FINAL REPORT ON PROJECT RP-3

IMPROVEMENT OF ASPHALTIC MATERIALS

by

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Report Prepared for

The Texas Highway Department

February, 1961

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Texas A. & M. College System
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Synopsis

The investigation reported herein concerns the changes which have occurred in asphalt cements recovered from test roads during six years of service. Results of standardized tests and special tests performed on the asphalts are shown to compare the initial properties of the asphalts with subsequent changes in physical and chemical properties.

Different testing instruments and methods were used to determine their desirability for evaluating fundamental and empirical properties of the asphalts used in the test roads.

The trend of changes in asphalt occurring with age is presented and tentative recommendations are suggested for the specification of asphalts in order to improve or to make better use of certain fundamental properties of asphalts.

This constitutes the final report of a cooperative study with the Texas Highway Department. Earlier progress reports on this research have been presented to the Texas Highway Department.

Conclusions & Recommendations

A study of the data presented shows that definite changes do occur in asphalts in the pavement and that the methods used in the laboratory to predict these changes do distinguish the capacities of asphalts to physical and chemical changes. The data also show that construction procedures are of paramount importance in their effects on performance of asphaltic pavements. Proper attention to the construction details of surface treatment type pavements makes it possible to overcome, in considerable measure, certain apparent weaknesses in the asphalt cement. The following are general recommendations for the specifications of asphalts to be used in pavements.

Acceptance Tests. The present standard tests used for the specifications of asphalts will not be discussed here since much has already been written concerning these. It would be desirable to include test methods that measure fundamental properties of asphalts and in the conditions simulating those in natural service exposure.

Consistency determinations should be made with a viscometer employing asphalt film thicknesses comparable to those in the pavement; the ideal would be a rotary-type viscometer.

An aging or artificial weathering test is recommended for distinguishing the aging susceptibilities of asphalts. From the data presented herein, it cannot be stated which one of the four methods used is the best or what limits to set to make distinctions between good and poor, but for ease and simplicity the Shell method is recommended.

A specification requirement for aggregate wetting would be of great value. The bond between the asphalt and aggregate must be established early in the construction process, otherwise, traffic will remove the coverstone. The demonstrated advantage of precoated coverstone leaves no question on this point.

Component analysis of asphalts is not recommended as such for acceptance tests, but should be performed by large consumers such as highway departments in order to correlate composition with road service. The method of Traxler and Schweyer is relatively simple and the results may be used to advantage in conjunction with asphaltene contents.

<u>Construction</u>. One of the reasons for failure in the surface-treatment pavements studied in this investigation has been poor surface-to-base bond. Particular attention to this condition should minimize pavement failures where this is a contributory factor. Adequate base density improves surface-to-base bond strength. In surface treatment work, the temperature susceptibility of the asphalt should be taken into consideration in establishing spraying temperatures. For some asphalts, the degree of fluidity for spreading may need to be obtained with certain additives rather than by temperature. Field tests have shown that regardless of application, air or ground temperatures the applied asphalt reaches ground temperature in less than three minutes. Many tests have shown temperature equilibrium in two minutes after spraying. Construction procedures in general use today do not make it possible to take advantage of the reduction in consistency caused by elevated temperature.

It has been common knowledge for many years that design and construction powerfully influence the success of a job regardless of material quality. Material quality is none the less important. The best job will, of course, result when proper attention is directed toward good design, adequate inspection by a qualified inspector and good construction techniques.

As a general rule, double surface treatments are to be preferred with attention directed toward the following factors:

1. Base density should be adequate to prevent the coverstone from being forced into the base due to service loads and tire pressures. For new construction it may be advisable to evaluate surface density in the field before aggregate size selection is made.

2. The prepared base should be properly primed to seal the surface capillaries, bind loose particles and prepare the surface for proper bond of the surface to follow.

3. The asphalt cement used to further waterproof the surface and hold the coverstone should be fairly hard at average use temperatures. For use in warm climates 100 to 150 penetration material is preferred. Certain areas of the southwestern United States may successfully utilize even harder materials.

4. Either crushed stone or rounded gravel of good quality may be used to produce good surface treatments. The grading should cover a very narrow band of sizes and the material should be dry and essentially free of dust when applied unless special precautions are taken to eliminate the effects of these factors. Coverstone size should be as large as the traffic noise level will permit. This allows greater tolerances in material quantities and construction techniques.

5. The use of heated coverstone and mechanical spreaders are highly recommended regardless of air and road temperatures.

6. Differences in the sizes of two grades of coverstone used, say, in a double, should not be too large. For example, it is not considered wise to use as the first course, a material graded from 1/4" to 3/4" (with most of the material retained on the 1/2" sieve) with a second course consisting of material graded from No. 20 mesh to 3/8" with 20% or less retained on the 1/4" sieve. For surface treatment and seal coat work, not more than five grades (size ranges) of stone are justified and these should contain groups of sizes that range from about 1-inch to about No. 10 mesh.

7. The amount of asphalt cement used to bind the stone to the surface should be adequate to embed the stone in its service condition to about 50%. Stone embedded 75% after two or three years of service indicates good judgement in design and construction. Due to the texture of the surface being sprayed, the asphalt required on the second shot of a double is about 50% greater than that required on the first shot. For example, if the first course alone required 0.35 gallons per square yard and the second course alone required 0.25 gallons per square yard for a total of 0.60 gallons, then in placing this surface one should use 0.25 on the first shot and 0.35 on the second shot; the larger amount being used on the second shot because the surface would have much more texture than the finished base had.

8. Rolling with pneumatic tired rollers is considered a definite advantage. Steel rollers may be used in the final rolling of multi-course surface treatments, but should not be used at all on single surface treatments or seals. This is particularly important with the softer coverstones and high density bases.

9. The surface should be swept free of loose stone after final stone seating is completed.

Introduction

The asphalt technologist, whether he be a producer, laboratory man, or in construction, has been aware for a long time that asphalts are different as to their compositions, handling or working characteristics, and service behaviors. Many investigations have been carried through in the field and laboratory in an attempt to determine the necessary properties of asphalt for the construction of durable pavements and the best methods of measuring these properties. These studies were made primarily to obtain a "yard-stick" to distinguish between satisfactory and unsatisfactory asphalts.

The primary objective of this investigation has been to obtain a general trend between the original properties of asphalts and service connected changes. In the search for this trend cognizance is made of the variations originating in the asphalt production, the construction of the road, the laboratory methods of determining such changes, and the environmental conditions. It is to be noted that the construction program of the surface-treatment (inverted penetration) test roads was not designed to meet any exceptional need; the test sections are in roads constructed according to the practice of the local Texas Highway Department District forces and with materials normally employed in the locality.

Another objective has been to investigate and use new or non-standard test methods that yield a measure of the fundamental properties of asphalts.

Considering the background given thus far, one will recognize that many important variables to be considered in the durability of surface-treatment pavements have not been isolated and for this reason much of the data and their evaluations are indicative only of trends.

This project, labeled RP-3, was originally organized to include the cooperation of the Texas Highway Department, the Texas Transportation Institute (TTI) of A&M College of Texas, and Texaco, Inc., one of the larger manufacturers of asphaltic materials in Texas. Subsequently, work on the original and recovered asphalts has been undertaken by the Bureau of Public Roads and the California Highway Department.

<u>Test Sections</u>

An important phase of this work was to determine changes in asphalt that occur in actual service conditions, and for this reason it was believed that the best type of test section would be a surface-treatment pavement. This type of construction is favored for secondary roads in Texas and the asphalt in the pavement would show a quicker response to the forces of nature than would a hot-mix asphaltic concrete pavement built to the State's requirements.

During the summer of 1954, sections of ten new and different surface-treatment pavements on primary and secondary highways were selected for observation and testing. In 1955, another section was added to the project. These surfaces were constructed in various localities within Texas on newly constructed bases which had been primed with a medium curing cut-back asphalt. These flexible bases were designed according to the Texas Highway Department method (1)* and the surfacing requirements were determined by the Kearby Method (2) or by some other service-proven procedure.

Figure I shows the locations of the numbered test sections along with isohyetal and isothermic lines for the State of Texas. Tables 1, 2 and 3 give the descriptions of the test roads along with data pertinent to the evaluation of the pavements and asphalts within.

A brief study of Figure I shows that the climate variation of the sample locations is such that the average yearly mean temperature ranges from about $59^{\circ}F$ to $74^{\circ}F$ and the average mean rainfall varies from approximately 19" to 66" per year.

Table 1 shows that seven different producers of asphalts are

*See reference citation.

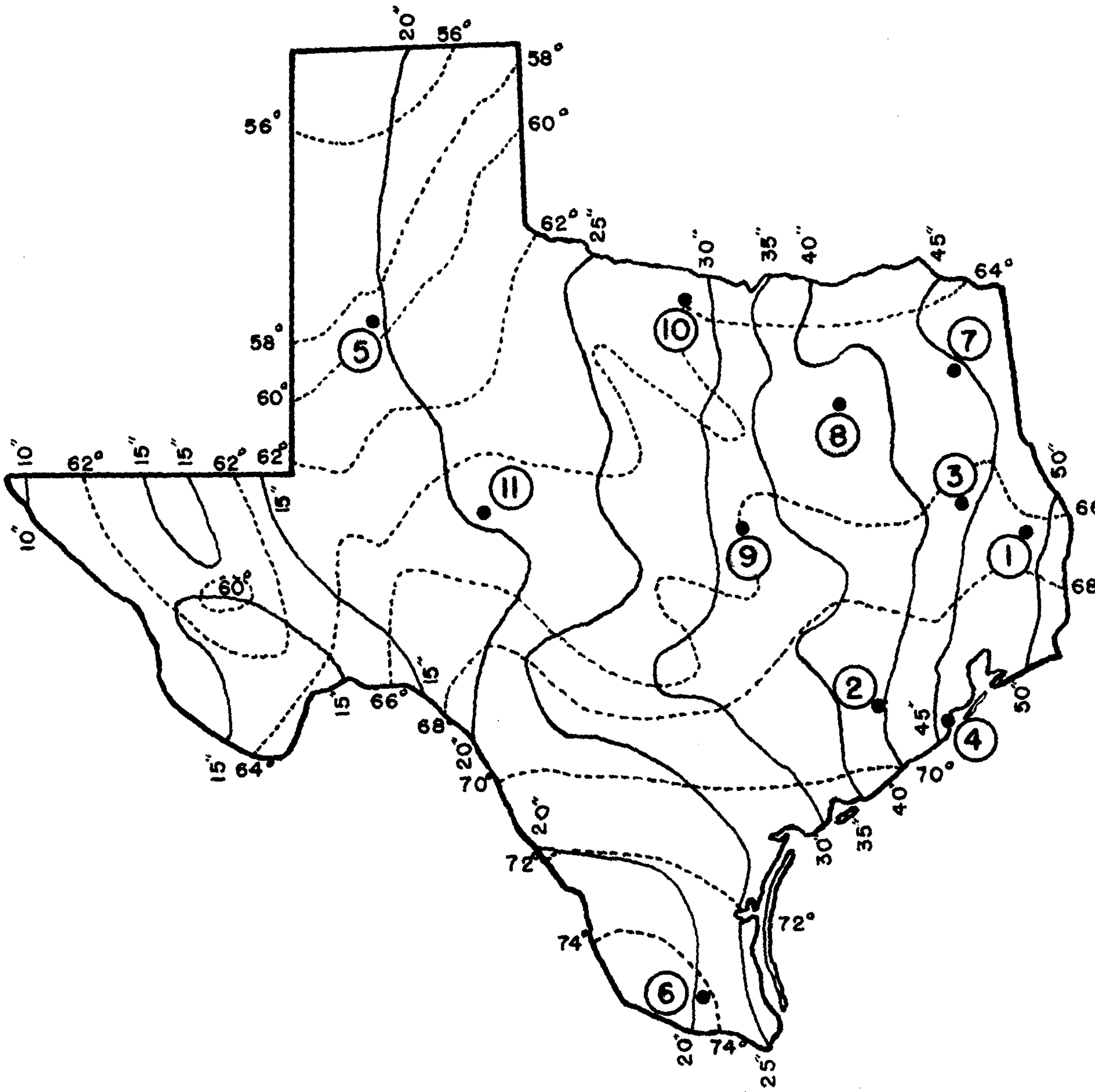


FIGURE I SAMPLE LOCATIONS; ISOHYETAL & ISOTHERMIC LINES

TABLE 1. Composition of Test Roads Constructed 1954

Sample No.-County	Producer	Asphalt Cement Pen. Grade	Cover Stone	Base	Asphaltic Prime	No. of Stone Courses
1-Jasper	A	OA-175	Crushed Limestone	9" Iron Ore Gravel	MC-1	2
2-Wharton	B	OA-175	Crushed Limestone	6" Gravel	MC-1	1
3-Angelina	C	OA-135	Crushed Limestone	6" Iron Ore Gravel	MC-1	1
4-Brazoria	B	OA-230	River Gravel	14" Sand 10" Shell	MC-1	2
5-Lubbock	D	OA-175	Crushed Limestone	10" Caliche	MC-1	4
6-Hidalgo	A	OA-135	Precoated Asphaltic Rock	18" Caliche	MC-1	2
7-Upshur	C	OA-135	River Gravel	10" Iron Ore Gravel	MC-1	1
8-Kaufman	E	OA-135	River Gravel	7" Crushed Gravel	MC-1	2
9-Coryell	F	OA-230	River Gravel	5 1/2" Limestone	MC-1	1
10-Clay	G	OA-175	Crushed Limestone	6" Sandstone	MC-1	1
11-Tom Green*	F	OA-175	Crushed Limestone	10" Caliche	MC-1	3

*Placed 1955.

TABLE 2. Traffic and Climatological Data for Test Sections

Sample No.	Location Section of State	Type of Terrain	Traffic ADT 1954	Avg. Annual Rainfall, In.	Mean Annual Temperature, °F
1-A	Extreme East	Wooded & Rolling	1200	48	67
2-B	Southeast Coastal	Flat	250	40	69
3-C	East	Wooded & Rolling	250	43	67
4-B	Southeast	Coastal Marsh	100	46	69
5-D	Northwest	Plains	7500	19	59
6-A	South	Plains	2300	21	74
7-C	Extreme Northeast	Wooded & Rolling	900	44	65
8-E	Northeast	Rolling	250	37	65
9-F	Central	Rolling	200	32	66
10-G	North Central	Plain	200	28	64
11-F	West Central	Plain	3000	21	65

TABLE 3. Quantities of Materials in Test Roads

Sample No.	Prime gals/sq.yd.	Asphalt Applied gals/sq.yd.	Asphalt Applied Temp.°F	Temperature, °F for SFV 75 Sec.	50 Sec.	Cover Stone sq.yd/cu.yd.	Grade of Cover Stone
1-A	0.20	0.21	300	286	317	60	B-1
		0.30				120	B-4
2-B	0.22	0.35	350	299	322	80	B-1
3-C	0.25	0.25	340	301	324	110	A-3
4-B	0.20	0.30	350	295	317	60	A-1
		0.25				40	A-9
5-D	0.20	0.22	300	280	299	50	B-Special
		0.35*				60*	B-1
		0.25				110	B-5
		0.22				140	B-10
6-A	0.22	0.12	350	290	320	40	1-P
		0.15				110	4-P
7-C	0.23	0.25	325	301	324	110	A-3
8-E	0.20	0.25*	345	-	-	110*	A-3
		0.25				115	A-3
9-F	0.20	0.34	300	262	286	100	A-4
10-G	0.25	0.30	300	297	320	100	A-3
11-F	0.20	0.22	335	265	290	60*	B-1
		0.33				100	B-5
		0.23				140	B-10

* Calculated Values

Generally, the sample was taken from the area traveled by a vehicle, but this location was not necessarily the area traveled by the right wheels.

The samples of the surfaces were taken to the Texas A&M laboratory where the base and priming materials were scrubbed off from the under side of the surfacing. The asphalt was extracted from the coverstone by the refluxing of a mixture of benzene and ethyl alcohol according to the Colorado method. After extraction, the asphalt was recovered from the alcohol-benzene solution by the Modified Abson Procedure. The recovered asphalt was stored in metal ointment cans until ready for testing.

Testing of the Asphalts

In discussing the results of various tests performed on a given asphalt, reference will be given as to its condition. That is, the asphalt obtained from the transport will be termed original, the sample taken from the distributor at the job site will be called unexposed, and the bitumen recovered from the pavement will be known as 1 year-old, 2 year-old, etc.

Standardized Tests

In asphalt paving technology, certain properties of asphalts have been found by experience to be necessary in a general way for the construction of good pavements. In an attempt to define or limit some of these properties, many tests have been standardized by various agencies, and the results from these tests are used to specify some characteristics of the asphalt desired. These tests have come to be known as "acceptance tests."

Table 4 shows the data on acceptance tests for the original asphaltic cements as obtained by the Materials and Test Division of the Texas Highway Department. The use of these asphalts in the construction of the test roads indicates acceptance of the materials. The one discrepancy in this table is that sample No. 9 showed a penetration on the loss on heating residue of less than the 125 as required by the Texas Highway Specifications (1955) item 350.2. These asphalts, as a group, also met the 1955 AASHO specifications except that four (1, 4, 5 & 11) samples failed to meet the ductility requirement and here, too, sample No. 9 failed to meet the necessary retained penetration (75%) on the loss on heating residue. The reaction of the asphalt of sample No. 9 to the standard spot test is a characteristic of its basic crude.

The acceptance of a certain asphalt that does not meet a set of specifications in its entirety is not an inconsistency, particularly if the asphalt has a known good-service record or if failure to meet specifications is dependent on one value whose limits are not wholly accepted as being significant. In general, the lues of Table 4 show all of the asphalts used in this program to be of approximately equal desirability. It is not the intention of this report to compare the various asphalts in the investigation with one another for the purpose of delineating a good or better asphalt. As a rule, any comparison will be made on asphalts from the same producer in analyzing the construction and service connected differences. It is evident that under good construction procedures, an inferior asphalt will perform better than a good asphalt that is mishandled and/or used with aggregates of questionable quality and grading.

TABLE 4. Test Values of Original Asphalts by Texas Highway Department

Sample	1	2	3	4	5	6	7	8	9	10	11	T.H.D. Specs. (1955)
Producer	A	B	C	B	D	A	C	E	F	G	F	
Grade	OA-175	OA-175	OA-135	OA-230	OA-175	OA-135	OA-135	OA-135	OA-230	OA-175	OA-175	
Penetration 77°F, pts.	170	185	135	250	176	132	132	138	237	172	171	
Ductility 77°F, cm.	90+	100+	100+	80+	89+	100+	100+	100+	100	112	73	(100+ OA-135 (70+ OA-175 (70+ OA-230
Flash Point C.O.C., °F	555	600	515	600+	550	530	535	490	575	600+	550	450+
Softening Point R&B, °F	105	110	110	101	106	111	111	110	110	105	109	(104-140 OA-135 (95-130 OA-175 (86-122 OA-230
Loss on Heating 325°F, %	0.02	0.01	0.07	0.02	0.03	0.02	0.03	0.13	0.04	0.04	0.10	0.75
Penetration of Res. 77°F, pts.	152	159	112	221	135	121	117	110	111	140	134	(70+ OA-135 (90+ OA-175 (125+ OA-230
Penetration of Res.% original value	89	86	83	88	77	92	88	80	47	81	78	
Solubility C Cl_4 %	99.9	99.7	99.9	99.7	99.7	99.9	99.9	99.9	99.9	99.7	99.9	99.5
Sp.Gr. 77°F	1.010	0.981	1.023	0.979	0.997	1.011	1.024	1.023	1.031	0.996	1.026	
Oliensis Spot	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Mod. Neg.	Neg.	Neg.	

Presented in Tables 5 and 6 are data on the unexposed samples which were taken from the distributors at the beginning of construction. The penetration and ductility values at 77°F shown in Table 5 do not meet reproducibility tolerances for those tests on the samples. This may be attributed in part to the time factor of as much as two years separating these tests and to differences in operational techniques in performing these tests at different laboratories.

Table 6 contains the results obtained in the Bureau of Public Roads Thin-Film Oven Weathering Test for the unexposed asphalts. It is interesting to note that this test predicts a shorter life for samples No. 5, 6 and 9 since less than fifty percent of the original penetration was retained. Also, the ductility on the residue from the Thin-Film Weathering Test was appreciably increased for seven of the eleven samples, which subsequently brought the three asphalts that had failed to meet the ductility requirement of 100, into specification value.

Special Tests

Viscosity. Viscosity is a fundamental property of asphalts. It may be termed the internal friction which gives a material such as asphalt resistance to flow or to a shearing stress. The unit of viscosity, $\frac{\text{dyne-sec.}}{\text{cm}^2}$, has been named poise after Poiseuille. The basic expression for viscosity is

$$\eta = \frac{S}{dv/dr} \qquad (1)$$

where η is the viscosity in poises

S is the shearing stress, gravitational

$\frac{dv}{dr}$ is the shear rate, reciprocal second

TABLE 5. Characteristics of Unexposed Asphalts

Sample No.	TTI Penetration 100 g. 5 sec. 77°F Pt.	B.P.R. Penetration 100 g. 5 sec. 50°F Pt.	60°F Pt.	77°F Pt.	B.P.R. Ductility 5 cm/min. 77°F cm.	B.P.R. Furol Viscosity @ 275°F sec.	Texaco, Inc. Penetration 100 g. 5 sec. 32°F Pt.	77°F Pt.	Texaco, Inc. Ductility 5 cm/min 39.2°F cm.	77°F cm.	Soft. Pt. R&B °F
1-A	143	32	62	167	132	145	38	167	4.8	120	105
2-B	153	22	46	172	158	154	29	169	5.0	200*	106
3-C	118	30	52	128	175	172	37	123	9.0	160	109
4-B	192	28	56	202	141	147	27	192	7.5	104*	107
5-D	210	33	71	202	77	162	36	153	8.5	93*	109
6-A	130	31	56	150	112	104	32	143	7.5	112*	111
7-C	113	29	50	131	193	180	31	125	10.5	141	113
8-E	104	29	48	123	198	174	34	116	9.0	162	115
9-F	226	35	75	233	71	77	32	217	8.5	70	104
10-G	129	20	43	145	136	165					
11-F	151	23	49	163	82	81					

* Floats

TABLE 6. BPR's Thin-Film Oven Weathering Test for Unexposed Samples

Sample No.	Penetration 100 g. 5 sec. at 77°F Points	Ductility 5 cm/min. at 77°F cm.	Test on Residue: Wt. Loss Percent	Test on Residue: Penetration 100 g. 5 sec. at 77°F Points	Test on Residue: Penetration Retained Pen.* Percent	Test on Residue: Ductility 5 cm/min at 77°F, cm.	Test on Residue: Softening Point, R&B °F
1-A	167	132	0.07	106	63	174+	115
2-B	172	158	-0.4**	112	65	155	113
3-C	128	175	0.40	75	58	186+	124
4-B	202	141	0.34	117	58	129	112
5-D	202	77	1.25	79	39	106+	122
6-A	156	112	0.56	76	49	179+	121
7-C	131	193	0.06	83	63	171	122
8-E	123	198	0.21	76	62	178	124
9-F	233	71	2.02	71	30	167+	120
10-G	145	136	0.04	94	65	191+	116
11-F	163	82	0.35	85	52	135+	117

* Percent of original value.

** Gain in Weight.

The mathematical basis for this expression may be found in reference 3 and in Appendix A.

Various types of viscometers used for highly viscous materials have been described by Traxler and Schweyer (4). The different types of viscometers used in this investigation consisted of three instruments generally known as (a) sliding plate (b) falling coaxial, and (c) rotary.

The sliding plate microfilm viscometer used at A&M has been described by Gallaway (5) in a previous report to this Association. This viscometer was patterned after the work reported by Griffin, Miles and Penther (6) in 1955. The data obtained from this viscometer are reliable and reproducible. The other participating laboratories furnished supplementary data obtained from sliding plate viscometers; their devices were of the commercial style such as made by Hallikainen Instruments. For this viscometer, the data required for the determination of viscosity are, (1) film thickness and sheared area, (2) shearing load, and (3) the time required for the load to move the free plate a prescribed distance. The flow properties of the material tested are obtained by using a minimum of three shearing loads. Generally, the test temperature is held constant at 77°F.

For a limited range of shear rates the log-log plot of viscosity versus shear rate may be considered to be essentially a straight line (7). The equation of this curve may be expressed as follows,

$$\eta = K\left(\frac{dv}{dr}\right)^{e} \qquad (2)$$

where η and $\frac{dv}{dr}$ are as previously described

K is the value of η at $\frac{dv}{dr}$ equals 1.0

e is the slope of the straight line.

The slope of this straight line gives an insight as to the rheological properties of asphalts. For the following it is considered that log shear rate is plotted on the abscissa and log viscosity on the ordinate and that the curve is viewed from the usual position (see Figure II). The plot for a material of simple flow (Newtonian) properties would appear as a horizontal line. Asphalts usually yield curves with an inclination down to the right; this is characteristic of complex flow (non-Newtonian). The degree of complex flow is the variation, (1+e) or C, from a horizontal line in the log-log plot. The Flow Complex, C, may be determined from the following expression (see Figure II).

$$C = \log 10 \frac{\eta_1}{\eta_2} = 1+e \qquad (3)$$

where $\frac{\eta_1}{\eta_2}$ is the smallest ratio of viscosities, η, for <u>one</u> cycle of shear rate, $\frac{dv}{dr}$.

C is the Flow Complex

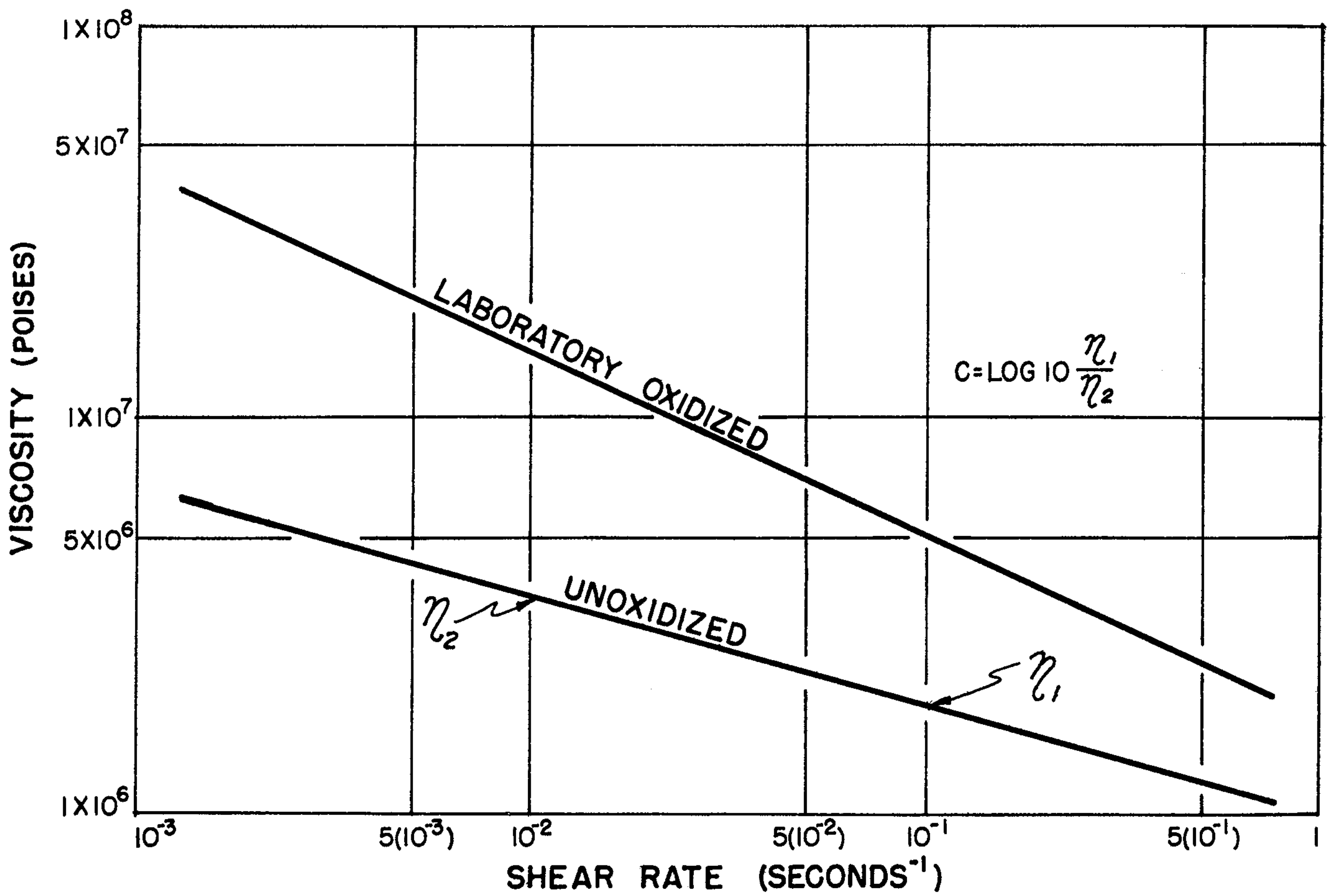
e is the arithmetic ratio of vertical to horizontal displacement between 2 points on the curve.

The viscosities reported are generally at a shear rate of $5 \times 10^{-2} \sec^{-1}$. This rate is accepted as one that is conveniently obtained in the laboratory.

The rotary viscometer was used by the laboratory at Texaco, Inc. to measure the viscosity and evaluate the flow characteristics of the unexposed asphalts from this project. The essential parts of this viscometer (8) are a stator and a rotor; the annulus between the stator and rotor is filled with asphalt. The rotor is given a constant angular velocity and the torque required to prevent the stator from rotating is measured

FIGURE NO. II

TYPICAL RHEOLOGICAL DIAGRAM
FOR AN ASPHALT CEMENT



after the system has reached equilbrium. Viscosity can be computed from the torque-angular velocity data since the torque and angular velocity are proportional to the shearing stress and shear rate respectively. Data from this instrument have been plotted as log shear rate versus log shearing stress, from which the Flow Complex, C, may be determined. Romberg and Traxler (7) have used the rotary viscometer for evaluating the rheological properties of asphalts, and report viscosities on the basis of a constant power input of 1000 ergs/sec/cc.

The falling coaxial cylinder used in this laboratory was developed at The Barber Asphalt Company and patterned after the one used by Pochettino (4,5). In this unit a cylinder is placed concentric to a ring and the annulus filled with asphalt. A shearing stress is produced on the asphalt by the weight of the cylinder and the shear rate is determined by timing the cylinder's fall over a specific distance. This instrument, in contrast to many others, is quite inexpensive.

Table 7 presents the absolute viscosity values obtained by four different laboratories using the sliding plate viscometer, for the <u>unexposed</u> samples. These values are for a standard condition at a shear rate of $5 \times 10^{-2} sec^{-1}$ and a temperature of $77^{o}F$. It can be seen that the reproducibility is in general very good among the four laboratories.

In an earlier report, Gallaway (5) made reference to the finding that the viscosity determined using microfilms (30-40 microns) of asphalt in the sliding plate viscometer was higher than the viscosity determined by use of the rotary viscometer in which the resistance to shear as determined by use of a thick (0.635 cm) mass of asphalt. This finding was explored further by comparing the viscosity values obtained

TABLE 7. Absolute Viscosities of Unexposed Samples in Poises x 10^6 at a shear Rate of 5 x 10^{-2} sec.$^{-1}$ at 77°F.

	TTI	B.P.R.			Texaco, Inc.		Calif.H.D.
Sample No.	Sliding Plate 77°F	Sliding Plate 50°F	60°F	77°F	Sliding Plate 77°F	Rotary 1000 ergs/s/cc 77°F	Sliding Plate 77°F
1-A	0.3	11.0	3.0	0.3	0.3	0.3	0.4
2-B	0.4	37.0	8.0	0.3	0.3	0.3	0.4
3-C	0.6	20.0	5.5	0.6	0.7	0.6	0.8
4-B	0.2	36.5	5.0	0.2	0.2	0.2	0.2
5-D	0.4	14.0	3.0	0.3	0.5	0.4	0.4
6-A	0.6	11.0	5.0	0.5	0.4	0.4	0.7
7-C	0.7	18.5	6.0	0.7	0.7	0.5	0.8
8-E	0.8	15.0	7.0	0.9	0.8	0.6	0.9
9-F	0.2	10.5	2.0	0.2	0.2	0.2	0.4
10-G	0.5	36.0	6.0	0.5	-	-	0.4
11-F	0.4	22.0	4.0	0.4	-	-	0.4

with the falling coaxial, rotary and sliding plate viscometers. Table 8 shows the three viscosities obtained by the three instruments at corresponding shear rates. The variable shear rates are due to limited data from the falling coaxial cylinder viscometer. The viscosity obtained by the coaxial was at one shear rate; therefore, for comparison viscosity at this shear rate was found for the other two instruments by interpolation of their viscosity-shear rate relationships. The values of Table 7 are plotted in Figures III and IV.

The plot of Figure III shows that the more viscous the asphalt the greater is the difference in viscosity as determined by the sliding plate viscometer and rotary or coaxial. The thickness of the asphalt specimen in the coaxial viscometer is also 0.635 cm. and from Figure IV it appears that there is not appreciable difference between the viscosity values obtained by the rotary and coaxial viscometers for the range of viscosity and asphalts used in this investigation.

The differences in viscosity noted between the sliding plate and rotary or coaxial may be attributed to differences in film thicknesses since this may affect the molecular attraction between the asphalt and shearing surface. Also, there is a trend (Table 10) indicating that the viscosity of asphalts increases as the amount of the "larger molecules" in the asphalt increases. It is probable that the greater the percentage of these molecules the greater would be the tendency of what may be termed "interlock" of these molecules. Mack (9) and more recently Winniford (10) have shown that viscosity of asphalts increases as the amount of asphaltenes (the larger molecules) increases.

The viscosity from the coaxial viscometer data was computed from an equation derived (see Appendix B) from the basic conditions of the

TABLE 8. Absolute Voscosities of Unexposed Samples by Different Viscometers (Shear Rate is Different for Each Sample)

Viscosities in Poises x 10^5 at 77°F

Sample No.	Shear Rate $1 \times 10^{-2} sec.^{-1}$	TTI Coaxial	Texaco, Inc. Rotary	Texaco, Inc. Sliding Plate
1-A	1.86	2.92	3.10	3.80
2-B	1.22	4.50	3.16	3.15
3-C	0.88	6.20	6.25	8.38
4-B	1.83	2.98	1.94	2.46
5-D	2.21	2.48	3.75	5.38
6-A	1.49	3.65	4.37	5.36
7-C	0.96	5.71	5.70	8.90
8-E	0.81	6.70	6.50	10.40
9-F	2.92	1.87	1.68	2.20

FIGURE NO. III

COMPARISON OF VISCOSITY BY SLIDING PLATE VS. ROTARY OR COAXIAL

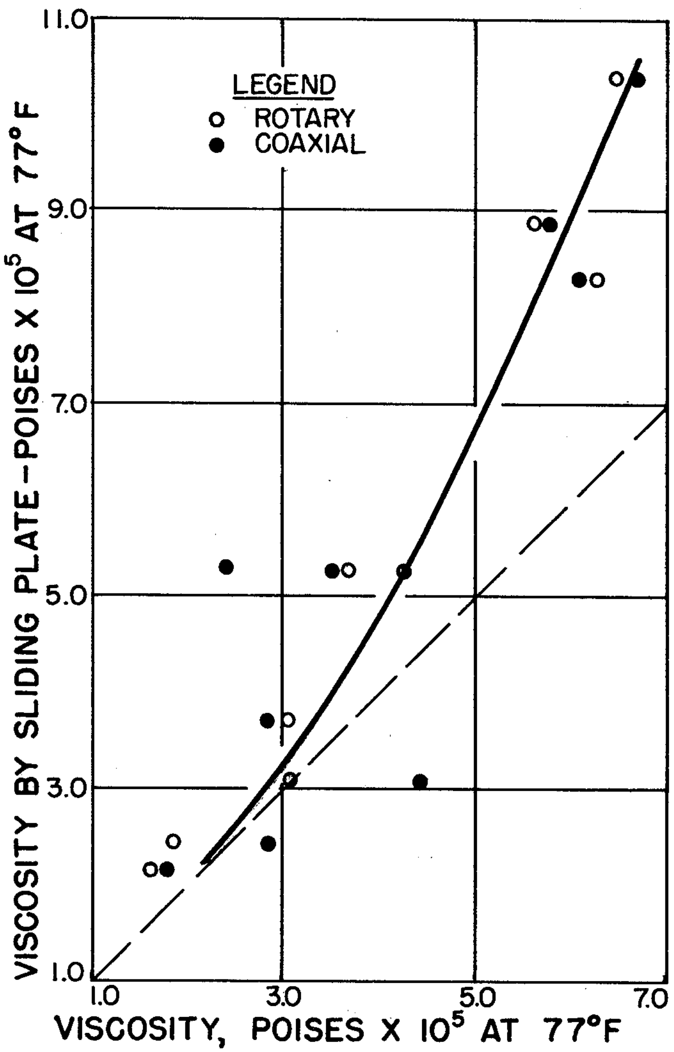
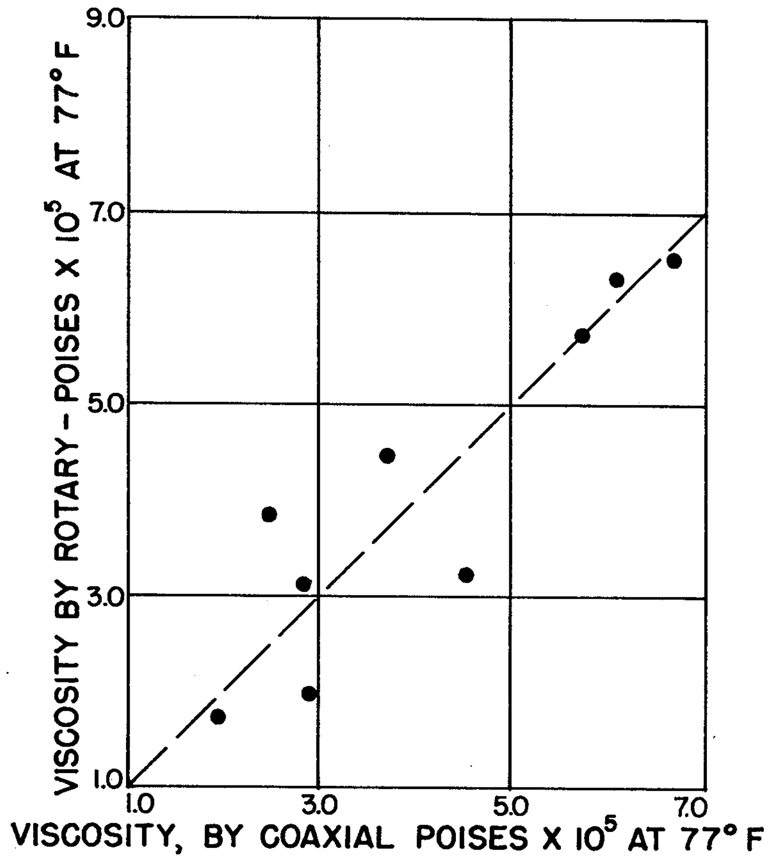


FIGURE NO. IV

COMPARISON OF VISCOSITY BY ROTARY AND COAXIAL



test method and equation 1. This equation is

$$\eta = \frac{(R-r)\ gWt}{2\pi\ rLH} \tag{4}$$

where η is viscosity in poises.

g is gravitational constant.

L is length of ring in centimeter.

H is movement of cylinder in centimeter corresponding to time t, sec.

R is inner radius of ring in centimeter.

r is radius of cylinder in centimeter.

W is effective weight in grams of cylinder accounting for bouyancy.

Laboratory Aging of Asphalt in Microfilms. Consideration must be given to the aging or weathering characteristics of asphalts in determining their relative performance in service. Three methods were used to evaluate this property; these were (a) modification of the method of Ebberts (5, 11), (b) the "Shell method" reported by Griffin et al (6) and, (c) the California Highway Department Sand-Abrasion Test (12).

The effects of artificial weathering (aging) were determined by the resulting changes in absolute viscosity and Flow Complex, C, as obtained from the sliding plate viscometer, Ebberts' oxidation value, and loss of material in the sand-abrasion test. In Table 9 the effects of aging are shown as the ratio of viscosities after aging to before aging and the loss of material in the sand-abrasion test. From this table it can be seen that there are great differences in the results obtained by these aging methods, but they are in agreement that sample No. 5 is very susceptible to the conditions imposed upon it. The Shell method indicates

TABLE 9. After to Before Aging Viscosity Ratios of Unexposed Asphalts and Sand-Abrasion Loss in Grams (Viscosity Determined by Sliding Plate Viscometer)

	TTI Ebberts		B.P.R. Shell	California H. D. Sand-Abrasion Test			
				After Mixing		After 500 hrs Weathering	
Sample No.	Oxidation Value	$\eta A/\eta B$	$\eta A/\eta B$	Abrasion Loss, gm.	$\eta A/\eta B$	Abrasion Loss, gm.	$\eta A/\eta B$
1-A	1.50	2.0	4.2	1.5	1.8	7.8	11.9
2-B	1.95	3.4	3.1	1.1	1.8	2.5	9.9
3-C	1.06	3.2	5.0	3.3	4.6	10.4	16.3
4-B	1.50	5.8	5.2	0.7	3.4	2.4	12.2
5-D	2.16	18.2	12.2	1.9	5.0	7.2	25.4
6-A	1.17	5.4	6.2	2.8	7.8	10.0	17.4
7-C	1.12	2.3	4.1	3.3	2.7	8.7	8.7
8-E	1.07	1.8	4.8	2.3	2.8	10.4	8.4
9-F	1.49	5.6	19.4	7.8	6.5	21.4	28.1
10-G	0.96	3.2	3.9	4.3	2.2	9.6	16.4
11-F	-	-	7.0	7.5	2.8	18.1	19.3

that sample Nos. 9 and 11 are also to be suspected of being very susceptible to hardening. From this work no definite limits of after to before aging viscosity ratio can be presented that will separate a durable asphalt from one that is not as good.

Limits as set for the sand-abrasion test show that sample Nos. 9 and 11 "might present a problem in durability."

Component Analysis. Since the pioneering of Marcusson in the fractionation of asphalts, much work has been done to separate asphalt into various components and to investigate the properties of these components. A basic understanding of these constituents of asphalt is necessary for an insight of the properties of asphalt.

Of the various fractionating methods available at the inception of this study, the component analysis method of Traxler and Schweyer (13) was selected for use because of its simplicity in separating asphalts into three fractions. These fractions were labeled (a) asphaltics which are made up of asphaltenes and some resins, (b) cyclics containing the unsaturated or aromatic oils, and (c) paraffinics or oils of saturated characteristics. These names for the three fractions have been used in previous reports (5) but in this presentation asphaltics will refer to fraction "I", cyclics to fraction "II" and paraffinics to fraction "III". This change in nomenclature has been brought about by the obsolesence of the original terms and by recommendation from Traxler, one of the originators of this method of fractionation.

Table 10 shows the percentages of these fractions in descending amounts for comparison with viscosity and aging characteristics of the unexposed asphalts. From these data it appears that viscosity increases as the amount of fraction I increases. The greatest exceptions to this

TABLE 10. Comparison of Amount of Asphalt Fraction with Viscosity and Aging Characteristics of Unexposed Asphalts

Fraction*						Viscosity** Poises x 10^6		Aging Methods					
I		II		III				Ebberts		Shell		Sand-Abrasion	
Sample No.	%	Sample No.	%	Sample No.	%	Sample No.	η	Sample No.	Oxid. Value	Sample No.	$\eta A/\eta B$	Sample No.	Loss gm.
2-B	47	9-F	27	10-G	57	8-E	0.8	5-D	2.16	9-F	19.4	9-F	21.4
4-B	47	8-E	23	5-D	51	7-C	0.7	2-B	1.95	5-D	12.2	3-C	10.4
7-C	39	3-C	23	9-F	48	6-A	0.6	1-A	1.50	6-A	6.2	8-E	10.4
1-A	38	7-C	20	6-A	48	3-C	0.6	4-B	1.50	4-B	5.2	6-A	10.0
3-C	34	5-D	20	1-A	44	10-G	0.5	9-F	1.49	3-C	5.0	10-G	9.6
8-E	34	6-A	19	3-C	43	2-B	0.4	6-A	1.17	8-E	4.8	7-C	8.7
6-A	33	1-A	18	8-E	43	5-D	0.4	7-C	1.12	1-A	4.2	1-A	7.8
10-G	31	10-G	12	2-B	42	1-A	0.3	8-E	1.07	7-C	4.1	5-D	7.2
5-D	29	4-B	12	4-B	41	4-B	0.2	3-C	1.06	10-G	3.9	2-B	2.5
9-F	25	2-B	11	7-C	41	9-F	0.2	10-G	0.96	2-B	3.1	4-B	2.4

* Obtained by TTI.

** By Sliding Plate Viscometer at TTI.

trend are sample Nos. 2 and 4. These two asphalts are from the same producer and this difference might be attributed to the method of manufacture of the asphalts or to the source of crude.

Another trend that may be established is the relationship between the amounts of fraction II and the losses of material after 500 hours of weathering in the sand-abrasion test. This trend is puzzling since it has been observed that fraction II is the tackiest of the three fractions found in this method of separation and also the amounts are the least susceptible to changes under natural weathering as indicated in Table 17. Wilkinson et al (14) states that a criterion for the evaluation of roof coating asphalts is that the amount of "cyclics" (fraction II) should be less than 12% for the sake of durability.

Refractive Indexes. The two fractions (II & III) of asphalts that are recoverable from the method of separation used were tested for their values of refractive indexes. These measurements showed that the refractive index values of fraction II were higher than for fraction III.

Changes in Asphalts after Service Exposures

As mentioned previously, the test sections were sampled every year for a period of five years after construction. The recovered asphalt was tested for the various properties described above. These data are tabulated in Appendix C and the following is an indication of trends found in the effect of service exposure to these properties.

In examining these data particular attention should be paid to the asphalt samples that were obtained from the same producer, these were sample Nos. 1 and 6, 2 and 4, 3 and 7, and 9 and 11. Cognizance must be made concerning the variabilities of climatic conditions, traffic volumes, construction practices, representative sampling of the pavement, and laboratory techniques. Also, since the recovery of asphalt from sample No. 6 included the natural asphalt of the coverstone, its changes with service as shown here are not representative of a manufactured petroleum asphalt.

Viscosity and Penetration. Tables 11 and 12 show the changes in viscosity and penetration respectively which have occurred with time of service of the asphalts. Figure V illustrates graphically a general relationship between viscosity and age for one of the samples. The trends in viscosity and penetration are as would be expected, that is, the viscosity increases and the penetration decreases for asphalts with exposure time.

Aging. The changes in the weathering characteristics are listed in Tables 13 through 16. The data of Table 13 show that the flow complex value in general decreases with age. This indicates that the asphalt is becoming more non-Newtonian in its flow characteristics. It is inferred from Tables 14 and 15 that the effects of laboratory oxidation on viscosity and flow characteristics are minimized as the period of exposure increases. The viscosity ratios vs. time are shown in Figure VI for one sample. The capacity of the asphalts for oxygen also decreases with service time as shown in Table 16.

Component Analysis and Refractive Indexes. Table 17 shows the variations in the percentages of the three-group fractionation of the recovered asphalts with years of service. In general, fraction I increases in amount with age, fraction II shows little change, and fraction III diminishes in amount. Figure VII shows a typical trend.

FIGURE NO. V

TYPICAL ABSOLUTE VISCOSITY CHANGES WITH AGE

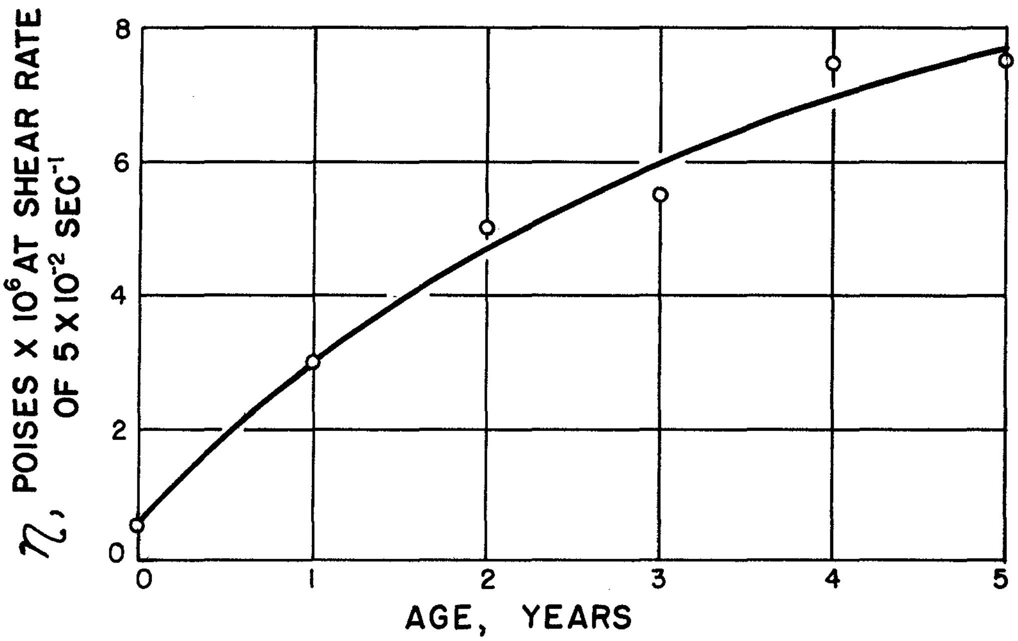


FIGURE NO. VI

CHANGE OF VISCOSITY RATIOS WITH AGE

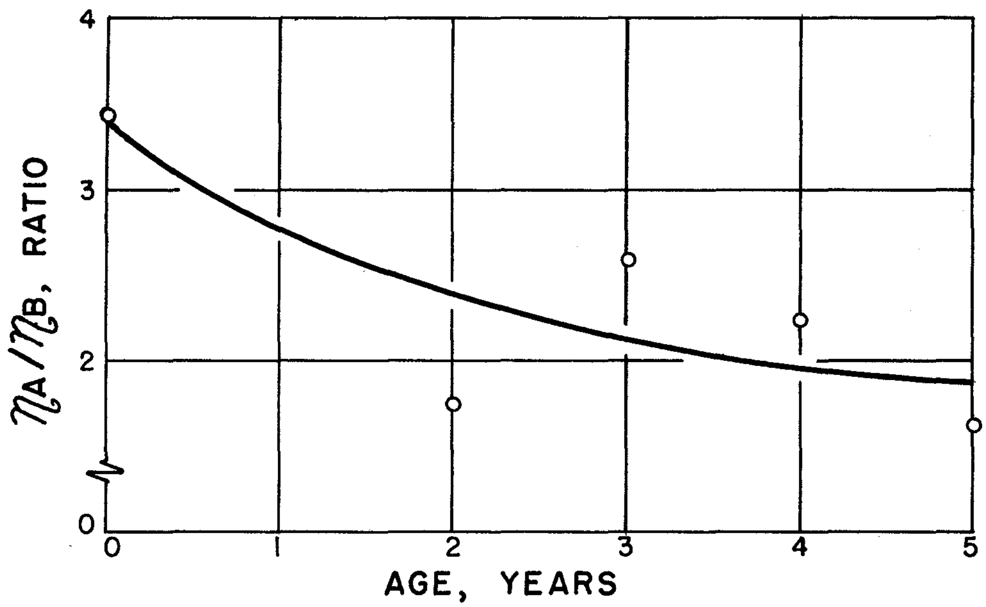
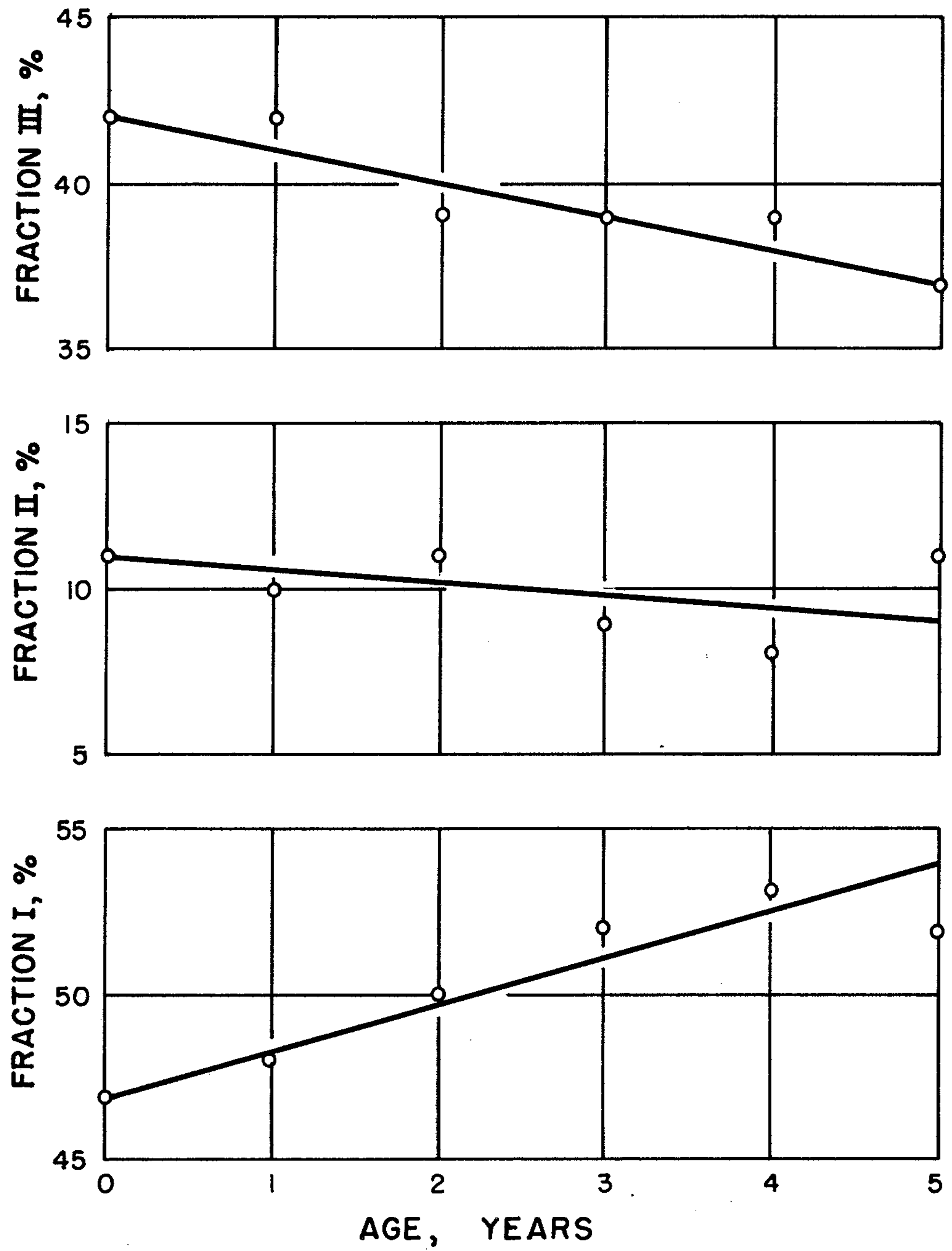


FIGURE NO. VII

EFFECT OF AGE ON COMPOSITION OF AN ASPHALT



It is probable that fractions II and III polymerize with age and enter into the next higher molecular weight group. It is also probable that the decrease of fraction III with age may be due to adsorption of the lighter fractions by the aggregate and these are not recoverable in the asphalt extraction process.

Table 18 presents the data on changes of refractive indexes of fractions II and III, with service time. It appears that the densities (R.I.'s) of these increase with time up to about 2 to 3 years of service and then they decrease. At the present, the reason for this trend is not understood.

Evaluation of Test Roads and Related Comments on Laboratory Data

Sample No. 1-A. This section has performed adequately for the six years of observation. The measurements on the original and recovered asphalt do not show extreme values or changes with time; except that the penetration value of the recovered asphalt has dropped to a value that may be considered fairly low. This road is located at a site of medium traffic, heavy rainfall, and mild climate. This double surface-treatment was properly designed and was adequately inspected during construction to insure that it was built as designed. This is considered the key to the excellent performance of the road.

Sample No. 2-B. This road was resurfaced in the summer of 1960. Laboratory data on the asphalt do not explain the failure of this road. Field observations, however, revealed severe crushing of coverstone during construction. A high density base and the use of a steel flat wheel roller caused this crushing. Construction procedure changes might have extended the life of this surface materially.

Sample No. 3-C. Failure of this pavement is credited to inadequate base design. This road is subjected to logging truck traffic. Early evaluation of the surface indicated that the surface-to-base bond was poor and stone embedment was limited. Failures were apparent within one year of service. This section was resurfaced in the spring of 1959. Extensive patches existed at this time.

Sample No. 4-B. Portions of this road were resealed within one year after construction, however, the section that was being sampled for this study has not been covered since construction. The asphalt in this sample was from the same producer as for sample No. 2. Field-sample comparisons between the two sections indicate that sample No. 4 was more susceptible to weathering than No. 2. This is found from the absolute viscosity and penetration changes being greater for No. 4. Examination of samples from both surfaces indicate that film thickness on these roads were different. Sample No. 4-B averaged about half as thick as those on sample No. 2-B. There was no difference between these two roads as to climate, but the traffic on the area from which sample No. 4 was taken was much lighter than that for the other road.

Sample No. 5-D. This road was resealed after the first year of service; since then it has performed adequately for the high traffic volume it receives. The BPR's Thin-Film Test predicted a limited life for this asphalt as did the other aging tests shown in Table 9. Reference to an earlier report will show that the asphalt content in this surface is quite high. In cross section, this surface resembles a penetration macadam. Penetration macadam construction is quite rare in Texas and for this reason some of the finer points and techniques so vital to the success of such construction were neglected. The seal that was required so soon might simply have been one step left off in the original job.

Sample No. 6-A. The measurements made on the recovered asphalt have no comparative meaning since the effects of the natural asphalt from the coverstone cannot be separated. This pavement was resealed in the summer of 1960.

Climatic conditions favored the extended life of this pavement. Reference to Figure 1 will show the low rainfall and high mean annual temperature. The design might well have been improved by increasing the asphalt content. Reference to pictures of surface cross sections shown in an earlier report by Gallaway will indicate that density was low for some time after the road was in service. The grading and particle texture of the asphalt rock are considered factors in resistance to construction and traffic densification. Similar factors were in evidence for sample No. 5; it, however, was resealed and further densified shortly after it was built. Three years after sample No. 6 was built, sections cut from the surface showed that densification was essentially complete. Access of the materials to water and air, although somewhat limited during this time, had its adverse effects.

Sample No. 7-C. This pavement failed and was resealed in the spring of 1958. The reason for this failure is not apparent from the data available, but it should be noted that section 3-C also had a short life. Unlike sample 3-C this road was structurally adequate for the traffic; however, the surfaces were alike in one respect and that was cover aggregate embedment depth. Embedment depth was limited for both surfaces. Sample No. 7 utilized a gravel coverstone with considerable range in particle size. The range was such that part of the stone was submerged, whereas other parts were not sufficiently embedded. Texas has recognized this deficiency in their specifications and has made corrective modifications in cover aggregate grading.

Sample No. 8-E. This road has given excellent service to date. Reference to earlier pictures and data will show that this road was properly designed for the base and traffic. The aggregate includes a narrow band of sizes; it was embedded from 50 to 70 percent, almost from the time of construction and the base density was such that with time traffic caused very little further intrusion of the stone into the base.

Sample No. 9-F. This sample contradicts the performance indicated by most acceptance tests and special ones; the unexposed asphalt failed the ductility test, the Thin-Film Weathering Test and showed great susceptibility to weathering by the three laboratory aging tests. The recovered asphalt showed extreme changes in consistency. Yet, in spite of these measurements, the pavement gave good service for six years. This fact points to the great importance in design and construction of surface-treatment roads.

Sample No. 10-G. The sandstone base of this road was degraded after compaction and presented a structure with very limited cohesion. Soon after the surface was put into service, traffic forced the coverstone into the base leaving a sheet of almost pure asphalt on the surface. It was possible to cut into the surface and remove asphalt and coverstone in much the same manner as one would remove a blanket from a bed. The road was resealed in the spring of 1957. The failure was attributed to poor surface-to-base bond and low base density.

Sample No. 11-F. According to construction records the asphalt used on this job was heated to a temperature higher than necessary for distribution purposes. Laboratory durability and aging tests indicate that this asphalt is much more susceptible to damage from over exposure to heat and air than certain other asphalts used in this series of tests. It is probable that, coupled with heavy truck traffic, the early failure of this road was due to excessive hardening of the asphalt caused in part, at least, from exposure to high temperature during construction. A highly absorptive limestone cover aggregate might also be considered a contributory factor.

Acknowledgement

Sincere appreciations are extended to the cooperating laboratories of the Bureau of Public Roads, California Highway Department and to Texaco, Inc. The authors are indebted to personnel of the Texas Highway Department for their aid in testing and sampling the test sections and especially to Dr. R. N. Traxler who aided immensely in the initial programing of this study and for his faith in this research.

APPENDIX A

The mathematical basis of equation 1 for viscosity may be derived from the following conditions (3). Assume two parallel surfaces r distance apart and the space between them occupied by a fluid, Figure VIII. Assume further than one surface moves at a velocity V with respect to the other. Three conditions are now imposed:

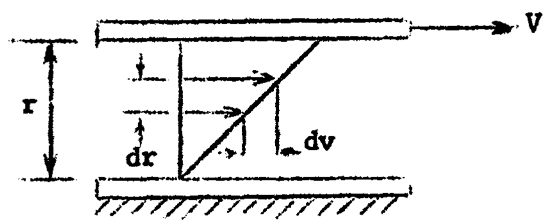


Fig. VIII

1. the fluid particles in contact with a surface have the velocity of that surface,
2. the rate of change of velocity is constant in a direction normal to the direction of motion, (this may not be strictly true)
3. the shearing stress in the fluid is proportional to the rate of change of velocity.

From condition 2 and similar triangles

$$\frac{V}{r} = \frac{dv}{dr}$$

and from condition 3, the shearing stress S, is

$$S = \eta \frac{dv}{dr}$$

where η is a proportionality factor called the coefficient of viscosity or simply viscosity.

Then

$$\frac{V}{r} = \frac{S}{\eta} \quad \text{or} \quad \eta = \frac{S}{V/r} = \frac{S}{dv/dr} \qquad (1)$$

Now, the viscosity of a material may be computed for the above arrangement knowing the shearing stress S, velocity V of the moving surface, and the distance r between the surfaces occupied by the fluid.

APPENDIX B

In the body of this paper, reference was given to the viscosity equation applicable to data from the falling coaxial cylinder viscometer (4). Under consideration of the slight difference in density between the bath and material being tested, this equation is represented as,

$$\eta = (\ln \frac{R}{r}) (\frac{gWt}{2\pi LH})$$

in which the symbols have the same meaning as for equation 4. In using the above equation, viscosity values obtained appeared to be unduly high on comparison with the rotary viscometer. For this reason, a viscosity equation for use with the coaxial viscometer was determined under the basic conditions explained in Appendix A. Figure IX is a sketch of the basic elements for a coaxial viscometer and reference is made to it in expressing the shearing stress S and shear rate $\frac{dv}{dr}$.

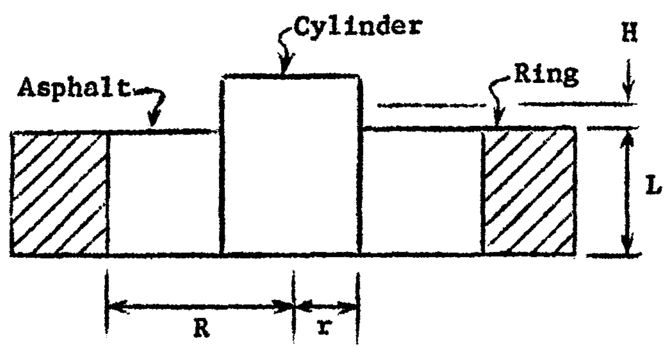


Fig. IX

$$S = \frac{Wg}{2\pi rL}$$

$$\frac{dv}{dr} = \frac{H/t}{R-r}$$

$$\eta = \frac{S}{dv/dr} = \frac{\frac{Wg}{2\pi rL}}{\frac{H/t}{(R-r)}}$$

$$= \frac{Wgt\ (R-r)}{2\pi rLH} \qquad (4)$$

For a specific distance and given viscometer equation, 4 is simplified to

$$\eta = Kt$$

where K is an instrument constant.

APPENDIX C

Values for the data presented in the following tables are those obtained by the Texas Transportation Institute.

TABLE 12. Changes in Standard Penetration of Asphalts With Years of Service

Sample No.	Lab.	Exposure in Years 0	1	2	3	4	5
1-A	TTI	143	60	60	50	39	47
	BPR	167				39	49
	Texaco	167				45	47
2-B	TTI	153	52	43	46	38	40
	BPR	172				38	40
	Texaco	169				45	39
3-C	TTI	118	42	36	39	33	
	BPR	128				34	
	Texaco	123				37	
4-B	TTI	192	70	47	30	24	36
	BPR	202					36
	Texaco	192				35	38
5-D	TTI	210	26	46	64	34	30
	BPR	202				39	30
	Texaco	153				40	33
6-A	TTI	130	28	16	14	13	11
	BPR	156				13	16
	Texaco	143				15	11
7-C	TTI	113	26	33	35		
8-E	TTI	104	29	42	38	26	28
	BPR	123				24	36 1/2
	Texaco	116				27	27
9-F	TTI	226	16	20	19	16	14
	BPR	233				18	14
	Texaco	217				20	15
10-G	TTI	129	29	36	38		
11-F	TTI	151	41	47			

TABLE 13. Changes in Flow Complex, C, of Asphalts with Years of Service

Sample No.	Lab.	Exposure in Years 0	1	2	3	4	5
1-A	TTI	.90	.80	.75	.80	.75	.80
	Texaco					.70	.65
2-B	TTI	.90	.80	.75	.85	.55	.60
	Texaco					.70	.60
3-C	TTI	.90	.75	.55	.85	.60	
	Texaco					.55	
4-B	TTI	.85	.85	.80	.65	.50	.60
	Texaco					.60	.60
5-D	TTI	.85	.80	.75	.80	.65	.50
	Texaco					.55	.40
6-A	TTI	.85	.70	.55	.70	.75	.60
	Texaco						.50
7-C	TTI	.95	.50	.60	.55		
8-E	TTI	.80	.65	.55	.75	.55	.35
	Texaco					.50	.40
9-F	TTI	.90	.70	.70	.80	.85	.55
	Texaco					.80	.35
10-G	TTI	.95	.75	.50	.55		
11-F	TTI	.80	.70	.85			

TABLE 14. Changes in Viscosity Ratio, $\eta A/\eta B$, of Asphalts with Years of Service

Sample No.	Lab.	Exposure in Years 0	1	2	3	4	5
1-A	TTI	2.00		2.85	2.00	1.25	1.15
	BPR					2.17	1.77
	Texaco					1.38	1.42
2-B	TTI	3.45		1.75	2.60	2.25	1.65
	BPR					1.60	1.47
	Texaco					1.23	1.18
3-C	TTI	3.15		1.70	1.65	1.25	
	BPR					1.65	
	Texaco					1.63	
4-B	TTI	5.80		2.20	1.45	1.70	1.30
	BPR						1.26
	Texaco					1.24	1.23
5-D	TTI	18.25		1.60	2.40	1.30	1.50
	BPR					1.87	1.35
	Texaco					1.39	1.28
6-A	TTI	5.35		2.90	1.20	2.45	1.55
	Texaco						1.26
7-C	TTI	2.30		1.55	1.30		
8-E	TTI	1.80		2.00	1.30	1.60	1.95
	BPR					3.09	1.59
	Texaco					1.71	1.39
9-F	TTI	5.65		3.50	1.10	2.60	0.75
	BPR					1.71	1.58
	Texaco					1.45	1.24
10-G	TTI	3.25		1.35	1.90		
11-F	TTI			2.40			

TABLE 15. Changes in Flow Complex Ratio, C_A/C_B, of Asphalts with Years of Service

Sample No.	Exposure in Years 0	1	2	3	4	5
1-A	.90		.30	.60	.65	.90
2-B	.85		.60	.65	1.35	.75
3-C	.65		.90	1.00	.85	
4-B	.60		.50	.60	1.00	.75
5-D	.55		.45	.50	.85	1.00
6-A	.70		1.25	.85	.95	.75
7-C	.80		.65	.55		
8-E	.80		.65	.55	.90	
9-F	.70		1.00	.60	1.00	
10-G	.80		.80	.80		
11-F			.90			

TABLE 16. Changes in Ebberts Oxidation Values of Asphalts with Years of Service

Sample No.	Lab.	0	1	2	3	4	5
		Exposure in Years					
1-A	TTI	1.50		1.03	0.95	0.66	0.38
	Texaco					0.95	0.79
2-B	TTI	1.95		1.20	0.88	0.67	0.40
	Texaco					1.02	0.83
3-C	TTI	1.06		0.96	0.94	0.96	
	Texaco					1.00	
4-B	TTI	1.50		0.98	0.87	0.73	0.30
	Texaco					1.27	0.79
5-D	TTI	2.16		1.32	1.12	0.73	0.50
	Texaco					1.10	1.02
6-A	TTI	1.17		1.03	1.00	1.10	0.43
	Texaco					1.17	1.31
7-C	TTI	1.12		1.11	0.99		
8-E	TTI	1.07		0.97	0.93	0.80	0.40
	Texaco					1.28	1.44
9-F	TTI	1.49		1.25	1.03	0.85	0.35
	Texaco					1.23	0.87
10-G	TTI	0.96		1.06	1.03		
11-F	TTI	1.05		0.92			

TABLE 17. Changes in Component Analysis of Asphalts with Years of Service

Sample No.	Fraction		0	1	2	3	4		5	
							TTI	Texaco	TTI	Texaco
1-A	I	%	38	37	38	39	38	37.6	37	37.2
	II	%	18	19	18	16	17	19.1	21	20.6
	III	%	44	44	44	45	45	43.3	42	42.1
2-B	I	%	47	48	50	52	53	52.0	52	53.9
	II	%	11	10	11	9	8	10.8	11	11.2
	III	%	42	42	39	39	39	37.2	37	34.9
3-C	I	%	34	35	38	38	38	37.1		
	II	%	23	23	22	22	21	22.3		
	III	%	43	42	40	40	41	40.6		
4-B	I	%	47	48	50	50	51	51.7	52	53.3
	II	%	12	11	10	10	10	11.3	11	11.9
	III	%	41	41	40	40	39	37.0	37	34.9
5-D	I	%	29	29	36	31	30	28.9	30	31.8
	II	%	20	19	21	18	19	19.8	20	20.3
	III	%	51	52	43	51	51	51.3	50	47.8
6-A	I	%	33	38	45	41	43	43.0	42	46.6
	II	%	19	24	22	25	24	24.5	27	23.4
	III	%	48	38	33	34	33	32.5	31	29.8
7-C	I	%	39	39	43	42				
	II	%	20	19	18	19				
	III	%	41	42	39	39				
8-E	I	%	34	34	38	38	38	37.8	38	32.7
	II	%	23	23	20	21	19	21.9	23	26.2
	III	%	43	43	42	41	43	40.2	39	41.1
9-F	I	%	25	26	30	30	28	28.5		37.5
	II	%	27	26	28	27	25	25.6		22.9
	III	%	48	48	42	43	47	45.9		39.5
10-G	I	%	31	31	35	38				
	II	%	12	12	14	14				
	III	%	57	57	51	48				
11-F	I	%	23	25						
	II	%	28	31						
	III	%	49	44						