ASPHALT CEMENT CONSISTENCY STUDY

Field Evaluation of Viscosity - and Penetration-Graded Asphalt Cements

FINAL REPORT

by

S. C. SHAH

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First and foremost the author wishes to acknowledge the cooperation and effort provided by the Asphalt Institute in conducting the various tests on asphalt cements, and the Asphalt Producers in providing the specified experimental asphalts. The help and guidance of some of the principal investigators, who during the course of this study were involved in some facet of the study, is likewise appreciated and acknowledged. Special thanks are due the bituminous research unit of the Research and Development Section for field and laboratory data collection.

IMPLEMENTATION

The study provides valuable input with respect to the aging characteristics of viscosity-graded and penetration-graded asphalt. The findings reported here will serve as guidelines for future revision of viscosity-grade specifications for asphalt cements. However, the major finding from this study addresses to the comparison of durability and performance of pavements constructed with softer versus harder grades of asphalt cements. The Department now has a data base to affect decisions on the use of the softer grade asphalts wherever and whenever traffic conditions warrant their use.

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1. INTRODUCTION

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 of viscosity with 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 and also 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 the viscosity. Also, variation in crude sources and refining processes of suppliers sometimes resulted in asphalt cements of a given penetration grade to exhibit marked differences in their viscosities at 60 C. This fact is emphasized in Figure 1.1. The data shows distribution of viscosities at 60 C for 60-70, 85-100 and 150-200 penetration grade asphalt cements. Each viscosity point represents a different supplier. The maximum difference between penetration was three penetration units for 60-70 and 85-100 penetration grade and seven units for 150-200 grade.

The opposing argument for viscosity grading arises due to differences in viscosity-temperature susceptibilities and the problem of pavement cracking due to harder asphalts. These controversies were resolved, however, and the current AASHTO

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*Underlined numbers in parentheses refer to list of references.

specification based on viscosity grading was adopted. Although a wealth of information (3) has been published on the aging characteristics of such asphalts and their effect on pavement performance, comparative data is lacking on the rheological properties of penetration and viscosity-graded asphalts and their performance in asphaltic concrete pavement. This report is an attempt to provide such comparisons with respect to the aging chracteristics of these asphalts and the associated relationships to pavement durability. The information presented here will necessarily limit application to the material, construction procedures, traffic and environmental conditions prevalent in Louisiana.

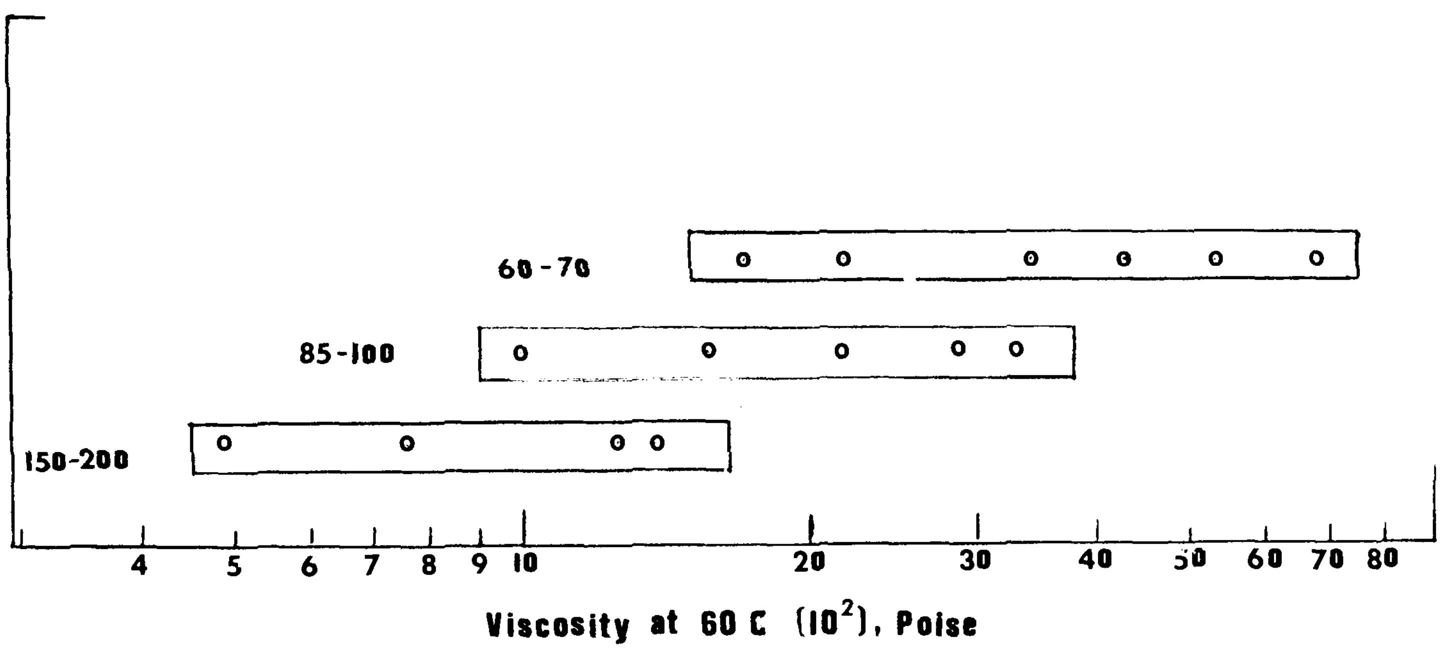


FIGURE 1.1: DISTRIBUTION OF VISCOSITIES AT 60 C FOR PENETRATION GRADE ASPHALT CEMENTS

2. OBJECTIVES

The major objectives of this study were three-fold and can be listed as follows in their order of importance:

(1) To seek data relative to the changes that occur with time in the physical characteristics of penetration and viscosity graded-asphalt cements.

(2) To determine the influence of the above characteristics on the durability (performance) of asphaltic concrete pavements.

(3) To relate the physical properties of the mix, specifically air voids, to the rate of hardening of the various asphalt cements.

3. STUDY DESIGN

Test Sections

The investigation was conducted towards the end of 1970 on State Route 1 approximately 65 Km (40 miles) from Baton Rouge. Test sections were constructed over an 8-kilometer (5-mile) stretch of existing 15.2-cm (6-inch) Portland Cement concrete pavement carrying 3100 vehicles per day. The construction contract required widening and an overlay of 5.1 cm (2.0 inches) of binder course and 3.8 cm (1.5 inches) of wearing course. Figure 3.1 identifies the location of the test project and 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 two types of asphalts: a penetration-graded asphalt cement and a viscosity graded-asphalt cement. The penetration-graded asphalt is the typical asphalt cement used in Louisiana, the consistency of which is controlled by penetration criteria. The viscosity-graded asphalt cements were controlled for consistency by absolute viscosity at 60 C. These latter grades were specifically prepared by the suppliers for this study. Table 3.1 lists the study specifications for the two types of asphalts. Table 3.2 is a listing of the physical properties of the original asphalts. 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. The primary purpose for inclusion of this softer grade was to seek information relative to its performance as compared to harder asphalts. Some of the viscosity and penetration values were in violation of the study specifications. However, since there was no corroboration between the laboratories and rather than impede the progress of construction, these asphalts

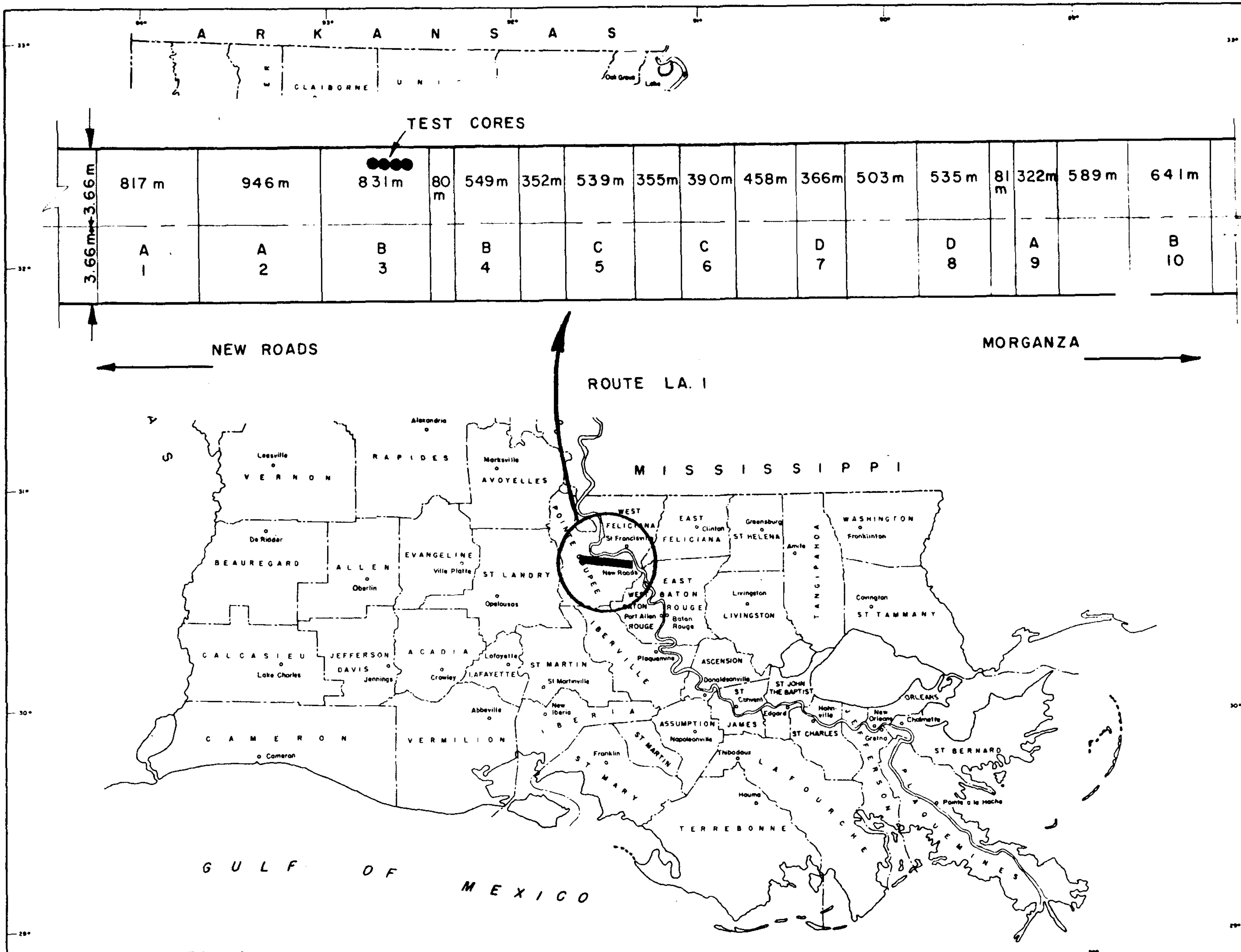


FIGURE 3.1: LOCATION OF TEST PROJECT AND LAYOUT OF TEST SECTIONS

TABLE 3.1
STUDY SPECIFICATIONS FOR ASPHALT CEMENTS

Test Property	Test Method	Asphalt Grade Penetration	Asphalt Grade Viscosity
Viscosity at			
135 C, SFS	ASTM E 102	260+	260 - 360
60 C, Poise	AASHTO T 202	3600+	3600 - 7000
Penetration at			
25 C 100g, 5 sec.	AASTHO T 49	60 - 70	50 max.
4 C 200g, 60 sec.	AASHTO T 49	20+	--
Flash Point, COC °C	AASHTO T 48	232	232
Thin Film Oven Test	AASHTO T 179		
Loss % @ 162.8 C		0.80-	0.80-
Penetration Retained, % Of Original		60+	--
Ductility of Residue @ 25 C	AASHTO T 51	100+	100+
Viscosity Index @ 60 C	--	--	5-
Solubility in Trichlor.	AASHTO T 44	99.0+	99.0+
Spot Test	AASHTO T 102	Neg.	Neg.

TABLE 3.2
PHYSICAL PROPERTIES OF ORIGINAL ASPHALT CEMENTS

TEST SECTION NUMBER	1	2	3	4	5	6	7	8	9	10
ASPHALT SUPPLIERS	A	A	B	B	C	C	D	D	A	B
SOURCE: 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
ASPHALT CEMENT TEST DATA										
VISC 135C,CS	630	546	744	611	597	598	654	579	338	418
VISC 60C,POISE	3508	4681	4810	4232	3296	4583	4717	5687	1786	1891
VISC 25C,MEGAPOISE	2.70	6.20	3.40	4.40	3.10	6.20	3.20	6.70	1.50	1.40
PEN 46.1C,50GM,5SEC		226	243	211	253	211	253	211		
PEN 25C,100GM,5SEC	64	41	58	48	61	34	56	39	74	81
PEN 15.6C,100GM,5SEC	23	12	21	17	22	10	22	14	23	29
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	150+	150+	150+	150+	150+	150+
DUCT 4C,1CM/MIN,CM	8.6	5.8	10.4	6.5	7.0	5.0	8.5	5.5	36.0	30.5
SOLUBILITY IN TRICHLOR.	99.83	99.91	99.84	99.66	99.66	99.79	99.88	99.95	99.90	99.85
SPECIFIC GRAVITY,25C	1.030	1.041	1.039	1.028	1.022	1.032	1.022	1.038	1.035	1.024
SPECIFIC GRAVITY,15.6C	1.035	1.046	1.044	1.033	1.027	1.037	1.026	1.044	1.040	1.029
SOFTENING POINT(R&B),C	52	54	53	53	52	54	53	54	48	47
THIN FILM OVEN TEST RESIDUE										
% WEIGHT LOSS OR GAIN	0.033	0.008	-.112	-.037	0.026	0.080	0.028	0.044	0.019	-.153
VISC 135C,CS	914	724	1299	854	842	760	990	905	494	615
VISC 60C,POISE	8392	9559	17015	10215	8161	8008	11736	16739	3809	5154
VISC 25C,MEGAPOISE	6.90	13.00	11.00	12.00	8.80	18.00	10.50	20.50	4.05	5.60
VISC 60C AFTER / BEFORE	2.39	2.04	3.54	2.41	2.48	1.75	2.49	2.94	2.13	2.73
PEN 25C,100GM,5SEC	45	30	37	33	42	26	39	27	50	51
PEN % RETAINED	70.3	73.2	63.8	68.8	68.9	76.5	69.6	69.2	67.6	63.0
DUCT 25C,5CM/MIN,CM	150+	150+	85.5	150+	150+	150+	98	82	150+	150+
DUCT 4C,1CM/MIN,CM	5.5	5.0	4.2	4.0	5.0	4.5	5.5	4.0	8.0	6.5

were accepted for use on the project.

Construction Control

Good construction control was maintained throughout the test section construction. Care was exercised to maintain all material and construction variables uniform with the exception of asphalt type and source. The mixture consisted of gravel, sand, and filler meeting the Department's standard requirements for Type 1 asphaltic concrete. Comprehensive data on mix design, gradation, and physical properties of mixtures appears in the Appendix.

Field Sampling Procedures

The sampling frequencies for evaluation of the aging charactertistics of asphalts and durability of asphaltic concrete since construction was formulated in advance as follows:

1, 36, and 110 days; 1 year, 3 years, and 5 years.

Four 12-inch samples were obtained from the outside wheel path from a randomly selected single sample site approximately 30-meters long, for each test section. The same sampling site and pattern were used through all of the sampling periods. In Figure 3.1 is shown a typical location of samples for a section. 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 towards this duplication in effort was to seek information relative to the variability associated in the extraction and recovery process.

4. DATA ANALYSIS

Data generated by both the laboratories, the Asphalt Institute and the Department, is presented in detail in the Appendix. Most of the test properties are self-explanatory except the following:

Penetration Index - This is the ratio of the penetration at 25 C of recovered (aged) asphalt to the penetration of the original asphalt.

Viscosity Index at 25 C and 60 C - Use of this term tends to eliminate the variability caused by differences in the viscosities of the original raw asphalt. This term, which is frequently termed the Aging Index, is simply the ratio of the viscosity of the aged asphalt at the temperature to the viscosity of the original asphalt (before aging).

Shear Index at 25 C - The Shear Index or shear susceptibility of the asphalt is determined as the tangent function of the *angle of the plot of log shear rate versus log viscosity; both* determined with the microviscometer.

Temperature Susceptibility - The rheological properties of asphalt are substantially affected by the temperature. This effect can be measured as the temperature susceptibility using the Walther relation as follows:

$$\frac{\log \log \eta_2 - \log \log \eta_1}{\log T_2 - \log T_1}$$

where η_1, and η_2 are the viscosities in centipoises at absolute temperatures T_1 and T_2. Absolute temperature is equal to the Fahrenheit temperature plus 459.

5. DISCUSSION

The specific test values of penetration, viscosity and other rheological properties are presented in detail in the Appendix. The hardening characteristics of each asphalt are depicted through graphical presentations. Furthermore, since the major thrust of the study is towards comparative evaluation of penetration-graded versus viscosity-graded asphalts from a given source (and not between sources), the discussion will be confined to each pair of asphalts and their performance in relation to each other. The basic rheological properties of penetration, viscosity and ductility for each pair of asphalts are presented as a figure. Thus, Figure 5.1 represents the hardening rate of penetration at 25 C, viscosities at 25 C and 60 C and ductility at 25 C for Sections 1 and 2. Likewise, Figure 5.2 represents similar data for Sections 3 and 4 and so on for other sections. In these figures the curves identified as LDH represent the Louisiana Department of Highways data and those identified as AI represent the Asphalt Institute data. The numerals after each acronym signify the section number.

Variation in Test Data

A cursory look at the data in these figures reveals the marked differences in the magnitude of the measured characteristics between the two laboratories. In a majority of the cases, these differences exceed the allowable ASTM tolerance for reproducibility for penetration and viscosity. Any of the factors, from sample storage and preparation to method of extraction and solvent type, could have contributed to such deviations. Since the State's testing procedures are certified by the AASHTO Material Reference Laboratory (AMRL), the question naturally arises as to the completeness of the standard test method used for asphalt recovery.

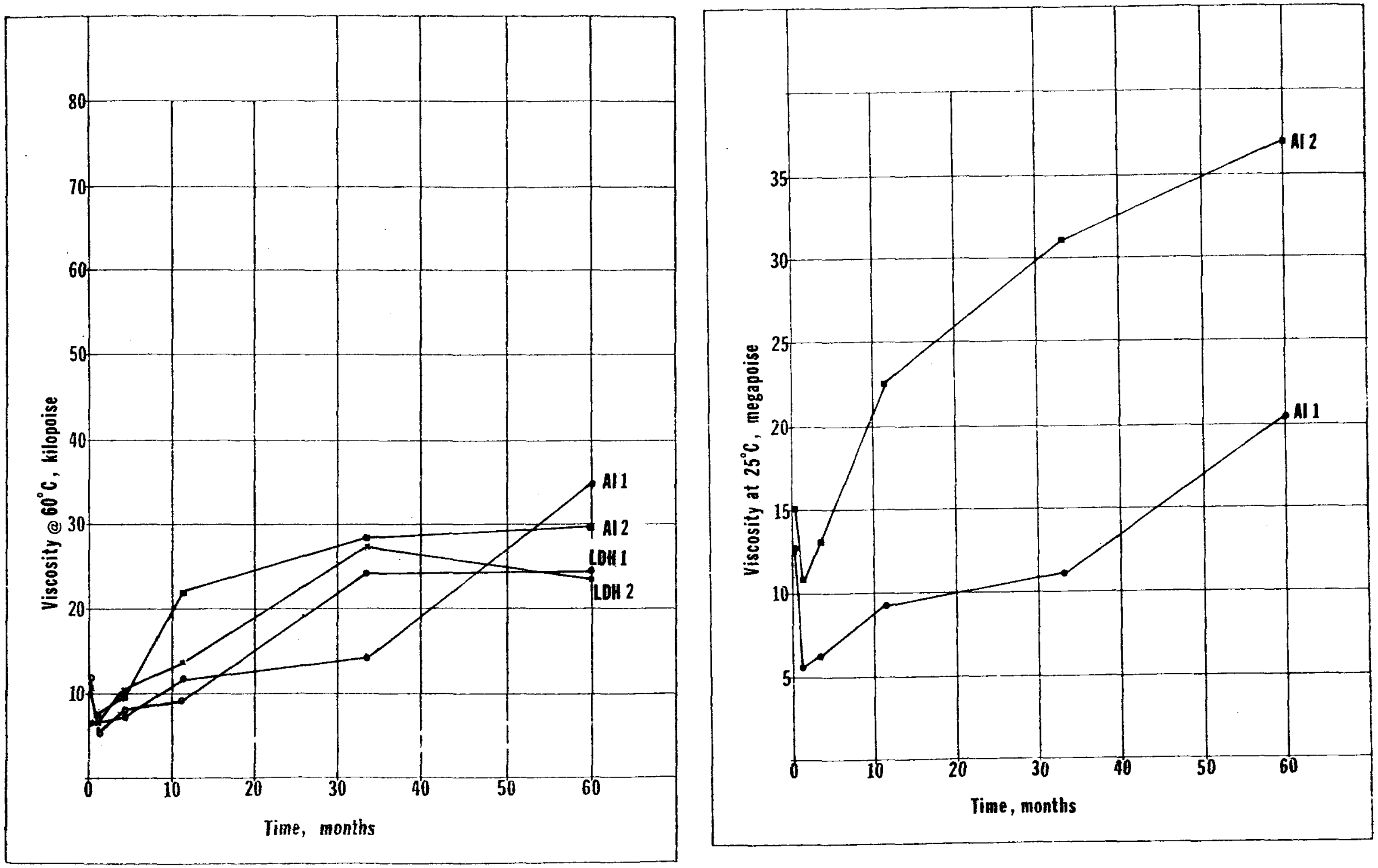
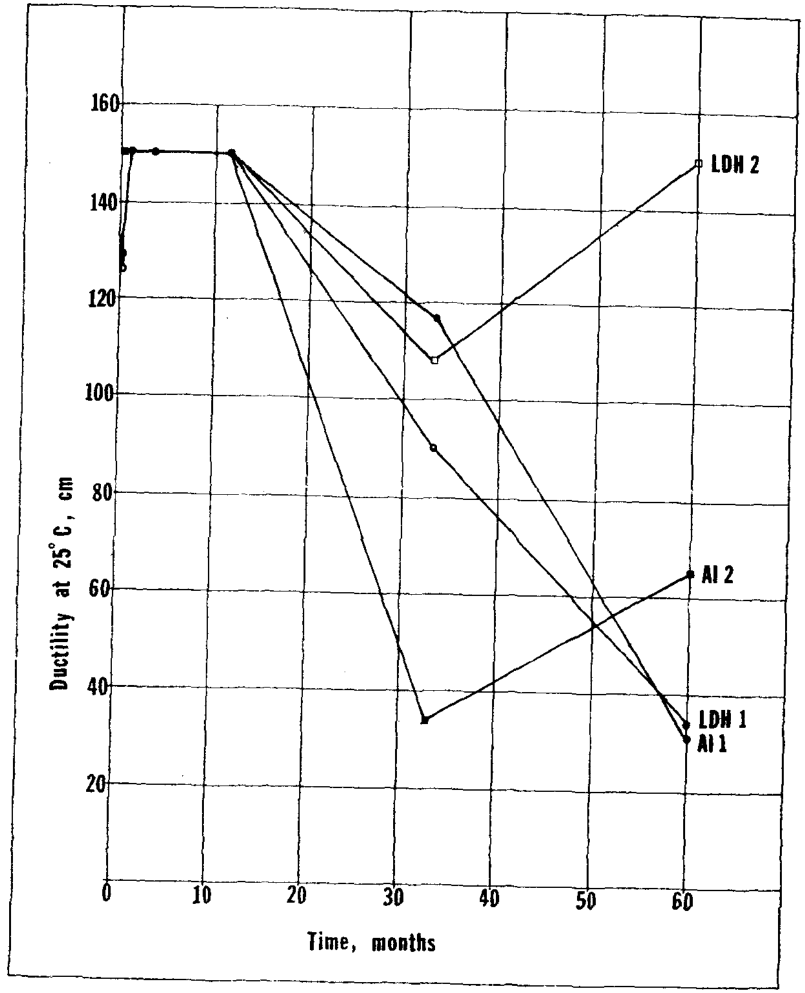


FIGURE 5.1: RATE OF HARDENING OF PENETRATION GRADE (SECTION 1) AND VISCOSITY GRADE (SECTION 2) ASPHALT CEMENT FROM SOURCE A



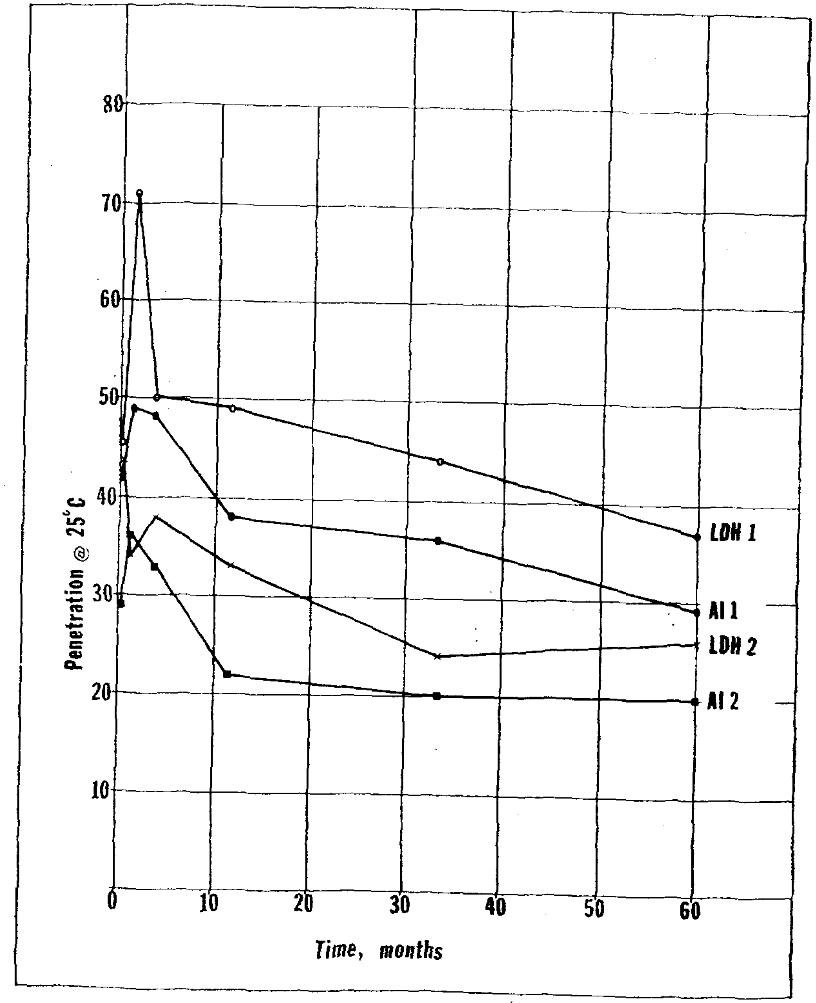


FIGURE 5.1 (CONT.): RATE OF HARDENING OF PENETRATION GRADE (SECTION 1) AND VISCOSITY GRADE (SECTION 2) ASPHALT CEMENT FROM SOURCE A

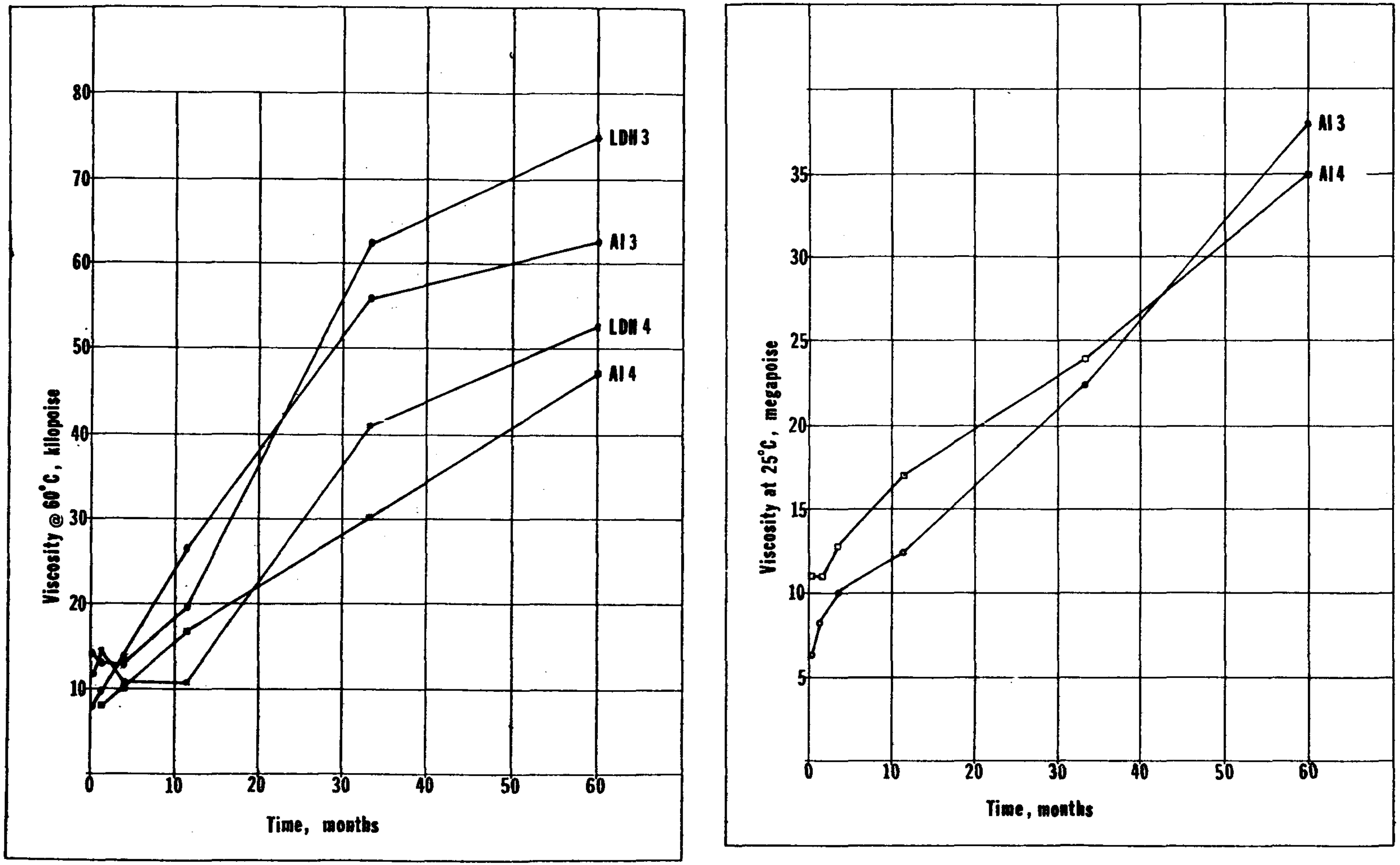


FIGURE 5.2: RATE OF HARDENING OF PENETRATION GRADE (SECTION 3) AND VISCOSITY GRADE (SECTION 4) ASPHALT CEMENT FROM SOURCE B

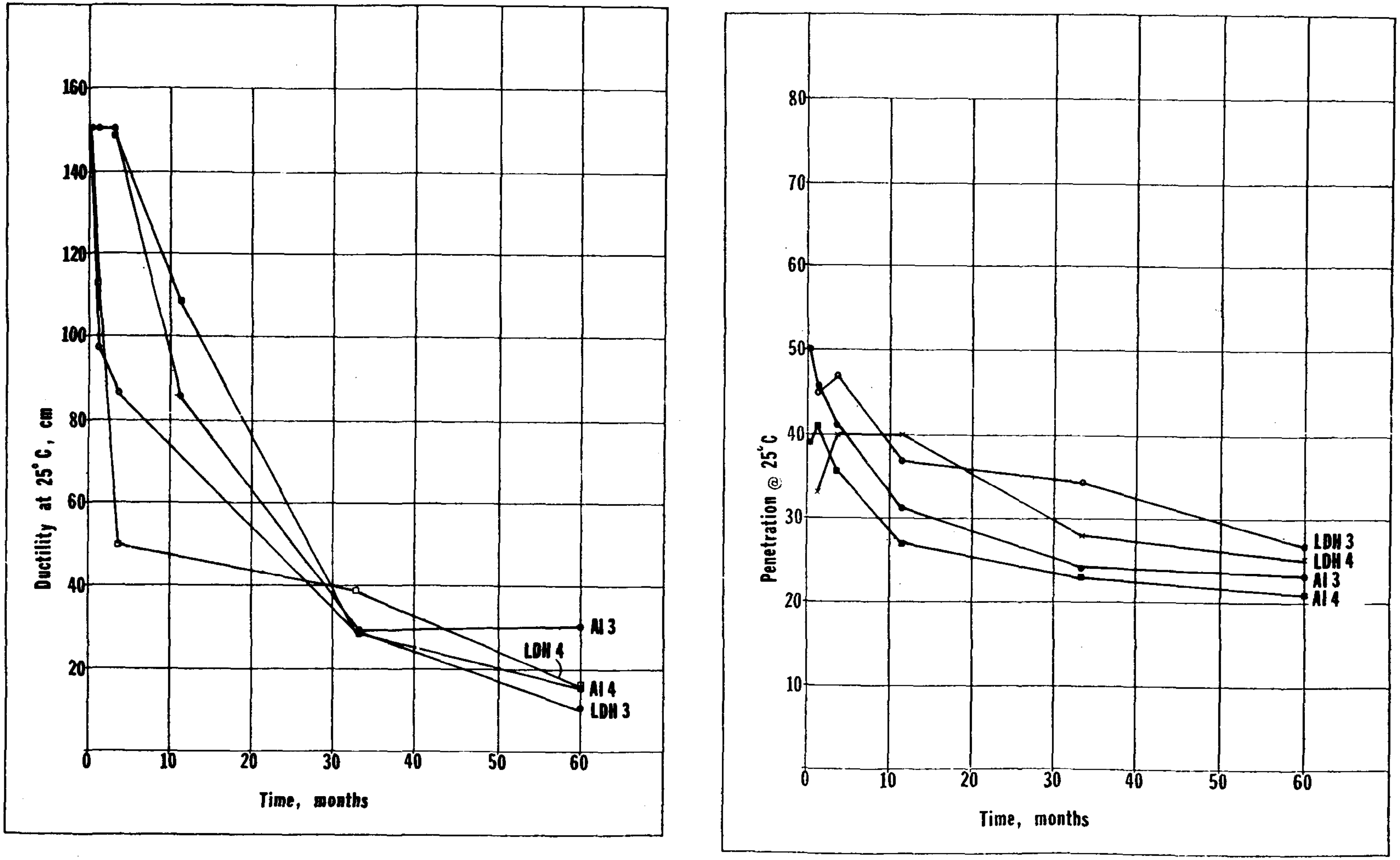


FIGURE 5.2 (CONT.): RATE OF HARDENING OF PENETRATION GRADE (SECTION 3) AND VISCOSITY GRADE (SECTION 4) ASPHALT CEMENT FROM SOURCE B

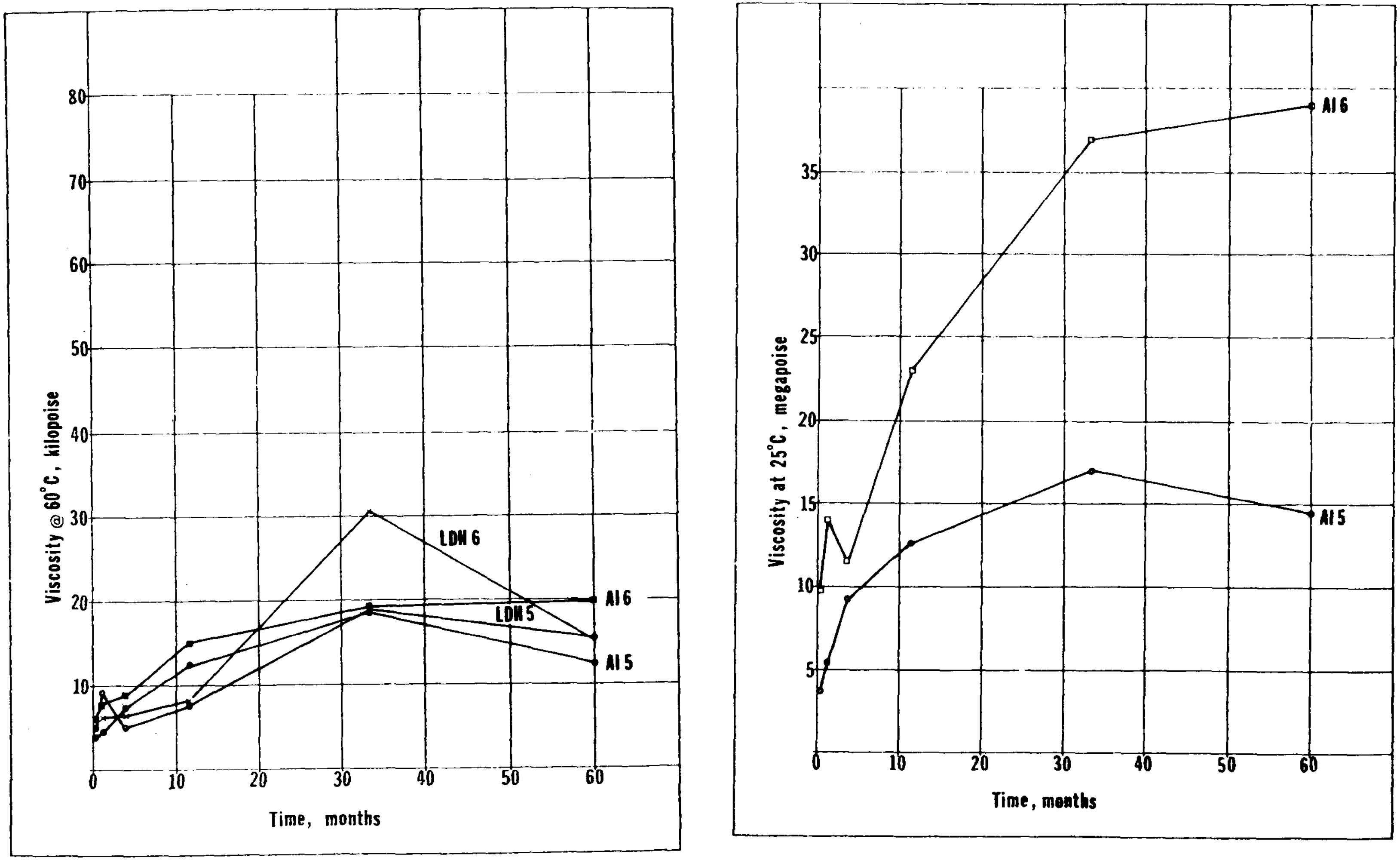


FIGURE 5.3: RATE OF HARDENING OF PENETRATION GRADE (SECTION 5) AND VISCOSITY GRADE (SECTION 6) ASPHALT CEMENT FROM SOURCE C

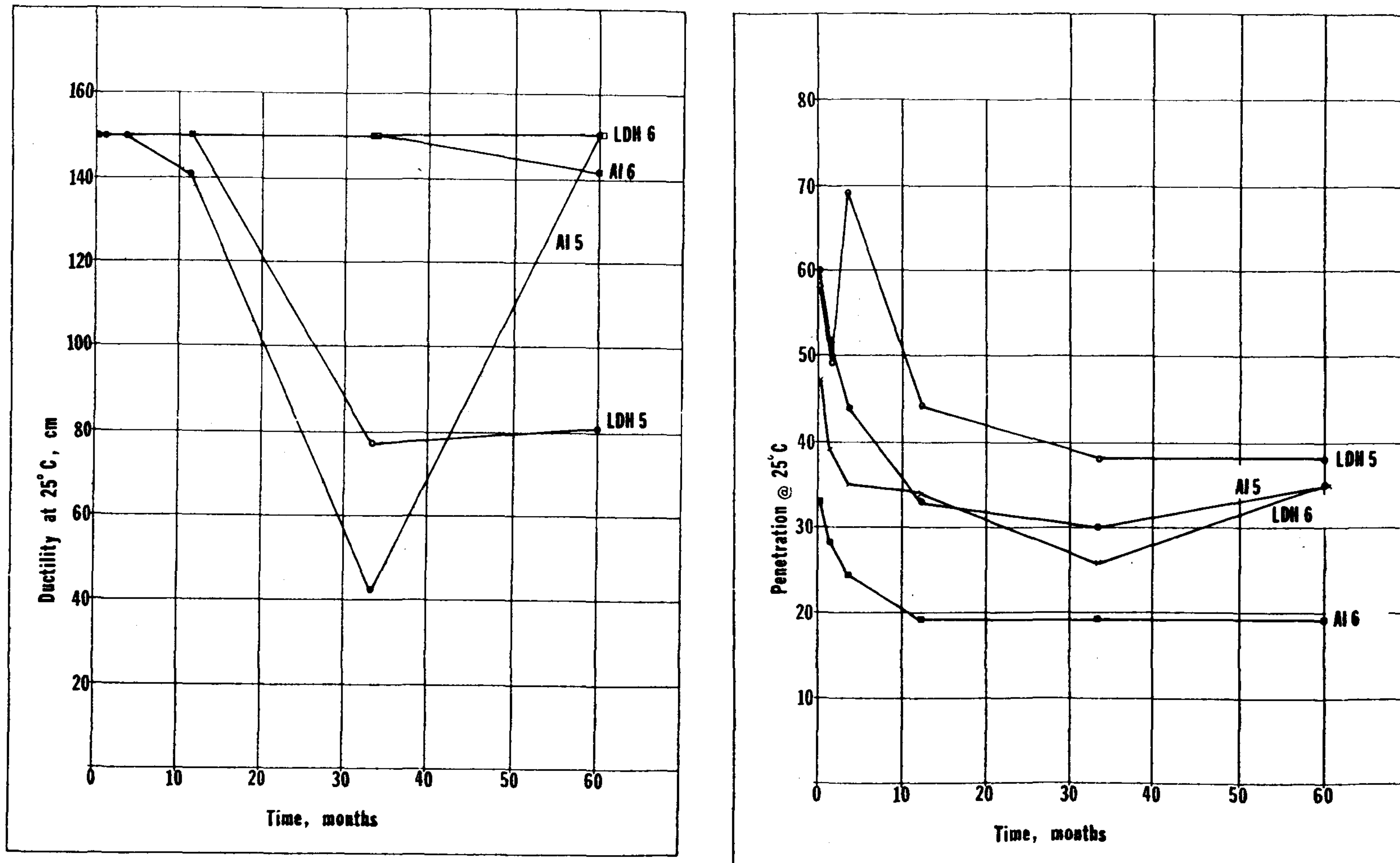


FIGURE 5.3 (CONT.): RATE OF HARDENING OF PENETRATION GRADE (SECTION 5) AND VISCOSITY GRADE (SECTION 6) ASPHALT CEMENT FROM SOURCE C

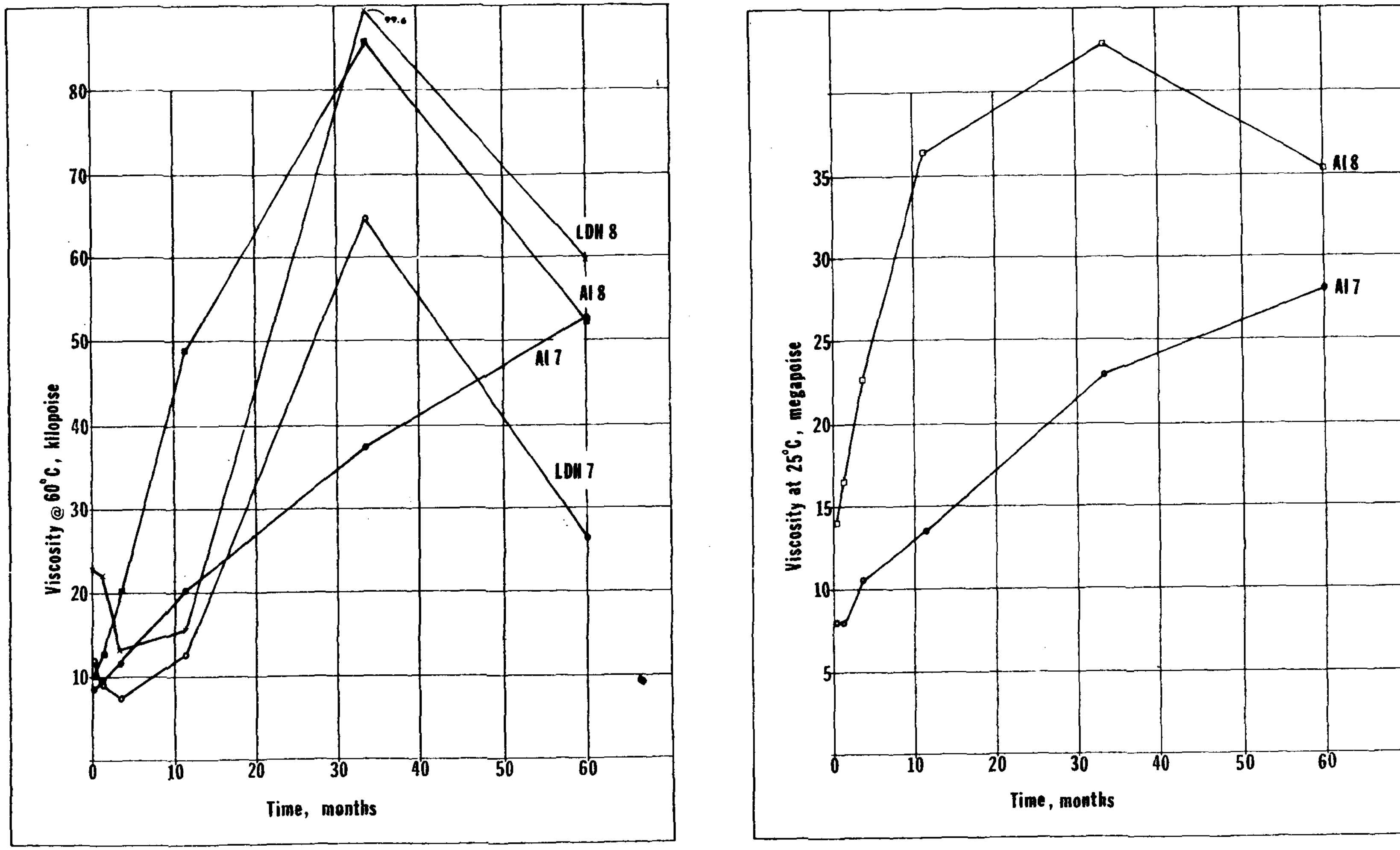


FIGURE 5.4: RATE OF HARDENING OF PENETRATION GRADE (SECTION 7) AND VISCOSITY GRADE (SECTION 8) ASPHALT CEMENT FROM SOURCE D

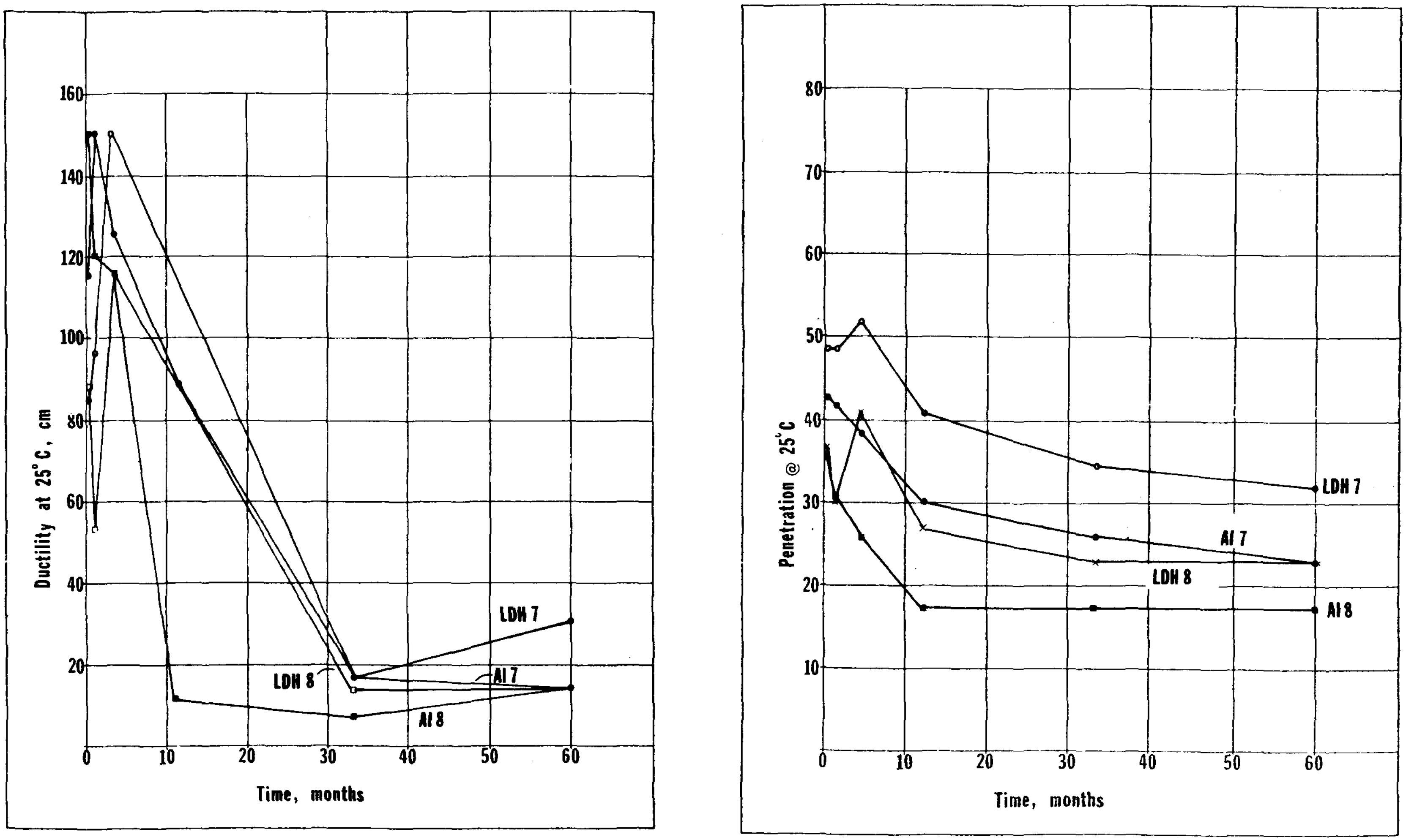


FIGURE 5.4 (CONT.): RATE OF HARDENING OF PENETRATION GRADE (SECTION 7) AND VISCOSITY GRADE (SECTION 8) ASPHALT CEMENT FROM SOURCE D

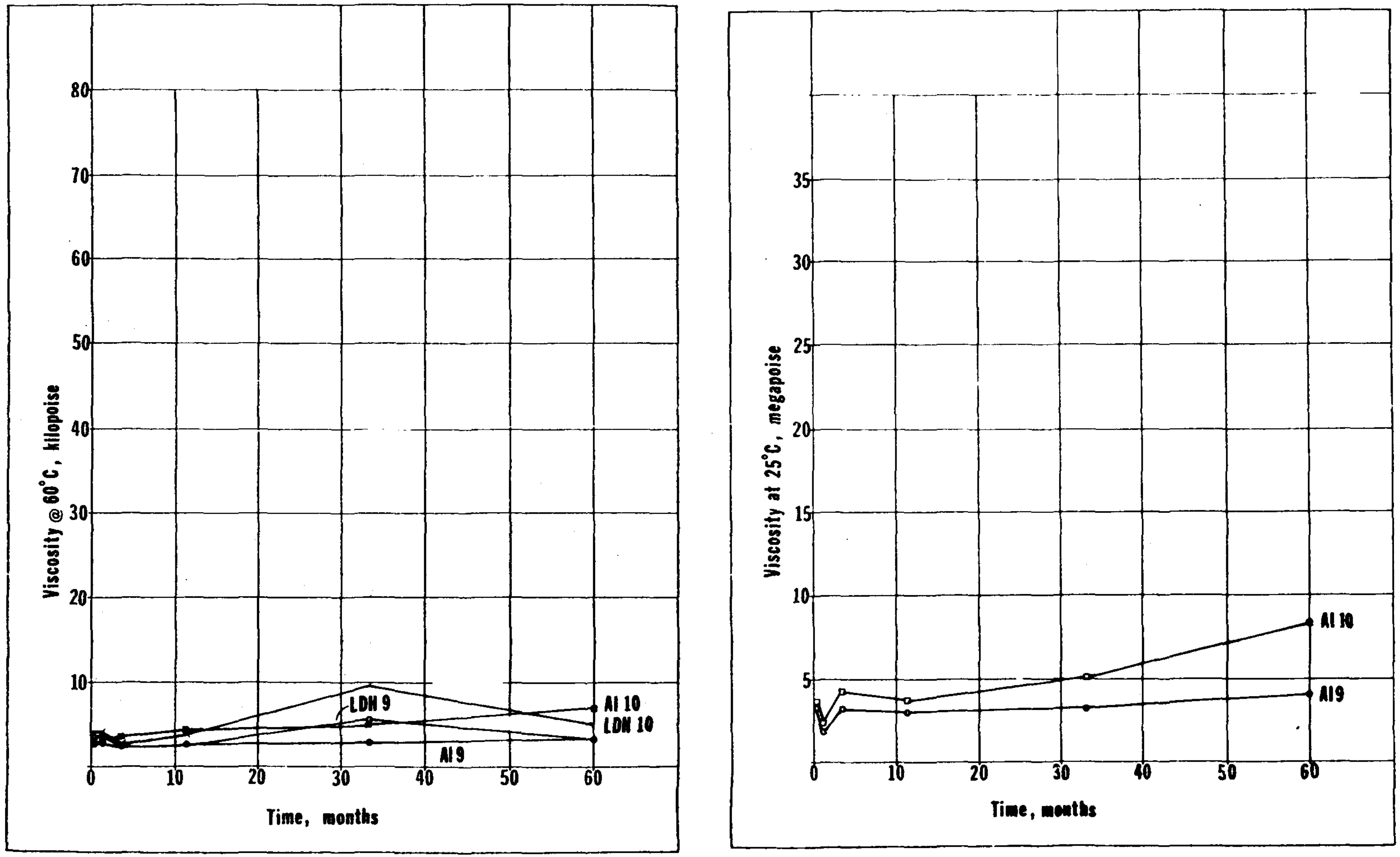


FIGURE 5.5: RATE OF HARDENING OF VISCOSITY GRADE ASPHALT CEMENTS FROM SOURCES A AND B

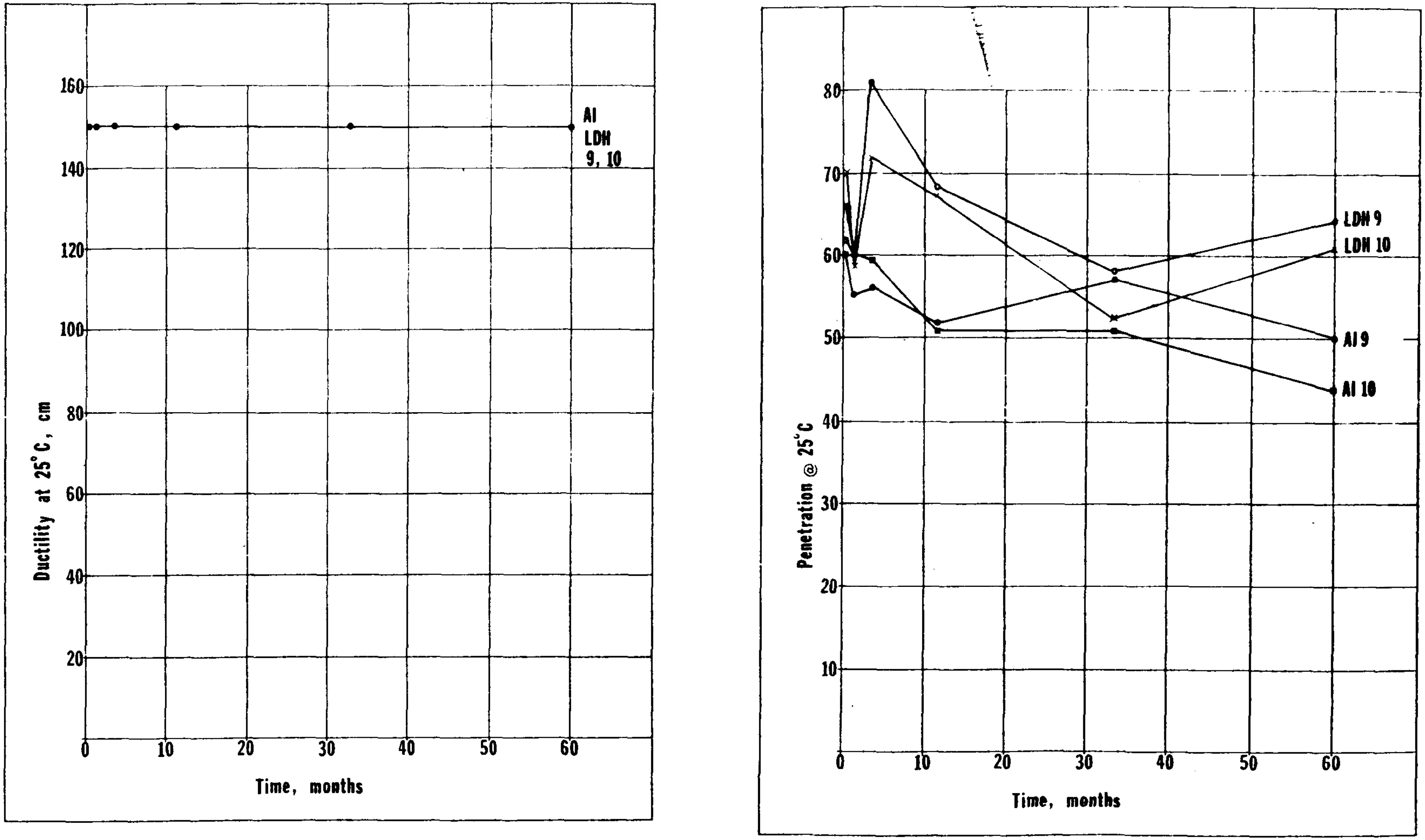


FIGURE 5.5 (CONT.): RATE OF HARDENING OF VISCOSITY GRADE ASPHALT CEMENTS FROM SOURCES A AND B

The point being made here is that whenever asphalt recovery from pavement samples that have been exposed to a prolonged aging period is contemplated, the present test procedures for extraction (ASTM D-2172) and recovery (ASTM D-1852) may necessarily require inclusion of the procedure for sample storage and preparation. The present procedure for asphalt recovery requires the entire procedure, from the start to the extraction to the final recovery, to be completed within eight hours. This seems too restrictive particularly if the hot extraction procedure (Method B in ASTM D-2172) is used. At no time during the course of this study was the LDH laboratory able to accomplish this in the specified time. It was determined that the reflux time increased with corresponding increase in age of the samples.

Relationship of Hardening of Asphalt with Time

In spite of the observed variations, the changes in the rheological properties (Figures 5.1 through 5.5), with the exception of some ductility data, seem to fit the hyperbolic function (4, 5, 6) of the following form:

$$\Delta Y = \frac{T}{a + bT} \quad \text{........ Equation 1}$$

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

Equation 1 can be rearranged as:

$$\frac{T}{\Delta Y} = a + bT \quad \text{........ Equation 2}$$

Equation 2 is recognized as linear in $\frac{T}{\Delta Y}$ versus T and will plot as straight line on simple coordinate paper. In Equation 1 the asymptotes are defined by the reciprocal of the slope b and represent the ultimate change of test variable at infinite aging time. It has been suggested (4, 5) 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 and viscosity at 60 C was fitted to Equation 2 to determine the constants a and b. Using the AI one-day aged data as zero life value and the last three periods as each subsequent time T, the constants were determined and are listed in Table 5.1. The values of the reciprocal of the slope b as the asymptotes of limiting values of the changes with time are also listed in Table 5.1. Some of the data did not show a good fit to the equation as is evident from the correlation coefficient R. Also 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 one-day data which was used as the base period for calculation of the difference ΔY. The initial threefold increase in the viscosity at 60 C, which was also confirmed by the LDH laboratory, may be significant since such an abrupt increase in hardness enhances the subsequent hardening process as is evidenced by the exponential trend fixed by the last AI data point. However, since the LDH data does not show this exponential trend the cause and effect enumerated here may be hypothetical.

Based on this limiting change criteria 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 as shown in the Table 5.1. Based on these values, asphalt 1 is the least durable of all and asphalts 9, 10 and 5, in that order, the most durable. Asphalts 9 and 10, it will be recalled, are the softer asphalts (viscosity at 60 C of 2000±400 poises and penetration at 25 C 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.

TABLE 5.1

LIMITING VALUE OF PROPERTY CHANGES WITH AGE

ASPHALT OR SECTION NO.	SLOPE PEN(R)*	SLOPE VISC(R)*	LIMITING CHANGE PEN	LIMITING CHANGE VISC[1]	ULTIMATE CHANGE PEN	ULTIMATE CHANGE VISC[1]
1	0.033(0.596)	-0.17(0.989)	30.3	**	12	**
2	0.105(0.999)	0.043(0.998)	9.5	23.3	19	33.5
3	0.033(0.999)	0.010(0.958)	30.3	100.0	20	108.1
4	0.049(0.999)	0.002(0.749)	20.4	500.0	19	509.0
5	0.041(0.993)	0.118(0.951)	24.4	8.5	35	12.5
6	0.072(1.000)	0.063(0.999)	13.9	15.9	19	21.9
7	0.044(0.997)	0.007(1.000)	22.7	142.9	20	151.8
8	0.051(0.999)	0.023(0.939)	19.6	43.5	16	53.9
9	0.083(0.420)	1.016(0.694)	12.1	1.0	48	3.9
10	0.044(0.947)	0.117(0.605)	25.0	8.6	41	11.6

* R IS CORRELATION COEFFICIENT IN PARENTHESIS

** INFINITY AT SOME FINITE TIME T

1 KILOPOISES

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

If durability and performance are synonymous, then there should be some correlation between the observed performance of these asphalts in the pavement and the above durability ranking. The data in Table 3.3 shows that there is, at least for extreme (good and poor) conditions of performance as reflected by overall subjective rating. Sections 9 and 10, the more durable asphalt sections, are performing much better than Section 1 with the least durable asphalt.

The above analysis and discussion indicate that originally soft asphalts 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 is the early manifestation of wheel path rutting. This may be true since the magnitude of ruts, although not of any great concern, is higher for Sections 9 and 10. Further evaluation of these sections may provide additional data on this aspect.

Changes in Rheological Properties

Penetration/Viscosity

The data for penetration in Figures 5.1 through 5.5 shows 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, is not consistent although the rate is slower for viscosity-graded asphalts than the corresponding penetration-graded sections. This is indicated by the Asphalt Institute data in Figure 5.6 which represents a plot of the Viscosity Index (Aging Index) at 60 C versus time of service on logarithmic scale. 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

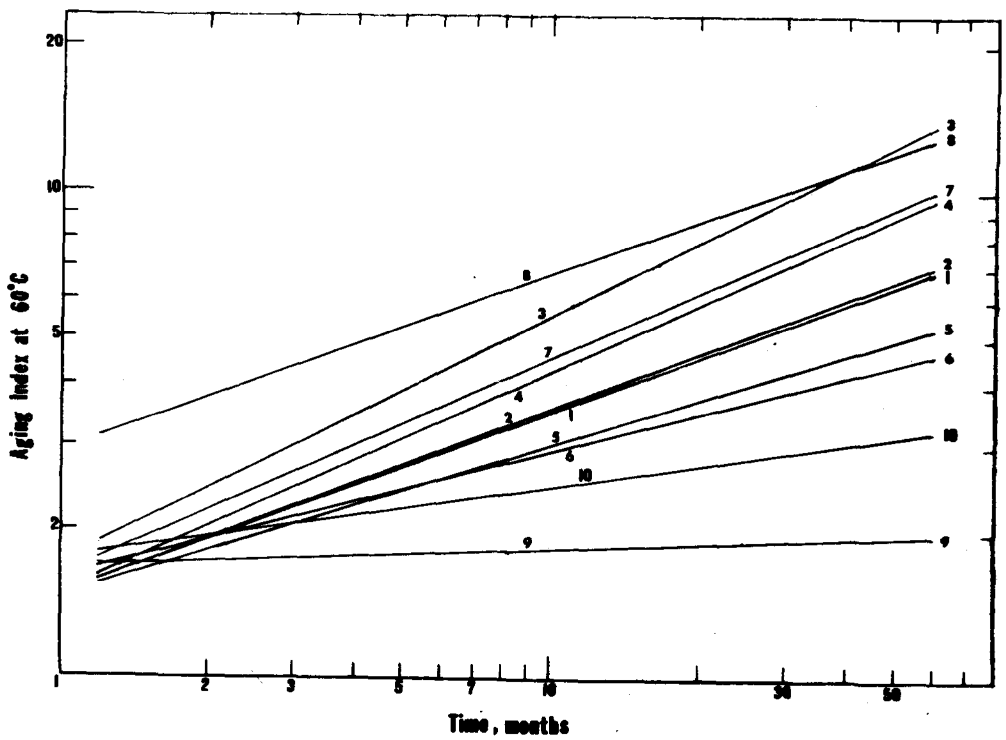


FIGURE 5.6: VISCOSITY INDEX AT 60 C VERSUS TIME RELATIONSHIP

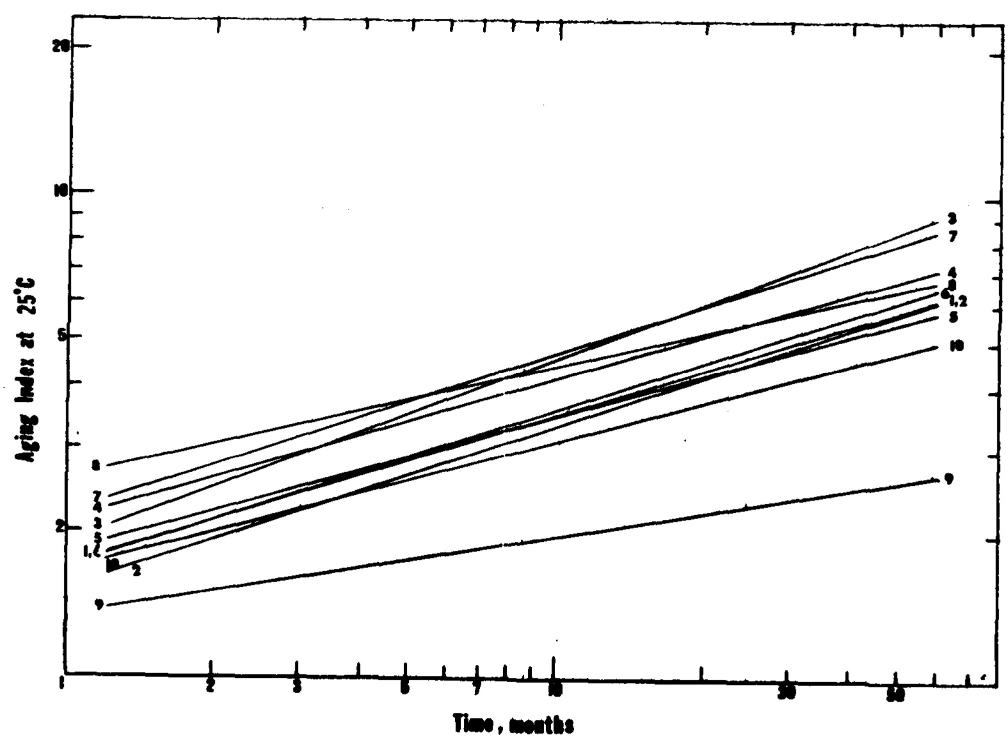


FIGURE 5.7: VISCOSITY INDEX AT 25 C VERSUS TIME RELATIONSHIP

viscosity. It is interesting to note from Figure 5.7 that the rate of viscosity changes at 25 C (at .05 $sec.^{-1}$ shear rate) is not as pronounced as at 60 C. However, Section 3 once again indicates the greatest increase in viscosity at this temperature after 60 months of service.

The slopes indicated by Aging Index versus time curves, in Figures 5.6 and 5.7, can be used as indicators of the relative durability of various asphalts. Specifically, a flat slope implies a more durable asphalt. Accordingly, based on 60-month data, all viscosity-graded asphalts in Figure 5.6 would be classified as more durable than the corresponding penetration-graded asphalts. Likewise, Sections 9 and 10, with the smallest slopes, have the most durable asphalts and Section 3 the least durable. A similar trend is indicated in Figure 5.7 by these same sections.

Figure 5.8 represents the graphical relationship between the empirical penetration test at 25 C and viscosity at 25 C. The relationship between the two variables is also expressed in the form of an equation. The degree of association between the two variables is expressed as R which, if 1.0, represents perfect association and if zero, none. The data indicates that the present criteria of penetration at 25 C is sufficient to control consistency at this lower service temperature.

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 Figures 5.1 through 5.5 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

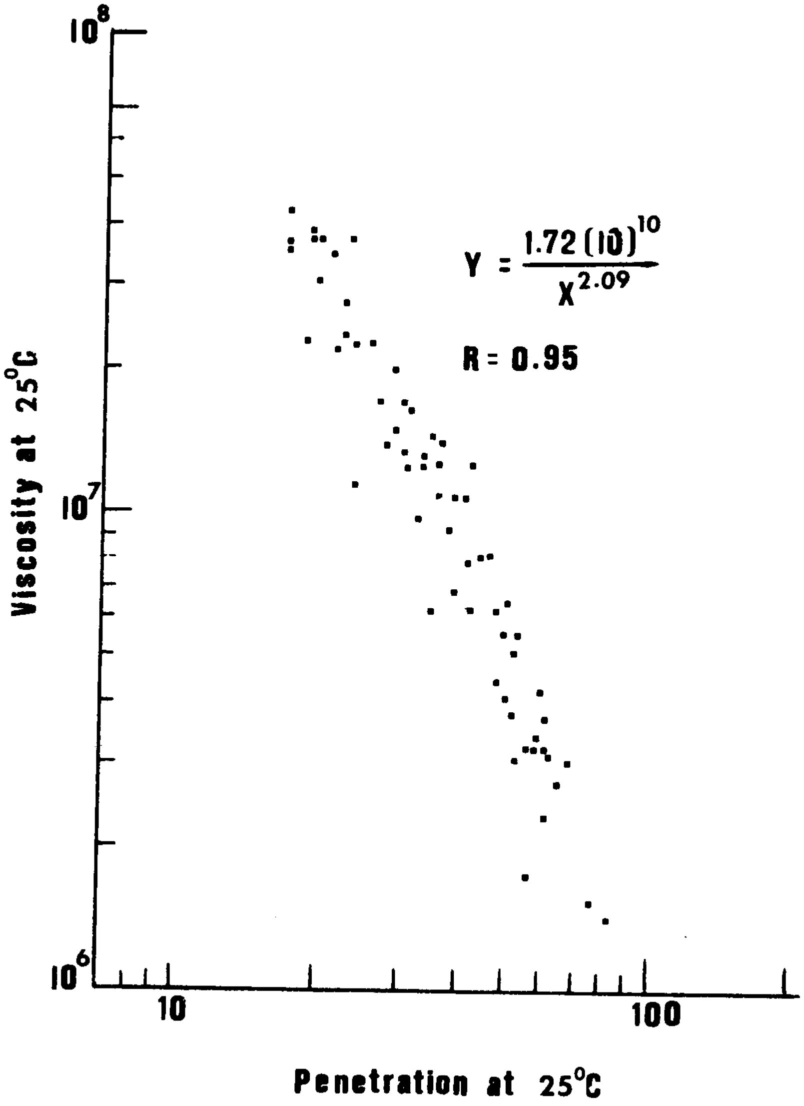


FIGURE 5.8: PENETRATION - VISCOSITY RELATIONSHIP AT 25 C

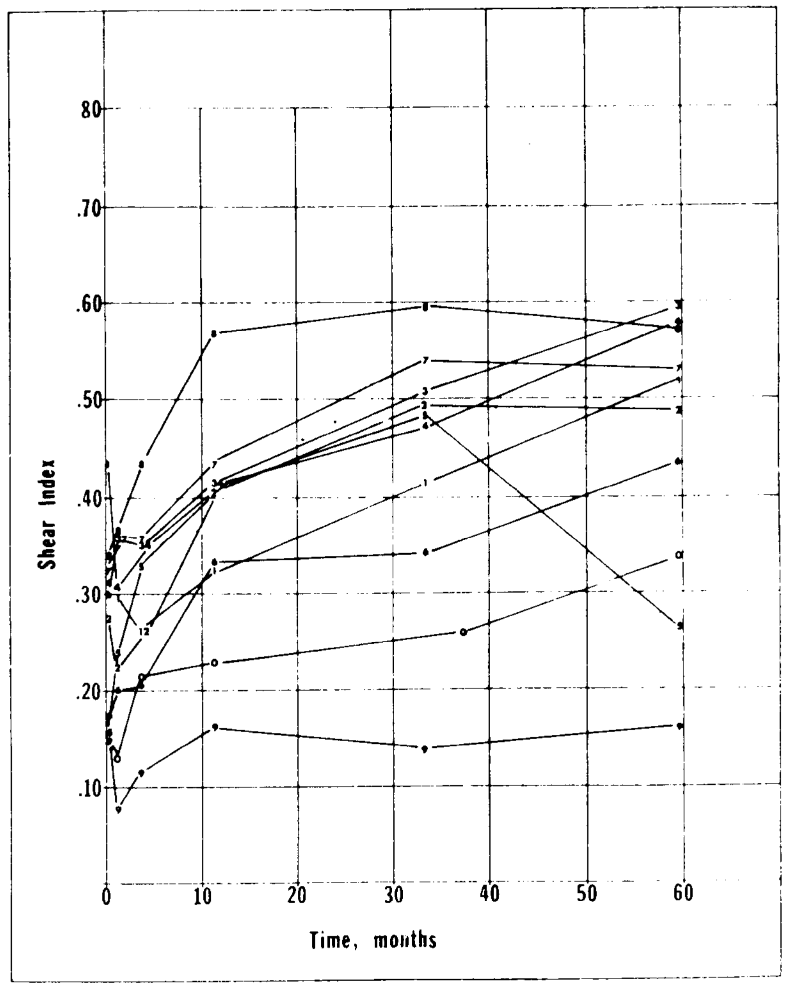


FIGURE 5.9: RATE OF CHANGE OF SHEAR INDEX WITH TIME

these same sections in Figure 5.6. A review of ductility values in the Appendix at lower temperatures (10 C) shows all sections, except 9 and 10, to have reached approximately the same magnitude of flexibility after five years of service.

Shear Index

The change in Shear Index characteristics with time is expressed in Figure 5.9. Once again the relative position of each curve is directly associated with its aging characteristics as was depicted by its rheological characteristics. Specifically, Sections 3, 4, 7 and 8 are more shear susceptible and Sections 9 and 10 less so. These sections had also exhibited an increased rate of hardening during the five-year period. Source (crude) may be an influential factor for such aging chractertistics. Asphalts exhibiting high shear susceptibility have correspondingly low ductility values. The plot in Figure 5.10 shows this trend. In general asphalts with Shear Indexes less than 0.40 have ductilities over 100 cm. The relationship may be useful as a basis of using the Shear Index value in place of the ductility test.

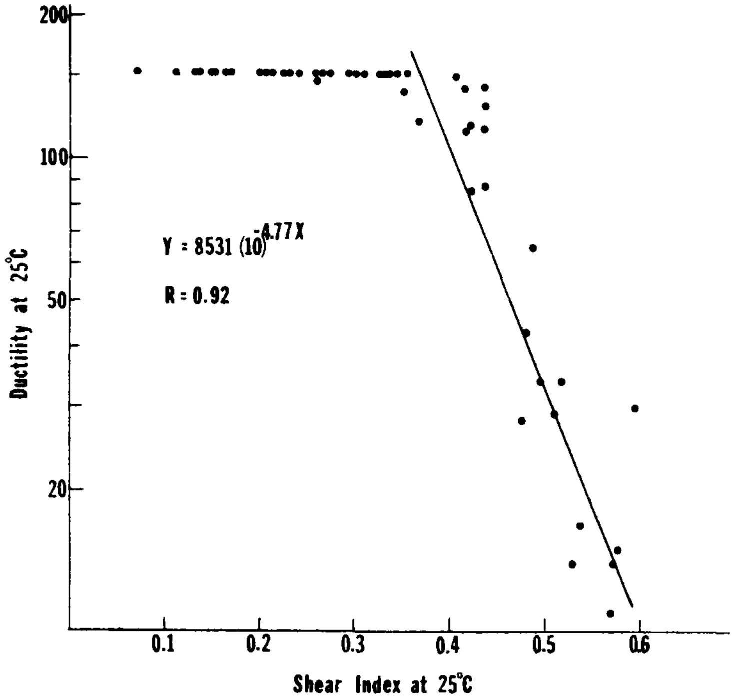


FIGURE 5.10: SHEAR INDEX VERSUS DUCTILITY (25 C) RELATIONSHIP

Durability

The laboratory durability test for viscosity-graded asphalts is based on viscosity at 60 C after the TFOT aging, while the penetration-graded asphalts uses penetration at 25 C as the durability criterion. In order to determine whether the low temperature (25 C) consistency requirement for durability is necessary for viscosity-graded asphalt, viscosity ratios at 60 C for original asphalt (after TFOT) and after 60 months of service were plotted against percent retained penetration at 25 C in Figure 5.11. The figure shows good association of the two variables and indicates that the present durability criteria for viscosity graded asphalts are sufficient. The TFOT durability test is recognized as a simulation of the hardening of asphalts that would occur during pugmill mixing of asphalts. The present requirement for this durability which is expressed as viscosity ratio at 60 C may be too liberal. The data in the Appendix show that it takes approximately one year for the asphalts to reach the present specified requirement of 5.0 maximum. Section 6, after 60 months, has not yet reached this value.

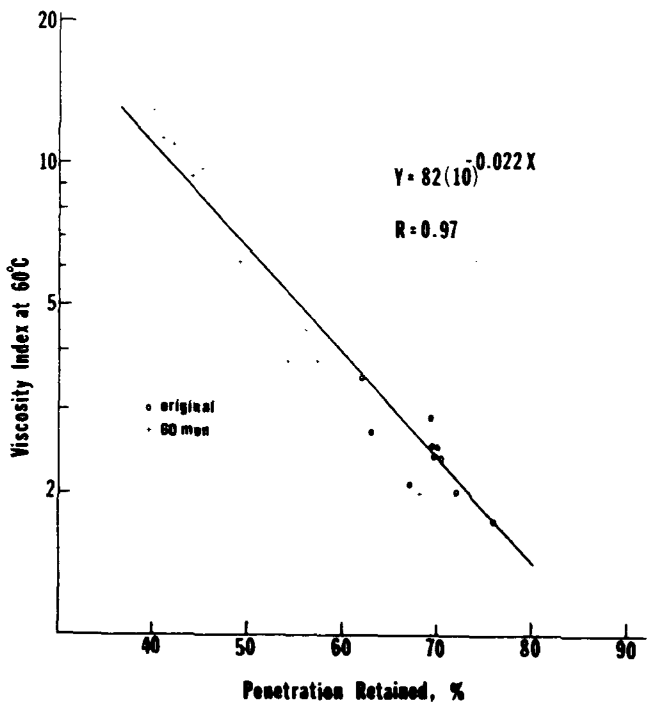


FIGURE 5.11: VISCOSITY RATIO (60 C) VERSUS PENETRATION RETAINED (25 C) RELATIONSHIP FOR TFOT RESIDUE

Temperature Susceptibility

Asphalt consistency is greatly affected by changes in temperature. The extent of this effect is expressed as temperature susceptibility which was defined in Chapter 4. The value of this property for each asphalt was evaluated for original and 60 month samples using the service temperature range of 25 C to 60 C and also mixing and compaction range of 60 C to 135 C. These values are indicated in the form of a bar chart in Figure 5.12. Figures 5.13 through 5.17 represent viscosity temperature relationships of the various sections. The slopes of the lines in each temperature range are the temperature susceptibility values of Figure 5.12.

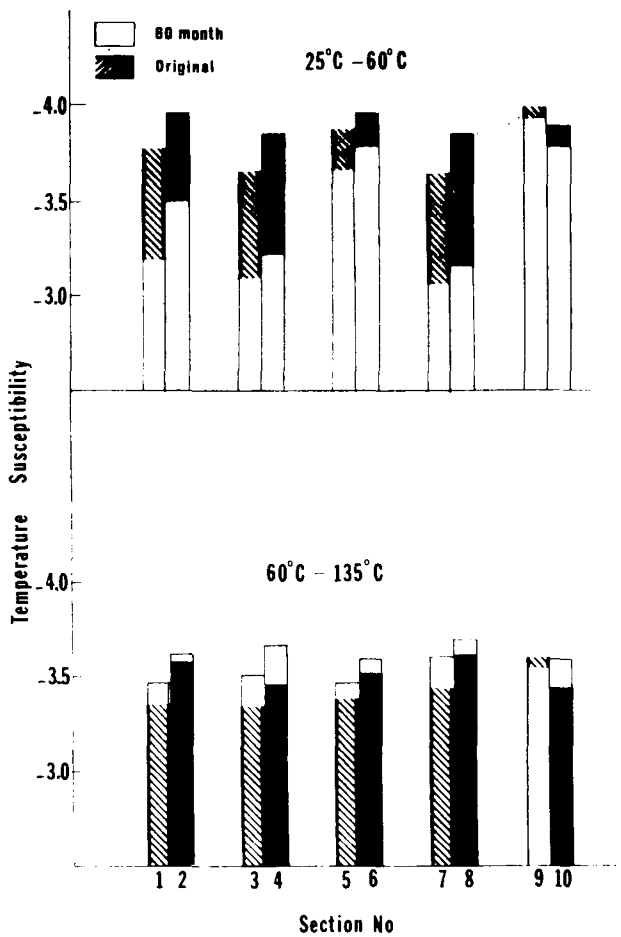


FIGURE 5.12: TEMPERATURE SUSCEPTIBILITY OF ASPHALT CEMENTS

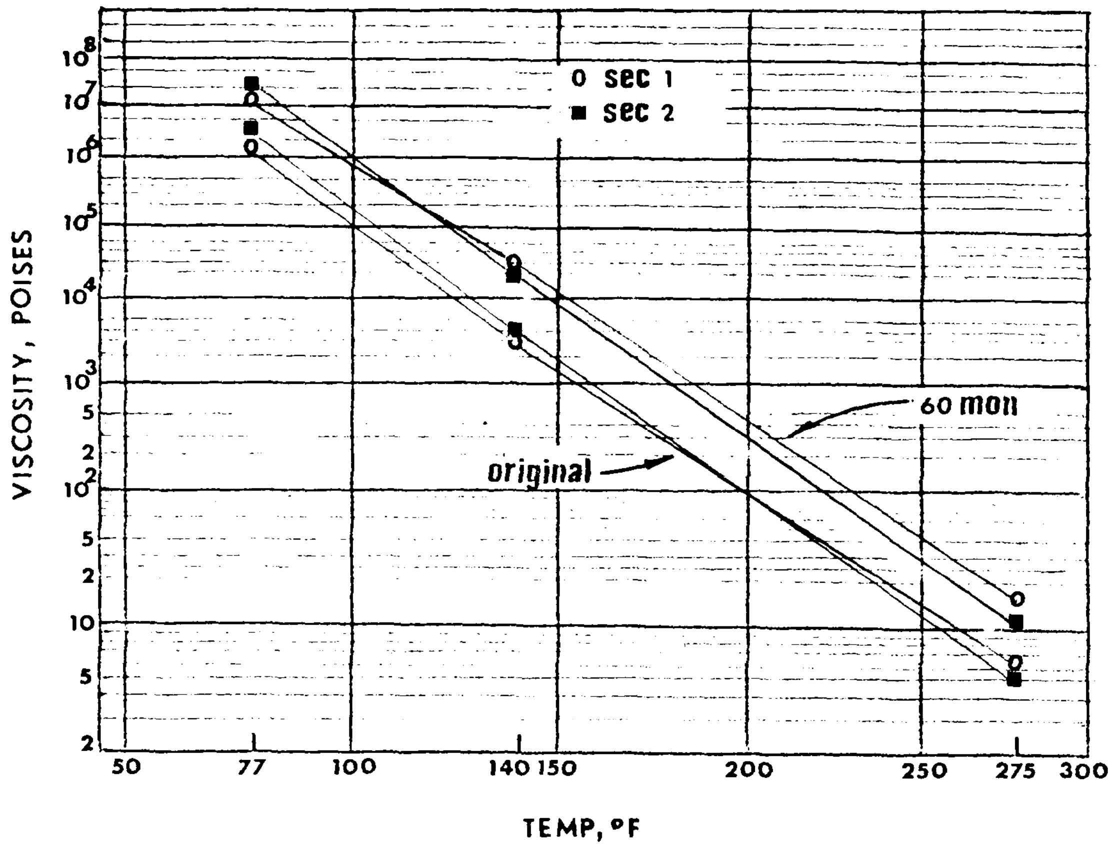


FIGURE 5.13: VISCOSITY - TEMPERATURE RELATIONSHIP OF ASPHALT CEMENT SECTIONS 1 AND 2

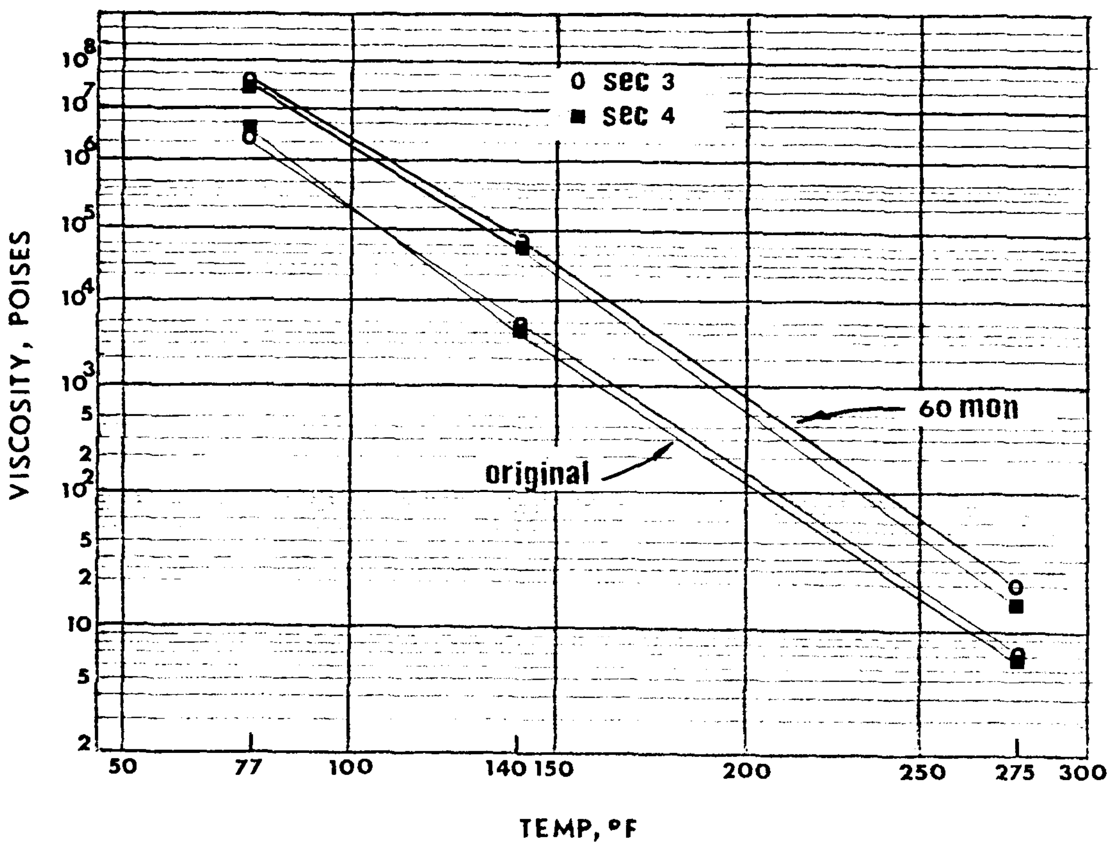


FIGURE 5.14: VISCOSITY - TEMPERATURE RELATIONSHIP OF ASPHALT CEMENT SECTIONS 3 AND 4

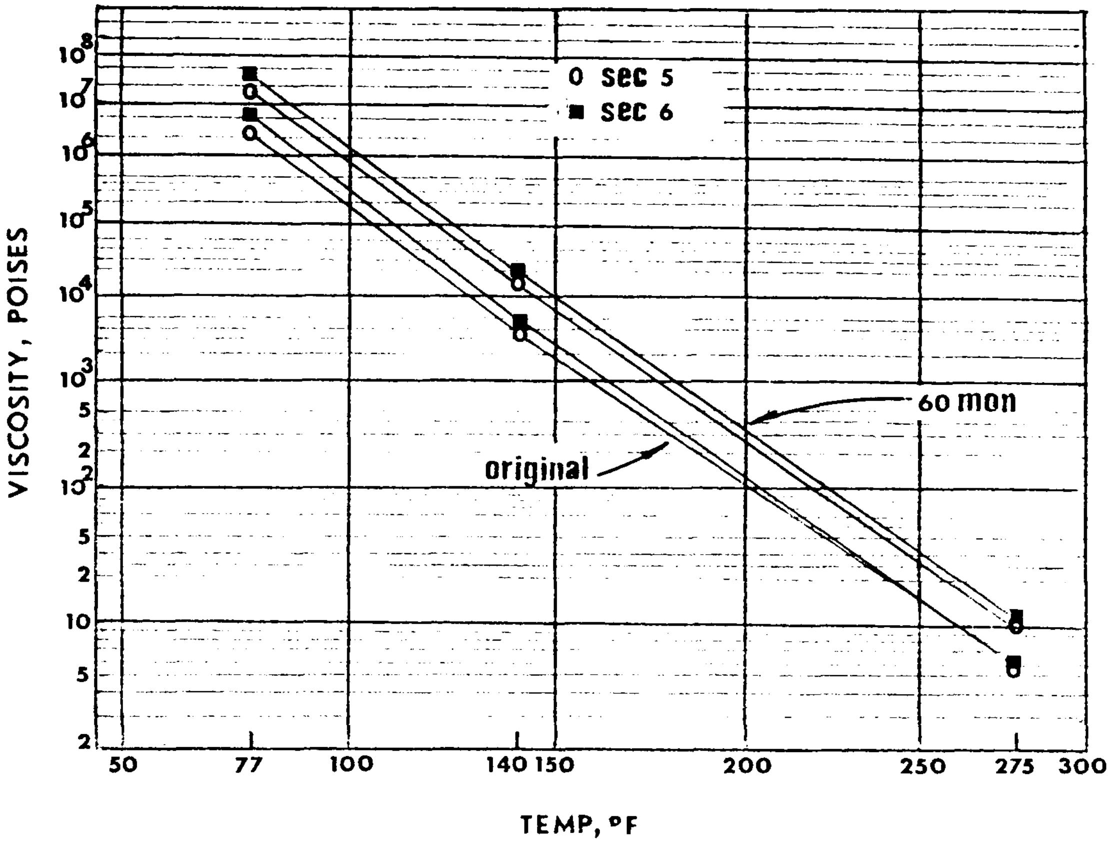


FIGURE 5.15: VISCOSITY - TEMPERATURE RELATIONSHIP OF ASPHALT CEMENT SECTIONS 5 AND 6

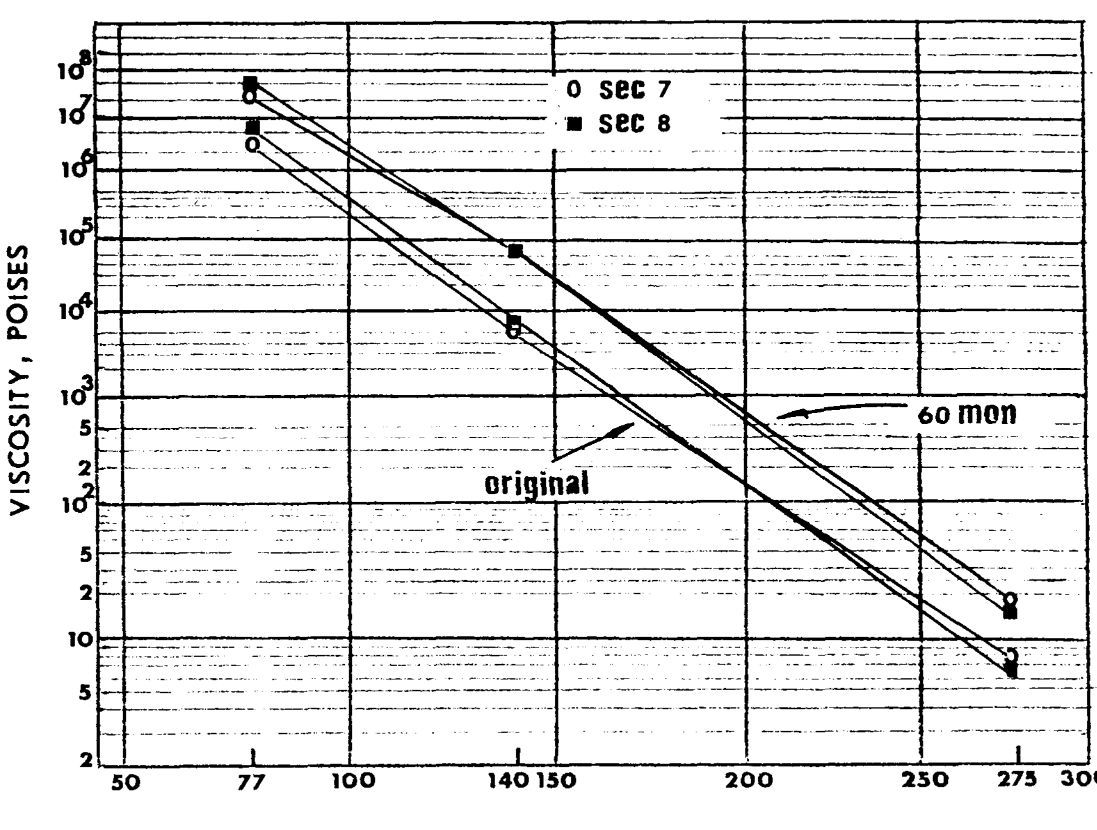


FIGURE 5.16: VISCOSITY - TEMPERATURE RELATIONSHIP OF ASPHALT CEMENT SECTIONS 7 AND 8

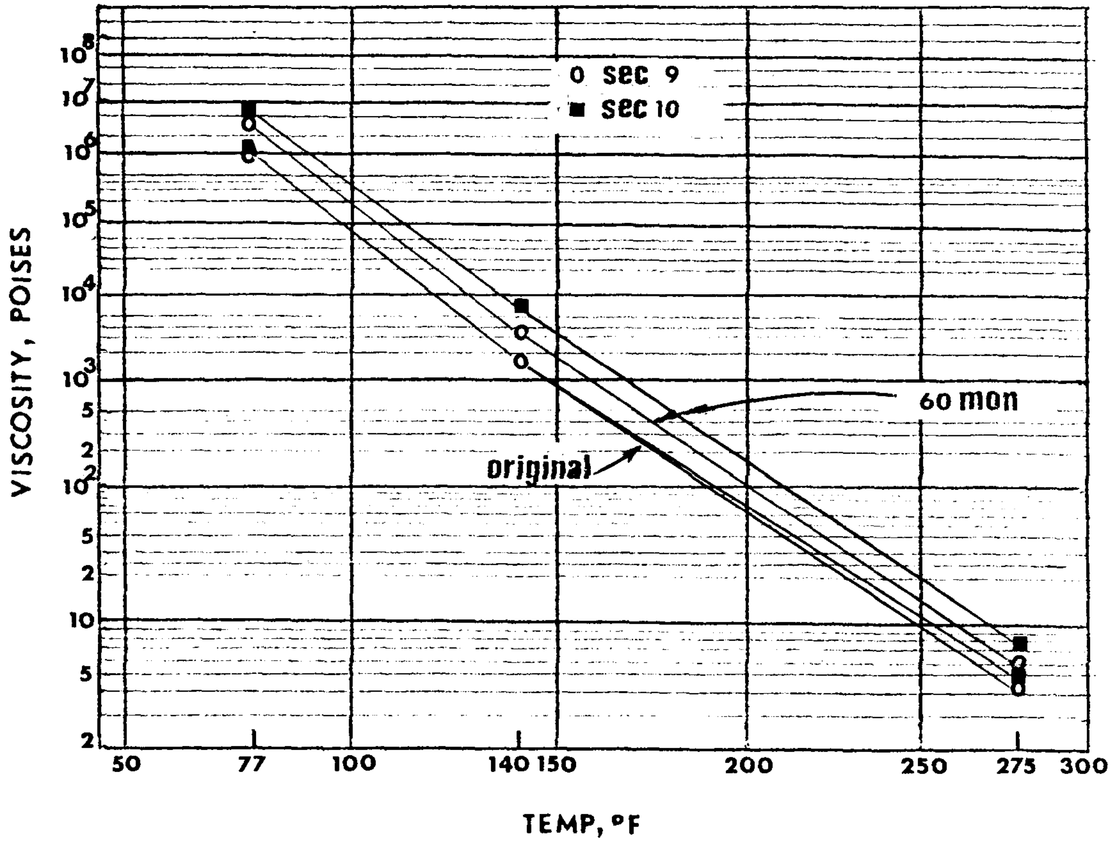


FIGURE 5.17: VISCOSITY - TEMPERATURE RELATIONSHIP OF ASPHALT CEMENT SECTIONS 9 AND 10

From Figure 5.12 it can be seen that the viscosity-graded asphalts are more susceptible to temperature changes than the corresponding penetration-graded asphalts. This is further indicated by steeper slopes of these asphalts in Figures 5.13 through 5.17. Figure 5.12 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 is indicated by Sections 2, 5, 6, 9 and 10. These sections indicate high retained ductility values after 60-month 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.

Temperature susceptibility values have been shown to be highly correlated with the transverse cracking in the pavement (7). The performance data indicated in Table 3.3 does 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

Figures 5.18 and 5.19 show changes in void content with time. Almost all sections had reached the void content of 5.0 percent within three years of traffic service. During the last two years, there has been practically no change in void content. The resistance to compaction may be associated to the consistency of asphalts. The harder the original viscosity, the greater may be its resistance to compaction. 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, the most.

It is generally recognized that the degree of initial and final compaction and/or void content in the pavement has an effect on the rate of hardening of asphalts. More specifically, the higher the initial void content, the greater will be the rate of hardening of asphalt in the pavement. In order to investigate this relationship Figure 5.20 was prepared. The plots show initial and final void content and Viscosity Index at 60 C and Penetration Index at 25 C. The data is 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 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 shows softer asphalt (9 and 10) to offer less resistance to compaction and as such is able to satisfy lower void content requirements.

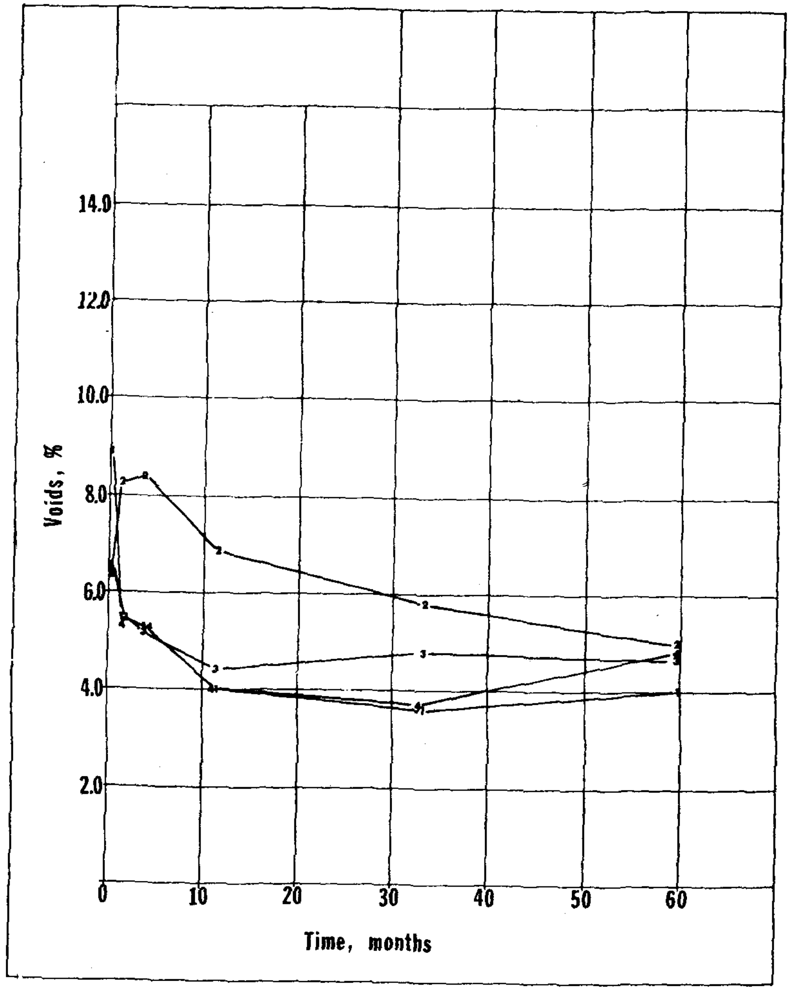


FIGURE 5.18: CHANGE IN AIR VOIDS WITH TIME

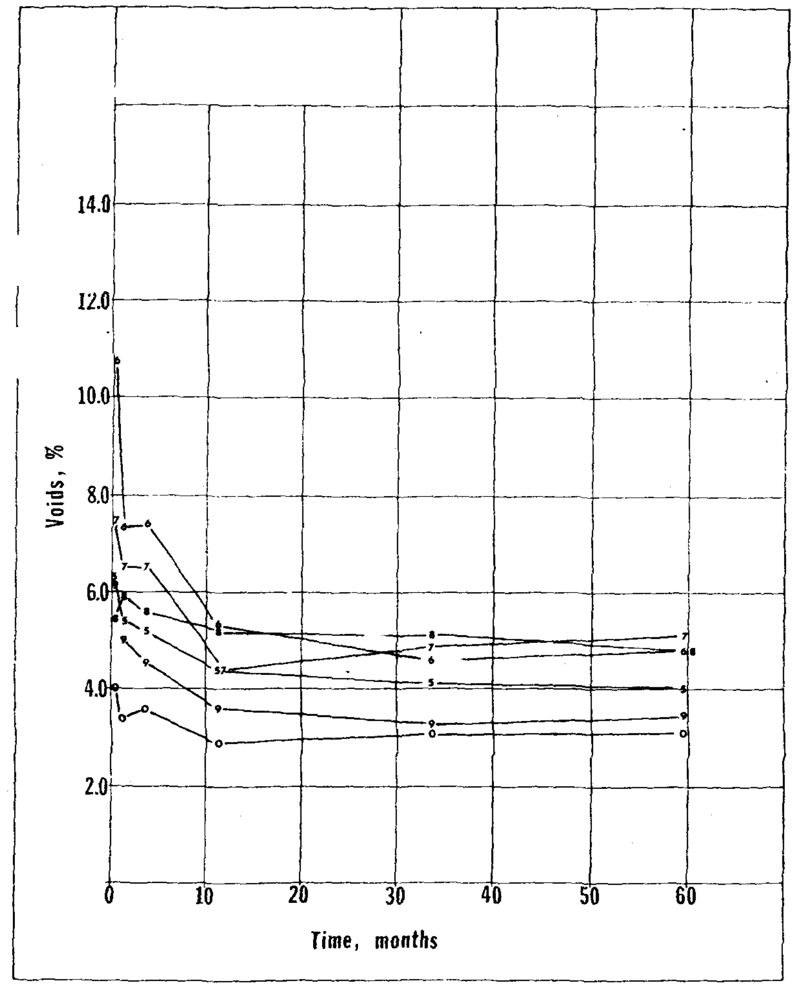


FIGURE 5.19: CHANGE IN AIR VOIDS WITH TIME

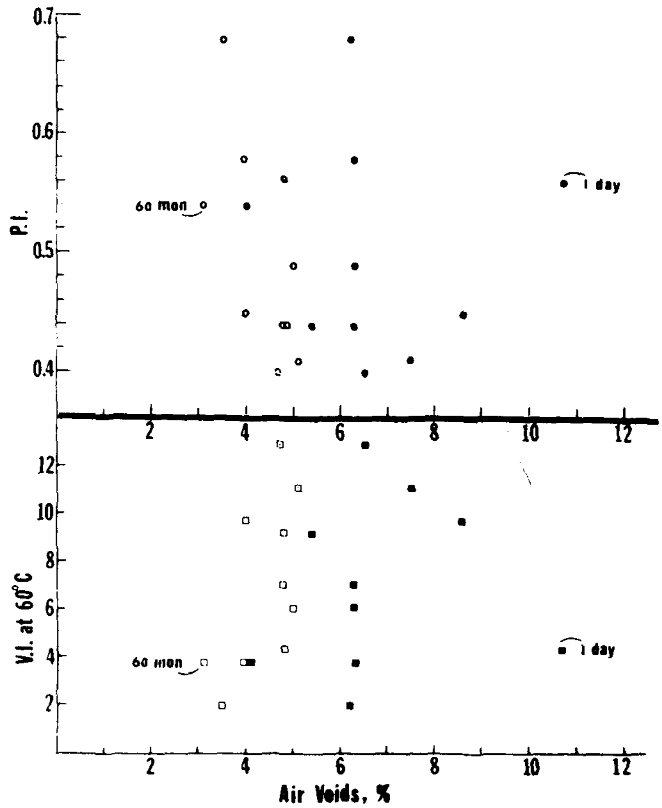


FIGURE 5.20: EFFECTS OF AIR VOIDS ON HARDENING RATE OF ASPHALTS

Gradation, Stability, etc.

After 60-months of traffic, no aggregate degradation seems to have occurred on these sections. As would be expected, the strength values have increased due to the increase in binder viscosity. The effect of asphalt content on the hardening characteristics of various binders could not be isolated since all sections had the same percentage of binder to start with.

6. FIELD PERFORMANCE VERSUS RHEOLOGICAL PROPERTIES

In the preceding section it was shown that asphalts exhibit a wide variation in their hardening characteristics. Specifications for asphalts generally relate to their durability which in turn relate to their useful life in pavements. 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 using criteria of limiting value and various aging indices. Based on these criteria, the ten 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 as discussed in Table 3.3. These comparative rankings are tabulated in Table 6.1. As was discussed before, the rankings according to various index criteria are based on the magnitude of the slopes of the Index-Time curve relationship, with flatter shopes indicative of more durable asphalts. The limiting value rankings were determined from a hyperbolic relationship (Equation 1) discussed in the early portion of Section 5 of this report.

It is seen from Table 6.1 that practically all durability criteria seem to be consistent with respect to the ranking of the most durable asphalt, namely, Sections 9 and 10. The rankings by these criteria are also consistent with the actual field performance rankings. However, there is no consistency for the least durable scale. Furthermore, prediction of durability using limiting value criteria correlates better with the observed field performance of various asphalts.

The data in the table does 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 the other. 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 criteria. The instability of the underlying layers may have contributed to the observed distress since deflection measurements with the dynaflect had indicated maximum value of this parameter for the section. However, because of lack of original data on deflection, this association may not be definitive. If major maintenance is not done on these sections, future evaluation may be accomplished to establish definite cause-effect trends of these sections.

TABLE 6.1
DURABILITY RANKING USING VARIOUS CRITERIA

DURABILITY CRITERION	SECTION OR ASPHALT TYPE									
	1	2	3	4	5	6	7	8	9	10
	RANKING									
FIELD PERFORMANCE (TABLE 3.3)	10	9	6	8	4	7	5	3	2	1
VISCOSITY INDEX (25C)	6	2	10	5	4	7	8	2	1	3
VISCOSITY INDEX (60C)	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 (60C)	10	5	7	9	3	4	8	6	1	2

7. CONCLUSIONS AND RECOMMENDATIONS

The primary intent of the study reported here was to make a comparative evaluation, with respect to durability and performance, of penetration- and viscosity-graded asphalt cements through field installation in asphaltic concrete mixtures. The principal findings summarized below are applicable within the constraints of the environment, materials, construction and traffic existing 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 with original high viscosity tend to harden more and at a rapid rate. This rate of hardening at 60 C is slightly lower for viscosity-graded asphalt than the corresponding penetration-graded asphalts.

(3) For a given asphalt source the difference in durability, as determined from their rheological characteristics, between the two types of asphalts was not significant. Likewise, no significant difference in their field performance was evident.

(4) By all durability criteria, asphalts one grade softer (AC-20) than the harder viscosity-graded asphalts (AC-40) project desirable durability characteristics and sections constructed with these asphalts are performing better than any other harder grade asphalt after 60-months of service.

(5) Viscosity-graded asphalts are more temperature susceptible than the corresponding penetration graded asphalts. However, there was no correlation between this characteristic and pavement distress.

(6) There was no association between voids in pavement and rate of hardening.

(7) All in all, the 60-month data does not confirm or refute the better performability of either type of asphalt cement.

(8) It is recommended that additional data points be collected to establish the advantages and/or disadvantages of penetration- and viscosity-graded asphalts as manifested by pavement performance.

8. REFERENCES CITED

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(4) A. B. Brown, et al., Rate of Change of Softening Point, Penetration, and Ductility of Asphalt in Bituminous Pavements, Proc. AAPT, Vol 26, 1957.

(5) P. S. Kandhal and M. E. Wenger, Asphalt Properties in Relation to Pavement Performance, Transportation Research Record No. 544, Transportation Research Board, 1975.

(6) Dah-Yin Lee, Asphalt Durability Correlation in Iowa, Highway Research Record No. 468, Highway Research Board, 1973.

(7) D. I. Anderson, et al., Evaluation of Viscosity Graded Asphalt Cements in Utah, Utah Department of Transportation, Materials and Research Division, January 1976.

APPENDIX

TABLE A.1
CONSTRUCTION DATA FOR VARIOUS TEST SECTIONS

TEST SECTION NUMBER	1	2	3	4	5	6	7	8	9	10
ASPHALT SUPPLIERS	A	A	B	B	C	C	D	D	A	B
SOURCE: 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
ROADWAY DATA										
UNIT WEIGHT,LB/CU FT	145.3	145.3	145.1	145.4	145.4	145.4	145.7	145.7	146.5	146.8
MARSHALL STABILITY,LB	1589	1589	1717	1783	1783	1570	1537	1762	1592	1369
FLOW,0.01INCH	7	7	10	12	12	12	10	8	11	11
COMPACTION,%	98	98	97	96	96	98	97	96	98	98
GRADATION DATA ,% PASSING										
3/4 INCH	100	100	100	100	100	100	100	100	100	100
1/2 INCH	94	94	95	96	96	94	94	95	91	94
3/8 INCH	84	84	86	87	87	83	86	85	80	85
NO 4	62	62	64	65	65	61	64	62	58	62
NO 10	46	46	47	47	47	47	50	45	42	46
NO 40	32	32	30	30	30	33	36	30	28	32
NO 80	12	12	12	12	12	12	12	12	9	13
NO 200	8.2	8.2	8.8	8.8	8.8	8.6	8.6	8.6	6.2	9.4
% AC	5.1	5.1	5.2	5.4	5.4	5.2	5.3	5.2	5.2	5.2

TABLE A.2

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 1

SECTION NO. 1-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	630	976	886	882	1041	1302	1697
VISC 60C,POISE	3508	10643	6605	7640	11699	14710	34292
VISC 25C,MEGAPOISE	2.70	12.80	5.60	6.22	9.20	11.00	20.50
VISC INDEX 25C		4.74	2.07	2.30	3.41	4.07	7.59
VISC INDEX 60C		3.03	1.88	2.18	3.33	4.19	9.78
PEN 25C,100GM,5SEC	64	42	49	48	38	36	29
PEN INDEX 25C		0.66	0.77	0.75	0.59	0.56	0.45
DUCT 25C,5CM/MIN,CM	150+	130	150+	145+	150+	116	31
SHEAR INDEX 25C	.165	.435	.295	.260	.325	.415	.516
ROADWAY DATA							
CORE THICKNESS,MM		42	50	48	51	52	44
UNIT WT,LB/CU FT		139.2	143.9	144.2	146.1	146.7	146.2
AIR VOIDS,%		8.6	5.5	5.3	4.0	3.6	4.0
VMA,%		18.8	15.4	15.1	14.1	13.7	14.0
MARSHALL STAB,LBS		723	674	788	1412	2106	2901
FLOW,.01INCH		17	16	15	13	17	13
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		97.2	96.4	95.3	95.8	96.9	94.5
3/8INCH		85.3	85.4	84.7	85.7	88.6	84.1
NO4		63.3	61.3	60.1	61.2	63.5	59.3
NO10		49.5	46.3	45.6	46.1	47.9	44.6
NO40		35.5	33.3	32.7	33.2	34.6	32.5
NO80		13.0	12.8	12.4	12.7	13.5	13.7
NO200		6.8	8.1	7.9	7.9	8.7	8.5
%AC		6.0	5.3	5.0	5.2	5.2	5.2

SECTION NO. 1-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	3654	11948	5132	7963	8834	24276	24388
VISC INDEX 60C		3.27	1.40	2.18	2.42	6.64	6.67
PEN 25C 100GM,5SEC	64	46	71	50	49	44	37
PEN 4C,200GM,60SEC	32	21	18	20	26	22	20
PEN INDEX 25C		0.72	1.11	0.78	0.77	0.69	0.58
DUCT 25C,5CM/MIN,CM	150+	126	150+	150+		90	34
DUCT 10C,5CM/MIN,CM		5.0	4.5	3.5		5.0	3.5

TABLE A.3

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 2

SECTION NO. 2-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	546	770	712	746	1023	1173	1294
VISC 60C,POISE	4681	10220	7557	9814	21875	28596	29893
VISC 25C,MEGAPOISE	6.20	15.00	11.00	13.10	22.50	31.00	37.00
VISC INDEX 25C		2.42	1.77	2.11	3.63	5.00	5.97
VISC INDEX 60C		2.18	1.61	2.09	4.67	6.11	6.11
PEN 25C,100GM,5SEC	41	29	36	33	22	20	20
PEN INDEX 25C		0.71	0.88	0.80	0.54	0.49	0.49
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	150+	34	65
SHEAR INDEX 25C	.115	.275	.225	.265	.405	.495	.484
ROADWAY DATA							
CORE THICKNESS,MM		42	51	50	49	45	38
UNIT WT,LB/CU FT		142.7	139.7	139.4	141.7	143.4	144.7
AIR VOIDS,%		6.3	8.2	8.4	6.9	5.8	5.0
VMA,%		16.2	18.0	18.2	16.8	15.5	14.9
MARSHALL STAB,LBS		485	461	544	1257	2607	4080
FLOW,.01INCH		23	17	17	14	14	11
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		95.6	98.2	98.7	97.6	96.8	97.4
3/8INCH		83.6	89.0	91.6	88.9	88.4	88.4
NO4		60.8	66.4	69.8	66.3	66.0	65.1
NO10		46.5	48.0	50.6	48.4	48.2	48.6
NO40		33.9	32.2	33.6	32.5	32.6	33.2
NO80		12.8	13.3	13.5	13.3	13.8	15.1
NO200		8.0	8.8	9.1	8.7	9.1	9.6
%AC		5.3	5.4	5.4	5.3	5.0	5.2

SECTION NO. 2-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	4823	6664	6690	10239	13601	27734	23571
VISC INDEX 60C		1.38	1.39	2.12	2.82	5.75	4.89
PEN 25C 100GM,5SEC	45	44	34	38	33	24	26
PEN 4C,200GM,60SEC		14	14	23	17	12	12
PEN INDEX 25C		0.98	0.76	0.84	0.73	0.53	0.58
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+		118	150+
DUCT 10C,5CM/MIN,CM		5.0	1.0	3.0		4.0	3.5

TABLE A.4

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 3

SECTION NO. 3-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	744	1036	1059	1203	1531	1965	2162
VISC 60C,POISE	4810	8092	9922	14019	27090	56030	62409
VISC 25C,MEGAPOISE	3.40	6.40	8.30	10.00	12.50	22.50	38.00
VISC INDEX 25C		1.88	2.44	2.94	3.68	6.62	11.18
VISC INDEX 60C		1.68	2.06	2.91	5.63	11.65	12.97
PEN 25C,100GM,5SEC	58	50	46	41	31	24	23
PEN INDEX 25C		0.86	0.79	0.71	0.53	0.41	0.40
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	86	29	30
SHEAR INDEX 25C	.210	.300	.350	.340	.420	.510	.593
ROADWAY DATA							
CORE THICKNESS,MM		37	42	44	43	42	35
UNIT WT,LB/CU FT		142.3	143.9	144.3	145.5	144.9	145.1
AIR VOIDS,%		6.5	5.5	5.2	4.4	4.8	4.7
VMA,%		16.4	15.6	15.1	14.6	14.4	14.6
MARSHALL STAB,LBS		849	900	975	1649	2679	4079
FLOW,.01INCH		17	17	16	13	16	12
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		95.8	95.3	95.2	94.3	93.2	94.3
3/8INCH		82.9	82.6	82.7	84.4	81.5	83.9
NO4		61.9	60.5	61.7	61.8	57.3	59.8
NO10		45.3	44.4	45.4	45.2	42.0	43.8
NO40		30.2	29.5	30.1	29.8	28.3	29.3
NO80		12.4	12.2	11.9	12.0	11.9	13.0
NO200		7.8	7.7	7.9	7.7	7.7	7.8
%AC		5.3	5.2	5.2	5.3	4.8	5.1

SECTION NO. 3-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	5687	14203	13102	12938	19720	62398	75123
VISC INDEX 60C		2.49	2.30	2.28	3.47	10.97	13.21
PEN 25C 100GM,5SEC	66	50	45	47	37	34	27
PEN 4C,200GM,60SEC	30	20	18	26	21	16	17
PEN INDEX 25C		0.[illegible]	0.68	0.71	0.56	0.52	0.41
DUCT 25C,5CM/MIN,CM	150+	150+	97	87		28	11
DUCT 10C,5CM/MIN,CM		9.3	5.[illegible]	1.0		4.0	4.0

TABLE A.5

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 4

SECTION NO. 4-AI

	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	611	828	834	858	1073	1255	1485
VISC 60C,POISE	4232	8915	7944	10045	16884	30081	47543
VISC 25C,MEGAPOISE	4.40	11.00	11.00	12.80	17.00	24.00	35.00
VISC INDEX 25C		2.50	2.50	2.91	3.86	5.45	7.95
VISC INDEX 60C		2.11	1.88	2.37	3.99	7.11	7.11
PEN 25C,100GM,5SEC	48	39	41	36	27	23	21
PEN INDEX 25C		0.81	0.85	0.75	0.56	0.48	0.44
DUCT 25C,5CM/MIN,CM	150+	150+	150+	138	118	28	15
SHEAR INDEX 25C	.180	.320	.310	.350	.420	.475	.579
ROADWAY DATA							
CORE THICKNESS,MM		40	43	42	43	42	37
UNIT WT,LB/CU FT		142.6	144.1	144.0	146.2	146.7	145.0
AIR VOIDS,%		6.3	5.4	5.4	4.0	3.7	4.8
VMA,%		16.1	15.2	15.3	14.2	13.6	14.7
MARSHALL STAB,LBS		945	903	901	1679	3161	4226
FLOW,.01INCH		19	16	15	14	16	11
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		93.7	96.2	97.0	97.3	96.2	96.5
3/8INCH		81.9	83.8	84.4	84.4	85.0	85.3
NO4		61.9	61.1	61.4	63.1	62.2	61.5
NO10		45.4	44.5	45.2	46.3	45.1	44.8
NO40		30.8	30.1	30.7	31.3	30.9	30.6
NO80		13.3	12.7	12.6	12.9	13.2	13.5
NO200		8.6	8.2	8.5	8.5	9.0	8.4
%AC		5.1	5.1	5.2	5.3	5.0	5.2

SECTION NO. 4-LDH

	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	4560		14699	11195	10817	40978	52566
VISC INDEX 60C			3.22	2.46	2.37	8.99	11.53
PEN 25C 100GM,5SEC	51		33	40	40	28	25
PEN 4C,200GM,60SEC			19	22	20	18	14
PEN INDEX 25C			0.65	0.78	0.78	0.55	0.49
DUCT 25C,5CM/MIN,CM	150+		113	49		39	16
DUCT 10C,5CM/MIN,CM			2.8	2.8		4.0	3.5

TABLE A.6

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 5

SECTION NO. 5-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	597	666	728	794	985	1038	1044
VISC 60C,POISE	3296	3979	4590	7254	12379	18567	12569
VISC 25C,MEGAPOISE	3.10	3.70	5.50	8.20	12.50	17.00	14.60
VISC INDEX 25C		1.19	1.77	2.65	4.03	5.48	4.71
VISC INDEX 60C		1.21	1.39	2.20	3.76	5.63	3.81
PEN 25C,100GM,5SEC	61	60	52	44	33	30	35
PEN INDEX 25C		0.98	0.85	0.72	0.54	0.49	0.57
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	141	43	150+
SHEAR INDEX 25C	.145	.155	.240	.330	.415	.480	.264
ROADWAY DATA							
CORE THICKNESS,MM		43	35	34	33	35	42
UNIT WT,LB/CU FT		142.7	144.0	144.4	145.5	146.0	146.1
AIR VOIDS,%		6.3	5.4	5.2	4.4	4.1	4.0
VMA,%		16.1	15.1	15.0	14.2	13.8	14.1
MARSHALL STAB,LBS		630	991	980	1713	3057	2579
FLOW,.01INCH		16	11	12	11	11	10
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		97.4	94.5	95.2	95.8	95.8	95.7
3/8INCH		87.1	84.3	85.1	85.4	85.0	84.3
NO4		61.8	62.5	62.4	61.2	61.7	62.3
NO10		43.7	46.0	46.5	45.4	45.8	46.8
NO40		28.8	31.8	32.3	31.6	31.9	32.9
NO80		11.8	13.3	13.2	13.0	13.3	14.2
NO200		7.7	8.3	8.6	8.3	8.6	8.7
%AC		5.3	5.0	5.1	5.0	4.9	5.2

SECTION NO. 5-LOH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	3427	4955	9157	5112	7138	18611	15217
VISC INDEX 60C		1.45	2.67	1.49	2.08	5.43	4.44
PEN 25C 100GM,5SEC	66	58	49	69	44	38	38
PEN 4C,200GM,60SEC	30	22	28	28	25	21	18
PEN INDEX 25C		0.88	0.74	1.05	0.67	0.58	0.58
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+		77	81
DUCT 10C,5CM/MIN,CM		7.8	1.5	1.5		4.0	4.0

TABLE A.7

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 6

SECTION NO. 6-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	598	682	742	777	1014	1124	1108
VISC 60C,POISE	4583	6016	7913	9129	15311	19385	19942
VISC 25C,MEGAPOISE	6.20	9.90	14.00	11.50	23.00	37.00	39.00
VISC INDEX 25C		1.59	2.26	1.85	3.71	5.97	6.29
VISC INDEX 60C		1.31	1.73	1.99	3.34	4.23	4.35
PEN 25C,100GM,5SEC	34	33	28	24	19	19	19
PEN INDEX 25C		0.97	0.82	0.71	0.56	0.56	0.56
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	150+	150+	142+
SHEAR INDEX 25C	.100	.170	.200	.205	.335	.341	.436
ROADWAY DATA							
CORE THICKNESS,MM		43	42	40	41	40	42
UNIT WT,LB/CU FT		136.0	141.2	141.0	144.2	145.2	144.9
AIR VOIDS,%		10.7	7.3	7.4	5.3	4.6	4.8
VMA,%		20.1	16.8	16.9	15.2	14.4	14.9
MARSHALL STAB,LBS		319	522	522	1278	2155	2739
FLOW,.01INCH		17	15	19	10	16	13
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		95.7	92.4	93.7	94.5	92.0	93.1
3/8INCH		82.8	80.0	83.1	82.4	81.6	82.7
NO4		61.0	59.0	61.2	61.4	60.2	60.2
NO10		48.2	45.4	47.0	47.3	46.3	46.0
NO40		35.6	33.3	34.3	34.7	34.0	34.0
NO80		14.1	12.5	11.8	12.6	12.3	13.0
NO200		9.0	7.6	7.7	7.7	7.8	7.7
%AC		5.3	5.0	5.1	5.2	5.0	5.3

SECTION NO. 6-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	4665	4936	6323	6483	8012	30670	14588
VISC INDEX 60C		1.06	1.36	1.39	1.72	6.57	3.13
PEN 25C 100GM,5SEC	43	47	39	35	34	26	35
PEN 4C,200GM,60SEC		15	18	21	14	14	12
PEN INDEX 25C		1.09	0.91	0.81	0.79	0.60	0.81
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+		150+	150+
DUCT 10C,5CM/MIN,CM		2.0	1.5			1.0	6.0

TABLE A.8
PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 7

SECTION NO. 7-AI

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	654	810	862	980	1194	1512	1709
VISC 60C,POISE	4717	8889	9652	11711	20327	37292	52948
VISC 25C,MEGAPOISE	3.20	8.00	8.00	10.50	13.50	23.00	28.00
VISC INDEX 25C		2.50	2.50	3.28	4.22	7.19	8.75
VISC INDEX 60C		1.88	2.05	2.48	4.31	7.91	11.22
PEN 25C,100GM,5SEC	56	43	42	38	30	26	23
PEN INDEX 25C		0.77	0.75	0.68	0.54	0.46	0.41
DUCT 25C,5CM/MIN,CM	150+	115	150+	125	88	17	14
SHEAR INDEX 25C	.200	.324	.354	.350	.435	.538	.530
ROADWAY DATA							
CORE THICKNESS,MM		42	44	42	44	46	42
UNIT WT,LB/CU FT		140.8	142.3	142.4	145.5	144.9	144.5
AIR VOIDS,%		7.5	6.5	6.5	4.4	4.8	5.1
VMA,%		17.3	16.0	16.2	14.6	14.8	14.9
MARSHALL STAB,LBS		403	518	545	1134	2024	2236
FLOW,.01INCH		17	13	17	13	14	13
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		93.6	90.0	93.0	93.7	93.3	93.1
3/8INCH		83.7	79.0	81.8	83.3	82.2	79.1
NO4		61.4	57.8	60.4	60.0	57.9	57.5
NO10		47.7	44.8	47.1	46.1	44.5	44.3
NO40		35.3	33.5	35.0	34.0	32.8	33.1
NO80		12.2	11.9	11.4	11.6	11.3	12.1
NO200		7.3	7.3	7.6	7.1	7.0	7.2
%AC		5.4	4.9	5.2	5.3	5.2	5.1

SECTION NO. 7-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	4799	12353	276	7016	12762	64200	26542
VISC INDEX 60C		2.57	1.93	1.46	2.66	13.38	5.53
PEN 25C 100GM,5SEC	64	48	48	52	41	34	32
PEN 4C,200GM,60SEC	30	21	24	31	22	19	18
PEN INDEX 25C		0.75	0.75	0.81	0.64	0.53	0.50
DUCT 25C,5CM/MIN,CM	150+	84	96	150+		16	31
DUCT 10C,5CM/MIN,CM		3.5	1.5			3.0	4.0

TABLE A.9
PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 8

SECTION NO. 8-A1

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	579	794	846	1023	1437	1695	1509
VISC 60C,POISE	5687	10400	12789	20087	48985	86220	52807
VISC 25C,MEGAPOISE	6.70	14.00	16.50	22.80	36.50	43.00	35.20
VISC INDEX 25C		2.09	2.46	3.40	5.45	6.42	5.25
VISC INDEX 60C		1.83	2.25	3.53	8.61	15.16	9.29
PEN 25C,100GM,5SEC	39	36	31	26	17	17	17
PEN INDEX 25C		0.92	0.79	0.67	0.44	0.44	0.44
DUCT 25C,5CM/MIN,CM	150+	150+	120	116	11	7	14
SHEAR INDEX 25C	.189	.340	.366	.433	.570	.597	.572
ROADWAY DATA							
CORE THICKNESS,MM		51	36	44	42	40	45
UNIT WT,LB/CU FT		143.7	143.3	143.7	144.4	144.5	144.9
AIR VOIDS,%		5.4	5.9	5.6	5.2	5.1	4.8
VMA,%		15.4	15.4	15.4	15.3	14.8	14.9
MARSHALL STAB,LBS		1024	1087	1285	1516	4188	3307
FLOW,.01INCH		11	12	14	11	12	17
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		94.1	94.1	95.2	96.8	94.3	95.8
3/8INCH		83.4	83.3	85.2	86.0	83.1	86.1
NO4		62.1	60.3	63.1	63.3	61.5	62.1
NO10		45.3	44.9	46.0	47.1	44.8	45.6
NO40		30.9	30.7	31.5	32.3	31.0	31.8
NO80		12.3	12.4	11.8	12.6	12.4	12.9
NO200		7.7	7.9	8.0	8.1	8.1	8.1
%AC		5.1	5.0	5.2	5.4	5.0	5.3

SECTION NO. 8-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	5354	22778	21131	13053	16611	99600	59609
VISC INDEX 60C		4.25	3.95	2.44	3.10	18.60	11.13
PEN 25C 100GM,5SEC	50	37	30	41	27	23	23
PEN 4C,200GM,60SEC		14	23	22	16	12	14
PEN INDEX 25C		0.74	0.60	0.82	0.54	0.46	0.46
DUCT 25C,5CM/MIN,CM	150+	88	53	116		14	14
DUCT 10C,5CM/MIN,CM		2.0	6.3			1.0	4.0

TABLE A.10

PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 9

SECTION NO. 9-A1

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	338	440	471	454	472	500	503
VISC 60C,POISE	1786	2885	3082	3225	3351	3245	3665
VISC 25C,MEGAPOISE	1.50	3.25	1.75	3.20	3.00	3.20	4.00
VISC INDEX 25C		2.17	1.17	2.13	2.00	2.13	2.67
VISC INDEX 60C		1.61	1.73	1.81	1.88	1.82	2.05
PEN 25C,100GM,5SEC	74	60	55	56	52	57	50
PEN INDEX 25C		0.81	0.74	0.76	0.70	0.77	0.68
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	150+	150+	150+
SHEAR INDEX 25C	.081	.150	.073	.113	.164	.138	.160
ROADWAY DATA							
CORE THICKNESS,MM		43	48	50	50	49	46
UNIT WT,LB/CU FT		142.8	144.7	145.4	146.7	147.3	147.0
AIR VOIDS,%		6.2	5.0	4.5	3.6	3.3	3.5
VMA,%		15.9	15.0	14.6	13.9	13.2	13.5
MARSHALL STAB,LBS		370	568	752	733	1541	1746
FLOW,.01INCH		14	11	12	11	12	13
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		94.0	94.3	94.5	93.9	92.8	92.9
3/8INCH		81.3	84.2	84.3	83.0	92.2	82.1
NO4		59.4	61.2	60.9	61.5	59.5	60.4
NO10		44.5	45.1	45.4	45.5	44.0	44.7
NO40		31.7	31.6	31.9	31.9	31.2	31.7
NO80		12.0	12.2	11.4	11.9	11.8	12.7
NO200		7.7	7.7	7.8	7.7	7.8	7.9
%AC		5.1	5.3	5.3	5.4	5.1	5.2

SECTION NO. 9-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	1857	3550	3499	2357	2757	5844	3393
VISC INDEX 60C		1.91	1.88	1.26	1.48	3.15	1.83
PEN 25C 100GM,5SEC	84	62	60	81	68	58	64
PEN 4C,200GM,60SEC		25	25	32		26	27
PEN INDEX 25C		0.74	0.71	0.96	0.81	0.69	0.76
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+		150+	150+
DUCT 10C,5CM/MIN,CM		2.0	12.0			1.0	18.0

TABLE A.11
PHYSICAL PROPERTIES OF AGED ASPHALT CEMENT AND ROADWAY MIX FOR SECTION 10

SECTION NO. 10-A1

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1825
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 135C,CS	418	619	558	640	596	632	669
VISC 60C,POISE	1891	3048	3695	3832	4415	4932	7175
VISC 25C,MEGAPOISE	1.40	2.95	2.30	4.20	3.70	5.10	8.20
VISC INDEX 25C		2.11	1.64	3.00	2.64	3.64	5.86
VISC INDEX 60C		1.61	1.95	2.03	2.33	2.61	3.79
PEN 25C,100GM,5SEC	81	66	60	59	51	51	44
PEN INDEX 25C		0.81	0.74	0.73	0.63	0.63	0.54
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+	150+	150+	150+
SHEAR INDEX 25C	.120	.150	.132	.213	.229	.268	.333
ROADWAY DATA							
CORE THICKNESS,MM		33	36	39	37	36	34
UNIT WT,LB/CU FT		146.3	147.0	146.8	147.9	147.5	147.5
AIR VOIDS,%		4.0	3.4	3.6	2.9	3.1	3.1
VMA,%		14.1	13.4	14.1	13.0	13.3	13.3
MARSHALL STAB,LBS		830	966	1024	1075	1790	2285
FLOW,.01INCH		13	13	13	10	14	10
GRADATION DATA,% PASSING							
3/4INCH		100	100	100	100	100	100
1/2INCH		95.1	91.7	93.1	95.3	91.4	90.9
3/8INCH		81.0	77.0	80.8	81.6	80.9	80.0
NO4		58.3	56.5	58.5	58.0	59.1	57.7
NO10		43.9	43.1	44.7	43.6	44.5	43.7
NO40		31.8	31.5	32.5	31.8	32.7	32.2
NO80		12.6	12.8	12.3	12.3	12.7	13.5
NO200		7.9	8.1	8.3	8.0	8.2	8.2
%AC		5.3	5.2	5.7	5.2	5.2	5.3

SECTION NO. 10-LDH

PAVEMENT AGE,DAYS	ORIG	1	36	110	345	1000	1800
PAVEMENT AGE,MONTHS		.03	1.20	3.67	11.50	33.33	60
ASPHALT CEMENT TEST DATA							
VISC 60C,POISE	1815	3900	3937	2825	3584	9299	4866
VISC INDEX 60C		2.15	2.17	1.56	1.97	5.12	2.68
PEN 25C 100GM,5SEC	96	70	58	72	67	53	61
PEN 4C,200GM,60SEC		31	26	37		25	31
PEN INDEX 25C		0.73	0.60	0.75	0.69	0.55	0.64
DUCT 25C,5CM/MIN,CM	150+	150+	150+	150+		150+	150+
DUCT 10C,5CM/MIN,CM		5.5	36.8			1.0	12.0