Asphalt Cement Consistency

S.C. Shah, Louisiana Department of Transportation and Development

Comparative data on viscosity-graded and penetration-graded asphalt cements with respect to their rheological and aging characteristics are discussed. Data on the durability of American Association of State Highway and Transportation Officials AC-40 and AC-20 asphalt cements are further discussed in light of the 60-month performance of sections constructed by using these asphalts from four suppliers. The principal findings are that (a) the hardening of asphalt cements is a hyperbolic function of time; (b) asphalt cements with original high viscosity tend to harden more and at a rapid rate; (c) there was no significant difference in durability between the two types of asphalts and, for a given source, there was no recognizable difference in their performance in pavements; (d) by all durability criteria, the AC-20 grade asphalts are more durable and sections constructed with these softer grade asphalts are performing better than any AC-40 grade asphalts after 60 months of service; and (e) there was no association between high-temperature-susceptible, viscosity-graded asphalts and pavement performance or between voids in the pavement and the rate of asphalt hardening.

For years the grading of asphalt cements was done on the basis of the empirical penetration test at 25° C (77° F). A considerable amount of data has been accumulated regarding asphalts and their behavior in terms of this test. However, some earlier studies (1, 2) had indicated a significant association between viscosity and strength parameters of asphaltic concrete mixtures. Such studies supported the concept of grading of asphalts on the basis of viscosity at 60° C (140° F) rather than penetration at 25° C. One of the arguments in opposition to the grading of asphalts by penetration alone is the fact that such a grading system does not represent the temperature conditions generally associated with maximum pavement temperatures or the temperatures used in some of the mixture design methods. Furthermore, the arbitrary number specified by penetration does not represent the fundamental flow or rheological property of the material as does viscosity. Also, variation in the crude sources and refining processes of suppliers has sometimes resulted in marked differences in the viscosities of asphalt cements of a given penetration grade at 60°C.

The opposing argument for viscosity grading arises because of differences in viscosity-temperature susceptibilities and the problem of pavement cracking caused by harder asphalts. These controversies were resolved, however, and the current specification of the American Association of State Highway and Transportation Officials (AASHTO) based on viscosity grading was adopted. Although a wealth of information has been published on the aging characteristics of such asphalts and their effect on pavement performance (3), comparative data are lacking on the rheological properties of penetration and viscosity-graded asphalts and their performance in asphaltic concrete pavement. This paper is an attempt to provide such comparisons with respect to the aging characteristics of these asphalts and associated relations to pavement durability. The information presented here necessarily limits application to the material, construction procedures, and traffic and environmental conditions prevalent in Louisiana.

STUDY DESIGN

Test Sections

The investigation was conducted toward the end of 1970 on LA-1 approximately 65 km (40 miles) from Baton Rouge. Test sections were constructed over an 8-km (5-mile) stretch of existing 15.2-cm (6-in) portland cement concrete pavement that carried 3100 vehicles/d. The construction contract required widening and an overlay of 5.1 cm (2.0 in) of binder course and 3.8 cm (1.5 in) of wearing course.

Figure 1 shows the layout of the various test sections. These test sections were constructed by using four different asphalt sources (suppliers). Each source was requested to supply a penetration-graded asphalt cement and a viscosity-graded asphalt cement. The penetration-graded asphalt was the typical asphalt cement used in Louisiana at the time, and its consistency was controlled by penetration criteria [60 to 70 penetration range at 25° C (77° F)]. The viscosity-graded asphalt cements were controlled for consistency by absolute viscosity at 60° C (140° F) [360 to 700 Pa·s (3600 to 7000 poises)]. These latter grades were specifically prepared by the suppliers for this study. Detailed listing of the specifications and physical properties of the original asphalts can be found elsewhere (4). Asphalts represented by sections 9 and 10 are both viscosity-graded asphalts, one grade softer than those represented by sections 2, 4, 6, and 8. This softer grade was included primarily to seek information on its performance compared with that of harder asphalts.

Construction Control

Good control was maintained throughout construction of the test section. Care was exercised to maintain uniformity in all material and construction variables except type and source of asphalt. The mixture consisted of gravel, sand, and filler that met the standard requirements for type 1 asphaltic concrete of the Louisiana Department of Transportation and Development.

Field Sampling Procedures

The sampling frequencies for evaluation of the aging characteristics of asphalts and durability of asphaltic concrete since construction were formulated in advance as follows: 1 d, 36 d, and 110 d; 1 year, 3 years, and 5 years.

Four 31-cm (12-in) samples were obtained from the outside wheel path from a randomly selected single sample site approximately 30 m (99 ft) long for each test section. The same sampling site and pattern were used in all sampling periods. A typical location of samples for a section is shown in Figure 1. To control additional hardening of asphalt cements in the mixture (after sampling), the samples were stored in a deep freeze until ready for extraction testing. Extraction, recovery, and testing of the recovered asphalts were performed by the department and the Asphalt Institute laboratory in Maryland. The major thrust in this duplication of effort was to investigate the variability associated with the extraction and recovery process.

Tests

Standard testing procedures of AASHTO and the American Society for Testing and Materials (ASTM) were used for penetration-viscosity-ductility determinations. The asphalt cement samples were obtained from the wearing course specimens by the reflux method of extraction and the Abson method of recovery (ASTM D 1856). Trichloroethylene rather than benzene was used as the solvent. The Asphalt Institute data reflect the centrifuge method of extraction with benzene as solvent.

At each periodic evaluation, gradation, density, stability, and air voids were determined by using standard testing procedures. The air voids were computed by using percentage of maximum theoretical design specific gravity. Performance or durability of asphaltic concrete was also evaluated in terms of riding quality by using the Mays road meter, longitudinal wheel-path depressions (rutting), and the magnitude of block and alligator cracking. The physical performance measurements were supplemented by visual rating of sections by a team of 14 engineers from the transportation department, the Asphalt Institute, and the suppliers of asphalt cement. The rating was done during November of 1975 after 60 months of service. The evaluation consisted of rating the different test sections for ride quality, raveling, cracking (block and alligator only), and loss of matrix. A 244-m (800-ft) section was randomly selected in each test section for this evaluation.

Table 1 gives a listing of the performance ratings of the sections (with the exception of rutting, these results are given in U.S. customary units of measurement). The subjective rating was converted to a numerical rating by using a scale of zero to three—zero indicating poor performance with respect to the condition evaluated and three signifying absence of the defects defined by these conditions. There has been no significant change in traffic volume since reconstruction; it has remained fairly stable at 3100 vehicles/d.

Based on the data given in Table 1, evaluation of surface condition indicates that section 1 seems to be performing poorly and sections 9 and 10 superiorly. These two extreme ratings were also found to be statistically significant. However, the magnitude of ratings within each source of asphalt is negligible and statistically insignificant. Performance is related to some rheological properties elsewhere in this paper.

DISCUSSION OF RESULTS

Comprehensive field and laboratory data on material characteristics for each test section can be found elsewhere (4). The hardening characteristics of each asphalt are depicted through graphical presentations. The rheological properties of penetration, viscosity, and ductility for each pair of asphalts are shown in Figures 2 through 4. In these figures, the curves represent Asphalt Institute data. The numerals signify the section number.

Relation Between Hardening of Asphalt and Time

Except for some ductility data, the changes in the rheological properties (Figures 2 through 4) seem to fit the hyperbolic function (5, 6, 7) of the following form:

$$\Delta Y = T/(a + bT) \qquad (1)$$

where

ΔY = difference between the zero life value (immediately after compaction) and any subsequent time T for a given test property,
T = time in months, and
a and b = constants of the equation.

In this equation, the asymptotes are defined by the reciprocal of the slope b and represent the ultimate change of the test variable at infinite aging time. It has been suggested (5, 6) that this limiting value of the change in any given property can be used as a measure of the durability of the asphalt. Specifically, larger ultimate change (1/b) would be considered a property of less durable asphalt.

Data from the present study for penetration at 25°C (77°F) and viscosity at 60°C (140°F) were fitted to this equation to determine the constants a and b. Using the 1-d aged data as zero life value and the last three periods as each subsequent time T, the constants b were determined and are given in Table 2. The values of the reciprocal of the slope b as the asymptotes of limiting values of the changes with time are also given in Table 2. The negative value of the slope for section 1 must necessarily invalidate the equation since at some finite time T the change in viscosity would be infinity. Such discrepancy for section 1 may be associated with the 1-d data, which had showed a threefold increase in the viscosity at 60°C. This initial threefold increase in viscosity may be significant since such an abrupt increase in hardness enhances the subsequent hardening process, as shown by the exponential trend fixed by the last data point.

Based on this limiting change criterion for penetration, all viscosity-graded asphalt cements seem more durable than penetration-graded asphalt cements because of lower ultimate change. However, the fact that all viscosity-graded asphalts had lower penetration values to start with should not be overlooked. To compensate for this, the ultimate limiting penetration values were computed (Table 2). Based on these values, asphalt 1 is the least durable of all and asphalts 9, 10, and 5—in that order—are the most durable. Asphalts 9 and 10, it will be recalled, are the softer asphalts [viscosity at 60°C (140°F) of 200 ± 40 Pa·s (2000 ± 400 poises) and penetration at 25°C (77°F) of 65+]. These limiting values do not provide any consistent trend as to the superiority, with respect to durability, of one type of asphalt over the other.

Application of this limiting value concept to viscosity data [60°C (140°F)] provides some correlation with penetration data. Asphalts 9, 10, and 5 indicate lower values of limiting viscosity, and asphalts 1, 4, and 3—in that order—indicate the largest values. Once again, no trend is discernible; no one group of asphalts (penetration versus viscosity) seems more durable than another.

If durability and performance are synonymous, there should be some correlation between the observed performance of these asphalts in the pavement and the above durability ranking. The data in Table 1 bear this out, at least for extreme (good and poor) conditions of performance as reflected by overall subjective rating. Sections 9 and 10, which have the more durable asphalt, are performing much better than section 1, which has the least durable asphalt.

The analysis and discussion above indicate that soft asphalts initially exhibit more desirable hardening characteristics than asphalts with higher original viscosities. Such low-viscosity sections, notably sections 9 and 10, have likewise shown less pavement distress than some of the other sections. However, an argument against the use of softer asphalts in the state of Louisiana is the early manifestation of wheel-path rutting. This may be true since the magnitude of ruts, which is not of any great concern, is nevertheless higher for sections 9 and 10.

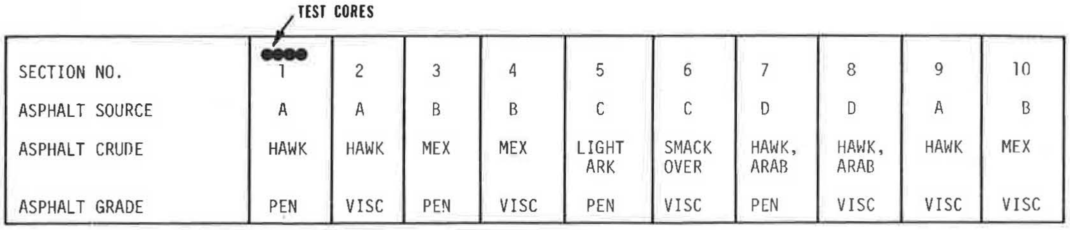
Changes in Rheological Properties

Penetration and Viscosity

The data for penetration in Figure 2 show that, for both types of asphalts, there is a rather rapid rate of hardening during the first 12 months and a decreasing rate thereafter. This rate of hardening with time, for viscosity at 60°C (140°F) (Figure 3), is not consistent although the rate is slower for viscosity-graded asphalts than for the corresponding penetration-graded sections. This is indicated by the Asphalt Institute data in Figure 5, which shows a plot of viscosity index at 60°C versus time of service on a logarithmic scale. The viscosity index, frequently called the aging index, is simply the ratio of the viscosity of the aged asphalt at a temperature to the viscosity of the asphalt before aging. Use of this term tends to eliminate the variability caused by differences in the viscosities of the original raw asphalt. Section 3, the penetration-graded asphalt section, shows a thirteenfold increase in this viscosity measurement after 60 months of service. Likewise, this section had the highest original and thin-film residue viscosity.

The slopes indicated by the curves for aging index versus time in Figure 5 can be used as indicators of the relative durability of various asphalts. Specifically, a flat

Figure 1. Layout and identification of pavement sections.



SECTION NO.	1	2	3	4	5	6	7	8	9	10
ASPHALT SOURCE	A	A	B	B	C	C	D	D	A	B
ASPHALT CRUDE	HAWK	HAWK	MEX	MEX	LIGHT ARK	SMACK OVER	HAWK, ARAB	HAWK, ARAB	HAWK	MEX
ASPHALT GRADE	PEN	VISC	PEN	VISC	PEN	VISC	PEN	VISC	VISC	VISC

Table 1. Pavement condition rating.

	Section									
Criterion	1	2	3	4	5	6	7	8	9	10
Riding	1.31	1.53	1.63	1.67	1.80	1.78	2.01	1.93	1.89	2.06
Raveling	2.08	1.52	1.79	1.81	2.21	1.62	2.03	2.21	2.28	2.51
Loss of matrix	1.95	1.41	1.70	1.76	2.09	1.64	2.12	2.34	2.37	2.47
Cracking										
Block and alligator	1.52	2.36	2.30	2.03	2.27	2.16	2.10	2.06	2.48	2.52
Transverse and longitudinal	1.51	1.98	1.93	1.67	1.91	1.95	1.95	2.04	2.18	2.45
Overall subjective rating	1.67	1.76	1.87	1.79	2.06	1.83	2.04	2.12	2.24	2.40
Rutting, mm	7.1	4.4	4.1	3.4	4.6	3.8	4.6	4.6	5.3	6.6
Mays roughness, in/mile	144	131	123	123	111	108	96	85	125	85
Dynaflect deflection, $^1/_{1000}$ in	1.64	1.40	1.35	1.27	1.33	0.95	1.03	0.89	0.91	1.32
Block and alligator cracking, ft^2/1000 ft^2	42.76	9.22	0.36	3.33	20.26	13.91	3.70	6.98	0.68	0.00

Note: 1 mm = 0.039 in.

Figure 2. Penetration at 25°C (77°F) versus time of aging.

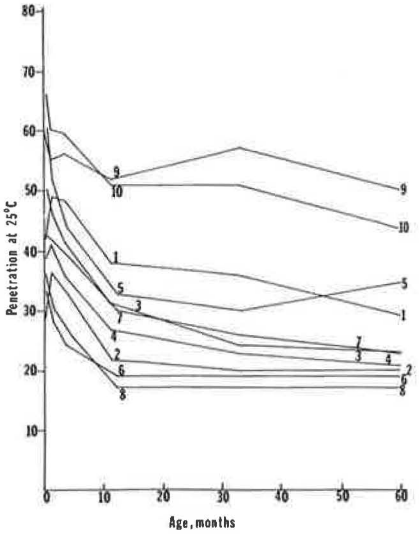
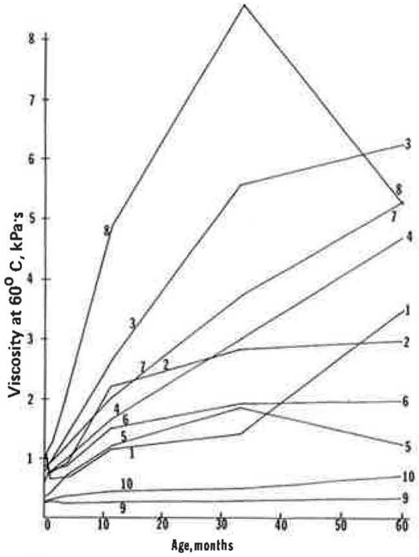


Figure 3. Viscosity at 60°C (140°F) versus time of aging.



Note: 1 kPa·s = 10 kilopoises.

slope implies a more durable asphalt. Accordingly, based on 60-month data, all viscosity-graded asphalts would be classified as more durable than the corresponding penetration-graded asphalts. Likewise, sections 9 and 10, which have the smallest slopes, have the most durable asphalts, and section 3 has the least durable asphalt.

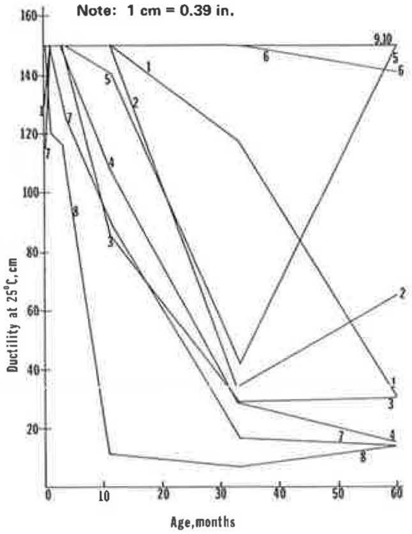
Ductility

The importance of ductility requirements in specifications has long been a subject of debate mainly because of the empirical nature of the test. However, it is recognized that the ductility values provide some measure of asphalt quality related to flexibility. In Figure 4, the ductility values for various asphalts indicate inconsistency in their rate of hardening. Sections 3, 4, 7, and 8, however, have hardened at a more rapid rate than the other sections. A similar trend was indicated by some of these same sections in Figure 5.

Shear Index

The change in the characteristics of the shear index with time is shown in Figure 6. Once again, the relative position of each curve is directly associated with its aging characteristics (as depicted by its rheological characteristics). Specifically, sections 3, 4, 7, and 8 are more susceptible to shear, and sections 9 and 10 are less so. These sections had also exhibited an increased rate of hardening during the 5-year period. Source (crude) may be an influential factor for such aging characteristics. A close association between ductility values and shear index was also observed from the data. In general, asphalts with shear indexes of less than 0.40 had ductilities greater than 100 cm (39 in) (4).

Figure 4. Ductility at 25°C (77°F) versus time of aging.



Temperature Susceptibility

Asphalt consistency is greatly affected by changes in temperature. The extent of this effect is expressed as temperature susceptibility, which can be measured by using the Walther relation. The value of this property for each asphalt was evaluated for original and 60-month samples by using the service temperature range of 25°C to 60°C (77°F to 140°F) and also the mixing and compaction range of 60°C to 135°C (282°F).

These values are shown in the form of a bar chart in Figure 7, where it can be seen that the viscosity-graded asphalts are more susceptible to temperature changes than the corresponding penetration-graded asphalts. The figure also shows that, for both groups of asphalts, the 60-month values are higher than the corresponding original values in the 60°C to 135°C temperature range. However, in the service temperature range of 25°C to 60°C, the 60-month data show a significant decrease in slope from the original.

High-ductility asphalts are more susceptible to temperature as shown by sections 2, 5, 6, 9, and 10 in Figure 4. These sections had indicated high values of retained ductility after 60 months of service. Correspondingly, their temperature susceptibility is also higher in the service temperature range. Furthermore, sections 9 and 10, which show no loss of ductility values after 60 months, also exhibit the least change in their temperature susceptibility in the service temperature range.

Values of temperature susceptibility have been shown to be highly correlated with the transverse cracking in the pavement (8). The performance data given in Table 1 do not show any correlation between the two variables. In fact, sections 9 and 10, the most susceptible sections, are the best performing sections with respect to any form of cracking distress.

Air Voids in Pavement and Asphalt Hardening

Figure 8 shows changes in void content with time. Almost all sections had reached the void content of 5.0 percent within 3 years of traffic service. During the past 2 years,

Table 2. Limiting value of property changes with age.

Section	Slope (b)		Limiting Change		Ultimate Change	
	Penetration	Viscosity	Penetration	Viscosity (kPa·s)	Penetration	Viscosity (kPa·s)
1	0.033	-0.17	30.3	-[a]	12	-[a]
2	0.105	0.043	9.5	2.33	19	3.35
3	0.033	0.010	30.3	10.00	20	10.81
4	0.049	0.002	20.4	50.00	19	50.90
5	0.041	0.118	24.4	0.85	35	1.25
6	0.072	0.063	13.9	1.59	19	2.19
7	0.044	0.007	22.7	14.29	20	15.18
8	0.051	0.023	19.6	4.35	16	5.39
9	0.083	1.016	12.1	0.10	48	0.39
10	0.044	0.117	25.0	0.86	41	1.16

Note: 1 kPa·s = 10 kilopoises.

[a] Infinity at some finite time T.

Figure 5. Viscosity index at 60°C (140°F) versus time of aging.

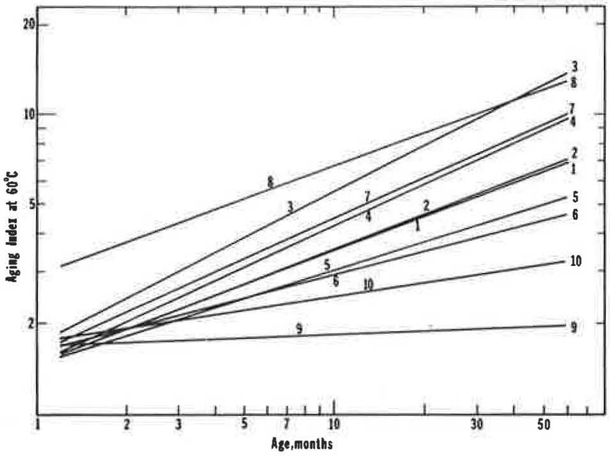


Figure 8. Void content in pavement versus time.

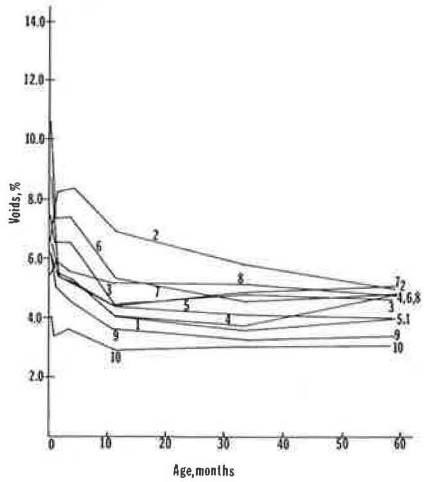


Figure 6. Shear index versus time of aging.

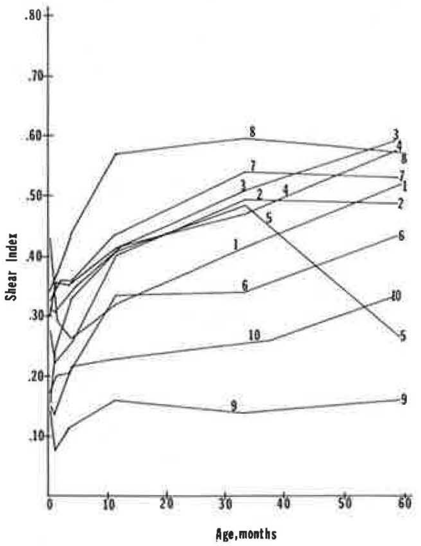
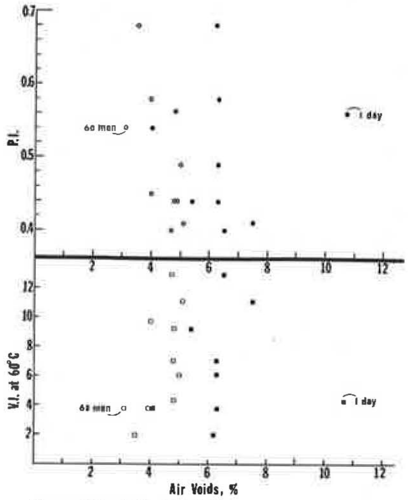
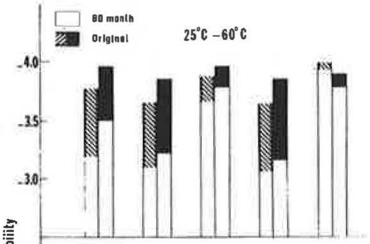


Figure 9. Effect of air voids on hardening of asphalts.



Note: t°C = (t°F - 32)/1.8.

Figure 7. Temperature susceptibilities of test sections.



Note: t°C = (t°F - 32)/1.8.

there has been practically no change in void content. The resistance to compaction may be associated with the consistency of asphalts. The harder the original viscosity is, the greater its resistance to compaction may be. Sections 9 and 10—the softer grade asphalt sections—have shown the least resistance to traffic compaction, and asphalt section 8—the high-viscosity asphalt—has shown the most resistance.

It is generally recognized that the degree of initial and final compaction or void content or both in the pavement has an effect on the rate of hardening of asphalts. More specifically, the higher the initial void content is, the greater the rate of hardening of asphalt in the pavement will be. Figure 9 was prepared to investigate this relation. The plots show initial and final void content and viscosity index (VI) at 60°C (140°F) and penetration index (PI) at 25°C (77°F). The data are too scattered to indicate any association of hardening rate with air void content in pavement. This disassociation should not be construed to mean that the magnitude of air void content does not affect the hardening rate of asphalt binder. What it

Table 3. Durability ranking by use of various criteria.

	Section or Asphalt Type									
Durability Criterion	1	2	3	4	5	6	7	8	9	10
Field performance[a]	10	9	6	8	4	7	5	3	2	1
Viscosity index										
25°C	6	2	10	5	4	7	8	2	1	3
60°C	6	7	10	9	4	3	8	5	1	2
Penetration index	5	8	10	9	4	3	6	7	1	2
Limiting penetration	10	6	5	8	3	7	4	9	1	2
Limiting viscosity (60°C)	10	5	7	9	3	4	8	6	1	2

Note: t°C = (t°F - 32)/1.8.

[a] See Table 1.

does indicate is the fact that the air void variability in pavement is so pronounced that it overshadows the resulting effect on the hardening process. In general, the binder viscosity of the original asphalt may be more critical since the data show that softer asphalt offers less resistance to compaction (sections 9 and 10) and is thus able to satisfy lower void content requirements.

Gradation and Stability

After 60 months of traffic, no aggregate degradation was evident in these sections. As would be expected, the strength values have increased because of the increase in binder viscosity. The effect of asphalt content on the hardening characteristics of various binders could not be isolated since all sections started with the same percentage of binder.

FIELD PERFORMANCE VERSUS RHEOLOGICAL PROPERTIES

It has been shown above that asphalts exhibit a wide variation in their hardening characteristics. Specifications for asphalts generally relate to their durability, which in turn relates to their useful life in pavement. However, the most complex problem is the establishment of a single criterion that would define durability and early prediction of performance in pavements.

The relative durability of penetration- and viscosity-graded asphalts was studied by using criteria of limiting value and various aging indexes. Based on these criteria, the 10 asphalts were ranked from the most durable to the least durable on a scale of 1 to 10 respectively. The rankings based on such criteria were then compared with the rankings of various asphalt sections with respect to their overall field performance (Table 1). These comparative rankings are given in Table 3. As was discussed before, the rankings according to various index criteria are based on the magnitude of the slopes of the index-time curve relation, and flatter slopes indicate more durable asphalts. The limiting value rankings were determined from the hyperbolic relation discussed previously (Equation 1).

Data given in Table 3 show that practically all durability criteria seem to be consistent with respect to the ranking of the most durable asphalt, sections 9 and 10. Rankings according to these criteria are also consistent with actual field performance rankings. However, there is no consistency for the least durable scale. Furthermore, prediction of durability by using limiting value criteria correlates better with the observed field performance of various asphalts.

The data in the table do not indicate any recognizable consistency in the performance of the two types of asphalts investigated in this study. Likewise, the various durability criteria also fail to provide any recognizable trend with respect to one type of asphalt being more durable than another. What is most indicative, by all criteria, is the fact that softer grade asphalts are more durable than harder asphalts. The poor performance of section 1 cannot with certainty be attributed to any single criterion. The instability of the underlying layers may have contributed to the distress observed since deflection measurements made by using the Dynaflect had indicated maximum value of this parameter for the section. However, because of a lack of original data on deflection, this association may not be definitive. If major maintenance is not done on these sections, they may be evaluated in the future to establish definite cause-effect trends.

SUMMARY AND CONCLUSIONS

The primary intent of the study reported here was to make a comparative evaluation of the durability and performance of penetration- and viscosity-graded asphalt cements by means of field installation in asphaltic concrete mixtures. The principal findings summarized below are applicable within the constraints of the environment, materials, construction, and traffic that existed at the test site:

1. Hardening of asphalt cements, regardless of how they are graded, is a hyperbolic function of time but at different rates.
2. Asphalts that have a high original viscosity tend to harden more and at a rapid rate. This rate of hardening at 60°C (140°F) is slightly lower for viscosity-graded asphalt than for corresponding penetration-graded asphalts.
3. For a given asphalt source, the difference in durability between the two types of asphalts was not significant. Likewise, no significant difference was evident in their performance in the field.
4. By all durability criteria, asphalts one grade softer (AC-20) than the harder viscosity-graded asphalts (AC-40) show desirable characteristics of durability. After 60 months of service, sections constructed with these asphalts are performing better than sections in which any other harder grade asphalt has been used.
5. Viscosity-graded asphalts are more susceptible to temperature than corresponding penetration-graded asphalts, but there was no correlation between this characteristic and pavement distress.
6. There was no association between voids in the pavement and rate of hardening.

ACKNOWLEDGMENTS

First and foremost, I wish to acknowledge the cooperation and effort of the Asphalt Institute in conducting the various tests on asphalt cements and that of the asphalt producers in providing the specified experimental asphalts. The study was conducted under the Louisiana highway planning and research program in cooperation with the Federal Highway Administration. I am solely responsible for the opinions, findings, and conclusions expressed.

REFERENCES

1. H. L. Lehmann and V. Adam. Application of the Marshall Method to Hot Mix Design. Louisiana Department of Highways, 1959.
2. J. Y. Welborn and others. The Relation of Absolute Viscosity of Asphalt Binder to Stability of Asphalt Mixtures. ASTM, STP 328, 1968.
3. Symposium on Viscosity Grading of Asphalts. HRB, Highway Research Record 350, 1971.
4. S. C. Shah. Asphalt Cement Consistency Study—Field Evaluation of Viscosity and Penetration-Graded Asphalt Cements. Research and Development Section, Louisiana Department of Transportation and Development, April 1977.
5. A. B. Brown and others. Rate of Change of Softening Point, Penetration, and Ductility of Asphalt in Bituminous Pavements. Proc., AAPT, Vol. 26, 1957.
6. P. S. Kandhal and M. E. Wenger. Asphalt Properties in Relation to Pavement Performance. TRB, Transportation Research Record 544, 1975, pp. 1-13.
7. D. Y. Lee. Asphalt Durability Correlation in Iowa. HRB, Highway Research Record 468, 1973, pp. 43-60.
8. D. I. Anderson and others. Evaluation of Viscosity Graded Asphalt Cements in Utah. Materials and Research Division, Utah Department of Transportation, Jan. 1976.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Materials.

Evaluation of Properties of Asphalt-Emulsion-Treated Mixtures by Use of Marshall Concepts

Ahmed Atef Gadallah, Cairo University
Leonard E. Wood and Eldon J. Yoder, School of Civil Engineering, Purdue University

Findings are reported of a laboratory investigation concerning the effect of asphalt emulsion content, added moisture content, and aggregate gradation on the design parameters and properties of asphalt-emulsion-treated mixtures (AETMs) by use of Marshall equipment. The evaluation was conducted at different curing stages of the mix. One type of aggregate (sand and gravel), one type and grade of asphalt emulsion, a modified Marshall method for preparing and testing AETM specimens, and autographic Marshall equipment that produced a continuous record of load deformation were used in the study. The evaluation resulted in a number of significant results. AETM properties are an outcome of a complex array of factors. Evaluating the mix properties in relation to only a single factor is not sufficient; the interaction of these factors influences the behavioral properties of AETMs and must be considered in the evaluation. The study also showed that water-sensitivity tests must be an integral part of the Marshall design procedure for AETMs.

This study reports the findings of a laboratory investigation that evaluated the effect of asphalt emulsion content, added moisture content, and aggregate gradation on the design parameters and properties of asphalt-emulsion-treated mixtures (AETMs) by using Marshall equipment. The evaluation was conducted at different curing stages of the mix. One aggregate type (sand and gravel) and one type and grade of asphalt emulsion were used along with a modified Marshall method developed by Gadallah, Wood, and Yoder (5) for preparing and testing AETM specimens and autographic Marshall equipment that produced a continuous record of load deformation.

The evaluation of AETM properties resulted in a number of significant results. AETM properties are an outcome of a complex array of factors. Evaluating the mix properties in relation to only a single factor is not sufficient; the interaction of these factors influences the behavioral properties of AETMs and must be considered in the evaluation.

EQUIPMENT AND MATERIALS

Marshall Equipment

The Marshall equipment used in the study consisted mainly of a mechanical compaction hammer and an autographic stability apparatus. The mechanical compaction hammer was used for compacting the standard Marshall specimens at 50 blows/side.

The stability apparatus used in this investigation is essentially the same as the standard Marshall equipment, but it provides a continuous recording chart for load (lb) versus deformation (0.01-in units) throughout the testing range from which stability and flow values can be obtained (since this equipment is calibrated in U.S. customary units of measurement, no SI equivalents are given). Figure 1 shows a typical trace for the Marshall test.

Mineral Aggregate

One type of aggregate, which consisted mainly of terrace sand and gravel, was used in this investigation. Three aggregate gradations that lie within an Indiana State Highway Commission (ISHC) gradation size 73B with a maximum size of 19 mm (0.75 in) were used (Figure 2): The first gradation (MG) follows the midspecification of the ISHC