ADDITIONAL RHEOLOGICAL PROPERTIES OF 85-100 PENETRATION ASPHALT CEMENTS USED IN FIELD TESTS INITIATED DURING 1963-64

by
R. N. Traxler
Research Chemist
Texas Transportation Institute

Progress Report No. 9
Study No. 2-8-59-9
Research Area 8

Submitted to
Research Committee
of the Texas Highway Department

August 1, 1966

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

Abstract

Report: Progress Report No. 9 - Study No. 2-8-59-9 of Research Area 8

Title: Additional Rheological Properties of 85-100 Penetration Asphalt Cements Used in Field Tests Initiated During 1963-64

Period: May 1, 1965 to July 1, 1966

Objective: Determination of viscosities at 60° and 50°F, and microductilities at 77° and 60°F.

Experimental: Viscosity measurements at 60° and 50°F were made on the asphalt cements used in the field tests started during 1963-64. Steel plates giving 100, 300 and 500 micron films were used in the sliding plate viscometer to determine viscosities at these low temperatures. Comparisons were made of viscosity values at 77°, 60° and 50°F. Degree of complex flow for each of the seventeen original asphalts were determined at 60° and 50°F.

Ductility tests at 77° and 60°F were made on the original and recovered asphalts from the seventeen test sites. The microductility apparatus used was developed by the California Division of Highways.

Conclusions:

(1) Determination of the viscosities of asphalt cements at 50° and 60°F has led to the conclusion that methods other than the thin film, sliding plate viscometer should be used to obtain rheological data on most asphalt cements at temperatures at or below 50°F. This statement refers in general to the research approach which should be made in the investigation of flow properties of asphalt cements at low atmospheric temperatures.

(2) Viscosity values for AC-20 and AC-10 asphalt cements at 60°F will not be desirable as specification tools. Viscosities at 77°F which have been recommended for qualifying asphalts at atmospheric temperatures are more practical and accurate.

(3) Ductility values obtained at 60° and 77°F on 90 penetration asphalt cements using the California microductility machine are interesting in respect to the corresponding viscosities but not particularly helpful in characterizing the asphalts tested.

Recommendations:

It is recommended that:
(1) An Instron Tester, equipped with an environmental control cabinet, (2) A Weissenberg Rheogoniometer and (3) a Thermal Differential Analyzer all be used in the future for studies of low temperature rheological properties of asphalt cements.

Future Work: Future work on the rheological aspects of Study No. 2-8-59-9 will be directed toward an analysis of low temperature properties of asphalt cements, using first the Instron Tester equipped with a temperature controlled cabinet which is available at Texas A&M University. The tests will be made in compression on discs of the asphalt.

A Weissenberg Rheogoniometer will be used in fundamental low temperature studies of the rheological properties of asphalt cements. This apparatus, which provides the best available means for studying materials possessing non-Newtonian characteristics, should be available in 1967 for the investigation of asphalts at temperatures above and below 77° F. The Rheogoniometer, which costs in the neighborhood of $30,000, will be the first piece of equipment installed in the newly created Rheological Research Laboratory at Texas A&M University. This laboratory will be housed in the new Space Research Center Building on the Campus, which will be ready for occupancy on November 1, 1966. Equipment in this centralized Rheological Laboratory will be available for use by any of the Engineering and Scientific disciplines of the University.

A Thermal Differential Analyzer will be used for analysis of temperature related properties of asphalt. It is expected that this apparatus will be available in the near future in the Chemistry Department of Texas A&M University.

CONTENTS

TABLES

FIGURES

ADDITIONAL RHEOLOGICAL PROPERTIES OF 85-100 PENETRATION ASPHALT CEMENTS USED IN FIELD TESTS INITIATED DURING 1963-64

I. OBJECTIVES OF STUDY NO. 2-8-59-9 OF RESEARCH AREA 8

The objectives of the project are to:

(1) Investigate the paving asphalts used by the Texas Highway Department,

(2) Establish specifications to assure use of superior asphalts by the Department, and

(3) Determine how the durability of asphalt cements can be improved.

The investigation discussed below applies to objectives (1) and (2) listed above.

II. HISTORY

Progress Report No. 8, "Hardening of 85-100 Penetration Asphalt Cements During Service in Pavement," described field tests started in 1963 and recorded viscosities of the original and extracted asphalts at 77°, 95°, 140°, and 275° F, together with asphaltene contents of the original asphalts and one year old samples and viscosities of the petrolenes from the original asphalts. General information was given concerning the aggregates used at the various experimental sites and the hardening of the bitumens during the preparation of the hot mixture, laying of the pavement, and during one year of service. The current report gives data on the viscosities at 50° and 60° F of the original asphalts discussed in Progress Report No. 8, and on four additional asphalts used in other field tests. Ductility data on all of the original and extracted asphalts at 60° and 77° F are discussed.

III. CONCLUSIONS

(1) Determination of the viscosities of asphalt cements at 50° and 60° F has led to the conclusion that methods other than the thin film, sliding plate viscometer should be used to obtain rheological data on most asphalt cements at temperatures below 50° F. This statement refers in general to the research approach which should be made in the investigation of flow properties of asphalt cements at low atmospheric temperatures.

(2) Viscosity values for AC-20 and AC-10 asphalt cements at 60° F will not be desirable as specification tests. Viscosities at 77° F which have been recommended for qualifying asphalts at atmospheric temperatures are more practical and accurate.

(3) Ductility values obtained at 60° and 77° F on 90 penetration asphalt cements using the California microductility machine are interesting in respect to the corresponding viscosities but not particularly helpful in characterizing the asphalts tested.

IV. RECOMMENDATIONS

It is recommended that:

(1) An Instron Tester, equipped with an environmental control cabinet,

(2) a Weissenberg Rheogoniometer and

(3) a Thermal Differential Analyzer all be used in the future for studies of low temperature rheological properties of asphalt cements.

V. FUTURE WORK

Future work on the rheological aspects of Study No. 2-8-59-9 of Research Area 8 will be directed toward an analysis of low temperature properties of asphalt cements, using first the Instron Tester equipped with a temperature controlled cabinet which is available at Texas A&M University. The tests will be made in compression on discs of the asphalt.

A Weissenberg Rheogoniometer will be used in fundamental low temperature studies of the rheological properties of asphalt cements. This apparatus, which provides the best available means for studying materials possessing non-Newtonian characteristics, should be available in 1967 for the investigation of asphalts at temperatures above and below 77° F. The Rheogoniometer, which costs in the neighborhood of $30,000, will be the first piece of equipment installed in the newly created Rheological Research Laboratory at Texas A&M University. This laboratory will be housed in the new Space Research Center Building on the Campus, which will be ready for occupancy on November 1, 1966. Equipment in this centralized Rheological Laboratory will be available for use by any of the Engineering and Scientific disciplines of the University.

The Thermal Differential Analyzer will be used for analysis of temperature related properties of asphalt. It is expected that this apparatus will be available in the near future in the Chemistry Department of Texas A&M University.

VI. EXPERIMENTAL WORK

1-Viscosities of Asphalt Cements at 50° and 60° F

Extensive data are available on viscosities of asphalt cements at 77° F and above. Currently, the most pressing problems are concerned with viscosities at temperatures below 77° F. A start on measurements of low

Table I

Viscosities of Original Asphalts Used at 1963-4 Field Test Sites.
Megapoises* at 77°, 60° and 50° F - Rate of Shear 5×10^{-2} sec^{-1}

SITE NO.	PRODUCER CODE NUMBER	77° F	60°F	50° F	η at60°/η at77°	η at50°/η at77°
12	2	0.86	16.4	68.0	19.0	79.0
1	3	1.15	9.2	44.0	8.0	38.0
9	3	1.18	13.9	70.0	11.8	59.0
15	3	1.26	18.0	66.0	14.3	52.0
17	3	1.48	18.4	58.0	12.4	39.0
13	5	0.81	13.6	66.0	16.8	82.0
11	6	0.56	16.6	46.0	29.6	82.0
14	6	0.58	9.0	36.0	15.5	62.0
18	6	1.68	25.2	80.0	15.0	47.5
6	7	0.96	25.0	59.0	26.0	61.5
8	7	0.86	17.4	40.0	20.0	46.5
3	8	1.00	8.8	40.0	8.8	40.0
4	11	1.17	16.0	36.0	13.5	31.0
10	11	1.12	11.6	32.0	10.3	28.5
7	15	1.00	16.6	27.5	16.6	27.5
16	16	0.66	13.0	46.0	19.7	70.0
2	18	0.90	8.2	43.0	9.1	48.0

Viscosities at 60° F range from 8 to 29.6 times harder than at 77° F.
Viscosities at 50° F range from 27.5 to 82 times harder than 77° F.
*1 megapoise = 1,000,000 poises.

temperature viscosities was made by using the thin film (sliding plate) Hallikainen viscometer to obtain viscosities, at 50° and 60° F, for the seventeen original asphalts used in field tests started in 1963 and 1964. In order to measure the relatively high viscosities encountered at these temperatures, steel instead of glass plates were used in the sliding plate viscometer. Spacers were used which gave films 100, 300 and 500 microns thick. The thickness selected depended on the hardness of the particular asphalt. Generally 100- and 300-micron films were used at 60° F and 300 and 500 microns at 50° F. Increasing the film thickness reduced the load that was required. We have found it undesirable to apply large loads to this viscometer because of the somewhat frail structure of the apparatus. Table I, facing, gives the data obtained.

The last two columns of the table show the ratios of the viscosities at 60° F and 50° F in respect to viscosity at 77° F for each asphalt. The differences in a particular set of ratios indicate differences in the temperature susceptibility of the asphalts.

Table II

Viscosities inMegaposises* at 50° and 60° F Determined at 3 Rates of Shear
Original Asphalts Used at Test Sites 1 through 18

SITE	PRODUCER CODE	at $5x10^{-2}$ sec^{-1}		at $1x10^{-2}$ sec^{-1}		at $1x10^{-3}$ sec^{-1}		Complex Flow "C"	
		50° F	60° F	50° F	60° F	50° F	60° F	50° F	60° F
12	2	68.0	16.4	90.0	19.5	130	24.5	0.85	0.90
1	3	44.0	9.2	73.0	12.9	148	21.0	0.70	0.80
9	3	70.0	13.9	90.0	15.3	140	18.0	0.85	0.90
15	3	66.0	18.0	113.0	22.5	240	31.5	0.65	0.85
17	3	58.0	18.4	95.0	26.0	189	42.5	0.70	0.85
13	5	66.0	13.6	90.0	16.9	142	23.5	0.80	0.85
11	6	45.8	16.6	55.0	17.0	71	18.0	0.90	0.95
14	6	36.0	9.0	53.9	15.0	93	16.0	0.75	0.90
18	6	80.0	25.2	120.0	31.5	275	43.5	0.75	0.85
6	7	59.0	25.0	100.0	30.5	120	40.0	0.70	0.90
8	7	40.0	17.0	65.0	18.3	133	20.0	0.70	0.95
3	8	40.0	8.8	75.0	12.4	175	20.8	0.60	0.80
4	11	35.8	16.0	57.0	17.0	112	19.0	0.70	0.95
10	11	32.0	11.6	63.0	14.0	160	19.0	0.50	0.90
7	15	27.6	16.6	66.0	19.4	230	24.4	0.45	0.90
16	16	45.8	13.0	77.0	15.0	160	18.2	0.70	0.90
2	18	43.0	8.2	60.0	10.3	100	14.5	0.80	0.85

* 1 megapoise = 1,000,000 poises.

2-Shear Susceptibility of Original Asphalts at 50° and 60° F

The viscosity values shown in Table I were all calculated at a rate of shear of $5x10^{-2}$ reciprocal seconds. As the temperature of measurement is decreased the degree of deviation from simple flow increases. This development of shear susceptibility is believed to be caused by the formation of thixotropic structures within the asphalt. Thixotropy is destroyed by application of a shearing force but the structure reappears when the applied force is removed. To measure "thixotropy," "shear susceptibility," "structural viscosity" or "degree of complex flow," it is necessary to measure the viscosity (at a particular temperature) at a minimum of three different rates of shear. This was done for the seventeen asphalts at 50° and 60° F. The data obtained are shown in Table II, (facing). It will be noted that the higher the rate of shear used, the lower is the apparent viscosity.

The values for "degree of complex flow" "C" shown in the final two columns of Table II are obtained as follows: Experimentally determined viscosities are plotted against rates of shear on log-log coordinates. A line is drawn through the plotted points (see Figure A-1, Appendix, page 17). From this plot the viscosity at a high rate of shear (from one end of a cycle) is divided by the viscosity at a low rate of shear (obtained from the other end of the cycle). Both of these values are determined from the straight line connecting the data points. The logarithm of 10 times this quotient is the average value of "C" (the degree of complex flow) for the sample. On a plot such as shown in Figure A-1, the "C" value of a horizontal shear rate—viscosity curve is 1.0 which indicates simple or Newtonian flow. Generally, the "C" value for asphalts is something less than 1.0 and may in extreme cases (highly airblown and hard asphalts) be as low as 0.3 or 0.4. The lower the value of "C" the more non-Newtonian or shear susceptible is the asphalt. In any case, the reported value of "C" is rounded off to the nearest 0.05.

The "C" values calculated for the 17 asphalt considered in this report are shown in the final two columns of Table II. The most complex flow at 60° F is shown by the asphalts used at Sites 1 and 3. For 50° F the most deviation from simple flow is shown by the asphalt used at Site 7.

It should be mentioned that different asphalts will not necessarily show the same increase in complex flow for the same drop in temperature. Also, it should be understood that two asphalt cements may have similar rheological properties at 77° F, but possess quite different viscous and elastic properties and different "degrees of complex flow" at lower temperatures. Such differences in behavior are due to variations in the chemical composition of the bitumens.

3-Future Measurements of Rheological Properties at Temperatures Below 77° F

The data shown in Table II point to the need for additional rheological invesitgations at 60° and 50° F and at much lower temperatures. In the writer's opinion, rheological studies of asphalt cements below 60° F will require more sophisticated types of apparatus than have generally been used to date. Machines that are being seriously considered for low temperature studies are:

(a) An Instron Tester, equipped with an environmental cabinet to measure deformation under compression. A disc of known dimensions and temperature will be subjected to accurately controlled rates of shear. It is hoped that this approach will offer a practical control method for evaluating the flow properties of asphalt cements at temperatures well below 77° F. Such equipment will soon be available in the TTI laboratories.

(b) A Weissenberg Rheogoniometer, which is a highly elaborate apparatus for evaluating rheological properties of materials of a wide range of viscosities (gases to hard asphalts) over a wide range of temperature, is being purchased for applications to various rheological problems at Texas A&M University. When this apparatus becomes available, it will make possible a scientific study of the non-Newtonian properties possessed by asphalt cements over a wide range of low atmospheric temperatures. It will be especially useful at those temperatures where viscous and elastic deformations are occurring simultaneously. In other words, the rheogoniometer will make it possible to unscramble viscous and elastic deformation.

(c) A Thermal Differential Analyzer, which measures physical changes in a material at constant rates of temperature change and over a wide range of temperature. This type of apparatus has been used to determine the "glass point" of asphalts which is the temperature where viscous flow becomes of little significance and elastic deformation is very important. The TDA also detects volume increase or decrease associated with changes in the physical state of the material being tested. It is expected that a Thermal Differential Analyzer will be purchased by the Chemistry Department of Texas A&M University, and become available for studies on the temperature related properties of asphalts.

Table III

Original and Recovered Asphalts
from
Field Test Sites 1 Through 18

Viscosities at 77° F of Samples
Possessing Highest Microductility Values

Site No.	Producer Code No.	Age of Sample Having Highest Ductility	Viscosity at 77° F Megapoises
3	8	Original	1.00
4	11	Original	1.17
9	3	Original	1.18
15	3	Original	1.26
10	11	Plant	1.28
16	16	Plant	1.40
11	6	Plant	1.45
17	3	Original	1.48
1	3	Plant	1.90
2	18	Paver	1.90
12	2	One Day	2.05
13	5	Two Weeks	2.26
8	7	Paver	2.40
6	7	Paver	2.60
7	15	One Day	2.85
14	6	Four Months	2.92
18	6	Plant	3.50

Maximum Microductilities range from 3.4 to 10.4cms (0.5cm/min).

Viscosities fall between 1.0 and 3.5 megapoises at rate of $5 \times 10^{-2} sec^{-1}$.

4-Microductility Tests on Asphalt Cements at 77° and 60° F

The type of microductility tester developed by the California Division of Highways and described by F. N. Hveem, E. Zube, and J. Skog in their paper "Proposed New Tests and Specifications for Paving Grade Asphalts" presented in Proceedings of the Association of Asphalt Paving Technologists, Volume 32, pages 324-27 (1963), has been used in an evaluation at 77° and 60° F of the asphalts discussed in the preceding pages of this report.

The machine is made to pull the asphalt at a rate of 0.5 cm per minute. A small sample (0.05 gram) of asphalt is required for a test. The usual practice is to obtain at least three determinations that check quite closely and use the average as the accepted value.

In order to determine what significance could be assigned to the ductility data, it was decided to obtain information on the original asphalts discussed above in this report, and also on the asphalts recovered during the 1963 and 1964 field tests. By this approach it was possible to obtain a correlations between the ductility at a particular temperature and the viscosity at the same temperature of progressively harder samples derived from a particular asphalt.

Table A-1 (Appendix, page 15) shows the ductilities and viscosities at 77° F for the samples available from the seventeen field tests. The underscore marks indicate the maximum ductility in cms for the original and recovered asphalts at each field site. Also, underscored is the viscosity at 77° F (shear rate $5x10^{-2}sec^{-1}$) for the sample possessing maximum ductility. These data are condensed in Table III, (facing), which shows that the maximum ductilities at 77° F are associated with a viscosity (at 77° F) of between 1 and 3.5 megapoises. Figure 1, page 10, is a log-log plot of ductilities versus viscosities (at 77° F) for the original and some recovered asphalts from Site No. 1 of the field tests. It will be noted that the maximum ductility (6.2 cms) corresponds to a viscosity of 1.9 megapoises.

It is interesting that R. N. Traxler, H. E. Schweyer and J. W. Romberg in a paper "Rheological Interpretation of Asphalt Tests" in Proc. ASTM 40 1191 (1940) showed that a series of progressively harder asphalts, processed in the same manner, behaved the same as the data discussed above. Their tests were made using the standard ASTM ductility test at 77° F. The advantage of the new machine is that definite values are obtained for the most ductile material whereas with the standard ASTM ductility test, high ductility values are recorded as 100+, 150+, or 200+ cms.

Table A-2 (Appendix, page 18) shows ductility and viscosity data on the above mentioned series of asphalts at 60° F. Samples are not shown which gave

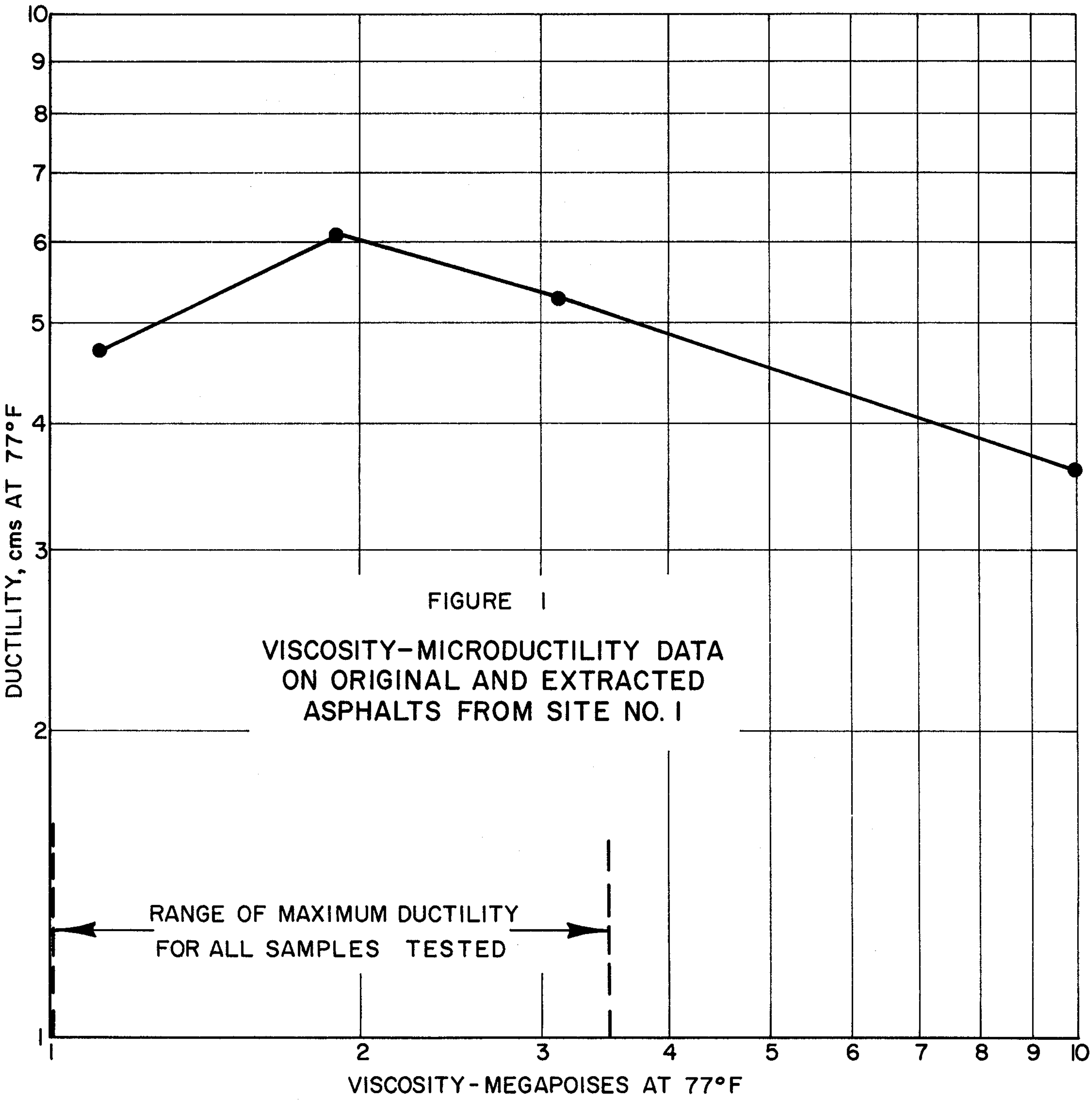

FIGURE 1

VISCOSITY-MICRODUCTILITY DATA ON ORIGINAL AND EXTRACTED ASPHALTS FROM SITE NO. 1

Table IV

Asphalts Used at Field Test Sites 1 Through 18

Viscosities at 60° F of Samples
Possessing Highest Microductility Values

Site No.	Producer Code No.	Age of Sample Having Highest Ductility	Viscosity at 60° F Megapoises
2	18	Original	8.2
3	8	Original	8.8
14	6	Original	9.0
1	3	Original	9.2
10	11	Original	11.6
16	6	Original	13.0
13	5	Original	13.6
9	3	Original	13.9
4	11	Original	16.0
12	2	Original	16.4
7	15	Original	16.6
11	6	Original	16.6
8	7	Original	17.4
15	3	Original	18.0
17	3	Original	18.5
6	7	Original	25.0
18	6	Original	25.2

Maximum Microductilities range from 2.4 to 10.3cms (0.5cm/min).

Viscosities fall between 8.2 and 25.2 megapoises at rate of $5 \times 10^{-2} sec^{-1}$.

ductilities below 0.5 cm. A condensation of the data is shown in Table IV, facing. Maximum ductilities were obtained in every case on the original asphalt at this lower temperature. The viscosities ranged from 8 to 25 megapoises at 60° F.

As pointed out above, it has been known for many years that ductility is connected with the viscosity (hardness) of an asphalt. At a low consistency (viscosity) an asphalt has a low ductility value, partly because it flows out of the mold too rapidly. However, as the viscosity increases a region of high ductility is eventually reached. Then as the consistency becomes still greater, a decrease in ductility results because the flow properties of the asphalt do not allow it to deform with sufficient rapidity at the high shearing stress applied and the thread breaks. Also, as the asphalt is hardened by processing, aging or decreased temperature, it develops marked "shear susceptibility" or "thixotropy" and the effect of the applied stress is greatly increased in the thread at the point of smallest cross section.

The ductility test has, for some reason, been most intriguing to many workers in asphalt technology. A fantastic number of man-hours have been spent in "further investigations and analyses" of the standard ductility test. This time could have better been expended on more basic rheological studies. The microductility method is appealing in that one always obtains a "number" for the higher values (and not a long list of 100+, 150+ or 200+ centimeters). But, basically the same situation is arrived at by using the new apparatus instead of the standard ASTM test.

VII. APPENDIX

INDEX

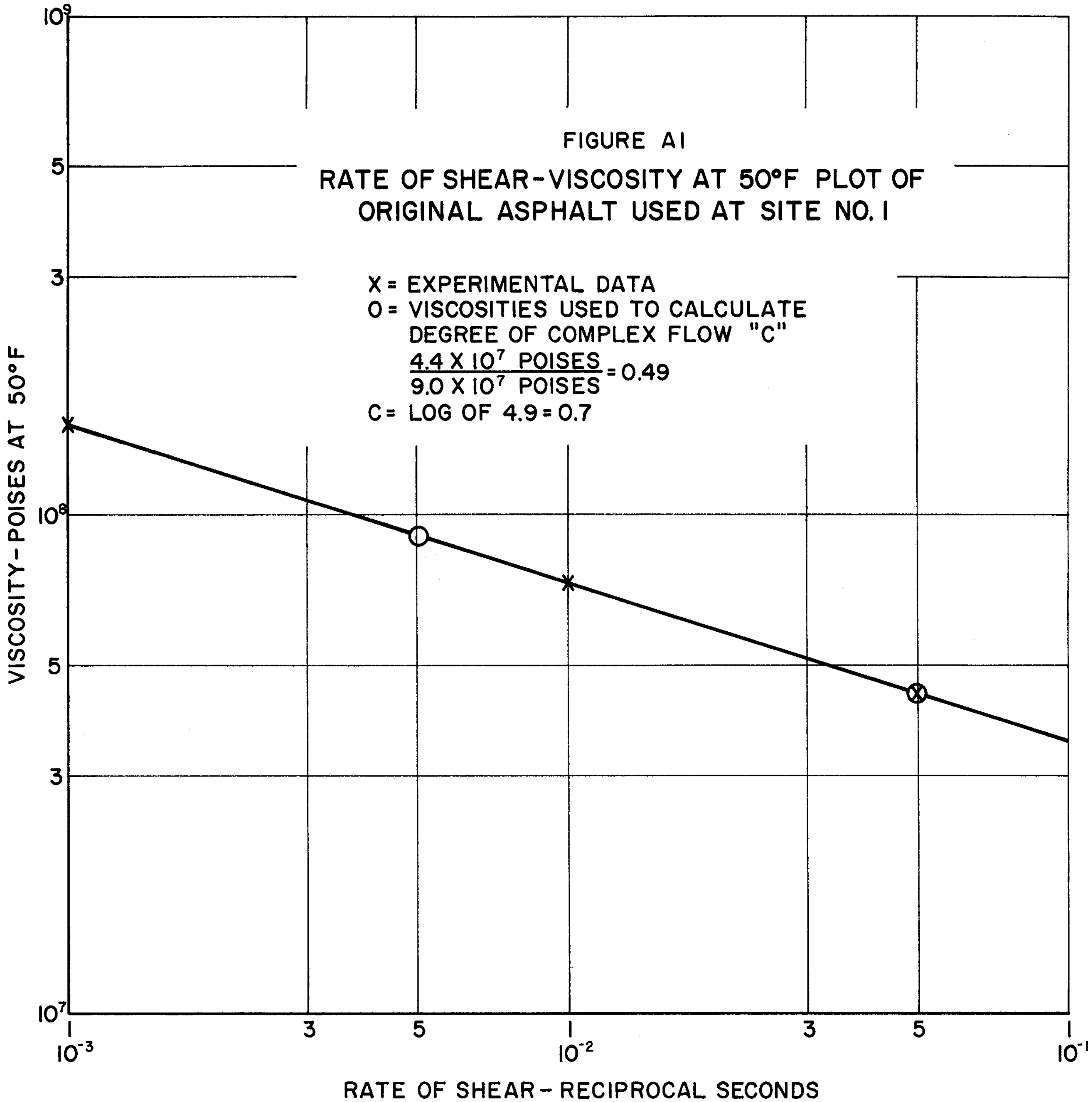

FIGURE A1

RATE OF SHEAR-VISCOSITY AT 50°F PLOT OF ORIGINAL ASPHALT USED AT SITE NO. 1

Table A 1

Correlation of Microductility at 77° F
with Viscosity at 77° F

Site	Producer	Age of Sample	Ductility @ 77° F @ 0.5cm/min, cms	Viscosity @ 77° F Megapoises $5x10^{-2} sec^{-1}$
1	3	Original	4.7	1.15
		Plant	6.1	1.90
		1 Day	5.3	3.15
		4 Months	3.6	10.30
		1 Year	2.6	10.40
		2 Years	1.5	10.60
2	3 (w)	Original	4.7	0.90
		Paver	8.1	1.90
		1 Day	8.0	2.80
		2 Weeks	8.1	3.20
		4 Months	7.7	8.35
		1 Year	3.2	12.00
3	8	Original	5.1	1.00
		Plant	3.0	2.30
		Paver	2.5	2.65
		1 Day	3.5	2.80
		2 Weeks	2.3	3.50
		4 Months	2.6	5.95
		2 Years	1.6	7.30
4	11	Original	4.3	1.17
		Plant	3.8	1.96
		Paver	2.2	2.06
		1 Day	2.3	2.36
		2 Weeks	1.9	2.56
		4 Months	1.2	11.40
		1 Year	1.0	12.40
		2 Years	0.5	15.00
6	7	Original	4.2	0.95
		Plant	5.9	2.50
		Paver	6.9	2.60
		1 Day	6.0	3.00
		2 Weeks	5.2	5.35
		4 Months	2.1	20.80
		1 Year	1.7	23.60
		2 Years	1.55	38.20

Continued

Site	Producer	Age of Sample	Ductility @ 77° F @ 0.5cm/min, cms	Viscosity @ 77° F Megapoises $5x10^{-2}sec^{-1}$
7	15	Original	3.2	1.00
		Plant	3.5	1.75
		Paver	3.1	1.85
		1 Day	4.2	2.85
		2 Weeks	3.6	4.35
		4 Months	1.6	13.20
		1 Year	1.1	14.50
		2 Years	0.9	24.40
8	7	Original	4.4	0.90
		Plant	5.8	2.35
		Paver	7.3	2.40
		1 Day	7.0	2.80
		2 Weeks	5.7	6.55
		4 Months	4.6	12.40
		1 Year	1.6	15.00
		2 Years	0.9	28.60
9	3	Original	5.0	1.18
		Plant	3.2	2.85
		Paver	3.1	2.82
		1 Day	2.9	2.80
		2 Weeks	3.1	5.56
		4 Months	2.5	8.76
		1 Year	0.95	12.00
		2 Years	0.40	13.30
10	11	Original	5.0	1.12
		Plant	5.8	1.28
		Paver	4.0	1.76
		1 Day	4.6	2.10
		2 Weeks	3.1	3.20
		4 Months	3.3	9.30
		1 Year	0.4	15.40
		2 Years	0.7	34.00
11	6	Original	5.0	0.56
		Plant	10.4	1.45
		2 Weeks	8.5	2.05
		4 Months	7.4	8.60
		1 Year	6.7	12.40
		2 Years	7.9	15.40

Continued-2

Site	Producer	Age of Sample	Ductility @ 77° F @ 0.5cm/min, cms	Viscosity @ 77° F Megapoises $5x10^{-2}sec^{-1}$
12	2	Original	5.6	0.86
		Plant	6.3	1.20
		Paver	6.8	1.40
		1 Day	6.8	2.05
		2 Weeks	5.0	2.20
		1 Year	5.4	13.20
		2 Years	2.6	38.00
13	5	Original	5.3	0.81
		Plant	6.4	1.78
		Paver	6.5	1.98
		2 Weeks	6.9	2.26
		1 Year	5.4	7.96
		2 Years	4.6	17.80
14	6	Original	6.5	0.58
		Plant	8.5	1.03
		1 Day	10.0	1.10
		4 Months	10.2	2.92
		1 Year	9.9	6.20
		2 Years	8.8	7.24
15	3	Original	4.55	1.26
		Plant	3.45	2.80
		2 Weeks	1.07	5.40
		4 Months	0.60	15.00
16	16	Original	4.3	0.66
		Plant	8.7	1.40
		1 Day	8.6	1.90
		2 Weeks	6.9	3.30
17	3 Vis. Specs	Original	3.4	1.48
		Plant	1.0	3.16
		4 Months	0.9	11.40
18	6 Vis. Specs	Original	8.9	1.68
		Plant	10.3	3.50
		1 Day	10.3	4.20
		2 Weeks	8.4	6.30

Table A2

Correlation of Microductility at 60° F with Viscosity at 60° F

Site	Producer	Age of Sample	Ductility @ 60° F @ 0.5cm/min, cms	Viscosity @ 60° F Megapoises $5 \times 10^{-2} sec^{-1}$
1	3	Original	3.7	9.2
		Plant	2.2	26.4
		1 Day	0.75	36.2
		4 Months	0.45	38.6
2	3 (w)	Original	4.85	8.2
		Paver	2.8	31.6
		1 Day	2.1	38.0
		2 Weeks	1.1	45.6
		4 Months	0.8	88.0
3	8	Original	2.9	8.8
		Plant	1.2	27.6
		Paver	1.0	32.6
		1 Day	0.75	34.0
4	11	Original	2.6	16.0
		Plant	0.8	27.0
		Paver	0.4	35.6
6	7	Original	4.7	25.0
		Plant	1.1	40.0
		Paver	0.75	49.0
7	15	Original	2.8	16.6
		Plant	1.15	32.0
		Paver	1.0	36.2
		1 Day	0.75	37.8
		2 Weeks	0.5	38.4
8	7	Original	6.0	17.4
		Paver	1.3	45.6
		1 Day	0.7	52.0
9	3	Original	2.75	13.9
		Plant	0.95	29.8
		Paver	0.7	48.0

Continued

Site	Producer	Age of Sample	Ductility @ 60° F @ 0.5cm/min, cms	Viscosity @ 60° F Megapoises $5x10^{-2}sec^{-1}$
10	11	Original	2.4	11.6
		Plant	0.6	18.0
11	6	Original	9.0	16.6
		Plant	5.0	23.6
		2 Weeks	1.55	41.0
		4 Months	0.9	73.0
12	2	Original	7.5	16.4
		Plant	3.3	18.4
		Paver	2.5	35.6
		1 Day	1.5	45.6
		2 Weeks	3.0	53.8
		4 Months	0.7	57.0
13	5	Original	8.0	13.6
		Plant	3.0	35.8
		Paver	1.25	37.6
		4 Months	0.9	59.0
14	6	Original	8.6	9.0
		Plant	8.1	19.6
		1 Day	5.0	24.0
		4 Months	1.4	38.0
		1 Year	0.8	72.0
15	3	Original	2.85	18.0
		Plant	0.70	34.6
		2 Days	0.40	72.0
16	6	Original	5.7	13.0
		Plant	5.0	27.0
		Paver	4.0	54.0
		1 Day	3.8	70.0
		2 Weeks	1.4	71.5
		4 Months	0.7	86.0
		1 Year	0.6	108.0
17	3	Original	2.65	18.4
		Plant	0.8	33.2
		1 Day	0.5	42.0
18	6	Original	10.3	25.2
		Plant	3.9	48.6
		1 Day	2.0	74.0
		2 Weeks	1.0	118.0
		4 Months	0.5	119.0