PAVING ASPHALT PROPERTIES

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This investigation of changes in asphalt contained in asphaltic mixes was undertaken to gain an understanding of the factors affecting the durability of asphalt pavements. Pavements were constructed to determine penetration-absolute viscosity relationships for the different asphalts used. Six different asphalts were used, varying in penetration and absolute viscosity. Three pavements were constructed by using the same 6 asphalts, but each was constructed with different aggregate types. Investigations were confined to the wearing course. The test pavements were asphaltic concrete overlays on portland cement concrete. Field data were accumulated during construction and periodically after construction. Penetration, absolute viscosity, and asphaltene determinations were made. Results from these projects indicate that a low-viscosity asphalt (90 to 100 penetration and 900 ± 200 poise viscosity) is performing as well as or better than the other asphalts. This is based on a rating system, devised by the authors, relating physical and chemical changes with air void changes with time.

•AN ASPHALT pavement is a system of layered viscoelastic solids. The layers that contain asphalt form 3-phase systems that consist of aggregates of various shapes and sizes, an asphalt film that binds the stones together, and air voids. As asphalt is but a minor component of a pavement (about 6 percent by weight), its contribution to the durability of the pavement is difficult to assess (1). Although much care has been exercised in the construction of asphalt pavements in the past, experience with some bituminous roadways in Pennsylvania indicates a deterioration of the roadways as manifested by cracking, raveling, bleeding, and abrasion losses. These deteriorating properties have been known to occur in asphalt pavements irrespective of the age of the pavement. It is thought that deterioration occurs because of the hardening or increasing brittleness that generally accompanies the in-service life of an asphalt pavement (2, 3, 4, 5). Hardening of an asphalt pavement is confined to the asphalt. Any investigation of the hardening of an asphalt mix should concentrate, therefore, on the changing properties of the asphalt. Under the sponsorship and with the cooperation of the Federal Highway Administration and the Pennsylvania Department of Transportation, the Civil Engineering Laboratories of the Pennsylvania State University have undertaken an investigation of the physical and chemical properties of asphaltic concrete material of in-service projects.

OBJECTIVES

The principal aim of this investigation is to study the physical and chemical changes of the asphalt and asphaltic concrete mixture with passage of time. In particular, the asphalt in these pavements will be tested for the purpose of arriving at relationships of penetration to absolute viscosity. Three pavements were constructed in order to determine whether penetration specifications for asphalt should be complemented by absolute viscosity specifications. The penetration-absolute viscosity relationship of the various asphalts used are being investigated for its influence on pavement durability.

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TEST PROJECTS

Each test pavement was constructed by using 6 different asphalt cements. The same 6 asphalts were used on each pavement. Within each test pavement, the same aggregate source and aggregate gradation was used. Different aggregate sources and aggregate gradations were used among test pavements, as follows:

County	Route	Aggregate
Clinton	LR 219	ID-2 crushed limestone
McKean	LR 101	ID-2 sand and gravel mixture
Jefferson	LR 338	FJ-1 sand mixture

These gradations are given in Table 1. The Clinton County project is in the central portion of Pennsylvania on US-220; the Jefferson County project is in the west-central portion on US-119; and the McKean County project is in the north-central portion on US-6.

The initial consistency properties of the asphalts evaluated in this study are given in Table 2. Some were typical road materials used in Pennsylvania and others were specially prepared for use in the study. The specification values are given along with the values obtained from tests performed on samples obtained at the paving contractor's plant. Other initial data, including construction data and time data, have been presented by the researchers and are available in the literature (6).

TESTING PROCEDURES

The sampling and construction procedures were formulated for each project in advance of field construction of each roadway. A complete discussion of these procedures was reported in 1967 (7). The testing procedures for an asphalt cement adopted for this investigation included: penetration, ASTM Designation D 5-65, and absolute viscosity, ASTM Designation D2171-63T.

Past studies (8, 9, 10) indicate a relationship between chemical composition and asphalt durability. Chemical analyses were performed by using a procedure described in earlier literature (11). The work of Rostler and White (8) defines asphalts as consisting of 5 basic constituents: asphaltenes, nitrogen bases, first acidaffins, second acidaffins, and saturated hydrocarbons. By precipitation, this method isolates these 5 constituents, the values of which are determined by differential weighing and then reported as percentages of the total sample weight. The initial values of the chemical composition are given in Table 3.

Specific gravity determinations, using Pennsylvania Department of Transportation specifications, were made on the mix samples by the department's laboratory to ascertain degrees of compaction at construction and during service life.

Asphalt cement samples were obtained from mix and field core specimens by the Immerex (immersion-reflux) method of extraction and the Abson method of recovery, ASTM Designation D1856-65. Benzene was used as the solvent to minimize any chemical reaction between solvent and asphalt during the contact time of the recovery process.

TABLE 1

TYPICAL GRADATIONS USED ON EACH PROJECT

Sieve	Percent Passing		
	Route LR 219	Route LR 101	Route LR 338
½ in.	100.0	100.0	100.0
⅜ in.	96.2	91.5	100.0
No. 4	65.6	67.7	98.0
No. 8	46.9	45.0	75.0
No. 16	34.3	32.9	53.0
No. 30	24.7	24.1	43.0
No. 50	13.6	12.3	32.0
No. 100	7.6	7.1	14.0
No. 200	5.3	3.6	6.0

RESULTS

The specific test values of penetration, absolute viscosity, and percentage of asphaltenes for each asphalt used on each test pavement have been presented elsewhere (6, 7, 12, 13). In order to look at asphalt hardening relative to all other asphalts, the authors believe a clearer picture of what has occurred is best accom-

TABLE 2

ASPHALT CEMENT SPECIFICATIONS

Asphalt	Route	Penetration at 77 F[a]	Viscosity at 140 F[b]	Reported Penetration at 77 F[a]	Reported Viscosity at 140 F[b]
I	LR 219	50 to 75	1,500 ± 200	59	1,732
	LR 101			59	1,895
	LR 338			67	1,782
II	LR 219	90 to 100	1,500 ± 200	89	1,548
	LR 101			91	1,472
	LR 338			86	1,630
III	LR 219	140 to 160	1,500 ± 200	146	1,440
	LR 101			130	1,701
	LR 338			136	1,526
IV	LR 219	90 to 100	900 ± 200	110	949
	LR 101			84	1,090
	LR 338			87	1,047
V	LR 219	90 to 100	3,000 ± 200	94	2,136
	LR 101			85	2,970
	LR 338			84	3,159
VI	LR 219	70 to 85	3,000 ± 200	77	2,951
	LR 101			74	3,124
	LR 338			74	3,092

[a] 1/10 mm at 100 gm, 5 sec. [b] Poises at 30 cm Hg vacuum.

plished through graphical presentations. Consequently, graphs are used in place of tabulated data wherever possible. All figures involving changes in penetration with time, viscosity with time, and so on are drawn by using the first sample that initiated an annual pattern of sampling on the particular test pavement. In the use of such samples, only the asphalt hardening that occurred from construction on is reflected in the figures. The penetration, viscosity, and asphaltene content of these samples were used as the base (authors now call these the original values) for determining percentage retained penetration, percentage of original viscosity, and percentage of original asphaltenes.

TABLE 3

ASPHALT COMPOSITIONS BEFORE MIXING

Asphalt	Route	Component[a] (percent)					Rostler Coefficient
		A	N	A_1	A_2	SH	
I	LR 219	20.9	22.5	16.0	29.0	11.6	0.95
	LR 101	17.2	23.1	15.3	28.0	16.4	0.87
	LR 338	19.0	23.1	16.8	29.5	11.7	0.97
II	LR 219	19.2	23.2	13.3	30.5	13.8	0.82
	LR 101	20.8	22.8	15.2	26.6	14.6	0.92
	LR 338	22.3	20.9	16.0	28.6	12.1	0.91
III	LR 219	26.8	15.9	14.7	30.9	11.8	0.72
	LR 101	29.6	14.5	16.8	25.2	14.0	0.80
	LR 338	27.8	19.0	17.4	27.3	9.4	0.99
IV	LR 219	19.5	18.9	13.7	33.7	14.3	0.68
	LR 101	15.2	25.6	16.8	28.4	14.0	1.00
	LR 338	16.8	23.0	15.6	31.5	13.1	0.87
V	LR 219	28.2	20.6	18.0	24.3	8.7	1.17
	LR 101	29.6	15.0	16.6	25.4	13.4	0.81
	LR 338	29.5	17.0	17.8	25.8	9.9	0.98
VI	LR 219	28.2	22.6	17.7	23.5	8.0	1.25
	LR 101	29.6	20.6	18.8	19.4	11.6	1.27
	LR 338	28.2	22.9	21.5	21.0	6.5	1.61

[a] A = asphaltenes; N = nitrogen bases; A_1 = first acidaffins; A_2 = second acidaffins; and SH = saturated hydrocarbons.

The percentages of air voids that existed for each test pavement were (based on the average of the 6 asphalts) as follows: LR 219, 10.4; LR 101, 7.8; and LR 338, 12.1. Comparisons of these values show that LR 101, as a whole, was constructed at a lower level of air voids than LR 219 and LR 338; and LR 219, as a whole, was constructed at a lower level of air voids than LR 338. Influence of air voids will be discussed more fully in later paragraphs.

Penetration

Figure 1 shows the penetration-time relationship for LR 219, LR 101, and LR 338. The relative positions of the asphalts in LR 219 show little change with passage of time.

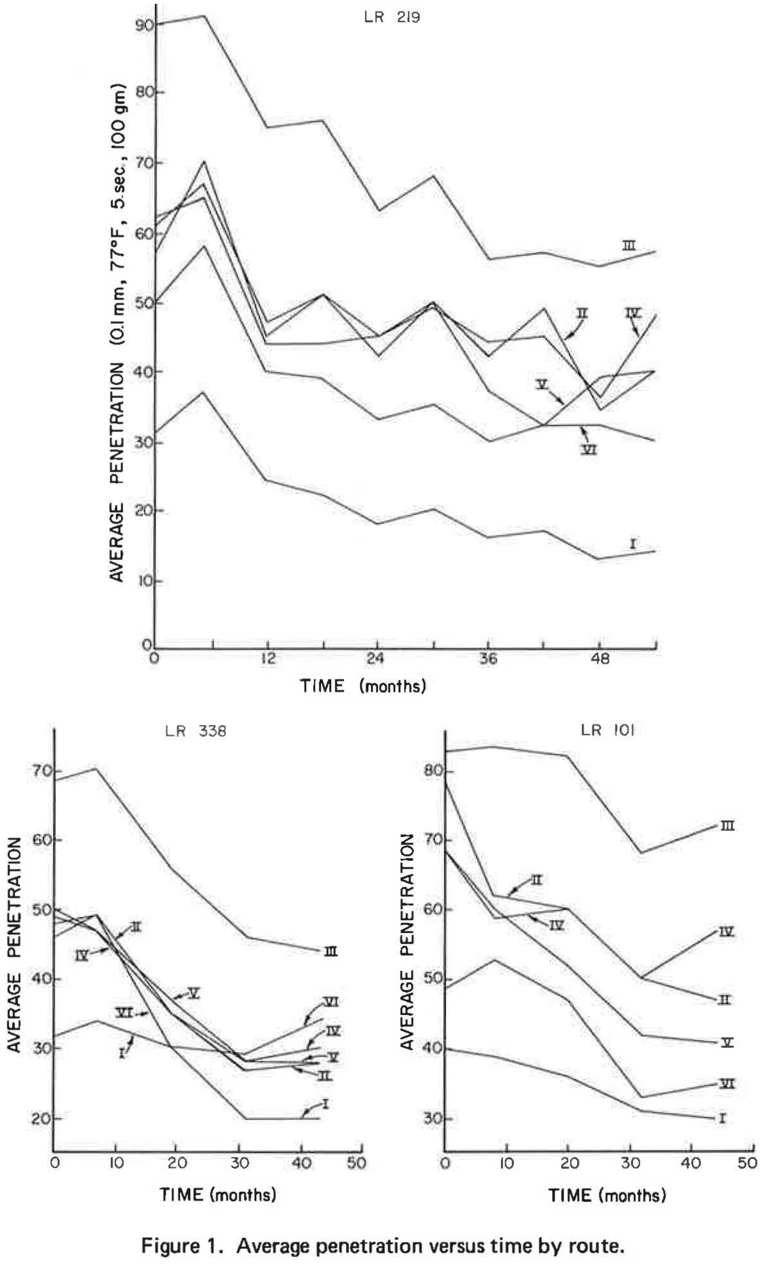

Figure 1. Average penetration versus time by route.

The penetration-time relationships for LR 101 and LR 338 do not exhibit the saw-toothed curves on a scale as grand as that of LR 219. The segments of the curves for LR 101 and LR 338 represent annual hardening whereas those for LR 219 represent biannual hardening.

Figure 2 shows the penetration-time relationships for the different asphalts. There are differences in levels of hardness of the asphalts among the pavements. It is not so

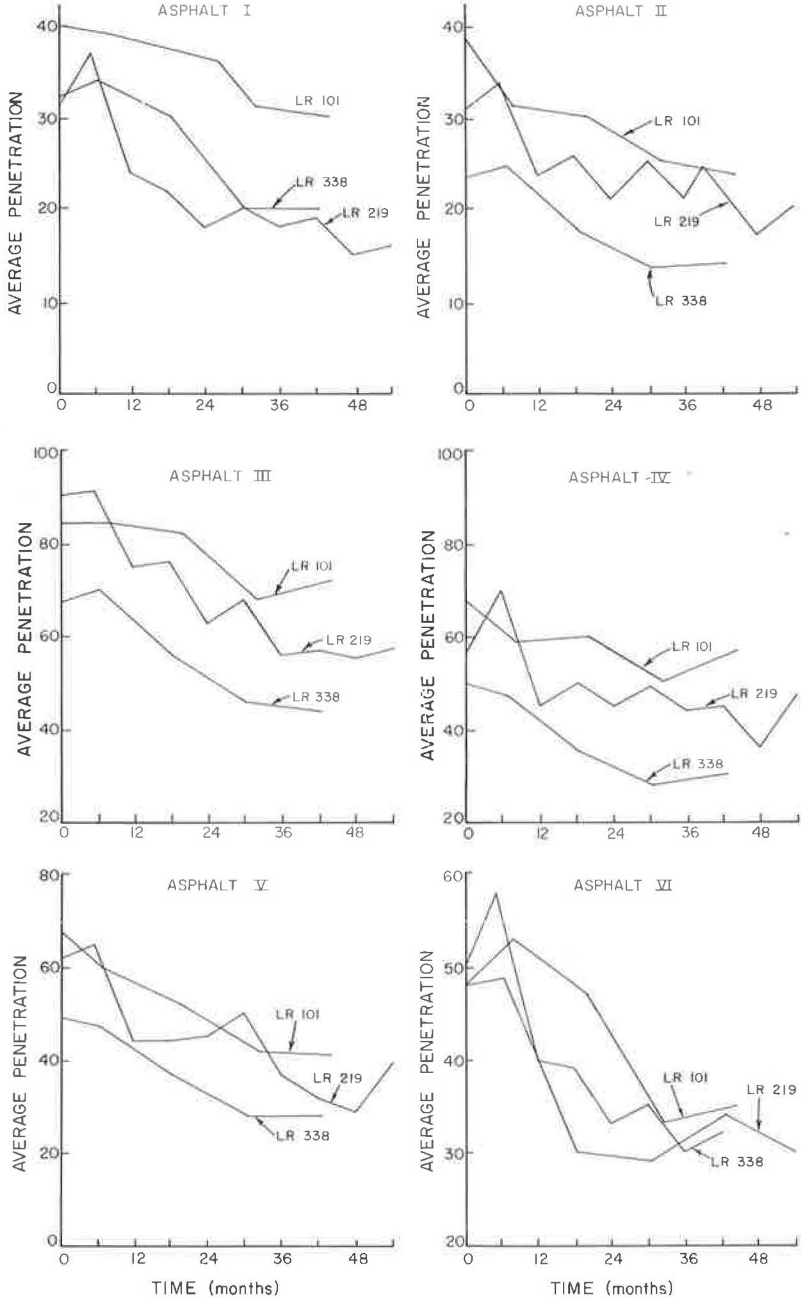

Figure 2. Average penetration versus time by asphalt.

readily observed whether there are differences in rates of hardening of the asphalts among pavements. Figure 3 is identical to Figure 2 (asphalt II) except for the manner in which penetration-time curves are drawn for LR 219. The dashed lines in Figure 3 show how the data for LR 219 are shown in Figures 1 and 2. The saw-toothed nature of the LR 219 curves in Figures 1 and 2 are believed to be explained in Figure 3 and is attributed to winter and summer environmental conditions. Additional discussion pertaining to this saw-tooth phenomenon is presented elsewhere (12). LR 219 has been sampled twice every year, and LR 101 and LR 338 have been sampled once a year. Therefore, data shown in Figure 3 for LR 219 were separated into 2 penetration-time curves: one based on spring-coring data and one based on fall-coring data. Each curve

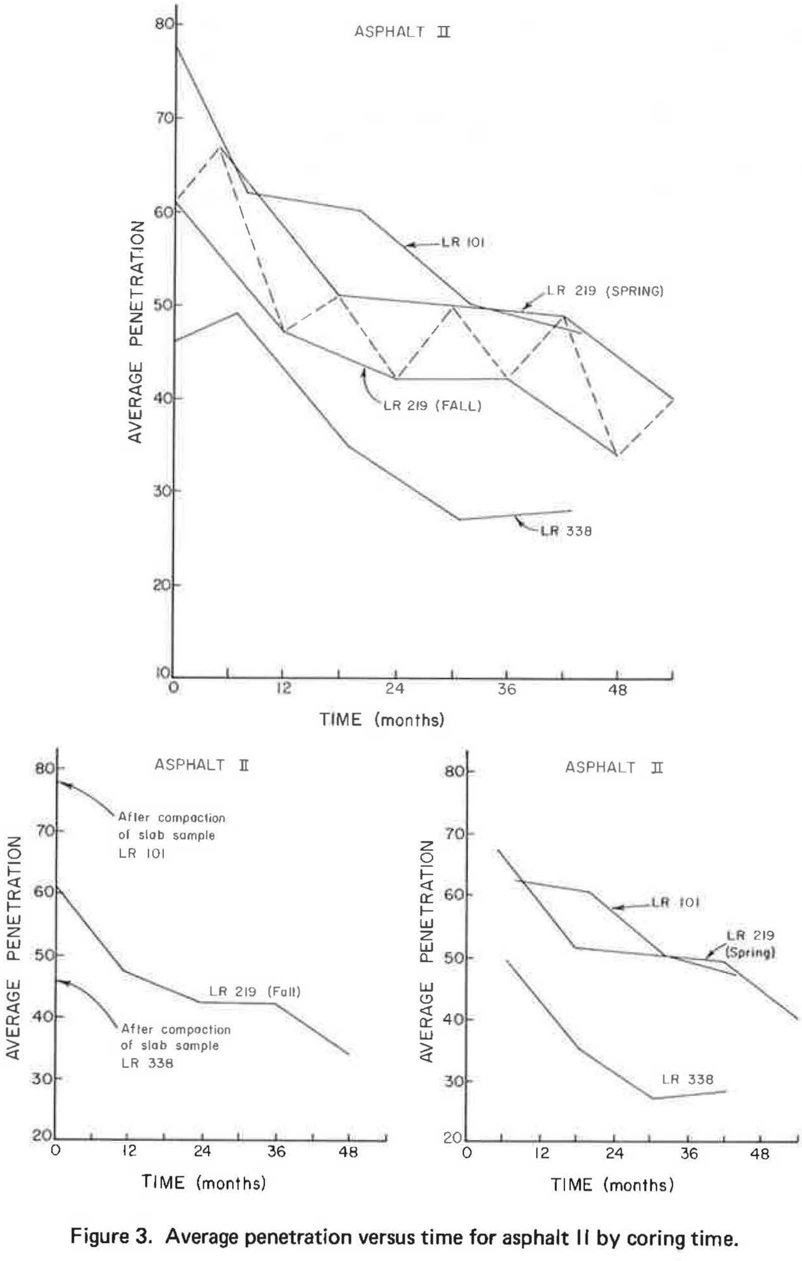

Figure 3. Average penetration versus time for asphalt II by coring time.

now represents annual sampling. It becomes apparent that consideration must be given to the time of the year that a test pavement is sampled. If, for example, LR 219 was sampled only in the fall, one would be led to believe that this pavement was hardening at some rate midway between LR 101 and LR 338. On the other hand, if LR 219 was sampled only in the spring, one would be led to believe that this pavement was hardening at some rate similar to LR 101.

Figure 3 also shows the data according to fall and spring sampling respectively. If a comparison of asphalt performance is to be made between the test pavements, it must be made from the spring sampling results. As a result, to put the 3 pavements on a direct comparison basis, the initial hardness of the pavement cannot be considered in the following analysis.

Figure 4 shows the percentage of retained (of original, as defined earlier) penetration values for the 4 years the pavements have been in existence. Asphalt performance may be compared within the pavements. Data for LR 219, fall coring, do not yield the same results as data for LR 219, spring coring. This is one of the most important findings of this investigation and was pointed out earlier (12). Asphalt IV has hardened to a lesser degree on the respective test pavements. Similarly, asphalt I for LR 219, asphalt VI for LR 101, and asphalt II for LR 338 have hardened to the greatest degree on their respective test pavements. When one asphalt shows a slower degree of hardening on one test pavement and a greater degree of hardening on another, one must

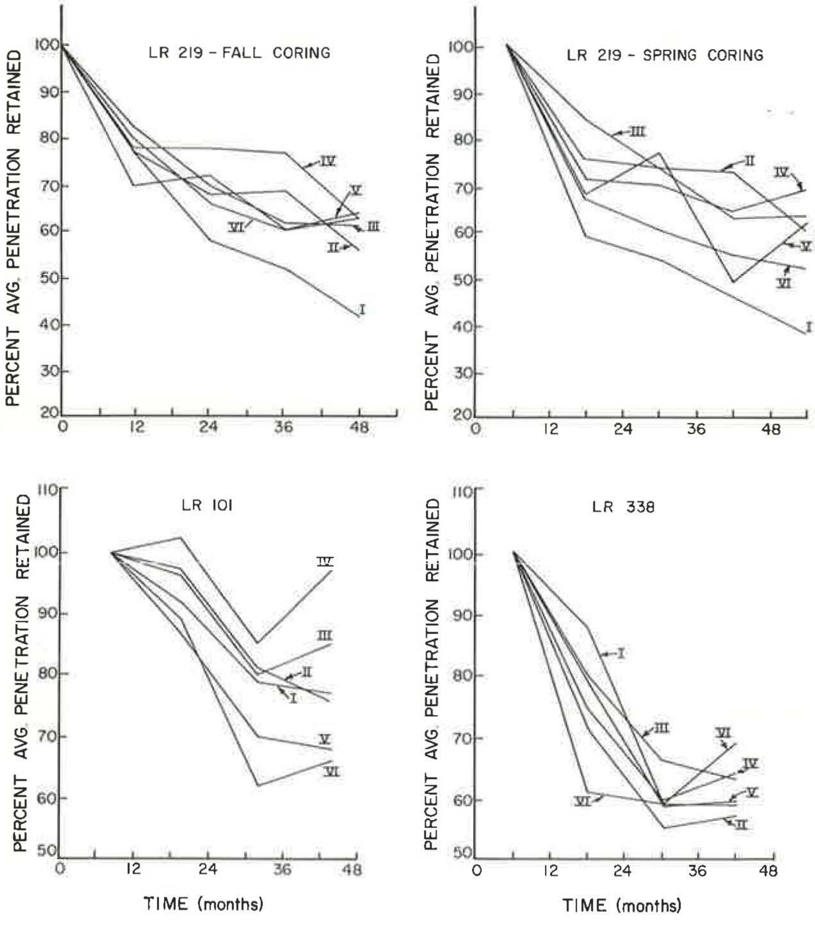

Figure 4. Average percentage of penetration retained versus time by route.

conclude that there must be one or more factors more important to asphalt hardening in a pavement than asphalt type.

Figure 5 shows more clearly the different manner in which the same asphalt is performing on the individual pavements. In 4 cases, the asphalts on LR 338 have hardened

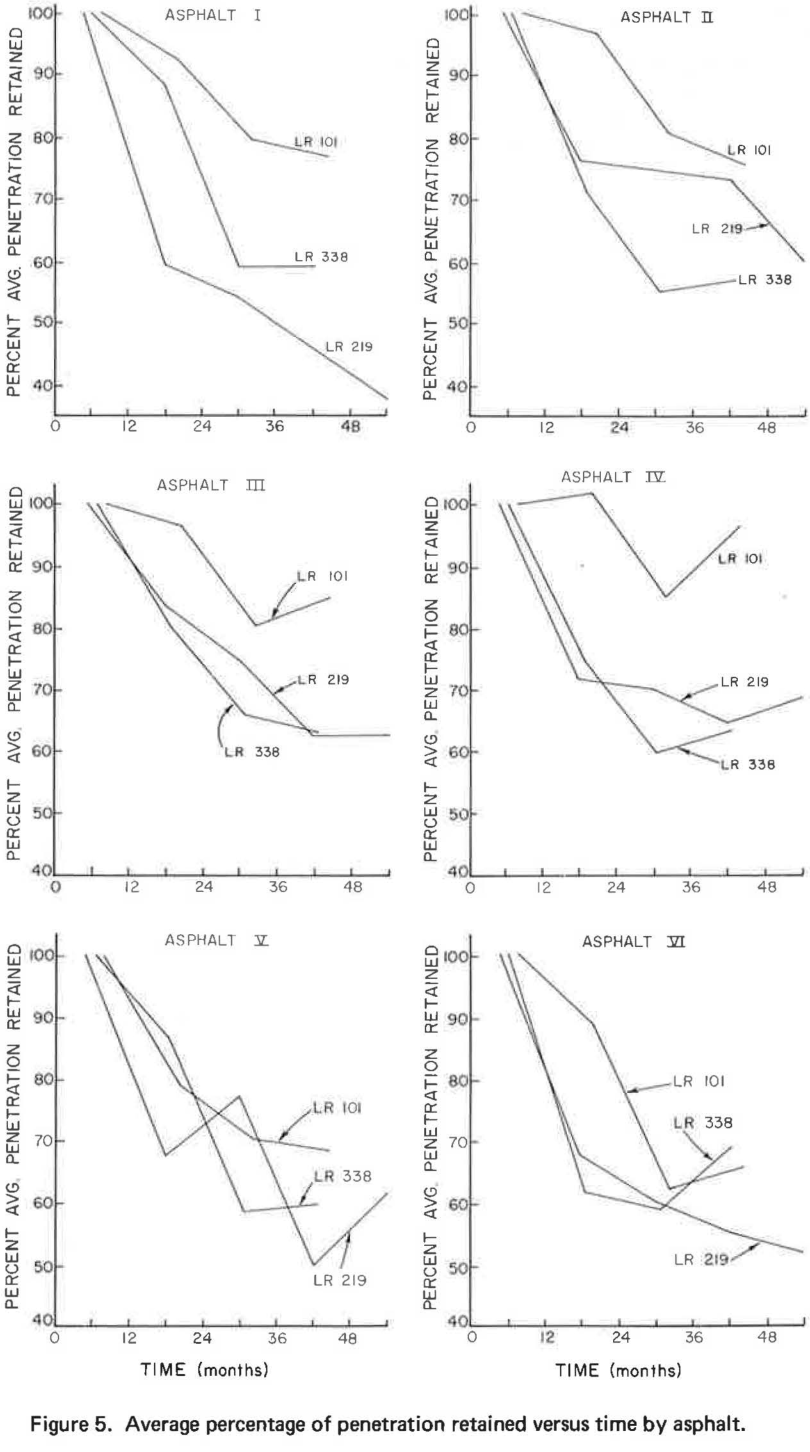

Figure 5. Average percentage of penetration retained versus time by asphalt.

to a greater extent in the same period of time than the asphalts on LR 219 and LR 101. Further, asphalts on LR 101 remain softer than those on the other 2 pavements. One obvious explanation for these differences is the differences in percentage of air voids among the pavements. As stated earlier, this subject will be discussed more fully in later paragraphs.

Absolute Viscosity

Figure 6 shows the absolute viscosity data for LR 219, LR 101, and LR 338. These curves and those in Figure 1 for the penetration results are presented in the same fashion. For observing asphalt hardening, it can be said that these viscosity-time relationships yield the same conclusions as those drawn for penetration-time relationships (7).

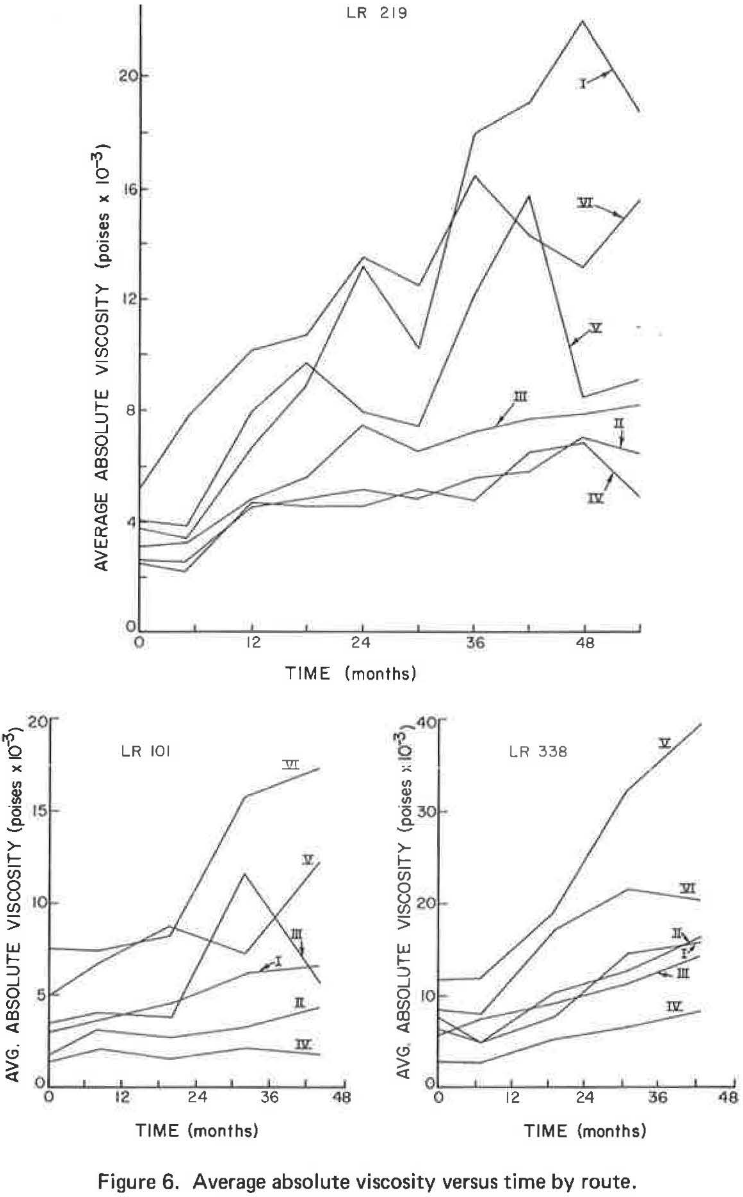

Figure 6. Average absolute viscosity versus time by route.

Data for LR 219 reveal the same saw-toothed trends as those shown on some of the previous penetration graphs. Figure 7 shows the percentage change of viscosity with time.

Chemical Composition

Figure 8 shows the continuing trends of asphaltene content with time. Asphalts I, II, and IV continue to show asphaltene contents lower than those of asphalts III, V, and VI. At the present time, it is still too early to determine what significance, if any, this may mean in terms of pavement durability. Figure 9 shows how the time of the pavement sampling can influence test results that may influence the durability comparison.

In the continuing studies of these 3 test pavements, it has been found that changes in the percentage of asphaltene fraction correlate with changes in penetration and absolute viscosity (7, 12). It has also been hypothesized (7, 12) that pavement variables such as air voids and permeability overshadow performance differences among asphalt cements. In essence, it may be summarized by the authors that a type A asphalt that differs in chemical composition from a type B asphalt should not be chosen over a type B asphalt but that both asphalts could be used in a highway pavement as long as air void specifications for the pavements were designed to compensate for the durability differences among asphalt cement types.

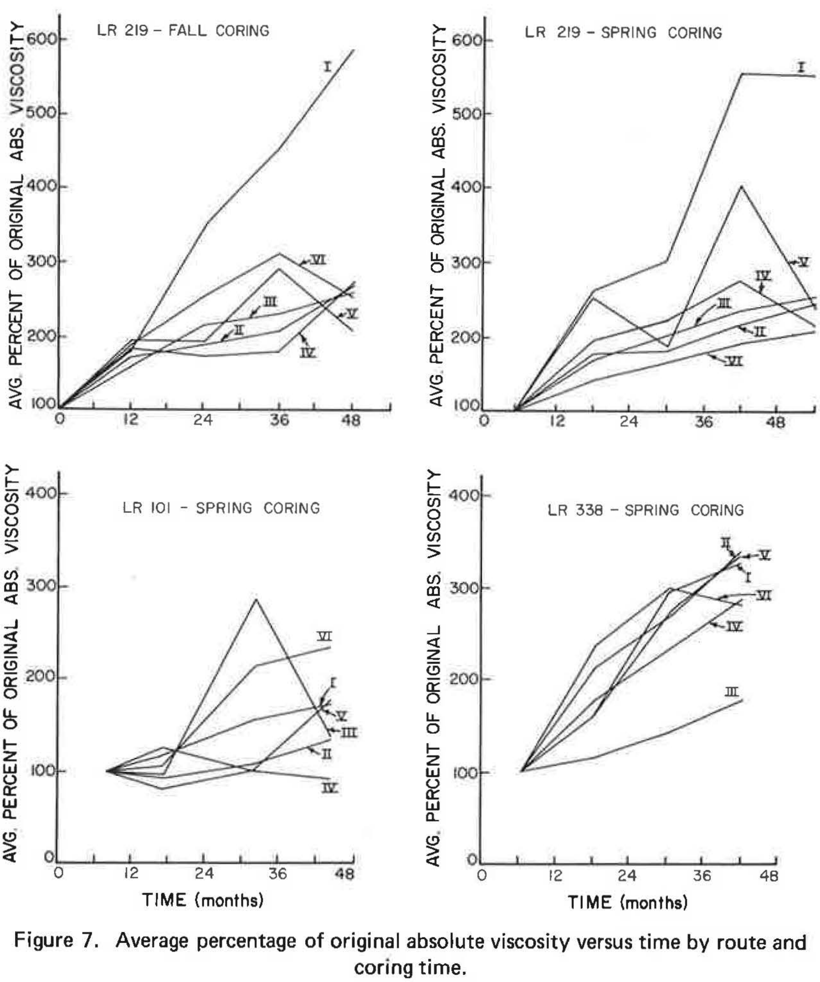

Figure 7. Average percentage of original absolute viscosity versus time by route and coring time.

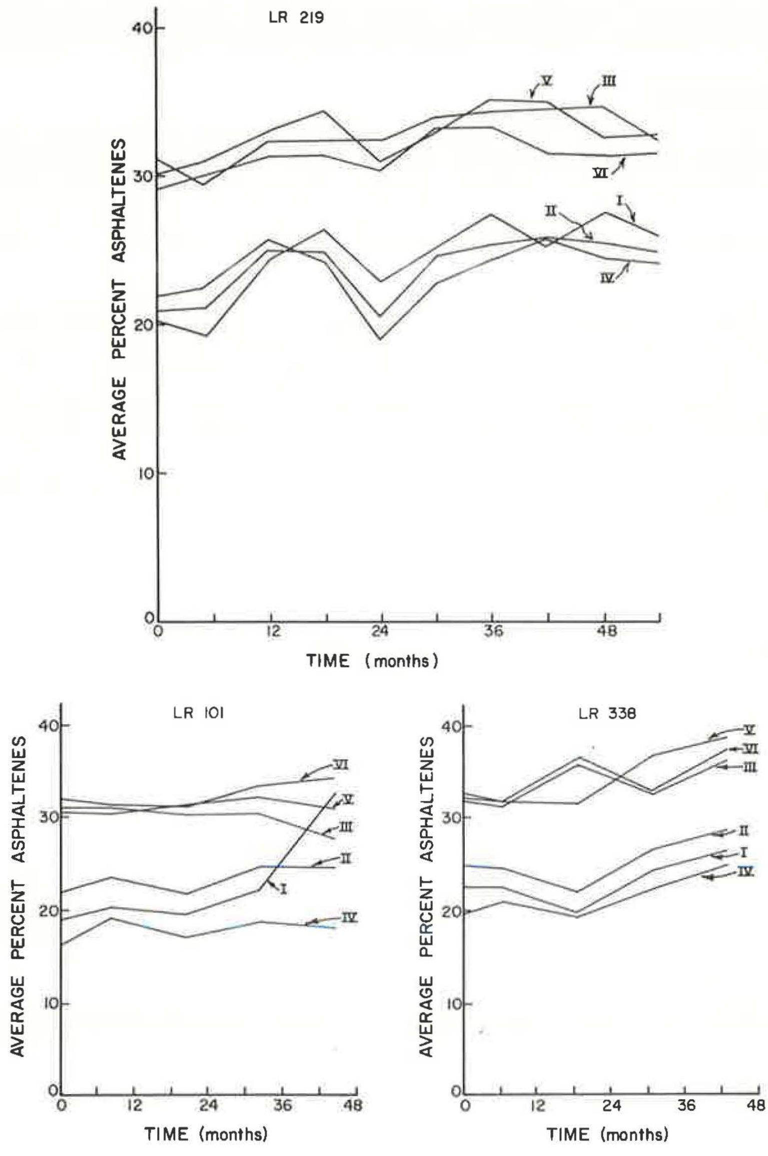

Figure 8. Average percentage of asphaltenes versus time by route.

Specific Gravities, Densities, and Air Voids

It has been suggested earlier in this report that air voids are one of the factors, if not the greatest factor, affecting the rate of hardening of an asphalt pavement. The influence of this variable appears to be so pronounced that it completely overshadows the performance of asphalt type and just about everything else.

Correlating asphalt cement performance with air voids is a very difficult task because of air void variability in an asphalt pavement. The following types of air void variability have been recognized in this research:

1. The inherent variability from point to point in a pavement due to varying degrees of aggregate interlock and asphalt content;

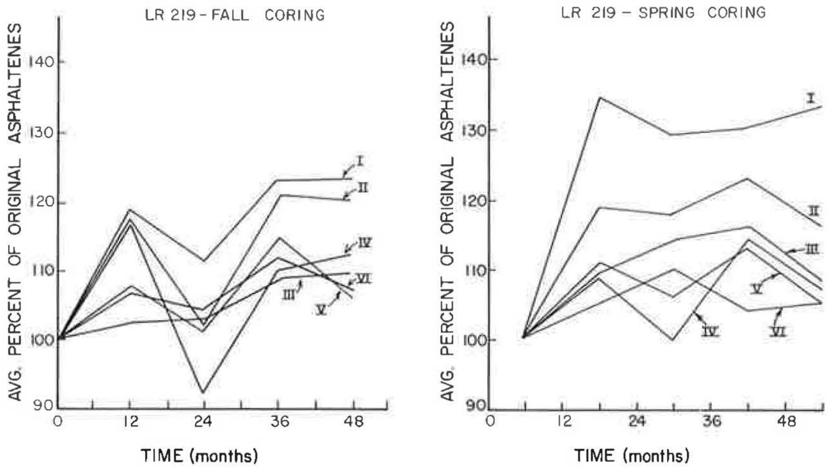

Figure 9. Average percentage of original asphaltenes versus time for LR 219 by coring time.

2. The gently sloping air void trends in the longitudinal direction of the pavement due to variability in gradation, asphalt content, mixing temperature, compaction temperature, and thickness of lift during the construction day;
3. The steeply sloped air void variability across the transverse direction of the pavement due to the decreasing lateral support of the mixture from the center of the traffic lane to its edges during compaction;
4. The air void variability among asphalt cement types on any one pavement due to differences in asphalt cement viscosity during compaction;
5. The air void variability among pavements due to gradation, aggregate type, and differences in degree of hardening in the pug mill;
6. The decrease in air voids with time due to traffic, particularly in the wheel or load zone of a pavement, and the variability in decreases in air voids among asphalt pavements due to differing traffic densities and the degree of initial compaction among pavements.

Figure 10 shows the changes in air voids with time for each asphalt on each pavement. As before, if any durability comparison is to be made between asphalt cement type and air voids, the air void values that must be used are those values that are obtained at the same sampling times each year.

Data given in Table 4 relate percentage of retained penetration and percentage of air voids. Because a comparison among pavements is as desired as a comparison within pavements, the results from the spring samplings must be used. Percentage of retained penetration is based on the first core sample for each pavement. The numbers given in Table 4 were obtained in the following manner (12): By considering only one test pavement and one sampling at a time, the asphalt that showed the highest percentage of retained penetration value was rated 1, the asphalt that showed the second highest percentage of retained penetration value was rated 2, and so on. The asphalt sample that had the lowest percentage of air voids was rated 1, the asphalt sample that had the second lowest percentage of air void value was rated 2, and so on. A tie between the air void and penetration columns means that the relative performance of that asphalt type compared to other asphalts used on the same pavement can be explained completely by the relative value of percentage of air voids for that sample. It should be mentioned that when the air void values among the asphalt mixtures are nearly equal, the asphalt cement type has a greater influence on the durability comparison. The number of ties and a number of instances where the ratings are very close support the strong influence of air voids on pavement durability.

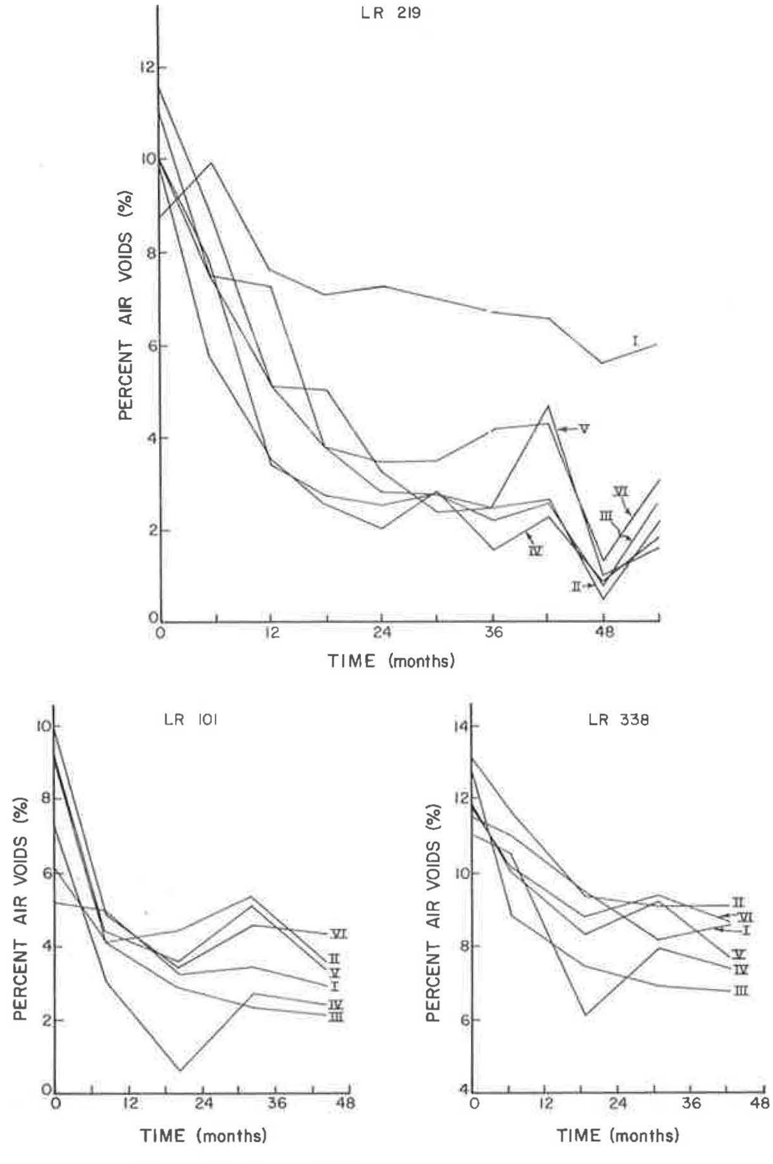

Figure 10. Percentage of air voids versus time by route.

TABLE 4

ASPHALT RATING SYSTEM

Asphalt	LR 219 42 Mo.	LR 219 54 Mo.	LR 101 44 Mo.	LR 338 43 Mo.	LR 219 42 Mo.	LR 219 54 Mo.	LR 101 44 Mo.	LR 338 43 Mo.
	Retained Penetration (percent)				Air Voids (percent)			
I	6	6	3	5	6	6	3	4
II	1	4	4	6	3	3	5	6
III	3	2	2	3	2	4	1	1
IV	2	1	1	2	1	2	2	2
V	5	3	5	4	5	1	4	3
VI	4	5	6	1	4	5	6	5
	Original Viscosity (percent)				Air Void-Time Curve Area			
I	6	6	4	4	6	6	3	5
II	2	4	2	6	3	3	6	6
III	3	5	3	1	2	2	2	1
IV	4	2	1	3	1	1	1	2
V	5	3	5	5	5	4	4	3
VI	1	1	6	2	4	5	5	4

The same analysis was performed by using percentage of original viscosity. The results are closely similar as would be expected because of the correlation that exists between penetration and viscosity (7).

In an attempt to consider the rate of decrease of air voids in a pavement, a slightly different approach can be used. The magnitude of the percentage of air void value is certainly important to the durability of an asphalt pavement, but probably the length of time that it remains at that value is just as important. In other words, will a pavement that remains at a constant level of, say, 4 percent air voids show a greater amount of hardening in some selected period of time than a pavement that had an initial void content of 9 percent air voids and was compacted to a level of 2 percent air voids? There can be no argument that a high initial void content is most detrimental to an asphalt pavement. Most asphalt hardening will occur in the first few years after construction. This hardening also tends to affect the rate of decrease of air voids due to traffic. Figure 11 shows the method employed to compensate for the rate of decrease in air voids with time in an asphalt pavement. Accumulative areas under the air void-time curve are computed for each point in time that a comparison is to be made (12).

Air void-time analysis was performed in a manner similar to that used for the other properties given in Table 4. The asphalt sections on each pavement with the lowest cumulative air void-time areas were rated 1 and so on. Approximately the same degree of success is achieved by this method of analysis as was achieved by simply using percentage of air void values. It would seem that this method of analysis is more logical than the preceding one.

One additional point must be mentioned. The asphalt sections with the lower air void values were constructed with the asphalts of lower initial absolute viscosities. This would mean that more desirable air void values could be achieved during construction of an asphalt pavement by simply using lower viscosity asphalts for identical construction operations used for higher viscosity asphalts. This conclusion has also been drawn by McLeod (14) who presented the advantages of well-designed mixes containing low-viscosity asphalt cements. A close examination of Table 4 indicates that asphalt IV seems superior. Asphalt IV is a 90 to 100 penetration, 900 ± 200 poise viscosity, and a low asphaltene content material.

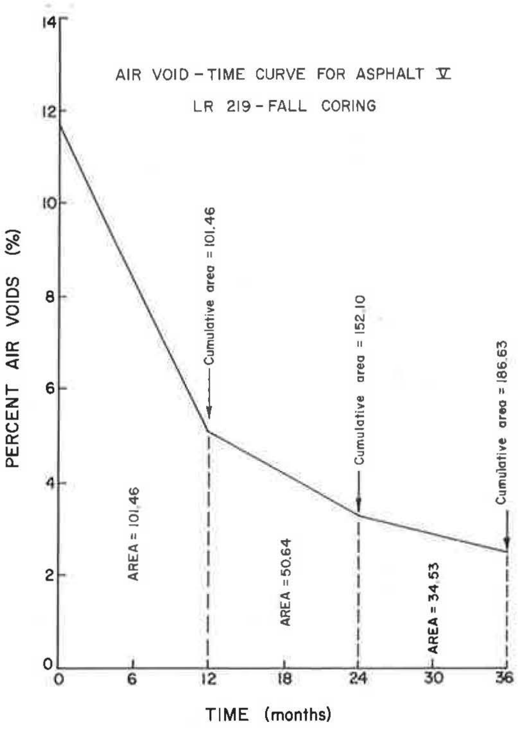

Figure 11. Air void versus time for asphalt V on LR 219, fall coring.

The decrease of percentage of air voids with time in the wheel or load zone of a pavement by traffic has further implications. Several photographs included in previous reports (12) showed that this compaction of the pavement has completely altered the drainage of water from the pavement to the shoulder. On practically every one of the asphalt pavements being investigated in this study, depressions exist in the wheel zone to the extent that water uses them as drainage ditches. One of the solutions to this problem is to construct asphalt pavements at lower percentage of air voids. Not only pavement safety but also pavement longevity will be increased.

FIELD OBSERVATIONS

During the spring and fall coring operations, a visual inspection was made on each of the 3 pavements. The most important observation made was that differences in performance among pavements are more noticeable than differences in performance among the different asphalts on the same pavement. Some texture and color differences among asphalts on the same pavement are observable.

The LR 219 pavement, after 54 months of service, continues to show some transverse cracking in all the asphalt sections. The road surface is good, with the asphalt I section being the roughest. It should be recalled that asphalt I has the highest percentage of air voids of all the sections and is hardening at a greater rate than the other sections. Severe edge-cracking as a result of poor shoulders and narrow traffic lanes has been shown photographically in another report (12).

The LR 101 pavement, after 44 months of service, shows some transverse cracking, some longitudinal cracking, and a high aggregate loss in some sections. The poorest conditions appear to exist on the section constructed with asphalt I. This pavement is located in the northern portion of Pennsylvania in an area where there is a high water table. With freezing temperatures, it is most probable that this pavement has been subjected to differential movement. This could be an explanation for the surface cracks that have developed.

The LR 338 pavement, after 43 months of service, continues to exhibit transverse reflection cracking and centerline cracking in all asphalt sections.

SUMMARY

It is still comparatively early to evaluate the quality and aging characteristics of the asphalts used in these experimental pavements. However, a very basic rating system indicates that asphalt IV (90 to 100 penetration and 900 ± 200 poise viscosity) is as good as or better than any of the other asphalts. This statement will be validated if the test projects are studied until final deterioration occurs or until portions of the pavements are reclaimed, reconstituted, or resurfaced.

From the data presented, the following conclusions can be made:

1. In general, all the asphalts are hardening with time based on physical test data and percentage of asphaltenes.
2. The time of year when a pavement is sampled is a factor influencing test results among test pavements and within test pavements. All test pavements should be sampled at the same time each year on an annual basis.
3. The major contribution to asphalt hardening appears to occur in the warmer months of the year. An additional 5 to 6 months of pavement life may be realized if the pavement is built in the fall rather than in the spring. This would allow some pavement compaction to occur prior to the time the agents of asphalt hardening become active.
4. The concept of percentage of retained penetration and percentage of original viscosity used in analyzing data may be a better indicator of the relative merits of the 6 test asphalts.
5. The air void volume of an asphalt pavement is a major factor influencing pavement durability and the safety of those using the pavement. Development of a rating system based on air void changes and asphalt property changes with time shows promise in evaluating the 6 text asphalts.

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