Effect of Emulsified Binders on Characteristics of Bituminous Mixtures

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The behavioral characteristics of bituminous mixtures as affected by high-float emulsified binders are discussed. Mixtures were prepared with a conventional base asphalt and a high-float emulsion, formulated by using the same base asphalt, and were tested in indirect tension mode at temperatures of -10°, 5°, 20°, 35°, 70°, and 140°F. The tensile properties were determined for use as indices of performance of the mixtures at low and high ambient temperatures. In addition, an attempt was made to predict the fatigue life of the mixtures. One-to-one comparison of the characteristics of the mixtures made with the binders under varying environmental conditions is presented. The results indicate that high-float emulsions can be used to improve the characteristics of the mixtures at low as well as high ambient temperatures. However, improvement of constant-strain fatigue life in the mixtures made with high-float emulsions is limited to low values of strain.

Asphalt pavements are structures or systems whose performance is influenced by a number of factors ranging from the nature of the traffic (weight and volume) to the whims of the environment (rainfall and temperature). The objective of the pavement design process (thickness of layers, type and quality of materials, and construction specifications) is to produce on the roadway a pavement that can withstand exposure to traffic and the elements and can provide a desirable level of performance without any signs of distress.

Cracking of the asphalt surfacing is generally considered to be one of the most significant manifestations of distress in asphalt-surfaced pavements. It impairs the riding quality and shortens the life of a pavement, resulting in increased maintenance and cost. Such distress often begins as a hairline crack that slowly extends and permits the ingress of water, which in turn weakens the underlying layers so that the distress manifests itself in the form of a structural failure.

Over the years, engineers have been able to categorize cracking in two phenomenological groups: load-associated and non-load-associated. The principal class of load-associated cracking has been described as fatigue cracking, the phenomenon of fracture under repeated or fluctuating stress having a maximum value less than the tensile strength of the material. With regard to asphaltic mixtures, the non-load-associated cracks manifest themselves in the form of low-temperature shrinkage cracks (1). One of the main reasons for shrinkage cracking in bituminous pavement is its brittle behavior at low temperatures or when the asphalt it contains becomes hard (2). Thus, bituminous mixtures exhibit both plastic and elastic properties depending on the temperature to which the mixtures are subjected and the viscosity of the asphalt in the mixtures. Tensile strength, strain at failure, and stiffness are temperature-dependent characteristics of a bituminous mixture, and variations in these characteristics are ascribed to the known variations of the asphalt binder (3).

A pavement with adequate design thickness may show shrinkage cracking in its first year of service. In view of this, an asphalt pavement with a desirable level of performance is one that is capable of mitigating any shrinkage cracks at low temperatures and is resistant to fatigue cracking, rutting, and shoving at medium to high temperatures. At the low temperature extreme, it is desirable to obtain as low a stiffness as possible; the present state of the art in this regard postulates the use of softer grades of asphalt binders. However, this can in turn result in too low a stiffness over the medium to high temperature range for fatigue and permanent deformation requirements. Ideally, a mix should have temperature-susceptible characteristics that will satisfy both ends of the temperature performance scale. Maximum performance of a bituminous mixture thus requires the selection of a binder of appropriate grade with suitable temperature-susceptible characteristics.

The temperature susceptibility of asphalt binders can be modified in many ways. Emulsification of the base asphalt is a feasible method of providing a residue with improved temperature-susceptible characteristics. In this regard, the use of high-float emulsions has been gaining popularity. The major emphasis of improved temperature-susceptible characteristics of the high-float emulsions, however, has been on the benefits associated with stability at high ambient temperatures. There has been relatively little recognition of the effects of this improved temperature susceptibility on the low-temperature characteristics of bituminous mixtures.

The purpose of this study was to examine the effects on bituminous mixtures of such modifications to the bituminous binder. Experiments were conducted on bituminous mixtures in indirect tension to measure their tensile properties for use as indices of performance of mixtures containing conventional and modified binders with varying temperature-susceptible characteristics (4).

MATERIAL AND MIXTURE PROPERTIES

The binders included one asphalt cement and one high-float emulsion residue, designated M1 and M2, respectively. The M1 binder, a Canadian asphalt chosen for its high temperature susceptibility, was provided by Pounder Emulsions, Limited, of Winnipeg, Canada. The M2 binder, a high-float emulsion with the Canadian asphalt as the base asphalt, was formulated in and supplied by the K.E. McConnaughay Laboratory of Lafayette, Indiana.

The physical properties of the binders are given below:

Property	M1	M2
Nominal penetration at 77°F	85-100	85-100
Ductility		
At 5 cm/min, 77°F	100+	100+
At 1 cm/min, 39.2°F	16	15
Softening point (°F)	113	204
Penetration at 77°F	105	80
Penetration index	-0.62	+7.55
Viscosity		
Absolute at 140°F (poises)	430	2500
Kinematic at 275°F (cSt)	155	-
Penetration-viscosity number	1.7	-0.14

A single aggregate of 100 percent crushed limestone at the following gradation was used:

Sieve Size	Percentage Passing
0.75 in.	100
0.5 in.	91
0.375 in.	76
No. 4	54
No. 8	46
No. 16	37
No. 30	25
No. 50	16
No. 100	7
No. 200	4

The mixtures were also identified as M1 and M2, according to binder type. The physical properties of the mixtures are summarized below:

Property	M1	M2
Asphalt by weight of aggregate (%)	6.25	6.25
Asphalt by weight of mixture (%)	5.88	5.88
Mix bulk specific gravity	2.418	2.410
Absorbed asphalt (%)	1.408	-
Aggregate bulk specific gravity	2.67	2.67
Asphalt specific gravity	1.012	-
Voids in mineral aggregate (%)	14.765	14.765
Air voids (%)	3.88	3.89
Stabilometer value	40	45
Cohesiometer value	289	311

EXPERIMENTAL SETUP AND PROCEDURE

Specimen Fabrication

Although the binder content was determined by the Hveem method of mix design, the compaction of the test specimens (4 in. in diameter by 2.5 in. high) was done with the gyratory testing machine. ASTM test method D3387-78, with some modification, was used. The modification in the prescribed ASTM procedure involved the number of gyrations. Because each mixture at the compaction temperature of 250°F had different compactibility, the number of gyratory revolutions was varied to achieve uniformity of density.

Curing of the freshly laid bituminous mixture in the field takes place in the compacted state. For hot emulsion mixes, it was ascertained that curing at 140°F for 15 hr followed by air curing at room temperature for 7 days achieved a cured state in which the curve of strength versus days of curing became flat, indicating that curing was complete. Hence, it was decided that all of the mixtures prepared with asphalt as well as with emulsion could be cured at 140°F for 15 hr, extruded from the mold, and air-cured at room temperature for 7 days.

Temperature Control System

Specimens were tested in a small constant-temperature chamber. The chamber was supplied with conditioned air from a large conditioning box that housed the heating and refrigerating units. A digital temperature indicator was used for temperature readout for the conditioning box and test chamber.

Temperature Monitoring of Specimens

A calibrated thermistor was used to sense the temperature at the geometric center of the specimen. The thermistor was inserted in a drilled hole in a dummy specimen of the same size and shape as the test specimens and was enclosed snugly with insulation. The specimens to be tested were conditioned in the testing chamber along with the dummy specimen. The temperature equilibrium between the dummy specimen and that of the testing chamber indicated that the test specimens were ready for testing.

Test Procedure

The indirect tension test or tensile splitting test was used to measure the tensile properties of the bituminous mixtures. A Material Testing System (MTS) electrohydraulic closed-loop testing machine was used as the loading system. The test specimen was loaded across a diameter in a compression testing frame. Tensile stresses induced in the direction of a diameter at right angles to the compressive loading eventually resulted in fracture of the specimen. Deformation along the horizontal diameter, resulting from the application of a load along the vertical diameter, was measured by a special kind of diametral extensometer. The extensometer transducer was a linear variable differential transformer with self-contained signal conditioning circuitry. Details of the diametral extensometer are shown in Figure 1.

The equations for tensile stress and strain at failure (4,5) for a specimen tested in the indirect tension mode are as follows:

$$S_T = -(2P/\pi ah)\,[\sin 2\alpha(\alpha/2R)] \quad (1)$$

where

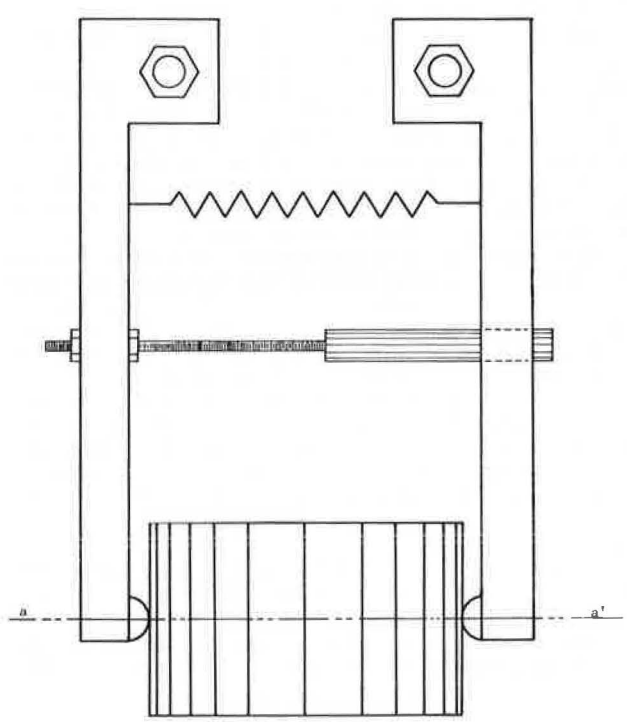
S_T = tensile strength,
P = maximum load at failure,
a = width of the loading strip,
h = height of the specimen, and
2α = angle in radians subtended by one-half the width of loading strip.

For a = 0.5 in., 2α = 14.291°, and α = 0.1247 radian, Equation 1 takes the following form:

$$S_T = 0.1556\,(P/h) \quad (2)$$

$$\epsilon_T = (X_{TF}/0.004)\,[(6.234 \times 10^{-4} + 1.8966 \times 10^{-3}\,\nu)/(0.2692 + 0.9976\,\nu)] \quad (3)$$

Figure 1. Plan view of diametral extensometer.



where

ε_T = tensile strain at failure,
X_{TF} = total horizontal deformation at maximum load, and
ν = Poisson's ratio (assumed to be 0.35 for this study).

$$S_{mix(t,T)} = \sigma_{(t,T)}/\epsilon_{(t,T)} \quad (4)$$

where

$S_{mix(t,T)}$ = mixture stiffness as a function of time of loading (t) and temperature (T),
$\sigma_{(t,T)}$ = tensile stress as a function of time of loading (t) and temperature (T), and
$\epsilon_{(t,T)}$ = tensile strain as a function of time of loading (t) and temperature (T).

The testing at temperatures of -10°, 5°, 20°, and 35°F was conducted at a testing speed of 0.003 in./min, and testing at temperatures of 70° and 140°F was conducted at a testing speed of 2 in./min. The lower testing speed was intended to simulate low-temperature shrinkage, and the higher testing speed was chosen to simulate high-speed traffic.

ANALYSIS AND DISCUSSION OF TEST RESULTS

Comparison of Stiffness Values at Low and High Temperatures

Low-temperature cracking is a function of ambient air temperature and thermal loading time. Loading times in the range of a half-hour to several hours are considered reasonable. Fromm and Phang (6) have suggested a loading time of 10,000 sec. McLeod (2) has suggested a loading time of 20,000 sec as the rate at which the pavement is stressed due to chilling to low temperatures. The loading time of 20,000 sec was chosen in this study as the basis for comparison of the stiffness values of the mixtures at low temperatures.

The experimental stiffness values at -10°, 5°, 20°, and 35°F were measured up to a loading time of roughly 700 sec. To extend the data to the loading time of 20,000 sec at low temperatures, time-temperature superposition techniques were used. This involved moving the experimental stiffness curves along the loading-time axis until each of the experimental curves was superimposed to form a single master curve. These master curves for stiffness versus reduced loading time for each mixture type, along with the corresponding shift factor (a_t) versus temperature curve (shown as an inset), are shown in Figures 2 and 3. These master curves make it possible to determine the stiffness at any temperature or time of loading. The stiffness values at -10°F for the loading time of 20,000 sec are as follows:

Mixture	Stiffness (000 psi)
M1	520
M2	200

In order to eliminate transverse pavement cracking, McLeod (2) has suggested a limiting stiffness value of 200,000 psi at -10°F and 20,000 sec. In this regard, comparison of the stiffness values for the mixtures given above suggests that mixture M1, which contained the highly temperature-susceptible Canadian asphalt, would not be able to mitigate transverse pavement cracking. On the other hand, the mixture containing emulsion residue, mixture M2, would be resistant to low-temperature transverse pavement cracking based on these criteria.

The following experimental values of stiffness at 140°F provide a comparison of stiffness values at high ambient temperatures:

Mixture	Stiffness (000 psi)
M1	0.57
M2	1.23

The values in this table and those shown in Figure 4 indicate that mixture M2, made with high-float emulsion residue, has a higher stiffness value than that made with the base asphalt, mixture M1.

Prediction of Fatigue Life

An attempt was made to predict the fatigue life of the mixtures by using the tensile properties determined by indirect tension test. The equation for predicting cycles to failure was developed from laboratory correlation studies, and its accuracy was limited to the mixtures originally evaluated by Maupin and Freeman (7). The relations used to

Figure 2. Master curve for M1.

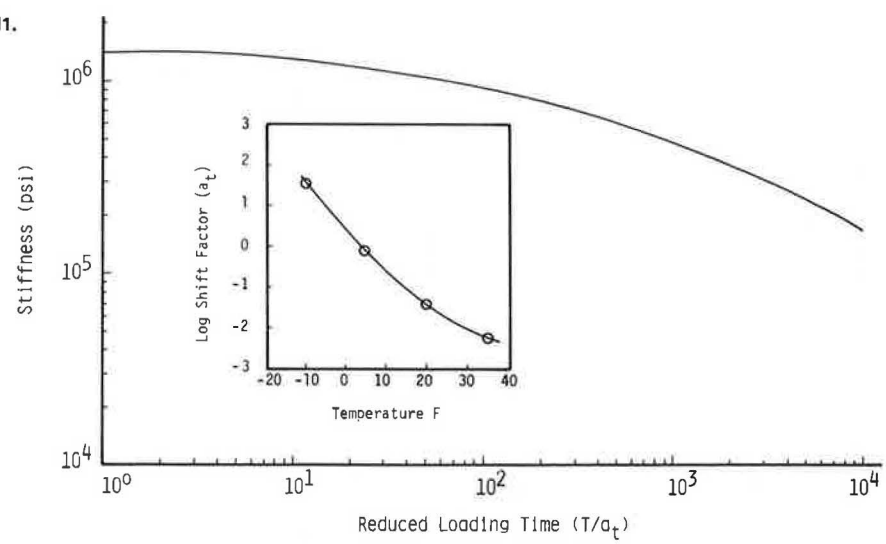


Figure 3. Master curve for M2.

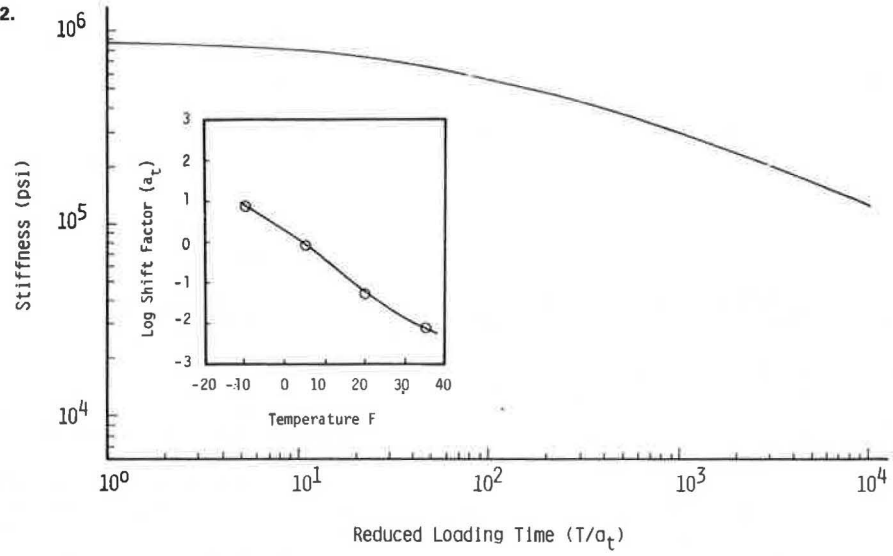


Figure 4. Comparison of limiting stiffness of binders at 140°F.

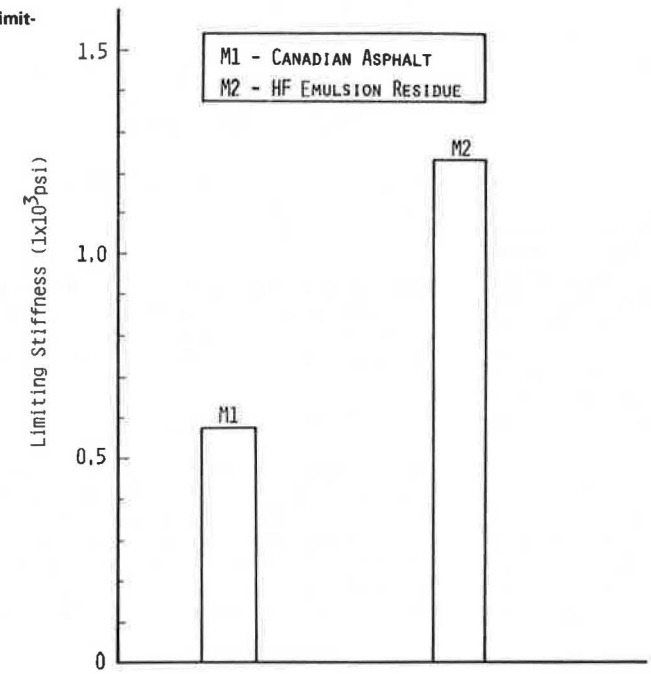
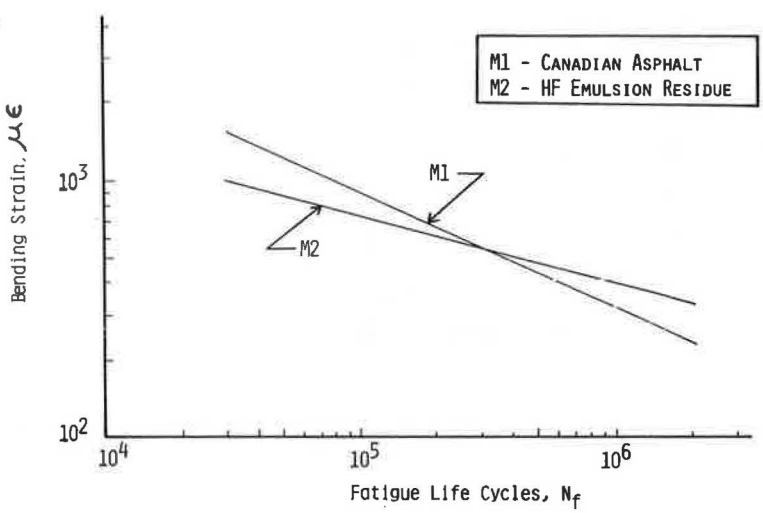


Figure 5. Fatigue life versus bending strain.



arrive at the constant strain fatigue life are as follows:

$$N_f = K(1/\epsilon)n \quad (5)$$

$$n = 0.0374\ S_T - 0.744 \quad (6)$$

$$\log K = 7.92 - 0.122\ S_T \quad (7)$$

where

N_f = cycles to failure,
K,n = constants,
ϵ = initial bending strain, and
S_T = indirect tensile strength.

After calculating the constants K and n, values of N_f were determined by substituting representative values of ϵ (strain level) in Equation 5. The calculated values of N_f for the range of 300 to 2,000 $\mu\epsilon$ are shown in Figure 5.

As Figure 5 shows, for values up to 550 $\mu\epsilon$ the high-float emulsion, M2, provided mixtures with higher fatigue life than the Canadian asphalt, M1. For strain values greater than 550 $\mu\epsilon$, the predicted fatigue life results in a reverse picture of performance.

CONCLUSIONS

Based on the experimental results of this study, the principal conclusions can be summarized as follows:

1. Emulsification of the base asphalt is a feasible means of improving the temperature-susceptible characteristics of asphalt binders.
2. In comparison with base asphalt, high-float emulsions provide mixtures with lower stiffness values at low temperatures and higher stiffness values at high ambient temperatures.
3. In comparison with base asphalt, high-float emulsions provide mixtures with improved constant-strain fatigue life for low values of strain.

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