marshall stability was obtained by using 0.5 percent of an AP-4 grade. At foamed asphalt contents of 1, 2, and 3 percent, the differences in the stabilities of mixes using AP-4, AC-2.5, and AC-20 were not great.

CONCLUSIONS

The conclusions of the first part of the study on the foaming characteristics of asphalts were as follows:

1. Increasing the foaming temperature from 300° to 350°F (149° to 177°C) had the effect of increasing the expansion ratios but decreasing the half-lives of the foams.
2. Increasing the water content of the foam from 1.5 to 2.5 percent also increased the expansion ratios but decreased the half-lives.
3. A trade-off of expansion ratio for half-life or vice versa was implicit in the selection of a particular foaming temperature and water content.
4. A foaming temperature of 325°F (163°C) and a water content of 2 percent were deemed to provide an acceptable trade-off of foaming temperature for half-life for making comparisons among the asphalts.
5. The RC-SC base had the highest expansion ratio, 19, and the longest half-life, 45 sec.
6. The lowest expansion ratio was 6, and the shortest half-life was 3 sec.
7. The AC-20 (42 penetration) had the best foaming characteristics, the AP-4 (69 penetration) was rated second, and the AC-20 (55 penetration) and AC-2.5 (185 penetration) were rated third.
8. The kinematic viscosity of the asphalts at the foaming temperature was not a sufficient parameter alone to explain the variations in the foaming characteristics.

The AC-20 (42 penetration), AP-4 (69 penetration), and AC-2.5 (185 penetration) were selected as the binders for the second part of the study. The conclusions regarding their uses as binders for a recycled mix were as follows:

1. It was necessary to dry the recycled mixes in a forced-draft oven at 140°F (60°C) for 1 to 1.25 hr after mixing so that reasonable compacted densities could be achieved.
2. Gyratory compaction with a ram pressure of 200 psi (1.38 MPa) and 20 revolutions produced densities of about 140 lb/ft^3 (2.25 g/cm^3); Marshall compaction with 75 blows of the hammer produced densities of about 125 lb/ft^3 (2.0 g/cm^3).
3. The Marshall stability values obtained by gyratory compaction were twice the values obtained by Marshall compaction.
4. The highest stability obtained was 6,000 lb (2720 kg) with 0.5 percent of the AP-4 foamed asphalt in the recycled mix.
5. Maximum stability occurred at the least flow for the gyratory-compacted mixes. Maximum stability and least flow did not coincide for the Marshall-compacted mixes.
6. The range of flow values for the gyratory-compacted mixes was from 10 to 17 (0.01-in. units); the range for Marshall compaction was from 16 to 34.
7. Maximum Marshall stiffness coincided with maximum stability for the gyratory-compacted mixes. The highest stiffness recorded was 102,000 lb/in. (18.1 Mg/cm) with 0.5 percent of the AP-4 foamed asphalt in the recycled mix.
8. Seventy-five blows of the Marshall hammer did not provide sufficient compaction to simulate initial compaction after construction. The possibility of achieving better results by using a greater number of blows could be investigated.
9. The effect of 7-day curing versus 1-day curing was quite pronounced for 0.5 and 1.0 percent of added foamed-asphalt binder.
10. Marshall stability values obtained after the water sensitivity test displayed a peak at 1 percent added binder. The effect of water decreased with an increase in the binder content.
11. Marshall stiffness values followed the same trends as the values for Marshall stability with regard to both curing and moisture sensitivity.
12. The percentage of water absorbed during the water sensitivity test decreased with increasing percentage of binder added.

ACKNOWLEDGMENT

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 FHWA. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. Foamed Bitumen: A New Development. Mobile Oil Australia Ltd., Tech. Bull. 6, March 1971.
2. R.H. Bowering and D.T. Currie. Experiences with Some Bitumen Treated Materials in Australia. 7th World Meeting, International Road Federation, Munich, 1973.
3. Laboratory Equipment and Test Procedures for the Evaluation of Soils Stabilized with Foamed Bitumen. Mobile Oil Australia Ltd., Tech. Rept. 714, Dec. 1971.
4. Foamed Asphalt Soil Stabilization: Mix Design and Associated Studies. Mobil Oil Australia Ltd., March 1973.
5. R.H. Bowering and C.L. Martin. Foamed Bitumen: Production and Application of Mixture, Evaluation and Performance of Pavements. Proc., Assn. of Asphalt Paving Technologists, Vol. 45, 1976, pp. 453-477.
6. Refining Technical Services Laboratory. FOAMIX$^{\text{TM}}$ Asphalt-Laboratory Dispenser Operating Variables. Continental Oil Co., Ponca City, OK, May 1978.
7. F. Abel. Foamed Asphalt Base Stabilization. Proc., 6th Annual Asphalt Paving Seminar, Colorado State Univ., Dec. 7-8, 1978.
8. L.H. Csanyi. Bituminous Mixes Prepared with Foamed Asphalt. Iowa Engineering Experiment Station, Iowa State Univ., Ames, Bull. 189, 1960.
9. 1976 Annual Book of ASTM Standards. ASTM, Philadelphia, 1976.
10. Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types. Asphalt Institute, College Park, MD, Manual Series 2, 1979.
11. Plant Setup for Foamed Asphalt. Construction Canada, July 1964, pp. 20-23.
12. A.A. Gadallah. A Study of the Design Parameters for Asphalt Emulsion Treated Mixtures. Joint Highway Research Project, Purdue Univ., West Lafayette, IN, Res. Rept. 30, 1976.

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