

Abridgment

Evaluation of Long-Term Behavior of Cold Recycled Asphalt Mixture

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The technique of recycling asphalt pavement materials has been widely used in the past decade, but unsolved problems such as rutting and instability still exist. Softening agents or low-viscosity binders such as emulsified asphalts are usually added during the cold recycling process, which may have a slow softening reaction. Thus, the properties of the recycled mixtures are controlled by several factors, including the oxidation hardening of the new bituminous materials and the softening effect of the softening agents or emulsions. An evaluation of the long-term behavior of such mixtures by means of both creep and Marshall tests conducted at 75°F is presented. The mixture was artificially aged by curing at 140°F up to 60 days and tested at different ages. The creep compliance of both virgin and recycled mixtures decreased rapidly at early ages due to the oxidation of the asphalt binder and then remained essentially the same. No large difference was observed in the creep behavior of the virgin and recycled mixtures. Neither creep nor Marshall test results support the hypothesis that the emulsified asphalt used in the study has a long-term softening effect on the old asphalt binder.

The asphalt pavement recycling technique has been widely used, but unsolved problems still remain (1,2). Rutting or instability of the recycled mixture has been observed in some projects a few years after construction. Because most of the pavement recycling projects have been recently constructed, the long-term performance of such pavements has not been well defined (3).

During the cold-mix recycling process, softening agents and low-viscosity binders such as emulsified asphalts are usually added to the reclaimed materials. The slow reaction of these added materials may be responsible for instability or rutting in the wheel path of the recycled pavement at later ages. On the other hand, oxidation takes place, causing an increase in the viscosity of the binder. Therefore, it can be expected that the viscosity of the binder changes after recycling based on an interaction of two factors: softening and oxidation hardening in addition to other factors (4). This behavior cannot be examined in the field except after a few years of observation. In the laboratory, however, artificially aged (weathered), recycled mixtures can be prepared and tested to simulate the long-term performance of the recycled pavements.

The objective of this study is to investigate the long-term effect of emulsified asphalt on the properties of cold-mixed recycled asphalt mixtures. Specimens were prepared and artificially aged in the laboratory, and then tested using both Marshall and creep tests. The properties of the recycled and new mixtures are compared.

MATERIAL ACQUISITION AND INITIAL TESTING

Old Asphalt Pavement Material

Old asphalt material was obtained by cold milling of an old deteriorated pavement in Buffalo, New York. Asphalt estimated at 6.9 percent by weight of aggregate was extracted from representative samples of the salvaged material according to ASTM D2172 by using the centrifuge method. The old aggregate remaining after the asphalt had been extracted was found to be limestone of the gradation given in Table 1. The properties of that aggregate were evaluated according to ASTM C127 as follows:

Property	Value
Bulk specific gravity	2.568
Bulk specific gravity (saturated surface dry)	2.678
Apparent specific gravity	2.888
Absorption (%)	4.30

Aggregate

Virgin crushed limestone was added to the old asphalt mixture. The new aggregate properties were evaluated as follows:

Property	Value
Bulk specific gravity	2.508
Bulk specific gravity (saturated surface dry)	2.669
Apparent specific gravity	2.856
Absorption (%)	3.93

Emulsified Asphalt

A high-float emulsion type HFMS-2 was used (ASTM D977). The properties of the emulsion are as follows:

Property	Value
Residue by distillation (%)	70
Penetration of residue after distillation at 77°F, (5 sec, 100 g)	>200
Specific gravity of emulsion at 77°F	0.970

MIX PREPARATION

Virgin Mixture

Marshall-size specimens were prepared in a cold condition by using limestone and emulsified asphalt. The mixing procedure followed the proposed method developed in a previous study (5). Water was added to aggregate at the rate of 1 percent, while emulsion was added to provide residue contents of either 3.5 or 4 percent by weight of aggregate. Fifty blows of the mechanical Marshall compaction hammer were applied on each side of the specimen. Specimens were artificially aged in a forced-draft oven

Table 1. Gradations of old and new aggregates and ASTM D3515 limits.

Sieve Size	Percentage Passing			ASTM
	Old Aggregate	New Aggregate	Aggregate Blend	
0.75 in.	100	100	100	100
0.5 in.	100	88	95	90-100
0.375 in.	92	74	85	
No. 4	68	47	59	44-74
No. 8	39.5	47	43	28-58
No. 16	22.5	46	32	
No. 30	15.5	31	22	
No. 50	11.5	16	13	5-21
No. 100	8.5	10	9	
No. 200	6	6	6	2-10

Figure 1. Creep test apparatus.

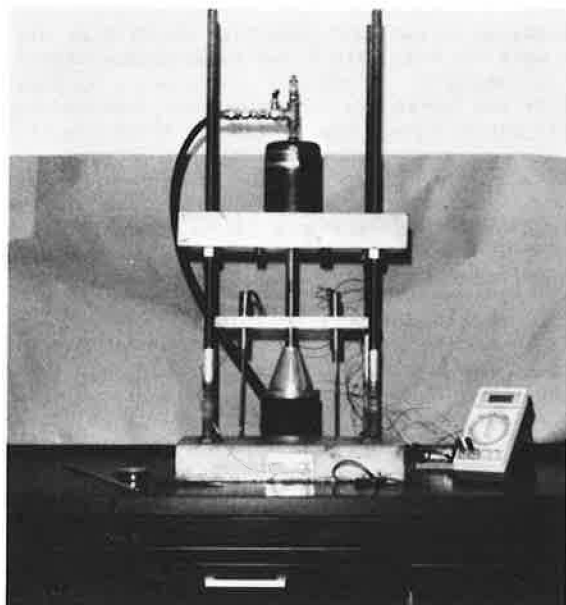
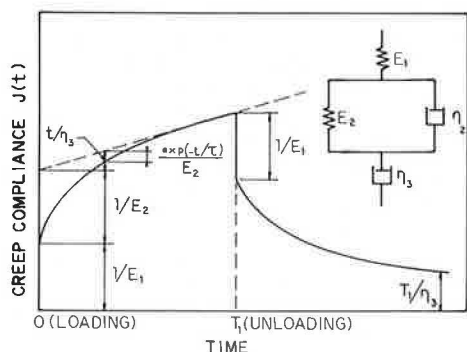


Figure 2. Analysis of creep compliance: Burgers model.



at 140°F for different periods (1, 7, 14, 21, 28, 40, and 60 days) before testing.

Recycled Mixture

Specimens consisting of a combination of recycled and new materials were fabricated. New aggregate was added to the old mixture to satisfy the gradation requirements. It was found that 40 percent new aggregate by weight broken down to specific sizes would provide an aggregate blend that satisfies the midpoint of the dense mixture gradation band of ASTM D3515 with a nominal maximum size of 0.5 in. The gradations of the old aggregate, new aggregate, and aggregate blend and the specification limits are given in Table 1. In addition, it was assumed that a portion of the old asphalt is inactive. New emulsion residue was added at rates of 2.5 and 3.7 percent by weight of aggregate in order to reach the equivalent rates of 3.5 and 4 percent asphalt in the finished mix that were used in the virgin mixture.

Marshall-size specimens were fabricated in a cold condition by following a procedure similar to that used in the virgin mixture except that the new aggregate was initially mixed with the reclaimed material at the specified rate before water was added. Like the virgin mixtures, the recycled specimens

were artificially aged out of the mold in a forced-draft oven at 140°F for different periods. The bulk specific gravity of both virgin and recycled specimens was determined before testing according to ASTM D2726. Two replicate specimens were fabricated and tested for each combination of factors.

CREEP TEST

The creep test was used to determine the viscoelastic properties of both virgin and recycled specimens. The equipment used in the creep test was similar to that used by Kumar and Goetz (6) and Iida (4), as shown in Figure 1. It consists of a loading frame, a double-acting type of air cylinder to apply the load, two linear variable differential transformers to sense the axial deformation, and a voltmeter to display the deformation. The load was applied by means of compressed air connected to the air cylinder.

After the specimens were aged, they were taken out of the oven, left at a room temperature of about 75°F for 4 hr, and then tested at the same temperature. Specimens were subjected to five cycles of loading and unloading, which is referred to as mechanical conditioning (6). Specimens were left in the frame for 10 min and then subjected to the test loading of 5 psi for 5 min. The voltmeter readings were recorded immediately before and after the load was applied. Readings were also recorded every 10 sec during the first 2 min and once a minute for the following 3 min. Because the creep test is nondestructive, the same set of specimens were tested at different aging periods.

Creep compliance as a function of time is defined as the strain that varies with time divided by the applied constant stress. Previous investigations (4) showed that the behavior of asphalt mixtures can be accurately analyzed by means of a four-element mechanical model, called the Burgers model, as shown in Figure 2. The creep compliance of such a model is given by the following mathematical equation:

$$J(t) = (1/E_1) + (1/E_2) [1 - \exp(-t/\tau)] + t/\eta_3 \quad (1)$$

where

$J(t)$ = creep compliance as a function of time,

E_1 and E_2 = moduli of elasticity of the Hookean bodies,

η_2 and η_3 = viscosities of the Newtonian bodies, and,

τ = retardation time = η_2/E_2 .

In this model, the asphalt mixture is assumed to be linear viscoelastic. A general form of the creep compliance for the Burger model during loading and unloading is shown in Figure 2. The experimental creep compliance values were fitted to the creep compliance curve of the Burger model by using a nonlinear regression analysis.

The elastic creep parameters, E_1 and E_2 , showed a general increase at early curing ages. This was followed by a slight decrease. At later ages (40 and 60 days), the elastic creep parameters remained basically unchanged. On the other hand, the viscous creep parameters, η_2 and η_3 , showed a rapid increase at early ages, after which it tapered off. It should be mentioned, however, that a large fluctuation in the creep parameters was observed in many cases. In addition, no significant difference was observed between creep parameters obtained from virgin and recycled mixtures.

The predicted creep compliance values were evaluated for creep times of 10, 60, and 300 sec for the

Figure 3. Creep compliance versus curing time for virgin and recycled mixtures.

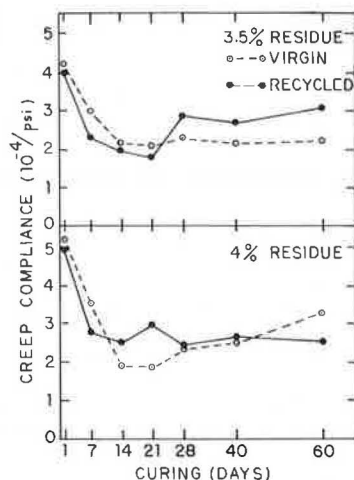
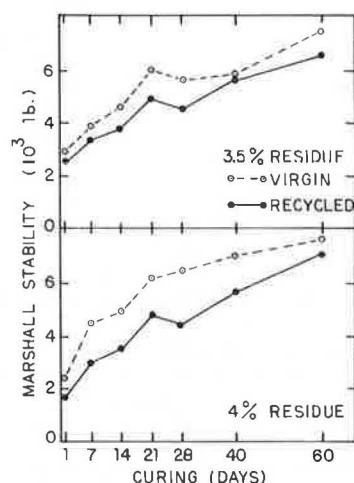


Figure 4. Marshall stability versus curing time for virgin and recycled mixtures.



different mixes. Figure 3 shows the creep compliance values for both virgin and recycled mixtures at a creep time of 300 sec. Clearly, creep compliance decreased rapidly at early ages (up to 21 days). This behavior can be explained by the evaporation of water from the mixture and oxidation of the emulsion residue. The creep compliance values increased slightly afterward and then remained essentially the same.

The virgin mixture showed slightly larger creep compliance values at early ages than the recycled mixture, possibly due to the presence of a larger amount of uncured emulsion in the virgin mixture. At longer-term curing, however, the recycled mixture resulted in larger creep compliance values than the virgin mixture at the 3.5 percent residue content level. No consistent pattern was observed at the 4 percent residue content level.

MARSHALL TEST

Because the specimens were relatively tender, particularly at early ages, the Marshall test was conducted at a room temperature of 75°F for both virgin and recycled specimens. Specimens were tested at aging periods similar to those used in the creep test. Different sets of specimens were fabricated

and tested at each aging period by taking into consideration the destructive nature of the Marshall test.

The change in Marshall stability at 75°F at different ages for both virgin and recycled mixtures is shown in Figure 4. A general increase in Marshall stability was noted for all mixtures, particularly at early curing ages. The recycled mixture resulted in smaller Marshall stability than the virgin mixture at all ages, especially when 4 percent residue was used. In addition, the Marshall flow of the recycled mixture at 75°F was larger than those of the virgin mixture; particularly at early ages. Both virgin and recycled mixtures resulted in close Marshall flow values at long-term ages.

On the other hand, the bulk specific gravity of the virgin mixture was larger than the bulk specific gravity of the recycled mixture in all cases. This indicates that the recycled mixture includes a larger amount of air voids than the virgin mixture. It also shows that the cold-mixed recycled mixture cannot be compacted to the same density as the virgin mixture by using the same compacting effort due to the smaller amount of new binder and, in turn, less lubrication in the recycled mixture.

CONCLUSIONS

The test results showed that creep compliance decreased rapidly at early ages because of the hardening of the emulsified asphalt, increased slightly afterward, and then remained essentially unchanged. No large difference was noted between the creep behavior of virgin and recycled mixtures. On the other hand, the Marshall stability values of the recycled mixtures at 75°F did not show any decrease at long-term curing. Both creep and Marshall properties of the recycled mixture do not indicate any significant long-term softening due to the existence of the emulsified asphalt for the materials and conditions used in this study. In addition, the same compacting effort did not compact the recycled mixture to the same density as the virgin mixture. Further research is needed that will include other types of asphalt binders and softening agents as well as hot and cold recycled mixtures.

REFERENCES

1. Guidelines for Recycling Pavement Materials. NCHRP, Rept. 224, 1980.
2. D.J. Brown. Recycling Asphalt Pavements. FHWA, Demonstration Project 39, 1979.
3. Recycling Materials for Highways. NCHRP, Rept. 54, 1978.
4. A. Iida. The Effects of Added Softening Agents upon the Behavior of Cold Recycled Asphalt Mixtures. Joint Highway Research Project, Purdue Univ., West Lafayette, IN, 1980.
5. M.S. Mamlouk, L.E. Wood, and A.A. Gaddalah. Laboratory Evaluation of Asphalt Emulsion Mixtures by Use of the Marshall and Indirect Tensile Tests. TRB, Transportation Research Record 754, 1980, pp. 17-22.
6. A. Kumar and W.H. Goetz. Asphalt Hardening as Affected by Film Thickness, Voids and Permeability in Asphalt Mixtures. Proc., Assn. of Asphalt Paving Technologists, Vol. 46, 1977, pp. 571-605.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures to Meet Structural Requirements.