(10)

1983

REFERENCES

1. R.W. Israel. Soil Stabilization and Cold Mix Recycling. Bomag, USA, 1982.
2. Materials for Stabilization. American Road and Transportation Builders Association, Washington, DC, Sept. 1976, 21 pp.
3. J.A. Epps. State-of-the-Art Cold Recycling. TRB, Transportation Research Record 780, 1980. pp. 68-100.
4. Cold Recycling in a Central Plant Takes Planning. Heavy and Highway Construction, July 1979, pp. 78+.
5. Standard Equipment Makes Old Road New. Heavy and Highway Construction, Feb. 1979, pp. 34-35.
6. J.F. Wood. Cold Recycling Equipment. Proc., Recycling Asphalt and Concrete Pavements, Univ. of Michigan, Ann Arbor, March 24-25, 1981, pp. 151-169.
7. Cold Recycling of Roads Paying Off in Texas. Civil Engineering, American Society of Civil Engineers, Nov. 1980, pp. 47-48.
8. H. Muncy. Recycling with Asphalt Emulsions. Rural and Urban Roads, March 1981, pp. 34+.
9. R.G. Maag. Cold Recycling of K-96 Scott County, Kansas. Proc., Asphalt Emulsion Manufacturers Association, Feb. 10-11, 1982.
10. R.G. Maag. Kansas Evaluates 1978-79 3R Experiments. Rural and Urban Roads, Nov. 1980, pp. 38+.
11. R. Watkins and W. Birt. What CALTRANS Learned on First Cold 3R Job. Rural and Urban Roads, March 1980, pp. 52-54.
12. ER-1000 Leads Cold Recycle Paving Train. CMI News, Spring 1982, pp. 12-13.
13. Cold In-Place Recycling Saves Money. Heavy and Highway Construction, June 1982, pp. 44-45.
14. R.F. LaForce. Cold Recycling of Asphalt Pavement, DeBeque East and West, Project I 70-1 (54). Colorado Department of Highways, Denver, Interim Rept., April 1982, 48 pp.
15. E.A. Thompson. Chemical Aspects of Asphalt Pavement Rejuvenation. Proc., Canadian Technical Asphalt Association, Vol. 26, Nov. 1981, pp. 84-96.
16. R.J. Holmgreen and J.A. Epps. Evaluation of Selected Recycling Modifiers. TRB, Transportation Research Record 777, 1980, pp. 22-25.
17. S.J. Escobar and D.D. Davidson. Role of Recycling Agents in the Restoration of Aged Asphalt Cements. Proc., AAPT, Vol. 48, Feb. 1979, pp. 375-393.
18. W. Canessa. Asphalt and Rejuvenators. Ontario Municipal Seminar on Asphalt Pavement Recycling, Ontario Ministry of Transportation and Communications, Downsview, Nov. 10-12, 1981, pp. 128-140 (preprint).
19. J.A. Epps, D.N. Little, R.J. Holmgreen, and R.L. Terrel. Guidelines for Recycling Pavement Materials. NCHRP, Rept. 224, Sept. 1980, 137 pp.

Use of Asphalt Emulsion and Foamed Asphalt in Cold-Recycled Asphalt Paving Mixtures

MANG TIA AND LEONARD E. WOOD

Increased interest in improving the quality of cold-recycled asphalt paving mixtures has made it necessary to understand the behavior of these mixes better. This laboratory study investigates the long-term behavior of cold-recycled asphalt paving mixtures by using asphalt emulsion and foamed asphalt as the added binders. An artificially aged paving mixture was used to make the recycled mixes for this study. Specimens of the recycled mixes were compacted with the gyratory testing machine. The resilient modulus, Hveem stabilometer R-value, and Marshall stability were obtained on the compacted recycled mixes at various levels of compactive effort, added binder, testing temperature, and curing time. Results indicate that most of the rejuvenating action of the added binder on the old binder takes place during the compaction process. The binders of the recycled mixes that undergo the initial softening during the compaction process generally increase in stiffness with increasing curing time. The recycled mix with foamed asphalt added had properties comparable to those of the mix with asphalt emulsion added. However, slightly more added binder is needed when foamed asphalt is used. The structural performance of these recycled mixes as a stabilized base in a typical low-volume road was also evaluated and compared with that of a standard asphalt concrete by using a linear elastic multilayer analysis.

The recycling of asphalt pavement is the process of reusing a deteriorated asphalt pavement material in a functionally new pavement. An existing asphalt pavement material usually contains a hardened asphaltic binder and a deteriorated aggregate and has lost such desirable characteristics as stability, flexibility, and durability. The fundamental process of asphalt pavement recycling involves the addition of rejuvenating agents to soften the hardened old asphaltic binders and the addition of virgin aggregates to upgrade the deteriorated aggregates. Basically, it involves (a) removing the old pavement material from the road; (b) remixing it, when necessary, with additional virgin aggregate, a virgin binder, or a rejuvenating agent; and (c) recompacting it. The process can be carried out either hot or cold. In a hot-recycled mix, the blending of the old binder and the virgin binder is relatively more homogeneous. In a cold-recycled mix, the virgin binder or rejuvenating agent tends to adhere to the old material (old aggregate coated with old binder) and to form a thin film around it. The diffusion of the virgin binder or rejuvenating agent into the old binder could be a function of time, temperature, and additional traffic compaction (1,2). This diffusion process could greatly influence the behavior of a recycled material, and thus a knowledge of its long-term behavior is very important in designing a recycled mix.

Asphalt emulsion is a commonly used added binder in cold recycling. Recently, increased interest has also been shown in using foamed asphalt as an added binder in cold recycling. This laboratory study investigates the long-term behavior of the cold-recycled asphalt paving mixtures that use asphalt emulsion and foamed asphalt as the added binders. The study has the following objectives:

Figure 1. Vertical deformation measuring device in resilient-modulus test.

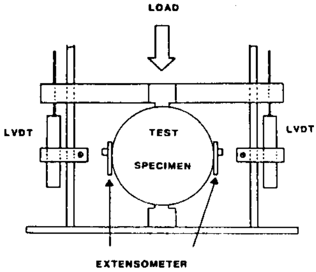
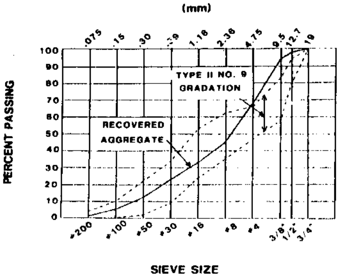


Figure 2. Gradation of recovered pavement aggregate.



1. To study the properties of cold-recycled asphalt paving mixtures under the effects of time, additional compaction, and temperature;
2. To compare the effectiveness of foamed asphalt with that of asphalt emulsion as an added binder in cold-recycled mixtures; and
3. To evaluate the structural characteristics of these cold-recycled mixes.

It is hoped that these findings would provide some guidelines for the design of cold-recycled asphalt mixtures that use these two materials as the added binders.

EQUIPMENT

The major pieces of equipment used in this laboratory study are the gyratory testing machine, the diametral resilient-modulus test equipment, the Hveem stabilometer, the autographic Marshall testing apparatus, and the laboratory Foamix asphalt dispenser.

The gyratory testing machine was used for compaction of the recycled mixtures. The gyratory machine had a fixed upper roller. The angle of gyration was set at 1 degree, and the ram pressure was adjusted to 1.38 MPa (200 psi).

The diametral resilient-modulus test equipment proposed by Schmidt (3) was modified and used in this study. The loading frame and the deformation measuring device of the test equipment are illustrated in Figure 1. A 222-N (50-lbf) pulse load of 0.1-s duration is applied to the test specimen every 3 s through a diaphragm air cylinder. The vertical deformation of the test specimen is measured by two linear variable differential transformers and plotted on the chart recorder.

Table 1. Physical properties of AE-150.

Property	Standard	Test Condition	Value
Residue by distillation	ASTM D244	Standard	70.0 percent
Oil portion of distillate	ASTM D244	Standard	1.5 percent
Test on distillation residue			
Penetration	ASTM D5	100 g, 5 s, 25°C	215 dmm
Specific gravity	ASTM D70	25°C	1.010
Float	ASTM D139	60°C	>200 s

Note: 1 g = 0.035 oz; t°C = (t°F - 32)/1.8.

Table 2. Physical properties of AC-2.5.

Property	Standard	Test Condition	Value
Penetration	ASTM D5	100 g, 5 s, 25°C	>300 dmm
Absolute viscosity	ASTM D2171	60°C	300 poises
Kinematic viscosity	ASTM D2170	135°C	160 cSt
Specific gravity	ASTM D70	25°C	1.024
Ductility	ASTM D113	25°C	>100 cm

Note: 1 g = 0.035 oz; t°C = (t°F - 32)/1.8; 1 poise = 0.1 Pa·s; 1 cSt = 0.01 cm^2/s; 1 cm = 0.39 in.

The standard Hveem stabilometer and Marshall apparatus as specified by the ASTM standards were used to measure the Hveem stabilometer R-values and Marshall stabilities of the recycled mixes.

The laboratory Foamix asphalt dispenser developed by CONOCO, Inc., was used to produce the foamed asphalt to be added to the recycled mixes.

MATERIAL

Artificially Aged Paving Mixtures

An artificially aged paving mixture was used to make the recycled mixes for this study. The material for each test specimen was batched separately. This was done in order to have less variability and better control of the mixes studied. The artificially aged mixture was made to resemble an old pavement material used in an earlier study (4). The aggregate was a limestone. Its gradation is depicted in Figure 2. The aggregate was mixed with 5.5 percent of AP-3 grade asphalt cement at 150°C (302°F). The mixture was then artificially aged by placing it in a forced-draft oven at 120°C (248°F) for 24 h. The recovered asphalt from the artificially aged mixture had the following physical properties [1 g = 0.035 oz; t°C = (t°F - 32)/1.8); 1 poise = 0.1 Pa·s]:

Standard Test	Avg Value
ASTM D5: penetration (100 g, 5 s, 25°C)	24 dmm
ASTM D2171: absolute viscosity (60°C)	32 300 poises

Added Binders

The added binders used in this study were a high-float anionic asphalt emulsion, designated AE-150 in the Indiana State Highway standard specification (5), and a foamed asphalt made from a soft asphalt designated AC-2.5. The physical properties of AE-150 and AC-2.5 are described in Tables 1 and 2, respectively.

RESPONSE VARIABLES

The three measured variables used to evaluate the recycled mixes in this study are the diametral resilient modulus, the Hveem stabilometer R-value, and the Marshall stability.

The resilient modulus is defined as the ratio of the applied stress to the recoverable strain when a repeated dynamic load is applied. It is essentially the dynamic elastic modulus of a viscoelastic material. In the diametral resilient modulus test used in this study, the resilient modulus is calculated from the following relationship:

$$M_R = -3.583P/td_v \tag{1}$$

where

M_R = resilient modulus,
P = applied pulse load,
t = thickness of test specimen, and
d_v = recoverable vertical deformation of specimen.

This relationship holds for a Marshall-size specimen [6.35 cm (2.5 in) in diameter] loaded diametrally.

The Hveem stabilometer R-value is usually used for the evaluation of stabilized base mixtures.

The Marshall stability is defined as the maximum load required to produce failure of a standard Marshall specimen in a Marshall test. It is a semiempirical figure that indicates the relative resistance of a material to plastic deformation. In this study, the Marshall tests were run at room temperature.

SPECIMEN PREPARATION PROCEDURE

The cold-recycled asphalt mixtures used for this study were prepared in the laboratory. The mixing and curing procedure adopted in previous studies on cold-recycled mixes was used (1). This procedure was originally developed by Gadallah in his study on asphalt emulsion-treated mixes (6) and has been used by other researchers (2,7). The specimen preparation procedure consisted of the following general steps:

1. The proper amount of the pavement material to be recycled was batched for one specimen.
2. The required amount of water was added to the material and mixed thoroughly with a mechanical mixer and then with a spoon by hand. The material was then left for 10-15 min.
3. The proper amount of virgin binder was added to the material and mixed with a mechanical mixer for 1.5 min and with a spoon by hand for 30 s.
4. The mix was cured for 1 h in a forced-draft oven at 60°C (140°F).
5. The mix was remixed for 30 s with a mechanical mixer and was compacted immediately in the gyratory machine.
6. After compaction, the specimen was extruded from the mold within 30 min and left to cure at room temperature.

The purpose of adding water to the mix was to facilitate the mixing process. When asphalt emulsion was used as the added binder, 1 percent water was added. When foamed asphalt was used, 3 percent water was added.

EXPERIMENTAL DESIGN

Design 1

The first set of experiments dealt with the artificially aged paving mixtures with AE-150 as the added binder. The experimental design is shown in Figure 3. The factors studied were the compactive effort (two levels), the percentage of AE residue added (five levels), the testing temperature (three levels), and the curing time (five levels).

Figure 3. Design for tests on artificially aged paving mixtures with AE-150 added.

CURING TIME	TEMPERATURE (° C)	20 REVS					60 REVS				
	% AE RESIDUE ADDED	0	.5	1	2	3	0	.5	1	2	3
1 DAY	23	X	X	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X	X	X
7 DAYS	23	X	X	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X	X	X
14 DAYS	23	X	X	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X	X	X
28 DAYS	23	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	40	X	X	X	X	X	X	X	X	X	X
ULTIMATE CURING	0	+	+	+	+	+	+	+	+	+	+
	23	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	40	+	+	+	+	+	+	+	+	+	+

NOTE : X RESILIENT MODULUS TEST, 2 SAMPLES PER CELL
\+ RESILIENT MODULUS TEST, 1 SAMPLE PER CELL
O R-VALUE & MARSHALL TEST, 1 SAMPLE PER CELL

Design 2

The second set of experiments dealt with artificially aged paving mixtures with foamed asphalt as the added binder. The experimental design is shown in Figure 4. The factors included were the compactive effort (two levels), the percentage of asphalt added (four levels), the testing temperature (three levels), and the curing time (five levels).

TESTING SEQUENCE

The testing sequence on the specimens was designed so that as much information as possible could be extracted from a fabricated sample. The testing sequence for the specimens is shown in Figure 5. Due to the nondestructive nature of the resilient-modulus test, the same specimens were used repeatedly in the resilient-modulus test at the various temperatures and curing times. After the resilient-modulus test had been performed on the specimens, they were evaluated in the R-value test and then in the Marshall test.

METHOD OF ANALYSIS

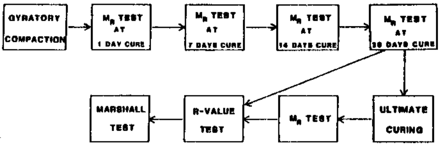
The response variables were analyzed with the aid of the analysis-of-variance (ANOVA) statistical method. The ANOVA determined whether the effects of certain factors and/or interactions of factors were statistically significant. The means of the response variables in each mix combination were used

Figure 4. Design for tests on artificially aged paving mixtures with foamed asphalt added.

CURING TIME	TEMPERATURE (°C) \ COMPACTION	20 REVS				60 REVS			
	% ASPHALT ADDED	0	1	2	3	0	1	2	3
1 DAY	23	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X
7 DAYS	23	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X
14 DAYS	23	X	X	X	X	X	X	X	X
	40	X	X	X	X	X	X	X	X
28 DAYS	23	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	40	X	X	X	X	X	X	X	X
ULTIMATE CURING	0	+	+	+	+	+	+	+	+
	23	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	40	+	+	+	+	+	+	+	+

NOTE: X RESILIENT MODULUS TEST, 2 SAMPLES PER CELL
+ RESILIENT MODULUS TEST, 1 SAMPLE PER CELL
O R-VALUE & MARSHALL TEST, 1 SAMPLE PER CELL

Figure 5. General testing sequence for specimen cured to 28 days or ultimate condition.



in looking for any physical trend that might be present.

RESULTS OF EXPERIMENTAL DESIGN 1

Resilient Modulus

The resilient moduli of the recycled mixes in design 1 are presented in Figures 6-9 as functions of curing time, from 1 day to 28 days. It can be observed that the resilient moduli increased significantly from 1 day to 7 days and leveled off after 7 days. The increase in resilient modulus with time can be explained by the increase in stiffness of the binder as the asphalt emulsion continued to cure (through evaporation of its water).

The ANOVA results indicated that the effects of percentage of AE residue added, compactive effort, curing time, and testing temperature were all significant.

Figures 10 and 11 present the resilient moduli at ultimate curing as functions of percentage of AE residue added. It can be noted that the optimum percentage of AE residue added increased as the testing temperature decreased. For the compactive effort of 20 revolutions, the optimum AE residue added was 0.5 percent at 40°C (104°F), 1 percent at 23°C (73°F), and 2 percent at 0°C. For the compactive effort of 60 revolutions, the optimum AE residue added was 0.5 percent at 40°C, 0.5 percent at 23°C, and 3 percent at 0°C.

Hveem R-Value and Marshall Stability

Figures 12 and 13 depict the Hveem R-values as functions of percentage of AE residue added. It can be observed that the optimum AE residue added was around 0.5 percent for the two compactive efforts and the two curing times.

Figures 14 and 15 present the Marshall stabilities as functions of percentage of AE residue added. Like the Hveem R-value plots, they indicated the optimum AE residue to be around 0.5 percent. Unlike the R-value, the Marshall stability increased significantly with higher compactive effort. For the Marshall stability, the difference between 28 days' curing and ultimate curing was not significant.

RESULTS OF EXPERIMENTAL DESIGN 2

Resilient Modulus

The resilient moduli of the recycled mixes in design 2 are presented in Figures 16-19 as functions of curing time, from 1 day to 28 days. It can be observed that the resilient modulus increased significantly with curing time from 1 day to 14 days and leveled off after 14 days. The increase in resilient modulus with time was due to the drying of the mixture through evaporation of its water. When most of the moisture in the mixture had evaporated, the effect of curing time became less significant.

Hveem R-Value and Marshall Stability

Figures 20 and 21 depict the Hveem R-values as functions of percentage of asphalt added. It can be noted that for the compactive effort of 20 revolutions, the R-value was relatively insensitive to the changes in percentage of asphalt added. For the compactive effort of 60 revolutions, the effect of percentage of asphalt added was more significant, and the optimum asphalt added could be noted to be around 1 percent.

Figures 22 and 23 present the Marshall stabilities as functions of percentage of asphalt added. It can be noted that for low compactive effort (20 revolutions), the Marshall stability was relatively insensitive to the changes in percentage of asphalt added. For high compactive effort (60 revolutions), the effect of percentage of asphalt added was more significant, and the optimum asphalt added could be observed to be around 1 percent. It can also be observed that higher compactive effort produced higher Marshall stability values.

STRUCTURAL CHARACTERISTICS OF RECYCLED MIXES

The resilient modulus, which was measured most extensively throughout this laboratory study, was an essential input parameter to the analytical pavement design method, such as the multilayer elastic analysis. In this section, the structural characteristics of the recycled mixes in this study are compared with those of the conventional asphalt cement by using a linear elastic multilayer analysis. From the results of this analysis, the structural coefficients of the American Association of State Highway and Transportation Officials (AASHTO) are estimated for these recycled mixes.

Figure 6. Effects of curing time on resilient moduli of artificially aged paving mixtures with AE-150 added: 20 revolutions, 23°C.

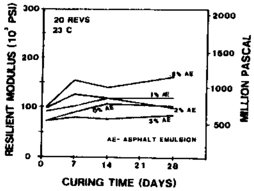


Figure 7. Effects of curing time on resilient moduli of artificially aged paving mixtures with AE-150 added: 60 revolutions, 23°C.

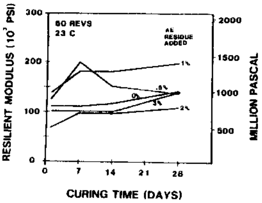


Figure 8. Effects of curing time on resilient moduli of artificially aged paving mixtures with AE-150 added: 20 revolutions, 40°C.

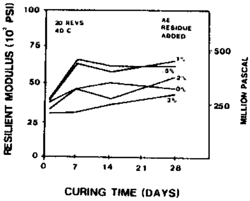


Figure 9. Effects of curing time on resilient moduli of artificially aged paving mixtures with AE-150 added: 60 revolutions, 40°C.

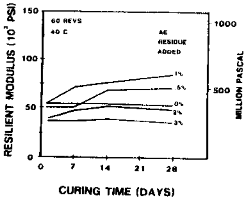


Figure 10. Resilient moduli at ultimate curing for artificially aged paving mixtures with AE-150 added: 20 revolutions.

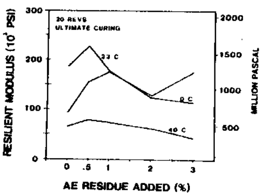


Figure 11. Resilient moduli at ultimate curing for artificially aged paving mixtures with AE-150 added: 60 revolutions.

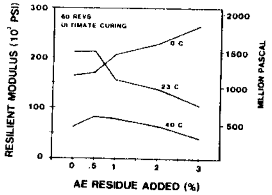


Figure 12. Hveem R-values of artificially aged paving mixtures with AE-150 added: 20 revolutions.

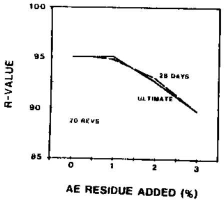


Figure 13. Hveem R-values of artificially aged paving mixtures with AE-150 added: 60 revolutions.

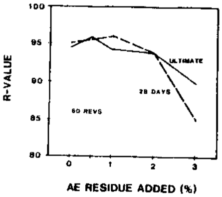


Figure 14. Marshall stabilities of artificially aged paving mixtures with AE-150 added: 20 revolutions.

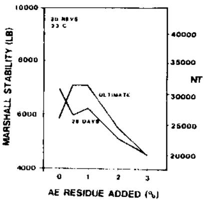
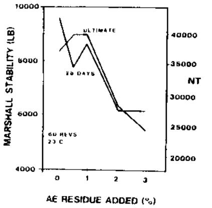


Figure 15. Marshall stabilities of artificially aged paving mixtures with AE-150 added: 60 revolutions.



Linear Elastic Multilayer Analysis

The resilient moduli of the recycled mixes in this study ranged from 345 to 2069 MPa (50 000-300 000 psi) at 23°C. The structural performance of these mixes (with the resilient moduli in this range) as stabilized bases was evaluated by using a hypothetical pavement system. The pavement system used in this analysis is depicted in Figure 24. This is a typical pavement structure for a low-volume road. The condition of the subgrade in this pavement structure is representative of the subgrade condition of State Road 16 in Indiana, where a recycling project has recently been completed. The pavement system was to be subjected to an arbitrary wheel load of 20 000 N (4500 lbf) with a tire pressure of 552 kPa (80 psi) and a circular contact area.

The bitumen structures in roads (BISTRO) computer program developed by Shell Research N.V. (8) was used to make the multilayer analysis. The induced vertical subgrade deformation was used as a means of measuring and comparing the structural performance of different pavement materials. Asphalt concrete 10.2 cm (4 in) thick was used as a reference base course in this hypothetical pavement system. The vertical subgrade deformation for this reference system was calculated to be 0.189 mm (0.007 45 in). The recycled mixture (with resilient modulus of 345-2069 MPa) was then used as the stabilized base of this hypothetical system, and the vertical subgrade

Figure 16. Effects of curing on resilient moduli of artificially aged paving mixtures with foamed asphalt added: 20 revolutions, 23°C.

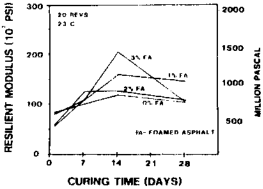


Figure 17. Effects of curing on resilient moduli of artificially aged paving mixtures with foamed asphalt added: 60 revolutions, 23°C.

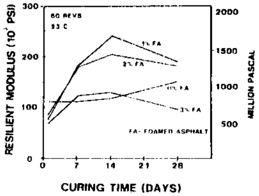


Figure 18. Effects of curing on resilient moduli of artificially aged paving mixtures with foamed asphalt added: 20 revolutions, 40°C.

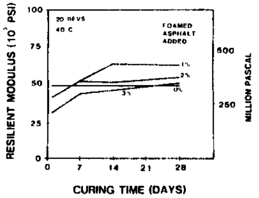


Figure 19. Effects of curing on resilient moduli of artificially aged paving mixtures with foamed asphalt added: 60 revolutions, 40°C.

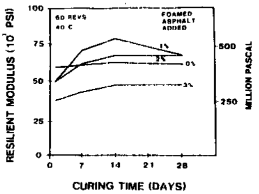


Figure 20. Hveem R-values of artificially aged paving mixtures with foamed asphalt added: 20 revolutions.

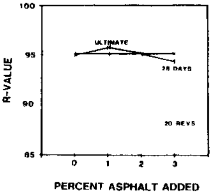


Figure 21. Hveem R-values of artificially aged paving mixtures with foamed asphalt added: 60 revolutions.

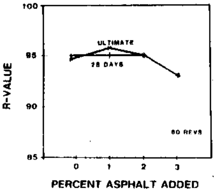


Figure 22. Marshall stabilities of artificially aged paving mixtures with foamed asphalt added: 20 revolutions.

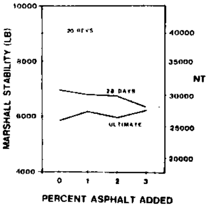
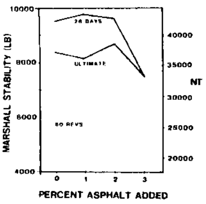


Figure 23. Marshall stabilities of artificially aged paving mixtures with foamed asphalt added: 60 revolutions.



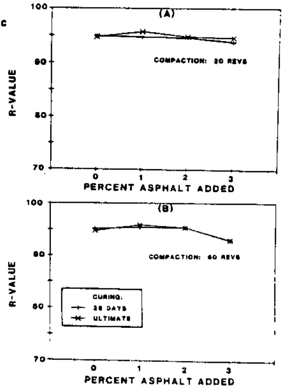


Figure 24. Pavement system for linear elastic multilayer analysis.

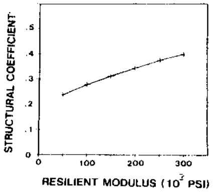


Figure 25. Estimated AASHTO structural coefficients of recycled mixtures.

deformations were calculated for various thicknesses of the stabilized base. For the range of resilient modulus considered, determination was made of the required thicknesses of the stabilized base for the vertical subgrade deformation to be the same (0.189 mm).

AASHTO Structural Coefficient

In the AASHTO pavement design method (9), the performance of a pavement section can be directly related to the structural number (SN), which can be expressed by the following general equation:

$$SN = a_1D_1 + a_2D_2 + a_3D_3 \qquad (2)$$

where

a_1, a_2, a_3 = structural coefficients;
D_1 = thickness of surface course (cm),
D_2 = thickness of base course (cm), and
D_3 = thickness of subbase (cm).

The structural performance can be measured by a combination of several variables. However, the most important variable is the vertical subgrade deformation. The study by Little and Epps (10) indicated that there was good correlation between the vertical subgrade deformation and the number of load repetitions to failure. Thus, when two pavement systems have the same subgrade deformations under the same loading condition, it is assumed that they have the same SN.

The structural coefficient of the reference asphalt concrete was known to be 0.44 (9). For the pavement systems with the same subgrade deformations and with everything else the same except for the stabilized base course, the following relationship can be established:

$$a_2D_2 = (0.44)(10.2\text{ cm}) \qquad (3)$$

where a_2 is the structural coefficient of the recycled material and D_2 is the required thickness.

By using the above relationship and the results in the previous section, the structural coefficients of the recycled materials can be estimated. Figure 25 presents the estimated structural coefficients of the recycled materials for the range of resilient modulus considered. It should be noted that using the calculated subgrade deformation to measure the structural performance of a pavement system was a simplified method. The derived structural coefficients were thus only estimated values.

CONCLUSIONS

The results of this extensive laboratory study have given us a better understanding of the behavior of the cold-recycled mixtures that use asphalt emulsion and foamed asphalt as the added binders. Major findings from this study are summarized as follows:

1. When a virgin binder or rejuvenating agent is added to the aged pavement material, most of the rejuvenating action of the new binder on the old binder will take place during the gyratory compaction process.
2. The binders of the recycled mixes, which undergo the initial softening during the compaction process, generally increase in stiffness with increasing curing time. This could be explained by the evaporation of the water from the mixes.
3. The optimum binder content increases with decreasing testing temperature.
4. Higher compactive effort generally produces higher resilient modulus and Marshall stability of the recycled mixture.
5. When the binder content is too high, higher compactive effort generally produces a lower Hveem R-value. When the mix is relatively stable, the Hveem R-value is insensitive to the changes in compactive effort.
6. The recycled mix with foamed asphalt added had properties comparable with those of the mix with asphalt emulsion added. However, slightly more added binder is needed when foamed asphalt is used.
7. The estimated AASHTO structural coefficients of these mixes range from 0.25 to 0.40 compared with 0.44 for asphalt concrete.

REFERENCES

1. M. Tia. Laboratory Investigation of Cold-Mix Recycled Bituminous Pavements. Joint Highway Research Project, Purdue Univ., West Lafayette, IN, Rept. JHRP-78-23, 1978.
2. A. Iida. Effects of Added Softening Agents Upon the Behavior of Cold Recycled Asphalt Mixtures. Purdue Univ., West Lafayette, IN, Rept. FHWA/IN/JHRP-80/13, 1980.
3. R.J. Schmidt. Practical Method for Measuring the Resilient Modulus of Asphalt-Treated Mixes. HRB, Highway Research Record 404, 1972, pp. 22-32.
4. M. Tia. Characterization of Cold-Recycled Asphalt Mixtures. Joint Highway Research Project, Purdue Univ., West Lafayette, IN, Rept. JHRP-82-5, 1982.
5. Standard Specifications. Indiana State Highway Commission, Indianapolis, 1978.