Predictability Techniques for Asphalt Durability

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A procedure is needed for predicting the durability requirements of asphalts. Development of this procedure should result in specifications for improvement of asphalt quality. First, testing techniques must be identified that will be sensitive to changes in asphalt quality. Second, these changes must be related to in-service changes in pavements. Third, the quality specifications must be imposed to curb the inevitable time-dependent changes to the degree desired. This study identified testing techniques that are sensitive to changes in asphalt quality by comparing the results of tests of (a) chemical composition, (b) vanadium content, (c) weatherometer exposure, and (d) rolling thin film oven aging to the durability of environmentally aged specimens. Durability is considered to be measured by the combination of viscosity and asphaltene increases with time. Rankings of each of these testing techniques are compared to actual environmental rankings to illustrate the techniques that best identify the durability changes. The major finding of the study is the high degree of correlation between the vanadium content and environmental rankings. If compositional considerations are such that any asphalt imbalance or high volatility is a minimal factor, then the vanadium content is the best single parameter for predicting asphalt durability.

The weathering or durability of asphalt and resulting deterioration with time have resulted in distress of pavement structures and have necessitated the replacement of many surface treatments. The aging of asphalt can be caused by a number of factors such as oxidation, loss of oils, and structure changes. Considerable expenditure of funds annually is a direct result of the deterioration of asphalt. These funds are used for either the replacement or rejuvenation of existing surfaces.

The literature dealing with the mechanisms of asphalt durability spans a period of more than 60 years. Early works of Hubbard and Reeve (1), Speilman (2), and Streiter and Snoke (3) all indicated that oxidation was a prime cause of asphalt deterioration. The problem has been that little previous work has led directly to improvements through specifications for asphalt quality and the subsequent reduction in asphalt deterioration.

A testing technique that identifies or differentiates asphalt quality has not been developed. Once a sensitive technique is developed, then its relationship to in-service pavements and subsequent durability specifications can be developed. This study was initiated to identify a testing technique sensitive to asphalt changes in durability.

Several potential laboratory techniques for predicting asphalt durability are explored, including (a) rolling thin film oven, (b) weatherometer exposure, (c) chemical composition, and (4) vanadium analysis. These techniques are related to environmentally exposed specimens to produce predictable responses. The responses and combination possibilities for two or more procedures are presented.

BLENDING PROGRAM

For several years we have been investigating the possibility of improving the durability of asphalts. The asphalt blending phase of these investigations played such an important part in formulating the total program that it became an integral part of this paper.

There is little doubt that, in addition to construction problems (e.g., air voids), the most important factor in asphalt durability is the chemical composition. Although some construction problems can be eliminated by changes in construction practices, chemical composition is a factor that may be amenable to laboratory control. This was the basis for initiating the blending research program.

Phase A

Initial efforts in the blending program were confined to the large-scale separation and recombining of the various asphalt fractions. The standard method of asphalt analysis used in phase A was a modification of the Rostler-Sternberg procedure (5, 8). Because this method separates the various fractions by their reactivity, we felt that the procedure could be adopted for large-scale separations.

Phase A was soon found to be impractical from both operative and economic standpoints. The neutralization step in the separation procedure is extremely temperature sensitive and the reaction is exothermic. This imposes requirements that make the procedure uneconomical as a full-scale operation. The refinery processing

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equipment that is needed makes the cost prohibitive. After sufficient quantities of each of the fractions were produced to carry out this phase of the program, the method was abandoned.

However impractical phase A proved to be, it did yield some valuable data concerning the function of the various fractions. For example, the contributions of the asphaltene (A) and second acidaffins (A_2) fractions to asphalt performance were found to be the most important. Inasmuch as the primary function of asphaltenes is to act as a bodying agent, it follows that an increase in asphaltenes will result in a harder asphalt. However, if sufficient solubilizing oils such as second acidaffins are present, the hardening effect of increasing asphaltenes can be largely offset.

This offsetting effect was found early in the testing of phase A blends in the rolling thin film oven (RTFO). Minimal amounts of the A_2 fraction were found to exert a powerful influence on the blend viscosity because of their solubilizing function. However, the addition of A_2 in slight excess had effects beyond that of viscosity alteration. The A_2 fraction is one of the more volatile asphalt fractions. Because the criterion for evaluating RTFO performance is a viscosity ratio (aged viscosity/unaged viscosity) = aging index, some RTFO results can be misleading. With a film thickness of 1350 μm (1350 microns) at 163°C (325°F) and air blowing across the sample, the excess volatiles are lost. The result is a sharp increase in viscosity that is not entirely caused by the increase in asphaltenes. This can be especially misleading when the aging index (AI) based on the RTFO is used as the sole means for predicting long-term durability. When excess volatiles are present, the difference in their loss at 163°C (325°F) with air blowing versus long-term loss at pavement temperatures must be considered. As would be assumed, variations in the percentage of A_2 in the blend have a great effect on the chemical reactivity ratio (CRR). Because the asphaltene fraction is omitted from the CRR parameter, increasing the second acidaffin content causes a drop in the CRR value. Too great a drop is probably an indication of structural instability in the asphalt. This instability or structural alteration is the probable cause of the mediocre performance noted in some of the environmental samples. Further work is needed to determine the optimum A_2 addition that will maintain the structural integrity of the asphalt.

The effects of varying the percentage of asphaltene fraction are more apparent in the resulting viscosity than in other parameters. It was possible to use this property in the phase A blends as well as in the later work. By increasing the asphaltene content, it was possible to incorporate more second acidaffins into a blend and produce an asphalt with higher strength and greater durability. An example of the usefulness of this procedure can be seen in a blend made later in the program. An asphalt possessing excellent aging properties lacked sufficient viscosity to be of maximum usefulness in highway construction. The addition of 5 to 10 percent asphaltenes improved the viscosity without noticeably changing the viscosity ratio. It is probable that the primary change in asphaltenes that occurs in asphalt aging is one of quantity. Possibly there is a slight change in molecular weight as well, but this change, if any, is not significant. If this is true, then an asphalt with lower initial asphaltene content will probably have a longer useful life. This is of course true when the other factors involved in durability are equal. In the case of asphaltene addition, the effect on the CRR will be one of dilution inasmuch as it is not included in the equation.

In view of the confirmation of the importance of the asphaltene and second acidaffins fraction, the negative commercial aspects of phase A can be minimized. Fortunately both the asphaltene and second acidaffin fractions are available in commercial quantities and are economically attractive. Gilsonite is an excellent source of asphaltenes having a very high molecular weight compared to asphaltenes from petroleum. The numerous rubber extender oils, especially the aromatics, are high in second acidaffins. The availability of these fractions enabled the study to proceed to the next phase.

Phase B

Phase B involved the blending of selected asphalt components with asphalts from several sources. During this part of the study, deliberate imbalances were made by using excessive amounts of the individual fractions. These blends confirmed the functionality of the fractions as determined in phase A when asphalts from the several fractions were recombined. Because of their availability, extensive use was made of Gilsonite and extender oils as the source of asphaltene and second acidaffin fractions.

Phase C

The third and final phase of the blending program involved the blending of the two base asphalts, either alone or with one of the components (usually A or A_2) added. This procedure, because of its simplicity and economic advantages, was the method used in eventually moving the blending program from the laboratory to construction projects. The blends currently under field studies are composed of two asphalts, each of which contributes its desirable properties to the whole. Further information on the blending program is available (6).

SELECTION OF SAMPLES FOR ENVIRONMENTAL EXPOSURE

From the total blends prepared, samples were selected for an environmental exposure study. Several factors were considered in this selection process:

1. Availability of a particular asphalt to Arizona,
2. Feasibility of blended asphalt from a commercial viewpoint,
3. Effect of adding selected asphalt components to the base asphalt or asphalts,
4. Effect of blending two asphalts to secure the desired properties, and
5. Blended asphalts, even though deliberately imbalanced by adding extremely large quantities of one or more asphalt components.

All of these factors were weighed, and availability and feasibility were considered the most important. Assessing the commercial feasibility of a particular blend requires that the effect on the supplier be determined. If the added component requires additional refinery processing or equipment, it would probably be economically impractical.

Adhering to this selection process as closely as possible resulted in the selection of 53 samples.

COMPOSITION OF SELECTED SAMPLES

The asphalts selected were made from paving grade asphalts from three sources. Since this project continued over a considerable length of time, the supply of base asphalt changed somewhat in composition. Typical

Rostler-Sternberg (7) analyses of the various base asphalts and additives are given in Table 1.

ENVIRONMENTAL EXPOSURE

Specimens 102 mm (4 in) in diameter and 102 mm (4 in) in height were prepared according to Arizona Test Method 802B for natural environment exposure. The specimens were all prepared in a like manner by using the same aggregate, grading, and mixture parameters (voids in mineral aggregate, air voids, and so on). The specimens were then placed on 152.4 by 152.4 by 13-mm (6 by 6 by ½-in) plywood squares and placed on the laboratory roof. All the specimens were placed on a level surface in an area where they would receive uniform environmental exposure. Environmental exposure in Phoenix represents the most severe exposures to sunlight and oxidation possible within Arizona. The specimens were not protected except for the surface resting on the plywood squares. It was believed that the relationships developed during laboratory evaluation could subsequently be correlated with actual in-service pavement viscosity increases after a predictability technique was developed.

After 3 years of exposure, the specimens were returned to the laboratory for sample preparation, testing, and evaluation (Figure 1). Approximately one-third of each cylindrical specimen was used for test purposes in an effort to obtain a representative sample for evaluation. By cutting along a vertical axis, the section obtained would closely approximate the exposure to environmental conditions experienced in an actual roadway. This is an important consideration in climatological conditions found in Arizona.

The extraction procedure was performed in a Soxhlet extractor by using methylene chloride as the extraction solvent. The extraction was continued until the extract recycled with no trace of color. Usually five or six cycles were sufficient to reach this degree of extraction. The bulk of the methylene chloride was removed from the sample by warming on a hot plate. The last portion of solvent was then removed under a vacuum of 710 mm (28 in) of mercury while the sample was heated by two 250-W infrared heat lamps.

The viscosities of the recovered asphalts were obtained with a sliding plate microviscometer (8). Viscosities were determined at 25°C (77°F) and were calculated to a shear rate of 0.05 sec^{-1} by regression analysis. Calculations were based on viscometer runs of five different weight loadings. A 3-year viscosity ratio was calculated for each sample by dividing the viscosity of the recovered asphalt by the viscosity of the original asphalt before outdoor exposure. The viscosity ratio was then considered to be an indicator of the relative aging rate of the asphalts under study.

Comparison of viscosity ratios must take into consideration the actual viscosity. Although an asphalt of very low initial viscosity may show a high viscosity ratio, the aged viscosity may still be well within acceptable limits. However, this may not be true for an asphalt of high initial viscosity. As determined in the microviscometer at 25°C (77°F), the upper limit of viscosity measurement is probably about 100 MPa·s (10 megapoises). Beyond this point there is a possibility of film failure by cracking. Perhaps of greater importance in the evaluation of viscosity ratios is the difference in viscosity of the aged asphalt and this upper limit of viscosity measurement. It is probable that the greater the difference is, the more durable the asphalt will be, providing the viscosity is high enough for structural stability.

The 3-year viscosity ratios for the asphalts subjected to outdoor exposure for 3 years are given in Table 2. The relative ranking of these asphalts is also given in the table. Asphalts with the lowest ratios retained more of their original softness than those with the higher ratios. The latter are characterized by their brittleness as was observed during preparation of the microviscosity plates. Those asphalts with the lowest viscosity ratios were assigned the best ranking.

The increase in asphaltenes closely follows the increase in viscosity for most of the samples. The ranking of the samples by this parameter therefore fairly well agrees with the ranking by 3-year viscosity ratio. However, because of the wide range of initial asphaltene contents, a given change in asphaltenes had a more pronounced effect on an asphalt with low initial content. Disagreement in ranking occurs in those asphalts with very high or very low percentages of asphaltenes.

Determination of the relative ranking of the 53 samples aged in a natural environment took into consideration the combined ranking of both the 3-year viscosity ratio and asphaltene increase. The sum of the two ranking methods was used to determine an overall rank for the samples. This overall rank is given in Table 3 for the 53 samples.

Blend Designation	Viscosity Ratio Rank	Asphaltene Rank	Sum	New Rank
2C	1	1	2	1
22B	2	3	5	2
21B	4	2	6	3
15C	5	6	11	4

The development of asphaltenes and viscosity is used as a means to quantify durability.

FRACTIONAL ANALYSIS

The asphaltene content is one of several asphalt fractions determined by the Rostler-Sternberg method of analysis. A complete Rostler analysis was performed on all the asphalts examined in this study. Parameters derived from the Rostler analysis have been suggested as indicators for asphalt durability (9). The ratio of nitrogen bases to paraffins (N/P) was examined in the course of this study. There are some instances where the same ratio existed for several asphalts. In these cases, the same ranking was given to all the asphalts to denote equality. However, this parameter was found to correlate rather poorly with environmental aging. Regression analysis of the N/P data yielded a correlation coefficient of 0.38.

Rostler's CRR parameter was also examined and, as with N/P, some samples had the same value and were given equal ranking. The relationship of reactive to unreactive fractions (CRR) is

$$CRR = \frac{N + A_1}{A_2 + P}$$

where

N = nitrogen bases,
A_1 = first acidaffins,
A_2 = second acidaffins, and
P = paraffins.

Use of the CRR as the sole parameter for predicting asphalt durability is inadvisable. When asphalts are tested in the as-received condition or when the asphalt is only slightly modified, the CRR in itself has a reasonable value. However, its usefulness is very limited when it is applied to asphalts whose composition has been radically changed. This was shown quite graphically in the work carried out in phase A of the blending program.

Table 1. Chemical composition of blending fractions.

Material	A (%)	N (%)	A_1 (%)	A_2 (%)	P (%)
Base asphalt					
LA basin 40-50	19.0	37.1	8.0	24.4	11.5
LA basin 85-100	18.5	33.7	13.7	22.3	11.8
Ciniza 85-100	3.7	24.9	23.4	36.9	11.2
Idaho 120-150	20.3	21.4	8.5	38.3	11.4
Additive					
Gilsonite	75.2	20.6	1.0	2.3	0.9
Asphaltenes	95.3	2.5	1.5	0.5	0.2
Nitrogen bases	4.7	87.3	4.1	3.0	1.0
First acidaffins	8.6	17.4	53.6	12.3	8.1
Second acidaffins	0.2	0.3	8.8	77.0	13.7
Second acidaffins and paraffins	0.5	0.8	4.0	48.7	46.0
Paraffins	—	—	—	—	100.0
Reclamite resin	0.6	32.3	16.2	34.8	12.9
Dutrex resin	—	22.6	25.7	45.6	6.1
Antistrip agent	—	—	—	—	—

Figure 1. Environmental specimens after 3 years' exposure.

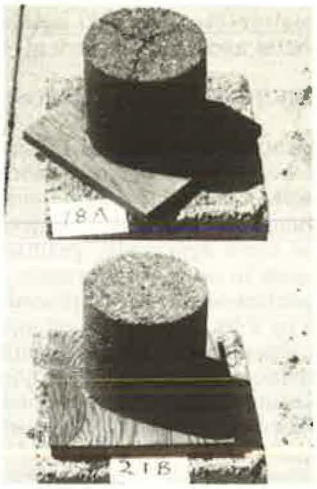


Table 2. Three-year viscosity ratio.

Blend Designation	Ratio[a]	Rank	Blend Designation	Ratio[a]	Rank
2C	7.6	1	10B	54.2	28
17C	9.1	2	19C	54.4	29
22B	9.1	2	18B-2	54.5	30
21B	9.3	4	19A	55.0	31
15C	9.4	5	15A	55.7	32
21A	10.0	6	22C	64.4	33
17D-1	11.3	7	23B	74.2	34
6C	11.3	7	9AX	77.6	35
16C	13.3	9	19B	78.8	36
16B	13.7	10	11SSY	82.9	37
16D	14.1	11	22E	83.2	38
7C	14.3	12	23A	90.0	39
16A	16.5	13	18C	93.0	40
8CY	18.0	14	19D	97.4	41
17D-2	20.2	15	14A	97.8	42
8CZ	20.8	16	6R	107	43
13SSB	23.6	17	24B	118	44
12SSA	26.0	18	10A	122	45
8CX	30.7	19	22F	124	46
11SS	35.6	20	18A	130	47
9A	37.6	21	5A	137	48
7C-1	39.0	22	24A	149	49
9C	40.8	23	18B-1	201	50
15D	46.3	24	2P	303	51
12SSB	46.7	25	18D	456	52
11SSN	48.9	26	3A	522	53
15B	51.5	27			

[a]Ratio = [microviscosity at 25°C (77°F) 0.05 s^{-1} (3 years)/microviscosity at 25°C (77°F) 0.05 s^{-1} (original)].

Table 3. Environment exposure ranking.

Blend Designation	Rank	Blend Designation	Rank
2C	1	19B	28
22B	2	18B-2	29
21B	3	5A	30
15C	4	22E	31
17C	5	6R	32
16B	6	11SSY	33
16C	7	10B	34
17D-1	8	23B	35
21A	9	15A	36
17D-2	10	7C-1	37
8CX	11	24B	38
7C	12	14A	39
16D	13	22C	40
8CY	14	19A	41
6C	15	23A	42
15D	16	2P	43
8CZ	17	19D	44
16A	18	9AX	45
11SS	19	24A	46
13SSB	20	3A	47
9A	21	18C	48
12SSA	22	18A	49
11SSN	23	10A	50
12SSB	24	22F	51
19C	25	18D	52
15B	26	18B-1	53
9C	27		

Figure 2. Rolling thin film oven test as an indicator of asphalt durability.

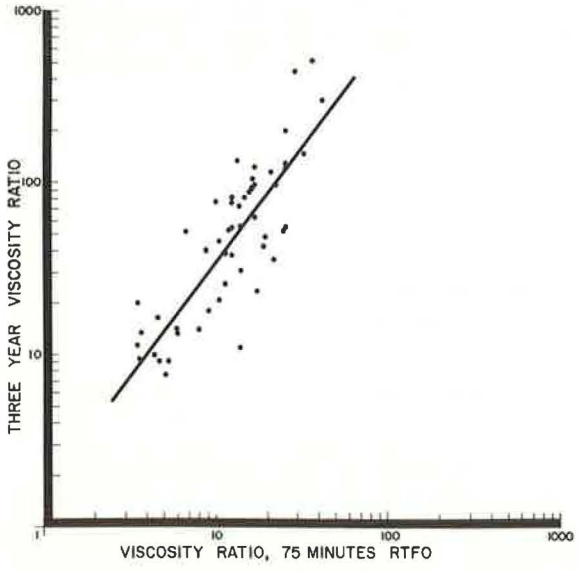
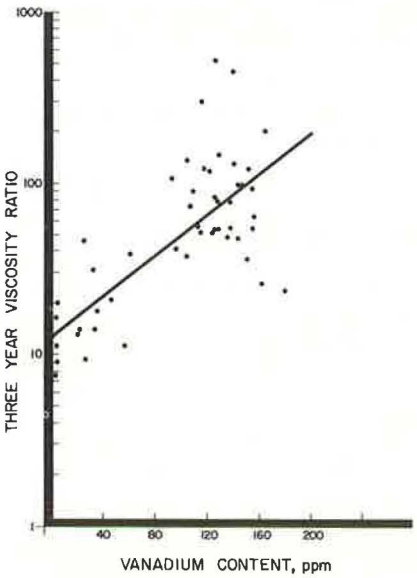


Figure 3. Vanadium as an indicator of asphalt durability.



All the asphalts in this part of the study were either recombined from various fractions or often deliberately imbalanced in composition. When the CRR of these phase A asphalts was added to the CRRs of the asphalts from phases B and C, the degree of correlation was radically altered. When only the straight or slightly modified asphalts from phases B and C were considered, the coefficient of correlation with the viscosity ratio was 0.60. When the CRR of the 16 asphalts from phase A were added and recalculated, the coefficient of correlation dropped to 0.28. The value of the CRR for predicting durability is most pronounced when used in combination with other parameters. This is discussed later.

ROLLING THIN FILM OVEN TEST

All the asphalts included for environmental exposure were tested by 75-min exposure in the rolling thin film oven in accordance with ASTM D 2872-70 (10). After the samples were removed from the oven, their microviscosities were determined.

A microviscosity ratio was determined by dividing the viscosity of the aged material from the RTFO by the viscosity of the original asphalt. The best correlation of the 75-min viscosity ratio with the 3-year viscosity ratio was found to occur as a log-log function (Figure 2). The regression analysis of the data yielded a correlation coefficient of 0.84.

Other parameters are also at work that prevent RTFO results from possibly more closely predicting the durability of an asphalt. A major drawback of the RTFO test is that it is conducted in darkness. Light is known to be an active weathering agent, especially in climates where there is a great deal of sunshine. This factor is of major importance where surface treatments are involved, such as in seal coats. Although the effects of ultraviolet radiation are confined to the surface, they cannot be disregarded. The weathering by rain and wind combined with abrasion from tires helps keep a new surface available for photooxidation. Tests such as weatherometer exposure, which directly or indirectly measure the effect of light, are useful in describing the aging characteristics of asphalt in the natural environment.

VANADIUM ANALYSIS

Previous work (11, 12) has suggested that the presence of vanadium (V) in asphalt affects the rate at which the asphalt ages. For the most part this work has been confined to the effects of vanadium on the rate of oxidation by actinic light. Weatherometer exposure has confirmed the catalytic action of vanadium in the photooxidation process. However, the effects of vanadium are not confined to this type of oxidation. Results of RTFO testing show a strong correlation with vanadium content. It is quite possible that this is the first time the role of vanadium in thermal oxidation of asphalts has been explored to this extent. Further work is being carried out to determine the distribution of vanadium in the various asphalt fractions. At this time it appears that the vanadium is almost entirely contained in the asphaltene and nitrogen base fractions, perhaps as much as 98 percent of the total.

The vanadium analysis was run on the environmentally exposed asphalts after their recovery from the cylindrical specimens by Soxhlet extraction. It was assumed that the vanadium content of the asphalt did not change during the 3-year exposure. The vanadium content was determined by atomic absorption analysis. Because of the small amount of recovered asphalt available, the average sample size was 7 g (0.24 oz). The instrument used for the analysis was a Perkin-Elmer model 306 atomic absorption spectrophotometer. The vanadium concentrations were typical of the asphalts normally used in Arizona.

Figure 3 shows the correlation between vanadium content and the 3-year viscosity ratio. The coefficient of correlation was 0.75. A similar effect of vanadium on the viscosity ratio of asphalt after 75 min in the RTFO has been noted. For these data, the coefficient of correlation was 0.81.

A good correlation exists between vanadium and the various aging tests used in this study. This suggests that vanadium content may have a significant influence on asphalt aging characteristics. The concentration of vanadium in asphalt is not a widely known parameter for estimating asphalt durability. The catalytic effect of vanadium and other metals may prove to be important in the choice of materials and design parameters for future specifications.

WEATHEROMETER ANALYSIS

Ten asphalts were selected as representative of the samples subjected to outdoor exposure. These asphalts were artificially aged in an Atlas 6000-W xenon arc weatherometer for periods of 25, 50, and 100 hours. The weatherometer was set to simulate sunlight only, and the wattage applied to the xenon lamp was adjusted to maintain a constant light intensity during the testing. The other variables were adjusted to maintain a specimen temperature of 38°C (100°F), a black panel temperature of 53°C (128°F), and a relative humidity of 50 percent.

Because the weatherometer was not acquired until well into this project, samples of the asphalt placed for environmental exposure were not available for testing. New samples were prepared to the same formulations as the specimens previously prepared for environmental exposure.

The sample mold was formed by attaching a 157-mm-diameter (6.25-in) by 6-mm (0.25-in) ring to a flat glass plate with epoxy cement. Special holders were prepared to hold the sample mold on the revolving specimen rack in the weatherometer. The sample molds could then be placed in the weatherometer in a vertical position facing the 6000-W xenon arc.

Asphalt films were formed in the molds by dissolving 1.000 ± 0.001 g (28 ± 0.003 oz) of asphalt in approximately 40 cm^3 (2.4 in^3) of reagent-grade benzene and pouring the solution into the sample mold. The evaporation of the benzene left a translucent asphalt film of approximately 50-μm thickness. If the film was not evenly cast in the mold, additional benzene was added to the mold to redissolve and recast the film (Figure 4).

After exposure in the weatherometer, the asphalt film was removed by scraping the mold with a square-ended spatula. Two scrapings, approximately 12 mm (0.5 in) wide, were made at 90 deg apart across the center of the mold to secure a representative sample of the exposed film for microviscosity determination. The remainder of the film was removed and analyzed by a modified Rostler analysis.

Figure 4 shows three of the specimens from sample 2C (number 2 in the rankings) and three from sample 10A (number 50 in the rankings). Exposure times are 25, 50, and 100 hours. The severity of the channeling is usually an indication of the aging taking place in the asphalt film. Photographs were made by transmitted light.

Microviscosities of the aged asphalts were determined and related to the microviscosity of the original asphalt by calculating a viscosity ratio (aged microviscosity/original microviscosity). The viscosity ratio after 100 hours' exposure was found to correlate best with the 3-year viscosity ratio. This relationship is shown in

Figure 4. Various exposures in weatherometer.

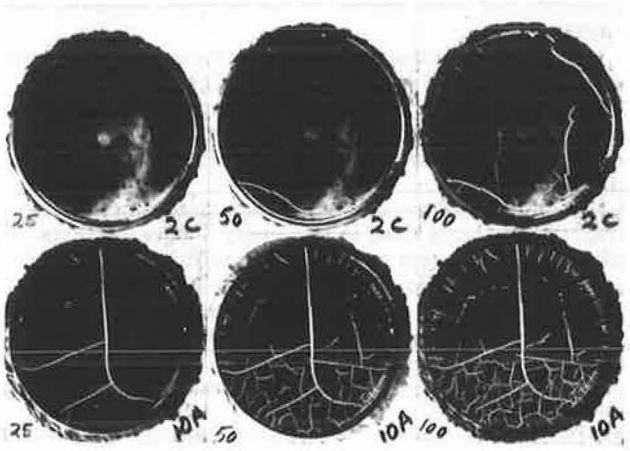


Figure 5. Weatherometer as an indicator of asphalt durability.

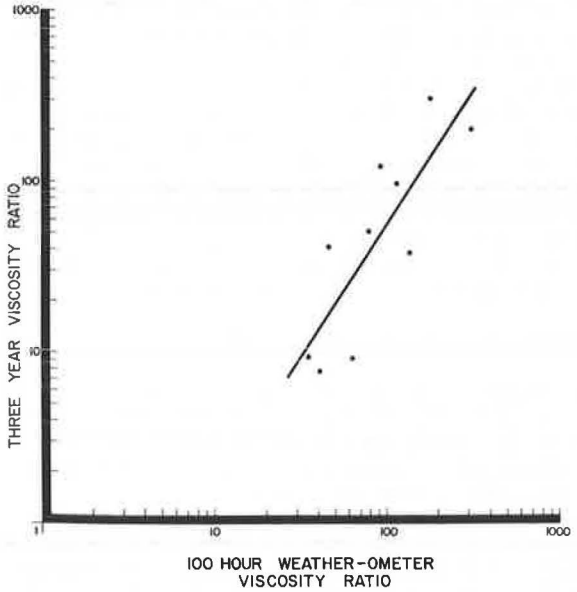


Table 4. Ranking and composition of blends.

Environment Exposure Rank	Sample	Composition	RTFO, 75 Min	Original N/P	Vanadium	Original CRR	Average Rank
1	2C	Cin 85-100	9	6	3	9	2
2	22B	Cin 85-100 + 5% A(G)	7	12	6	16	10
3	21B	Cin 85-100 + 5% A(G)	7	12	3	16	6
4	15C	Cin 85-100 + 5% A	3	7	13	9	3
5	17C	Cin 85-100 + 6.9% A(G)	10	18	3	16	13
6	16B	Cin 85-100 + 5% A(G) + 1% AS	4	12	1	16	4
7	16C	Cin 85-100 + 5% A	12	7	10	9	6
8	17D-1	Cin 85-100 + 6.9% A(G) + 1% AS	1	18	6	16	10
9	21A	Cin 85-100 + 5% A(G) + 1% AS	5	12	1	16	5
10	17D-2	Cin 85-100 + 6.9% A(G) + 1% AS	1	2	6	16	1
11	8CX	Cin 85-100 + 100% LA 40-50	30	25	14	27	21
12	7C	Cin 85-100 + 7% A	14	7	15	14	14
13	16D	Cin 85-100 + 5% A + 1% AS	11	7	11	9	6
14	8CY	Cin 85-100 + 33% LA 40-50	16	21	16	24	16
15	6C	Cin 85-100 + 12.5% A	31	26	18	48	30
16	15D	Cin 85-100 + 5% A + 1% AS	18	7	12	9	12
17	8CZ	Cin 85-100 + 50% LA 40-50	18	24	17	26	17
18	16A	Cin 85-100 + 5% A(G)	6	12	6	16	9
19	11SS	Idaho 120-150	43	3	45	1	19
20	13SSB	Idaho 120-150 + 6.7% A	39	4	53	2	22
21	9A	LA 40-50	24	45	22	42	37
22	12SSA	Idaho 120-150 + 6.4% A + 15% N	20	44	51	5	28
23	11SSN	Idaho 120-150 + 15% N	41	40	38	6	32
24	12SSB	Idaho 120-150 + 3.3% A + 15.5% N	40	41	43	4	33
25	19C	LA 85-100 + 1% AS	22	29	32	50	37
26	15B	LA 40-50 + 33% Cin 85-100 + 1% AS	13	37	27	33	26
27	9C	LA 40-50 + 50% Cin 85-100	15	32	21	38	23
28	19B	LA 85-100	24	29	35	50	41
29	18B-2	LA 40-50 + 10% D	46	20	39	28	37
30	5A	LA 85-100 + 20% A_2	27	17	23	7	15
31	22E	LA 85-100	24	29	32	50	40
32	6R	LA 85-100 + 30% R	35	26	20	48	35
33	11SSY	Idaho 120-150 + 23% N	32	53	31	14	36
34	10B	LA 40-50 + 6.2% A_2	45	33	36	38	42
35	23B	LA 40-50 + 43% Cin 85-100	28	34	24	28	27
36	15A	LA 40-50 + 33% Cin 85-100	28	37	26	33	31
37	7C-1	LA 85-100 + 100% Cin 85-100	21	23	19	28	18
38	24B	LA 40-50 + 12% A(G) + 23% R	42	51	30	40	45
39	14A	LA 85-100 + 6.5% A	44	28	44	50	46
40	22C	LA 40-50	36	45	50	42	52
41	19A	LA 40-50 + 1% AS	23	45	48	42	43
42	23A	LA 40-50 + 43% Cin 85-100 + 1% AS	34	34	25	28	29
43	2P	LA 85-100 + 10% P	53	1	28	25	24
44	19D	LA 40-50	36	45	47	42	51
45	9AX	LA 40-50 + 33% Cin 85-100	17	39	39	33	34
46	24A	LA 40-50 + 20% R	51	43	36	36	47
47	3A	LA 85-100 + 6.5% A + 35% A_2	52	5	34	3	20
48	18C	LA 40-50 + 1% AS	33	45	48	42	48
49	18A	LA 40-50 + 10% R	46	51	42	40	53
50	10A	LA 40-50 + 9.6% (A_2+P)	49	22	29	8	25
51	22F	LA 40-50 + 1% AS	36	45	46	42	49
52	18D	LA 40-50 + 10% R + 10% D	50	42	41	36	50
53	18B-1	LA 40-50 + 10% D	46	36	52	28	44

Figure 5. The 10 asphalts represented are not sufficient for a statistically satisfactory curve; however, a definite correlation can be seen.

Weatherometer testing of asphalts appears to provide an indication of how an asphalt will behave after exposure to the outdoor environment. The close matching of sunlight and temperature between the two environments could possibly provide a better correlation with outdoor exposure than is currently possible if sufficient data could be accumulated to determine correlation constants.

RANKING SUMMARY AND EQUATIONS

A summary of the ranking methods is given in Table 4. The asphalt blends are ranked in order of their overall 3-year outdoor exposure ranking. The other ranking methods discussed are given in this table for direct comparison of the various ranking parameters. The symbols used in this table are as follows:

Cin = Ciniza base asphalt (Four Corners),
LA = Los Angeles basin asphalt,
Idaho = Idaho base asphalt (American oil),
A(G) = asphaltenes from Gilsonite,
R = reclamite resin,
D = Dutrex resin, and
AS = antistripping agent.

Comparison of the various ranking methods shows that many times the rankings given an asphalt disagree. But it is interesting that, although the individual rankings may vary, the average of the rankings is quite close to the 3-year overall rank. Individual ranking methods may have inconsistencies inherent in them, or the asphalt properties may be too complex for such a simple ranking method, but the average of the individual methods seems quite consistent.

Table 5 gives the equations for the curves of the various parameters presented. The curves were prepared by calculating various forms of the available data by linear regression analysis to determine which form of the data yielded the best coefficient of correlation (linear, semilog, or log-log). The regression line was then calculated, and the data were plotted. Because of the nature of these parameters and the complex characteristics of asphalts, a great deal of precision cannot be expected from these equations. However, they may be helpful as guides when asphalts are compared to determine their approximate aging rates.

Just as the average of several ranking methods will often agree with the 3-year overall ranking more closely than any of the individual rankings, so also the final equation may help bring the calculated viscosity ratio into closer agreement with the 3-year viscosity ratio. This equation was derived by multiple linear regression analysis, and, when applied to the asphalts from phases B and C, it appears quite good. The equation involves two parameters, both of which are derived from chemical analysis. While the correlation lessens when phase A samples are included, the same two parameters are involved. The coefficient of correlation for vanadium content remains the best single parameter.

These relationships are derived from data pertaining to the asphalt sources used in this study. They may or may not apply to other asphalts from other sources.

CONCLUSIONS

1. The blending of asphalt or the addition of selected components can affect durability, as indicated by comparison of Tables 3 and 4.
2. Because the average rankings of the four parameters considered (Table 4) agree more favorably with the environmental exposure rankings than any single parameter, a combination of parameters should be used to predict asphalt durability.
3. The combination of parameters that produced the best durability prediction was vanadium content and chemical reactivity ratio (CRR). This relationship is expressed as

$$\text{Log viscosity ratio} = 0.48 + 0.0049 + 0.56\ \text{CRR}$$

4. If compositional considerations are such that any asphalt imbalance or high volatility is a minimal factor, the vanadium content offers the best single parameter for predicting asphalt durability.

This study attempted to produce a laboratory technique for predicting durability or viscosity increases. It indicated that means are available for reasonably predicting these increases. The necessary work ahead requires the development of limiting values that are desired. The prediction of asphalt durability for 3 years of exposure or any other time element must be equated to actual in-service values and future design for asphalt quality based on a time-related acceptance value.

Although limited data were available regarding the weatherometer studies in this report, we are encouraged that it may also offer a satisfactory testing technique for durability prediction. Responses from the weatherometer closely parallel responses from the other techniques, but additional studies are warranted.

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Table 5. Statistical analysis of data.

Phase	Parameter	Equation	R-Value
B and C[a]	Vanadium	Log viscosity ratio = 0.0053 (V) + 1.07	0.85
	RTFO	Log viscosity ratio = 1.25 (log 75 min) + 0.26	0.78
	N/P	Log viscosity ratio = 0.71 (N/P) - 0.38	0.75
	CRR	Log viscosity ratio = 1.43 (CRR) - 0.13	0.60
	WO samples (7)	Log viscosity ratio = 0.0075 (WO) + 0.83	0.67
A, B, and C[b]	Vanadium	Log viscosity ratio = 0.00593 (V) + 1.106	0.75
	RTFO	Log viscosity ratio = 1.338 (log 75 min) + 0.207	0.84
	N/P	Log viscosity ratio = 0.372 (N/P) + 0.657	0.38
	CRR	Log viscosity ratio = 0.804 (CRR) + 0.760	0.28
	WO samples (10)	Log viscosity ratio = 1.549 (log WO) - 1.349	0.82

Note: The best relationship was log viscosity ratio = 0.48 + 0.0049 (V) + 0.56 (CRR) for $R^2 = 0.87$ and F = 98.5.
[a]37 samples. [b]53 samples.

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