Identifying Tender Asphalt Mixtures in the Laboratory

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ABSTRACT

Physical and chemical properties of asphalt cements and physical properties of paving mixtures were determined in the laboratory. An attempt was made to relate these properties to tender and slow-setting paving mixtures. Asphalts that are low in asphaltenes have a greater probability of producing slow-setting mixtures. Modified indirect tension and resilient modulus tests have the potential to identify tender mixes in the laboratory. It is apparent that an asphalt cement will not produce a tender mixture when a high-quality aggregate is employed.

Since the 1973 oil embargo numerous field construction and maintenance personnel throughout the United States have claimed that asphalt cements have changed and that these changes in asphalts have resulted in construction and early-life performance problems in asphalt concrete mixtures. The general belief of field personnel is that the oil companies are taking the "goodies" out of the asphalt and are using them as feedstock for the petrochemical industry. Another widely held belief is that the oil embargo, this country's dependence on foreign crudes, the rapid development of new producing crude oil fields, and economic pressures have forced the oil companies to use less than desirable crudes to manufacture asphalt. Field personnel are convinced that the present asphalt specification tests, which are routinely performed, do not identify the important properties that control field construction and pavement performance (1,2).

As evidence of these statements, the field engineers cite a general increase in the occurrence of problems such as placement difficulties (tender mixes), excessive displacement under traffic (low stability), thermal cracking, raveling, and stripping (water susceptibility) of asphalt concrete pavements. These problems result in higher maintenance costs, shorter service life, higher life-cycle costs, and criticism by the driving public.

Certainly the opinions of these experienced field engineers must be accepted; however, caution is in order. For example, Hveem (3) indicated that tenderness problems were evident in California pavements in the 1940s. Field engineers complained that asphalt "ain't as good as it used to be" as early as the 1930s (2,4), and asphalt cracking problems were evident early in the history of asphalt concrete use (5). In addition, these claims are often vague in nature and are not supported by definitive physical and chemical property data.

Most construction and early performance problems are associated with more than one potential cause. For example, raveling of an asphalt concrete surface course can be caused by one or a combination of the following factors: poor asphalt quality, low asphalt content, asphalt brittleness, high air void content of mixture, susceptibility to damage by moisture, shear forces due to traffic, and so forth. Clearly, the engineer should investigate all possible causes before "laying blame." Similarly, the properties of the asphalt cement should not necessarily be blamed for the recent increase in construction and early performance problems experienced on our nation's highways. Basic societal changes including increased weight and number of vehicles, air quality, and worker safety requirements and the development of equipment to increase production have placed ever-changing demands on paving materials.

In an attempt to more adequately define historic changes in asphalt cements, research programs were initiated by the Asphalt Institute (6), the Federal Highway Administration (FHWA) (7,8), and the National Cooperative Highway Research Program (NCHRP) (1,9). This report summarizes portions of the NCHRP effort that was performed under Project 1-20, "Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance." (Temperature susceptibility of an asphalt is the change in consistency with changing temperature.) A comprehensive research and development program on asphalt is now being formulated by NCHRP and FHWA in response to increased concern over paving problems and the results obtained from the previously mentioned studies.

The original objectives of NCHRP Project 1-20 are

1. To determine the range or extent of variability in temperature susceptibility of asphalt cements currently being used in road construction.
2. To evaluate the effects of the identified variability, in relation to other factors and over the full range of service temperatures, on pavement construction operations and short-term performance of pavements.
3. To identify the limits of variability in temperature susceptibility that can be accommodated through application of known asphalt technology, by changes in asphaltic concrete construction procedures, and mix design considerations.

TENDERNESS DURING AND AFTER CONSTRUCTION

During the course of this research, it has become apparent that there are two distinctly different types of paving mixtures that are commonly referred to as "tender." One exhibits tenderness during construction and is characterized by being easily overstressed during compaction, that is, shoving under steel wheel rollers or resisting compaction at normal temperatures. The other mixture is slow setting after construction and is characterized by plastic deformation or scuffing within a few weeks after construction, particularly during periods of hot weather. Frequently, both of these characteristics will be exhibited by the same material.

Tenderness during construction is primarily an aggregate problem (caused by smooth, rounded aggregate, a high percentage of sand-size particles or a low percentage of filler-size particles) that is aggravated by a highly temperature susceptible asphalt. This mixture must be allowed to cool until the asphalt viscosity increases to a point where sufficient internal friction will prohibit overstressing by the steel wheels of the breakdown roller. Tenderness after construction is an asphalt cement-related problem (caused by slow-setting asphalt) that will manifest itself only when an aggregate of a critical gradation is used. The problem usually disappears after a few weeks when the asphalt "sets up."

Tenderness during construction appears to be related to asphalt temperature susceptibility whereas tenderness after construction appears to be related to chemical properties of the asphalt cement such as asphaltene content or degree of peptization. A slow-setting mixture will usually show some degree of tenderness during construction, but a mixture that is tender during construction is not necessarily slow setting. A slow-setting mixture is presently more difficult to accommodate than is a mixture that is tender only during construction.

ASPHALT PENETRATION VERSUS TIME

Standard penetration tests at 77°F were conducted in accordance with a predetermined schedule to determine whether "structuring" or "setting" of asphalts could be detected. Asphalt cements were conditioned while undisturbed and covered to prevent surface oxidation at a temperature of 77°F (25°C) for 275 days. Thirteen asphalts with a wide range of properties were tested. Penetration continually decreased during the 275-day time period. At the end of the aging period, the asphalts were heated to 275°F and stirred to eliminate any structuring that may have occurred. Generally, all of the asphalts returned to their original penetration after heating.

Penetration of four asphalts is plotted as a function of time for 275 days in Figure 1. Asphalts B1, B2, and B3 are highly temperature susceptible asphalts produced from California valley crudes, which are grades AR-1000, AR-2000, and AR-4000, respectively. Asphalt K is produced from California coastal crude and is an AR-2000 and is not highly temperature susceptible. Penetration of all the asphalts began to decrease after about 20 to 30 days. This illustrates that asphalt setting rate is not related to temperature susceptibility. This is supported by additional data (9).

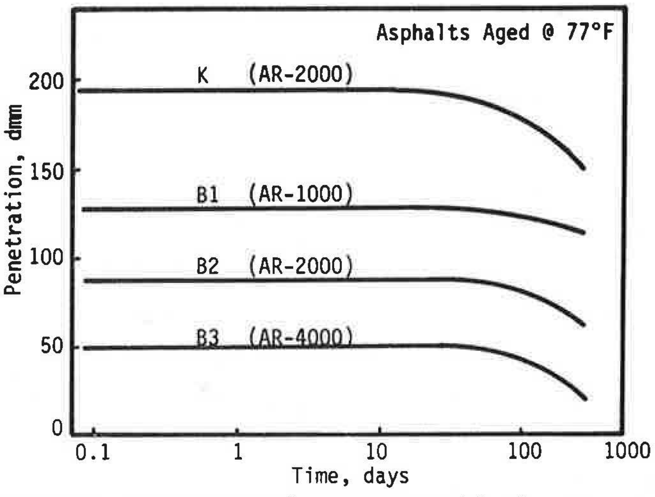

FIGURE 1 Penetration at 77°F as a function of time for neat asphalts.

Figure 2 shows penetration as a function of time from 0 to 275 days for the original and thin film oven-aged asphalts from two field projects located at White Deer, Texas, and Glendive, Montana. The original White Deer asphalt is harder at 77°F (lower penetration) than the original Montana asphalt; but the order is reversed after the thin film oven test (TFOT). The Montana asphalt is significantly more susceptible to oven aging than is the White Deer asphalt. After approximately 100 days of conditioning, the two oven-aged asphalts approached the same value of penetration. The White Deer paving mixture was slightly tender during construction but slow setting after construction. The Montana paving mixture was tender during construction but quite tough as soon as the pavement cooled to ambient temperature. The resistance to hardening on heating exhibited by the White Deer asphalt appears to be related to the tenderness exhibited during the early life of the pavement. After this mixture "set up," it became fairly tough as evidenced by only slight rutting after an extremely hot summer and subjection to heavy loads.

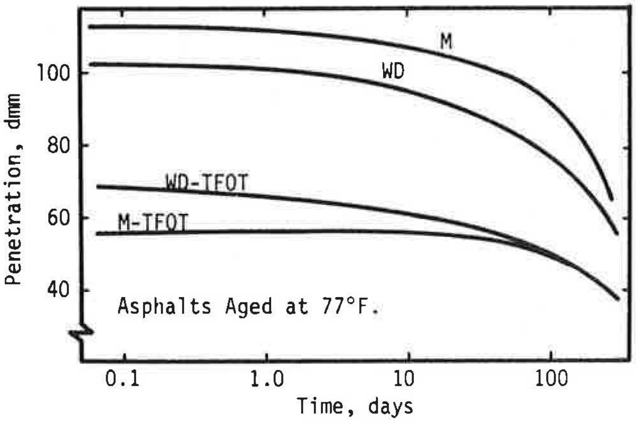

FIGURE 2 Penetration at 77°F as a function of time for asphalts before and after TFOT.

A subjective numerical tenderness scale was developed to indicate relative tenderness of the asphalt as determined from field experience. The tenderness rating is based on a scale from zero to five; zero indicates that tenderness or slow-setting problems are not normally associated with the asphalt; five indicates that these problems are always associated with the asphalt.

Figure 3 is a plot of percentage decrease in penetration after 103 days versus the asphalt tenderness rating. No correlation is apparent. It is, therefore, concluded that asphalts will "set up" at varying rates and that this "setting" of asphalts (thixotropic properties) is detectable by using the standard penetration device at 77°F. Furthermore, this structuring can be eliminated by heating the asphalt to 275°F. However, this structuring does not correlate well with the asphalt setting rate in the field.

ASPHALT VISCOSITY VERSUS TIME

Four asphalt cements were selected and the viscosity at 77°F was measured as a function of time for 100 days. A sliding glass plate microviscometer was used to measure viscosity. Test specimens were prepared in the usual fashion between two glass plates and

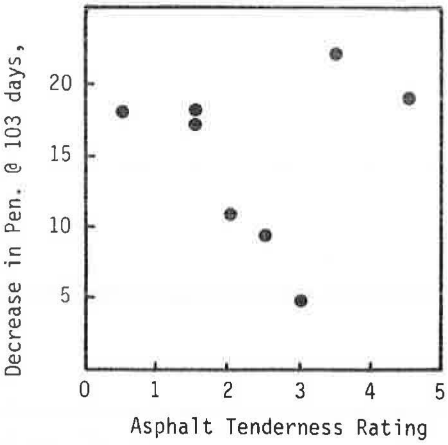

FIGURE 3 Decrease in penetration at 77°F after 103 days conditioning as a function of mixture tenderness.

stored undisturbed at 77°F in the absence of direct light for predetermined periods before viscosity was measured. Figure 4 shows consistent increases in viscosity with time. Because the asphalt specimens were shielded from light and the bulk of the specimens was protected from oxidation, it is assumed that the increases in viscosity are related to thixotropic properties of the asphalt cements. "Structuring" rates or setting rates of the different asphalts (slopes of the curves) are seen to vary significantly and correlate reasonably well with field experience.

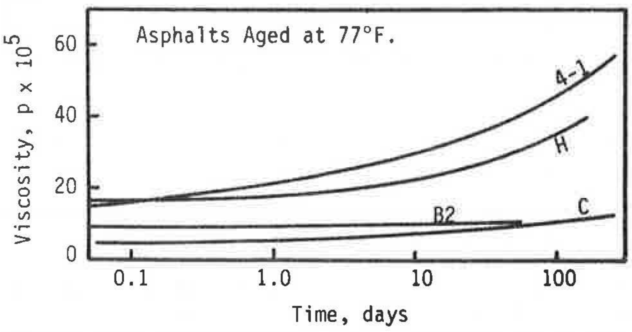

FIGURE 4 Viscosity at 77°F as a function of time.

Asphalt C is highly temperature susceptible and reputed to produce very tender and slow-setting mixtures. Asphalt C exhibited the lowest initial viscosity at 77°F and a relatively slow setting rate compared to the other asphalts tested. It appears that the problems associated with this asphalt are most probably due to the low initial viscosity as well as the slow setting rate.

Asphalt H is not highly temperature susceptible but has been associated with slow-setting pavements. Both the viscosity as a function of time and the penetration as a function of time show that the consistency of Asphalt H increases faster than does that of Asphalt C. Comments by users of these asphalts indicate that this difference is reflected in their setting rates in the field.

Asphalt B2 and the asphalt from Refinery 4-1 are both highly temperature susceptible. However, the asphalt from Refinery 4-1 exhibits a comparatively rapid increase in viscosity with time whereas Asphalt B2 exhibits almost no increase in viscosity with time. This correlates reasonably well with user comments about these asphalts.

Viscosities of Asphalts C and 4-1 were measured after reheating. However, they were not heated to 275°F. They were heated using the heating lamp that is employed during preparation of the asphalt-glass plate specimens. Most likely a temperature of only 160°F to 180°F was attained. The viscosity of Asphalt 4-1 returned to its original value and the viscosity of Asphalt C remained at the aged value.

This short experiment was performed primarily to determine whether the sliding plate microviscometer is capable of detecting stearic hardening of asphalt cements. Apparently it is. Furthermore, these data again indicate that setting rate of asphalt is not related to temperature susceptibility. To define criteria that can be applied to predict the probability of slow-setting mixtures, considerably more testing would be required.

CHEMICAL ANALYSIS

Chemical analyses of nine asphalts were performed using the Rostler-Sternberg procedure (10). The limited data in Figure 5 indicate that mixture tenderness is somewhat dependent on asphaltene content of the asphalt. The tenderness rating is subjective and based on uncontrolled field data; and tenderness, of course, can be caused or intensified by a number of factors. This may, in part, explain some of the scatter in these data.

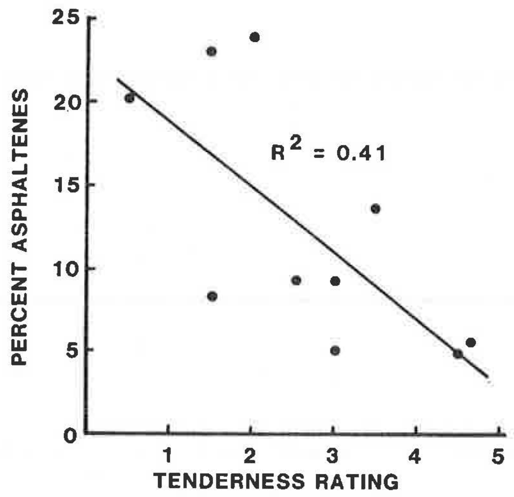

FIGURE 5 Asphaltene content versus asphalt tenderness rating.

Asphaltene content and temperature susceptibility for 70 asphalts were tabulated by Anderson and Dukatz in their Fingerprinting Study for FHWA (11). These data have been plotted along with the data generated in the NCHRP Study (1). Figures 6-8 clearly show that there is no correlation between asphaltene content and asphalt temperature susceptibility. None of the other Rostler constituents nor the Rostler parameter showed any correlation with susceptibility.

Studies (12-14) have indicated that liquid chromatography may be an important analytical tool for characterizing asphalts. Gel permeation chromatography (GPC) was used in the NCHRP study (1) to measure the distribution of molecular sizes of the different chemical components comprising an asphalt. The two asphalts that were most often associated with tender

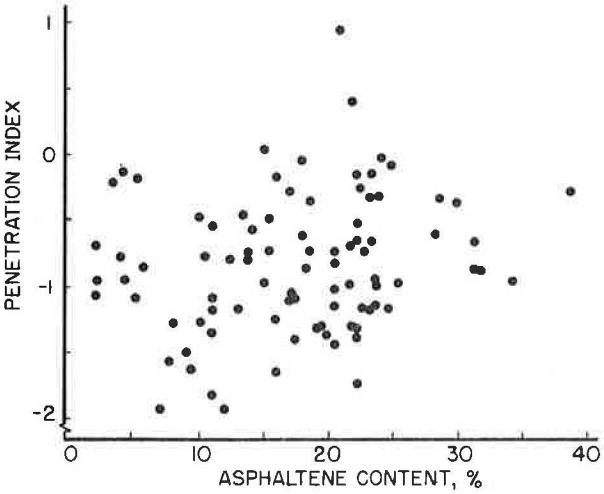

FIGURE 6 Penetration index as a function of asphaltene content.

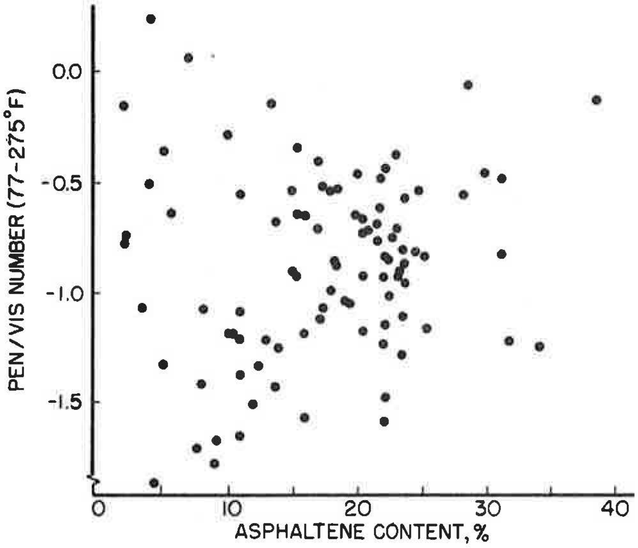

FIGURE 7 Penetration/viscosity number as a function of asphaltene content.

mixtures exhibited chromatograms shaped like the dashed line in Figure 9. Typical asphalt chromatograms appear as the solid line in Figure 9.

MATERIAL, MIXTURE, AND CONSTRUCTION FACTORS

Table 1 gives a rating scale to identify the material, the mixture, and the construction factors that contribute to tender mixes. Important aggregate factors are (a) shape and surface texture of both the coarse and the fine aggregate, (b) quantity of sand-size materials, (c) filler or minus No. 200 sieve fraction, and (d) maximum size of aggregate in the mixture. Recognized asphalt properties of importance are (a) asphalt content, (b) consistency (penetration or viscosity, or both), (c) temperature susceptibility, (d) hardening in thin film oven tests, (e) asphaltene content, (f) setting characteristics, and (g) use of low-viscosity liquid additives.

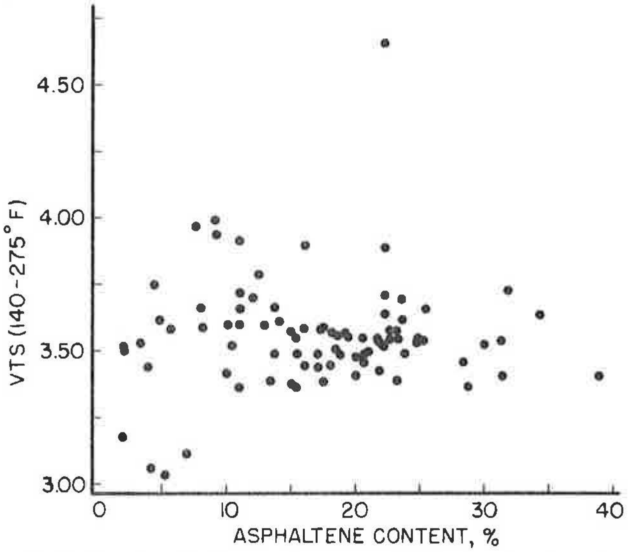

FIGURE 8 Viscosity temperature susceptibility as a function of asphaltene content.

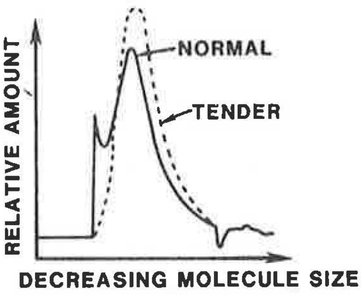

FIGURE 9 Generalized chromatograms for normal (typical) and tender asphalt.

Construction operations also have an impact on the development of tender mixtures. Important factors are (a) mixing temperature, (b) compaction temperature, (c) amount of asphalt hardening during construction, (d) type of air quality control equipment, and (e) moisture content of the mix during compaction.

As discussed previously, all these factors can influence the development of a tender mixture; however, some are more important than others. For example, mixtures that contain angular, rough surface textured aggregates in dense gradations and with proper filler contents rarely exhibit tenderness problems regardless of asphalt properties or construction operations. Mixtures containing subrounded aggregates with smooth surface textures, relatively high sand contents (gap graded), and low filler contents will often be tender particularly when low-viscosity asphalts are used. When the anticipated hot plant hardening of the asphalt is not achieved and when asphalts with low asphaltenes are used, the problem is amplified (15).

Ideally, a mathematical equation containing the listed material, mixture, and construction variables could be developed. Each of these variables would be properly "weighted" to indicate its relative influence on tender mix development. A sufficiently large data base from which a reliable equation could be developed was not available to this project. A large and continuous research effort would be needed to develop such an equation. In the interim, the field engineer will have to assign the proper importance to each identified factor (Table 1) on the basis of experience.

TABLE 1 Rating Scale to Identify Tender Mixtures

Material or Mixture Variable	INCREASING TENDERNESS → 1	2	3	4	5	6	7	8	9	10
Aggregate										
Shape	Angular		Subangular				Subrounded		Rounded	
Texture	Very Rough		Rough				Smooth		Polished	
Maximum Size	>3/4-inch		<5/8-inch		<1/2-inch		<3/8-inch		<1/4-inch	
-#30 to + #100*	Suitable				Excessive				Large Excess	
-#200	>6%		5%		4%		3%		<2%	
Asphalt Cement										
Content	Low				Optimum				High	
Viscosity	High				Medium				Low	
Penetration	Low				Medium				High	
Hardening Index	High				Medium				Low	
Temp. Susceptibility	Low				Medium				High	
Setting Characteristic	Fast				Medium				Slow	
Asphaltene Content	>20%				10 to 20%				<10%	
Mixture										
Softening Additives	None				Some				Much	
Moisture Content	<0.5%				1 to 2%				>2.5%	
Construction										
Rolling Temperature	Low				Medium				High	
C-value (15)	>50				30 - 50				<30	
Ambient Temperature	<70		80					90	>100	

LABORATORY TESTS

Project 1-20 (9) investigated a number of laboratory tests to possibly identify tender mixtures. These tests included

1. Resilient modulus,
2. Indirect tensile strength,
3. Marshall stability,
4. Hveem stability,
5. Asphalt temperature susceptibility (as defined by several parameters),
6. Asphalt consistency versus time relationship (viscosity and penetration),
7. Asphaltene content,
8. Asphaltene settling test (16), and
9. Gel permeation chromatography (GPC) (12).

Results from the tests performed on (a) selected asphalts, (b) mixtures obtained from field projects, and (c) laboratory prepared mixtures indicate that the resilient modulus and the indirect tension tests performed on mixtures and the asphaltene content of the asphalt cement are the most meaningful tests for identifying potentially tender mixtures in the laboratory.

Criteria for each of these tests as developed from project results are given in Table 2. On the basis of the criteria of Table 2, it is suggested that the indirect tensile test or the resilient modulus test, or both, be performed on laboratory mixed and laboratory compacted specimens and that the listed criteria be used.

The criteria given in Table 2 have been developed for the following specific conditions:

1. Gyratory compaction (modified or standard),
2. Air void content at standard or higher values,
3. Test temperature of 104°F or 77°F,
4. Loading rate of 2-in. per minute for indirect tensile test,
5. Load duration of 0.1 sec for resilient modulus test, and
6. Sample age of 90 min or 24 hr.

TABLE 2 Criteria for Tough and Tender Mixes

Type of Samples Tested	Method of Test	Tough Mix (psi)	Tender Mix (psi)
Modified compaction of laboratory mixtures (≅8% air voids)	M_R at 104°F at 24 hr	>7,000	<6,000
	TS at 104°F at 24 hr	>5	<5
Modified compaction of field mixtures (8-10% air voids)	M_R at 104°F at 24 hr	>30,000	<20,000
	TS at 104°F at 24 hr	>20	<15
Standard gyratory compaction of remolded field cores	M_R at 104°F at 90 min	>130,000	<125,000
	TS at 77°F at 90 min	>165	<140

Note: M_R = resilient modulus, TS = tensile strength.

If an agency does not have the equipment available to duplicate these conditions, a laboratory testing program should be initiated to define new criteria for their specific capabilities.

CONCLUSIONS

1. Asphalts containing less than 10 percent asphaltenes, particularly the softer grades, appear to have a greater probability of producing slow-setting paving mixtures. However, an asphalt will manifest itself as slow setting only if the aggregate type or gradation is such that a critical paving mixture is produced (even though the aggregate may meet specifications) or, possibly, if densification of the pavement is inadequate.

2. The data indicate that there is no correlation between asphalt temperature susceptibility and asphaltene content. There is no relationship between asphalt temperature susceptibility and other chemical constituents of asphalts as determined by the Rostler-Sternberg analysis or the Rostler parameter.

3. Asphalt consistency increases with time when asphalts are left undisturbed at 77°F; furthermore, on heating to 275°F the asphalt will return to its original consistency. Although this thixotropic property of asphalts is detectable using the standard penetration test or the sliding glass plate microviscometer at 77°F, it does not correlate well with setting rate in the field.

4. Asphalt properties alone will not cause a tender mixture during construction. If the aggregate quality is marginal such that a critical or tender paving mixture is produced, a highly temperature susceptible asphalt will aggravate the problem at the higher compaction temperatures. When a high-quality aggregate is employed, any asphalt meeting standard specifications can be used to produce a satisfactory paving mixture. High-quality aggregate is largely angular, without an excess of sand-size particles, and is well graded with top size of 3/8 in. or greater and contains sufficient minus No. 200 sieve size particles.

5. The indirect tensile test and the diametral resilient modulus test are quite sensitive to asphalt consistency. Indirect tensile and resilient modulus tests at 104°F have the potential to identify tender and slow-setting hot mix asphalt concrete mixtures in the laboratory. Guidelines are presented herein that a specifying agency can follow to develop criteria that can be used in the laboratory to avoid tender paving mixtures. To avoid tender mixtures, tensile strength of laboratory specimens molded with approximately 8 percent air voids should exceed 6,000 psi when tested at 104°F 24 hr after molding.

6. Because it is reported that the range in physical properties of asphalt cements is about the same now as it was in 1964 and immediately before the 1973 embargo (9), performance problems may be more related to quality control during construction. Emphasis should be placed on better training of design and construction personnel, improved inspection practices by highway departments, and, possibly, tighter materials and construction specifications (better compaction, angular aggregate, and so forth). Quality control to minimize the probability of mixture tenderness should include (a) high-quality aggregate properties as listed in Conclusion 4, (b) asphalt grade that corresponds with the climatic region, (c) asphalt specifications that address temperature susceptibility, (d) close monitoring of mixture temperature during compaction, and (e) roller wheel diameter and weight appropriate to prevent overstressing of the paving mixture.

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Discussion

Richard L. Davis*

The authors are to be congratulated on a fine paper. They have avoided the problem of extrapolating from higher temperatures by determining the viscosities of asphalt at temperatures that are near those of the pavement. There is a second extrapolation that should not be forgotten when trying to understand pavement conditions: the variation in viscosity at different levels of stress. Asphalts become more non-Newtonian as the temperature of measurement is reduced to ambient. Asphalts vary in their non-Newtonian effects but some vary by a factor of 40 between the low stresses at which viscosities are usually measured in the laboratory and the high stresses found in pavement under traffic. The interpretation of test results can often be greatly simplified if not only the scatter due to temperature extrapolation but also the scatter due to stress extrapolation can be eliminated or reduced.

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Innovations in Oklahoma Foamix Design Procedures

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ABSTRACT

Little attempt has been made in Oklahoma to investigate foamed asphalt mixes or to take advantage of these mixes for road construction purposes. To demonstrate the efficacy and applicability of this type of asphalt mix, a study of factors that affect fine aggregate-foamed asphalt mixtures formulated from materials indigenous to the state was undertaken. In addition to verifying the effects of the amount of fines (percentage of aggregate material passing the No. 200 sieve), mixing moisture content, asphalt content, and curing condition on foamix properties as reported by previous investigators, this study introduced two unique investigative concepts: (a) the use of an aggregate's "particle index" along with the percentage passing the No. 200 sieve to predict its performance in a foamix and (b) the use of a multilinear regression model or equation for determining the optimum premolding moisture content for a foamix. Although only a part of the original investigation, these two aspects of the study are considered directly applicable to foamix mix design procedures. The "particle index" (a measure of angularity and surface texture of aggregate particles) proved to be an excellent indicator of the suitability of marginal quality aggregates for foamixing. By using the predictive multilinear regression equation, the optimum premolding moisture content for a foamix can be ascertained without extensive laboratory testing.

A foamed asphalt mix has been defined as a mixture of wet unheated aggregates and asphalt cement mixed while the asphalt is in a foamed state. These mixes normally produce fairly stiff, stable mortar-type material in which the asphalt is concentrated primarily in the finer fraction of the aggregate, especially the fine sand and silt fraction (1-6). The selective ability of foamed asphalt to coat the fines and form a mortar between the larger aggregate particles creates a new type of asphalt-aggregate structure that is different from other asphalt mixtures.

INTRODUCTION

Some factors have proved to significantly affect the quality and properties of foamed asphalt mixtures both in the laboratory and as finished pavement layers in the field. These factors can be summarized from the literature as follows:

Aggregate Quality

A minimum of 3 to 5 percent passing the No. 200 sieve is considered a basic requirement to get a