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FINAL REPORT

HIGHWAY RESEARCH PROJECT 17

CHANGES IN PHYSICAL PROPERTIES OF ASPHALT CEMENT UNDER SERVICE CONDITIONS

J. R. Bassett

Civil Engineering Department
University of Arkansas

in cooperation with

Arkansas Highway Department

and

Department of Transportation
Bureau of Public Roads

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TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

This investigation was sponsored by the Arkansas Highway Department and the Department of Transportation, Federal Highway Administration -- Bureau of Public Roads, under the Joint Agreement between the University of Arkansas and the Arkansas Highway Department. The work was accomplished in the Civil Engineering Laboratories at the University of Arkansas.

An earlier study of flexible pavements (3)[1] found that some pavements cracked at an early age while other pavements did not show the cracking even after a longer service period. These cracks were single isolated cracks in both longitudinal and transverse directions. The longitudinal cracks usually occurred at about the quarter point of the width and sometimes extended for distances of one hundred feet or more. The transverse cracks extended entirely across the traffic lane and were sometimes spaced at distances as close as 15 to 25 feet. The results of this earlier investigation showed some correlation between the loss of ductility of the asphalt cement and cracking. Those pavements having asphalt cements with very low or no ductility were cracking, whereas, other pavements with higher ductility in the asphalt cement did not crack. Again, some of the newer pavements had asphalt cements with low ductility, and some of the older pavements contained asphalt cement with some appre-

[1]Figure in parentheses refers to number of article in references.

ciable ductility left. There did not appear to be a correlation between the penetration of the asphalt cement and cracking or between the remaining penetration and the ductility of the asphalt cement in the pavement.

The construction records of these earlier pavements did not reveal all of the information desirable for a complete history. This and the small number of samples limited the reliability of this work but the trends indicated that further investigation might prove fruitful.

The project was approved in February, 1964, and actual research work began with the approval of the work plan on June 22, 1964. The project was planned for a duration of four years but difficulties were encountered in finding sufficient number of paving projects during the first two years. Also the extraction of asphalt cement from the pavement samples was slower than anticipated. The project was extended an additional year to allow for more time in service for some of the jobs.

The work plan anticipated that the three brands of asphalt cement produced in Arkansas would be studied but it was found that only one paving project was using Brand C asphalt. Samples were taken on the one job using Brand C, however, it is questionable whether six samples is enough to establish any firm results. The results are reported along with those from other jobs.

Early in the planning of the study of asphalt cements it was determined that it would be desirable to include both the physical and chemical properties in the investigation. The investigations were divided into two projects. The field work in obtaining the samples of asphalt concrete and extracting the asphalt cement along with penetration, ductility and some viscosity studies would be placed under one project. This project was to be sponsored by the Civil Engineering Department of the University. The studies of the chemical phases of the work were to be done by the Chemical Engineering Department of the University. This project, Highway Research Project 21, "Rheology of Asphalt Cements" is directed by Dr. J. R. Couper.

A part of each sample of asphalt cement obtained in this work is given to Project 21 along with all of the pertinent information on the sample. In this way a complete physical and chemical record is obtained for each job.

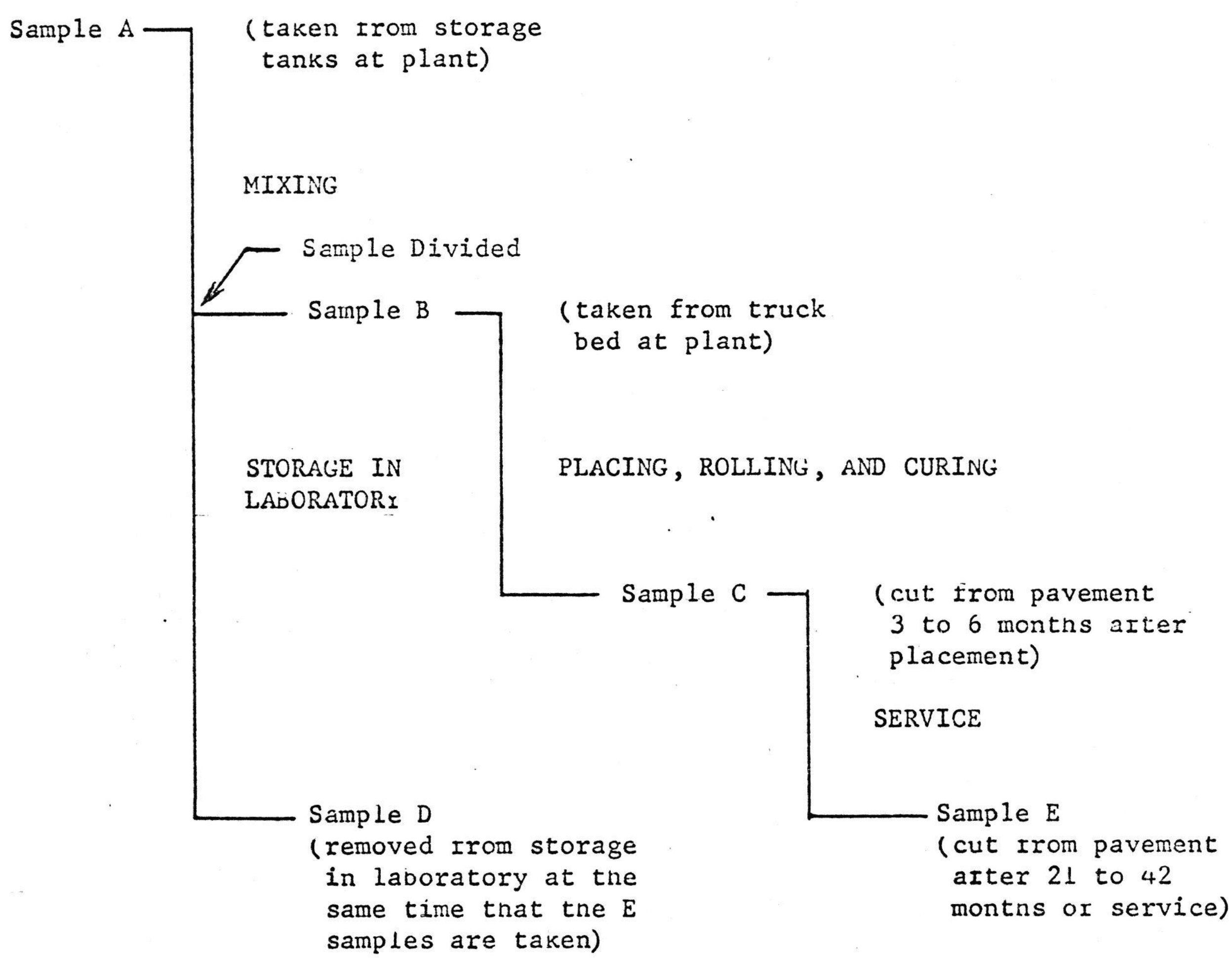
METHOD OF INVESTIGATION

SAMPLING

A work plan was devised that would obtain all possible information about each sample. It was determined that six separate samples should be obtained for each job. The term job referred to in this report is the designation given to a single construction contract by the Arkansas Highway Department. The job number is that assigned by the Highway Department. It was not possible in every case to obtain six samples on each job. In some cases the job was of very short duration and other work interfered with the acquisition of samples.

Figure 1 shows a flow diagram of the sampling operations. This sequence was followed for each sample taken on each job. Complete information on time and temperature was taken at each step of the operation.

Sample A is the sample of asphalt cement as it is received on the job. This sample was taken from the storage tank at the hot-mix plant. The size of the sample varied from one-half to one gallon. It was dipped from the storage tank. These tanks have an arrangement such that the material is constantly stirred. A pump forces the asphalt cement out of the tank through a line to the pugmill. When the asphalt from the tank is not flowing into the weighing bucket at the pugmill it is returned to the



FLOW DIAGRAM OF SAMPLING OPERATIONS

FIGURE 1

storage tank through a bypass line. The temperature of the asphalt cement was obtained with a pyrometer immediately after removing from the tank.

About 75 pounds of the hot-mix asphalt concrete was obtained from the truck immediately after it was dumped from the pugmill into the truck. Samples of all of the aggregates were also obtained at this time. The temperatures of the aggregates and the asphalt cement along with the time of mixing were obtained.

Marshall samples were molded from part of the hot sample immediately on some of the jobs. The remainder of the sample was placed in a 50 pound can and taken to the laboratory for further work. The truck from which the sample was taken was followed from the plant to the pavement location and the exact location on the pavement where this load of material was placed was marked. The haul time and the temperatures at the paver and after the hot-mix was spread behind the paver were obtained. The can containing the sample was taken to the laboratory usually within 24 hours after the sample was obtained. The sample in the can was warmed in hot water so that it could be removed from the can and handled. Half of the sample was then placed in plastic bags, covered with distilled water and sealed in one gallon syrup buckets. These buckets were labeled "Sample DL" and stored in the laboratory for future study. The Marshall specimens were labeled "Sample DM" and stored under the same conditions as Sample DL.

The asphalt cement was extracted from the remaining one-half of the sample of hot-mix immediately after being received in the laboratory. This asphalt cement recovered from the hot-mix immediately after mixing is referred to as "Sample B".

"Sample C" is the asphalt cement extracted from samples of asphalt concrete cut from the pavement three to six months after the pavement was put into service. These samples were cut with a core drill using an eight inch diameter cutting tool. The samples were, in all cases, taken from the inner wheel path at the marked locations on the jobs. Circumstances prevented the obtaining of Sample C from some of the jobs.

"Sample E" is the asphalt cement extracted from the pavement samples obtained in the same manner and location as Sample C but at a later date. These samples vary in age from 21 to 42 months and are the final samples taken. Three to five 8-inch cores were cut at each sample location. Cores for the entire depth of the pavement were cut at each location. All of these samples were cut from the inner wheel path. The various layers of material were separated in the laboratory and only the surface course was used for this study. The mixes stored in the laboratory as Sample DL and Sample DM were removed from storage and the asphalt cement extracted from the samples at the time that the asphalt cement was extracted of the matching Sample E.

The asphalt cement was extracted from the pavement mixtures by using the hot reflux method described in ASTM D2172-63T, Quantative Extraction of Bituminous Paving Mixtures, Method D. Trichloroethylene was used as the solvent in this extraction. Abson and Burton (1) and Wofford (5) found that the use of trichloroethylene did not change the properties of the asphalt cement when used as a solvent for the extraction. The asphalt cement was recovered from the solution by the distillation process specified in ASTM D762-49, Hot Extraction of Asphalt Materials and Recovery of the Bitumen by the Modified Abson Procedure. Only minor changes were necessary in the procedure using trichloroethylene. The solution boiled at a temperature of about 190°F. Carbon dioxide was introduced into the flask when the temperature reached 200°F and the flow of gas was maintained as specified. The asphalt cement recovered by this process was placed in 3- and 6- ounce ointment boxes for testing.

Table I lists the jobs that were sampled along with other information about the jobs and samples.

TABLE I

LIST OF JOBS SAMPLED

Job Number	County	Highway Number	Date Placed	Age Final Sample Months	No. Smpl.
4473	Logan	SH 22	July 64	42	5
2-509	Arkansas	SH 11	Aug 64	41	4
1370	Faulkner	SH 36	Aug 64	41	6
2661	Arkansas	SH 130	Sept 64	40	4
8-516[1]	Conway	SH 113	July 65	--	5
2-528	Jefferson	US 76 (264)	Aug 65	31	6
2-534	Jefferson	SH 81	Sept 65	30	6
11-524[1]	Phillips	US 49	Sept 65	--	2
9-518	Boone	US 62	Oct 65	31	6
2-536	Lincoln	SH 81	Oct 65	27	6
2-527	Ashley	US 82	Oct 65	31	6
9432	Washington	US 71	Aug 66	21	6
11-681	Phillips	US 49	Oct 66	26	3

[1]Maintenance operations obliterated the surface at the test locations on these two jobs therefore no final samples taken.

TESTING

All testing methods conformed to the American Society for Testing and Materials and the American Association of State Highway Officials Standard Methods of Tests in so far as they applied.

Penetration tests were made at 77°F - 200 grams, 60°F - 100 grams, 60°F - 200 grams, 45°F - 100 grams, 45°F - 200 grams, 39.2°F - 100 grams and 39.2°F - 200 grams in addition to the usual 77°F - 100 grams.

Ductility tests were made at 77°F, 60°F, 45°F and 39.2°F. The rates of strain were 1 cm/min for the tests at 45°F and 39.2°F. The ductilities at 77°F and rate of strain of 5 cm/min were not satisfactory because the original samples all had ductilities of over 150 cm. which is the capacity of the machine. Ductility at 60°F and strain of 5 cm/min seems to be the best substitute for the standard 77°F test.

Absolute viscosities were determined at 140°F by ASTM Designation D2171-63T using the Cannon-Manning Viscometer. The temperature was 140°F and the vacuum was 30 cm. of mercury. It was found that in a few cases it was not possible to obtain viscosities because the asphalt cement had a viscosity above the range of the largest Cannon-Manning Viscometer.

All of the samples taken for this work were taken from normal construction jobs. No changes were made in the usual Arkansas Highway Department construction specifications and no special conditions were imposed during the taking of any of the samples. Each sample taken represented one truck load of material usually requiring five pugmill batches to load the truck. Sample B was extracted from the mix removed from the truck and this sample was a composite from all of the batches. The batch mixing time was 15 seconds dry mix and 40 seconds wet mix. The entire sample was discarded if any of the batches were held in the pugmill longer than 65 seconds. Likewise, the sample was discarded if there was any variation from routine during the process of hauling and spreading the mixture on the road.

The Arkansas Highway Department maintained a control laboratory at each hot-mix plant during the entire job. The laboratory inspector makes check tests of the aggregate gradation, asphalt content, densities and temperatures. All of this information was made available to the investigators during the investigations.

The pertinent data for each job are shown on the following pages 12 through 24.

JOB 4473

Placed	-- July, 1964
Type Construction	-- Surface Course on 2" - 4"; Type 2 Binder, Emulsion Tack
Thickness	-- 1.5"
Asphalt Cement Brand	-- "A"
Coarse Aggregate	-- Crushed Sandstone 72%
Fine Aggregate	-- Local Sand 23%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature °F	-- 300 - 315
Placing Temperature °F	-- 300 - 312
Asphalt Cement Temperature °F	-- 300
Asphalt Cement Content	-- 5.6
Percent Voids, as placed	-- 4.5
Percent Voids, "E" Sample	-- No. 1 - 0.6 No. 4 - 2.5
Absolute Specific Gravity Coarse Aggregate	-- 2.59
Bulk Specific Gravity Coarse Aggregate	-- 2.53
Absorption Coarse Aggregate 24 Hours	-- 0.89
Specific Gravity Mineral Filler	-- 2.70

JOB 2 - 509

Placed	-- August, 1964
Type Construction	-- Resurfacing - Emulsion Prime
Thickness	-- 1.5
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Syenite 85%
Fine Aggregate	-- Local Sand 10%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature °F	-- 290°; 280°; 305°; 295°.
Placing Temperature °F	-- 285 - 290
Asphalt Cement Temperature °F	-- 300
Asphalt Cement Content	-- 6.0 - 5.9
Percent Voids, as placed	-- 3.2
Percent Voids, "E" Sample	-- 3.1
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity, Coarse Aggregate	-- 2.57
Absorption Coarse Aggregate 24 Hours	-- 0.82
Specific Gravity Mineral Filler	-- 2.70

JOB 1370

Placed	-- August, 1964
Type Construction	-- Emulsion Tack; Resurface Old Double Seal
Thickness	-- 1"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Local Crushed Sandstone 47%
Stone Screenings	-- Crushed Sandstone 28%
Fine Aggregate	-- Arkansas River Sand 20%
Mineral Filler	-- Batesville Limestone Dust 5%
Mixing Temperature °F	-- 300 - 310
Placing Temperature °F	-- 285 - 300
Asphalt Cement Content	-- 5.5
Percent Voids, as placed	-- 3.2 - 4.3
Percent Voids, "E" Sample	-- 3.3 - 3.5
Absolute Specific Gravity Course Aggregate	-- 2.67
Bulk Specific Gravity Course Aggregate	-- 2.58
Absorption Course Aggregate 24 hours	-- 1.38

JOB 2661

Placed	-- September, 1964
Type Construction	-- Resurfacing Old Asphalt Pavements, Type 2, Emulsion Tack Coat
Thickness	-- 1.5"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Syenite 75%
Screenings	-- Crushed Syenite 10%
Fine Sand	-- Local pit 10%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature ^{o}F	-- 295 - 300
Placing Temperature ^{o}F	-- 285 - 300
Asphalt Cement Temperature ^{o}F	-- 290
Asphalt Cement Content	-- 4.7% - 5.0%
Percent Voids, as placed	-- 4.2
Percent Voids, "E" Sample	-- 4.0 - 4.1
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity Coarse Aggregate	-- 2.57
Specific Gravity Sand	-- 2.62
Specific Gravity Mineral Filler	-- 2.70
Absorption Coarse Aggregate	-- 0.90

JOB 8 - 516

Placed	-- July, 1965
Type Construction	-- Type 3; Surface on New Crushed Sandstone Base
Thickness	-- 1.25"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Sandstone 70%
Fine Aggregate	-- Local Sand 25%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature ^{o}F	-- 300 - 310
Placing Temperature ^{o}F	-- 285 - 300
Asphalt Cement Temperature ^{o}F	-- 300
Asphalt Cement Content	-- 5.3
Percent Voids, as placed	-- 5.0 - 5.3
Absolute Specific Gravity Coarse Aggregate	-- 2.60
Bulk Specific Gravity Coarse Aggregate	-- 2.52
Absorption Coarse Aggregate	-- 0.85
Specific Gravity Mineral Filler	-- 2.70

JOB 2 - 528

Placed	-- August, 1965
Type Construction	-- Type 3; Resurfacing Old Asphalt Pavement, Emulsion Tack
Thickness	-- 1.5"
Asphalt Cement Brand	-- "A"
Coarse Aggregate	-- Crushed Syenite
Fine Aggregate	-- Crushed Syenite
Fine Sand	-- Local
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature °F	-- 310 - 305
Placing Temperature °F	-- 295 - 305
Asphalt Cement Temperature °F	-- 305
Asphalt Cement Content	-- 6.1
Percent Voids, as placed	-- 5.0
Percent Voids "E" Sample	-- Sample 1 - 1.0 Sample 3 - 0.9
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity Coarse Aggregate	-- 2.57
Absorption Coarse Aggregate, 24 Hours	-- 0.82
Specific Gravity Mineral Filler	-- 2.70

JOB 2 - 534

Placed	-- September, 1965
Type Construction	-- Resurfacing Old Asphalt Concrete, Emulsion Tack
Thickness	-- 1.5"
Asphalt Cement Brand	-- "C"
Coarse Aggregate	-- Crushed Syenite 80%
Fine Aggregate	-- Local Sand 15%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature °F	-- 310 - 300
Placing Temperature °F	-- 310 - 295
Asphalt Cement Temperature °F	-- 310 - 310
Asphalt Cement Content	-- 6.0%
Percent Voids, as placed	-- 5.5 - 5.3
Percent Voids, "E" Sample	-- 4.9 - 5.1
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity Coarse Aggregate	-- 2.57
Absorption Coarse Aggregate, 24 Hours	-- 0.82
Specific Gravity Mineral Filler	-- 2.70

JOB 11 - 524

Placed	-- September, 1965
Type Construction	-- Type 3; Resurfacing Old Asphalt Concrete Pavement
Thickness	-- 1.5"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Limestone 77%
Fine Aggregate	-- Local Sand - 23%
Filler	-- Dust From Coarse Aggregate (6.6%)
Mixing Temperature °F	-- 305
Placing Temperature °F	-- 285 - 310
Asphalt Cement Temperature °F	-- 305
Asphalt Cement Content	-- 5.4
Percent Voids, as placed	-- 4.5
Absolute Specific Gravity of Aggregate	-- 2.85
Bulk Specific Gravity of Aggregate	-- 2.78
Absorption Coarse Aggregate, 24 Hour	-- 0.72%

JOB 9 - 518

Placed	-- October, 1965
Type Construction	-- Type 3; Resurfacing Old Asphalt Concrete Pavement
Thickness	-- 1.5"
Asphalt Cement Brand	-- "A"
Coarse Aggregate	-- Local Crushed Limestone 83%
Fine Aggregate	-- Local Sand - 17%
Filler	-- Local Limestone Dust (6%)
Mixing Temperature °F	-- 295 - 300
Placing Temperature °F	-- 295 - 290
Asphalt Cement Temperature °F	-- 300
Asphalt Cement Content	-- 5.70
Percent Voids, as placed	-- 4.1
Percent Voids, "E" Sample	-- 3.9
Absolute Specific Gravity Coarse Aggregate	-- 2.73
Bulk Specific Gravity Coarse Aggregate	-- 2.52
Absorption Coarse Aggregate 24 Hours	-- 1.20%

JOB 2 - 536

Placed	-- October, 1965
Type Construction	-- Type 3, Resurfacing Old Asphalt Concrete
Thickness	-- 1.25" - 1.50"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Syenite 85%
Fine Aggregate	-- Local Sand 10%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature ^{o}F	-- 295 - 290
Placing Temperature ^{o}F	-- 285 - 290
Asphalt Cement Temperature ^{o}F	-- 300
Asphalt Cement Content	-- 6.0
Percent Voids, as placed	-- 5.8
Percent Voids, "E" Sample	-- 5.6
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity Coarse Aggregate	-- 2.57
Absorption Coarse Aggregate, 24 Hours	-- 0.82
Specific Gravity Mineral Filler	-- 2.70

JOB 2 - 527

Placed	-- October, 1965
Type Construction	-- Type 3, Resurfacing Old Asphalt Concrete
Thickness	-- 1.5"
Asphalt Cement Brand	-- "A"
Coarse Aggregate	-- Crushed Syenite 65%
Fine Aggregate	-- Local Sand 30%
Filler	-- Batesville Limestone Dust 5%
Mixing Temperature ^{o}F	-- 285 - 300
Placing Temperature ^{o}F	-- 275 - 290
Asphalt Cement Temperature ^{o}F	-- 295 - 305
Asphalt Cement Content	-- 5.5%
Percent Voids, as placed	-- 4.2
Percent Voids, "E" Sample	-- 4.1
Absolute Specific Gravity Coarse Aggregate	-- 2.63
Bulk Specific Gravity Coarse Appregate	-- 2.57
Absorption Coarse Aggregate	-- 0.82
Specific Gravity Mineral Filler	-- 2.70

Job 9432

Placed	-- August, 1966
Type Construction	-- Type 3; Surfacing on 2" Type 2 Binder Course - New Construction
Thickness	-- 1.5"
Asphalt Cement Brand	-- "A"
Coarse Aggregate	-- Crushed Limestone 52%
Fine Appregate	-- Crushed Limestone 38%
Fine Sand	-- Arkansas River, Van Buren 10%
Filler	-- Local Limestone Dust
Mixing Temperature °F	-- 305 - 320
Placing Temperature °F	-- 300 - 310
Asphalt Cement Temperature °F	-- 300
Asphalt Cement Content	-- 5.8 - 5.9
Percent Voids, as placed	-- 4.9 - 5.0
Percent Voids, "E" Samples	-- 4.9 - 5.0
Absolute Specific Gravity Coarse Aggregate	-- 2.77
Bulk Specific Gravity Coarse Aggregate	-- 2.72
Absorption Coarse Aggregate 24 Hours	-- 0.68

JOB 11 - 681

Placed	-- October, 1966
Type Construction	-- Type 3; Surface on Type 2 Binder, New Construction
Thickness	-- 1.5"
Asphalt Cement Brand	-- "B"
Coarse Aggregate	-- Crushed Limestone
Fine Aggregate	-- Local Sand
Filler	-- Dust from Coarse Aggregate 6%
Mixing Temperature °F	-- 300
Placing Temperature °F	-- 290
sphalt Cement Temperature °F	-- 300
t Cement Content	-- 5.1%
oids, as placed	-- 4.5
ercent Voids, "E" Sample	-- 4.2
Absolute Specific Gravity Coarse Aggregate	-- 2.84
Bulk Specific Gravity Coarse Aggregate	-- 2.75
Absorption Coarse Aggregate 24 Hours	-- 0.78

MATERIALS

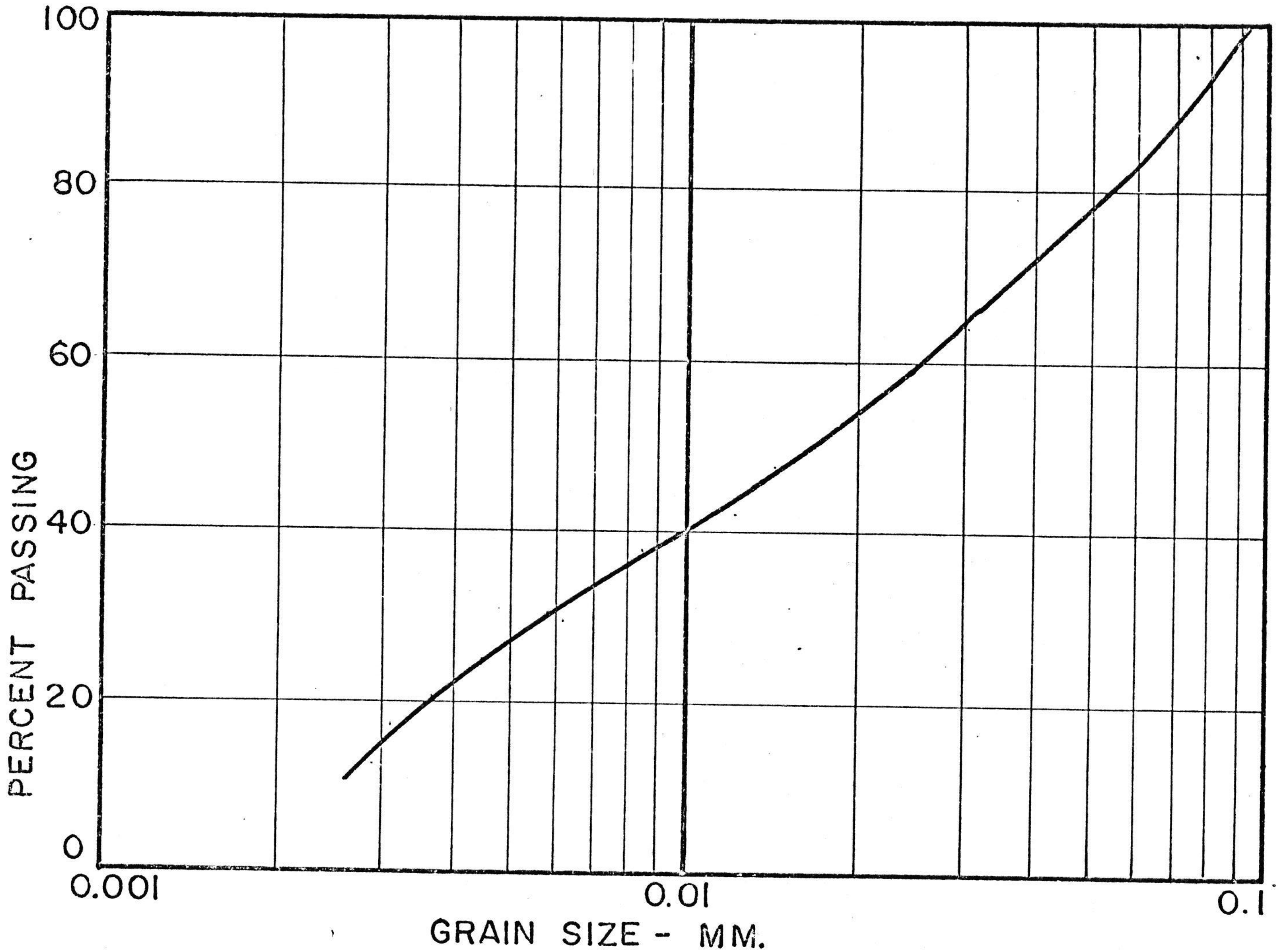
AGGREGATES

Six of the thirteen jobs studied used syenite, a dense fine - grained igneous rock as the aggregate. The absolute specific gravity of this syenite is 2.63, and the 24 - hour absorption of water is 0.82%. All of this material is obtained from a quarry near Little Rock. The fine aggregate was syenite screenings from the same plant. Fine sand was used to supplement these screenings. Five of the jobs used crushed limestone obtained locally and two of the jobs used local crushed sandstone.

Some sand was used in all the jobs, the amount varying from 10 percent to 25 percent. This sand was obtained from the Arkansas River at various locations near the job sites. The sand has a specific gravity of 2.65.

Nine of the jobs used Batesville limestone dust as mineral filler. This is a dust produced from a commercial quarry at Batesville, Arkansas. The remaining four jobs used limestone dust as the mineral filler, this dust being obtained from the same crusher as the coarse aggregate. The Batesville limestone dust has no plasticity.

Figure 2 is a grain size curve for the Batesville limestone dust.



MINERAL FILLER
BATESVILLE LIMESTONE DUST

FIGURE 2

ASPHALT CEMENTS

The asphalt cements used on these jobs were very consistent in their properties. It was sometimes found that the asphalt cement for two or more Arkansas Highway Department jobs were being supplied from the same refinery tank and that one sample served for several jobs.

Asphalt Cement Brand "A" was used on five of the jobs and Brand "B" was used on seven of the jobs. Brand "C" was used on only one job. Six samples were taken of the Brand "C" job, but it is believed that this is not sufficient to give any meaningful results.

Both Asphalt Cements Brand "A" and Brand "B" are refined from the same crude oil. This crude oil is locally known as "Smackover Select." Asphalt Cement Brand "C" is obtained from an entirely different crude oil.

THE EFFECT OF VARIATIONS IN MIXING TEMPERATURE

An attempt was made to study the effect of the variations in mixing temperatures by mixing small batches in the laboratory. A local limestone was chosen for the aggregate with Batesville limestone dust as the mineral filler. The asphalt cement was Brand "B" from the same producer as that used by the Highway Department.

Forty-pound batches were mixed in a Heatherington and Berner twin-shaft heated pugmill. The aggregate and asphalt cement were heated in electric ovens to the desired temperature prior to mixing. The mixing time in the pugmill was one minute. Four mixing temperatures, 250°F, 275°F, 325°F, and 350°F were used.

The asphalt cement was extracted from these batches after the mixture had cooled. Penetration and ductility tests at 77°F, 60°F, 45°F, and 39.2°F were made on the extracted asphalt cement from these mixtures. Table II shows the results of these tests. These results do not indicate any effect due to the changing of the mixing temperature. At 77°F the loss in penetration varied from 21 percent to 23 percent. Three of the four batches showing a loss of 23 percent with both the batches mixed at 250°F and 350°F showing a 23 percent loss. The same effects are apparent for the other test temperatures.

The change in ductility showed the same lack of variation. For instance, the original ductility at 60°F was 48 cm. and the ductility after mixing varied from 10 cm. at 250°F to 9 cm. at 350°F.

Table III shows the relationship of the mixing temperature to change in ductility and penetration of all of the samples taken in the field. Penetrations and ductilities shown are those of the asphalt cement extracted from the "B" Samples taken immediately after mixing. There seems to be no relationship between penetration and ductility and the various mixing temperatures.

TABLE II

EFFECT OF

VARIATION IN MIXING TEMPERATURES

PENETRATION

Test Temp °F	Orig A.C.	Mixing Temperature °F 250 Pen	250 % Loss	275 Pen	275 % Loss	325 Pen	325 % Loss	350 Pen	350 % Loss
77	56	43	23	43	23	44	21	43	23
60	27	21	22	21	22	22	19	22	19
45	12	9	25	10	17	9	25	9	25
39.2	9	7	22	7	22	7	22	7	22

DUCTILITY

Test Temp °F	Orig A.C.	Mixing Temperature °F 250 Duct	250 % Loss	275 Duct	275 % Loss	325 Duct	325 % Loss	350 Duct	350 % Loss	Speed cm/min
77	150+	76		90		116		106		5
60	48	10	79	10	79	10	79	9	81	5
45	7	5	19	5	19	5	19	4	43	5
39.2	7	5	19	5	19	5	19	5	19	1

TABLE III

RELATIONSHIP OF MIXING TEMPERATURES TO

CHANGE IN DUCTILITY AND PENETRATION DURING MIXING

BRAND A

	Penetration 77°F	Ductility 60°F	Temperatures °F Mixing	Asphalt Cement	At Paver
Job 4473					
Sample 1	42.8	16.4	315	296	305
2	40.0	18.9	310	-	312
3	45.4	18.4	300	280	-
4	32.6	17.0	295	285	290
5	33.0	10.0	295	310	285
Job 2528					
Sample 1	51.9	32.7	310	300	295
2	51.0	20.6	305	308	305
3	48.7	21.4	305	300	295
4	44.5	11.7	305	305	295
5	43.1	11.7	300	305	300
6	43.0	12.9	300	300	295
Job 9518					
Sample 1	33.0	12.5	300	300	-
2	30.8	11.0	-	-	285
3	32.2	11.1	-	305	295
4	32.6	15.4	-	-	290
5	34.7	13.6	290	300	-
6	31.8	13.2	290	-	295
Job 2527					
Sample 1	45.0	16.9	285	285	275
2	47.3	18.6	300	300	265
3	42.5	13.6			
4	44.6	12.1			
5	45.0	14.0			
6	47.5	17.1			

TABLE III - continued

BRAND A CONTINUED

	Penetration 77°F	Ductility 60°F	Temperatures °F Mixing	Asphalt Cement	At Paver
<u>Job 9432</u>					
Sample 1	44.6	25.6	320	285	320
2	44.2	21.6	315	300	315
3	38.6	13.5	-	285	285
4	35.8	5.0	310	285	310
5	38.3	13.5	305	290	305
6	31.5	5.8	260	275	255

TABLE III - continued

BRAND B

	Penetration 77°F	Ductility 60°F	Temperatures °F Mixing	Asphalt Cement	At Paver
Job 2509					
Sample 1	49.2	8.50	290	290	270
2	50.4	7.62	280		280
3	49.4	10.12	305	290	290
4	54.6	9.75	295		280
Job 1370					
Sample 1	41.5	12.37	300	-	285
2	44.2	24.87	310	-	300
3	43.2	12.3	300	-	-
4	59.7	11.2	-	-	295
5	53.8	14.8	-	-	-
Job 2661					
Sample 1	43.6	14.2	295	275	300
2	50.1	14.4	280	285	-
3	44.1	8.5	300	285	285
4	44.6	8.9	290	290	275
Job 8516					
Sample 1	50.5	12.2	300	-	285
2	51.1	11.8	-	-	300
3	50.4	12.8	305	-	295
4	49.8	10.8	310	285	305
5	53.3	12.2	285	-	285
Job 11-524					
Sample 1	41.4	11.9			
2	50.1	12.4			
Job 2536					
Sample 1	48.2	16.5	295	275	285
2	45.5	10.5	295	275	275
3	45.0	11.5	290	285	290
4	49.1	13.5			
5	49.4	12.5			
6	53.2	12.5			

TABLE III - continued

BRAND B CONTINUED

	Penetration 77°F	Ductility 60°F	Temperatures °F Mixing	Asphalt Cement	At Paver
Job 11-681					
Sample 1	-	-			
2	45.7	13.2			
3	45.8	12.0			

BRAND C

	Penetration 77°F	Ductility 60°F	Temperatures °F Mixing	Asphalt Cement	At Paver
Job 2534					
Sample 1	54.2	17.4	310	-	310
2	47.5	27.5	300	305	295
3	43.9	13.9	290	-	285
4	48.6	17.6	305	-	300
5	50.6	17.9	305	320	300
6	53.3	15.0	280	320	275

THIN FILM OVEN STUDIES

The investigation reported in this chapter was not planned as a part of the original investigation into the physical changes of asphalt, however, some of the results presented here may prove of value in examining the results of the whole investigation.

This work was accomplished by Mr. Jerry Baber, Graduate Research Assistant, for the purpose of his Master's Thesis. The purpose of the investigation was to study and compare the physical changes in two Arkansas asphalts when subjected to exposure for varying lengths of time in the oven under the standard conditions of the Thin Film Oven Test, ASTM D 1754 - 60T.

Many attempts have been made to predict the aging characteristics of asphalts under service conditions. Lewis and Halstead (4) found that five hours in the thin film oven test approximated the changes that take place in an asphalt during mixing in a hot-mix plant. The time in the oven on this investigation was extended to 24 hours to provide data for comparison with the results of the primary investigation.

The asphalt cements used in this investigation are the same Brands "A" and "B" as those used in the primary investigation of the physical properties of asphalt. Samples of each Brand "A" and Brand "B" were obtained in the 60 - 70 penetration grade and the 85 - 100 penetration grade. The samples were taken at the refineries from tanks held for shipment to the Arkansas Highway Department jobs. The samples were received from the refineries in five gallon containers. These containers were placed in a water bath and heated until the material was soft enough to be transferred to one pint friction top cans. The pint containers were heated to 275°F in an electric oven during preparations for each individual test. The material in the pint cans were not heated a second time. Any material remaining from the original sample preparation was discarded.

The only variation from the Standard Thin-Film Oven-Test was in the time in the oven. The times in the oven for the different samples were 2, 5, 12, 18, and 24 hours. Three tests of each asphalt cement were made at each time in the oven. At the end of each test the asphalt was transferred from the thin film oven dish to six ounce ointment boxes for subsequent testing. The tests performed on the residue from the oven were: Penetration ASTM D5-61, Ductility ASTM D113-44, and Absolute Viscosity ASTM D2171-63T using the Cannon Manning Vacuum Viscometer at 140°F.

Tables IV through VIII show the results of these tests.

Figures 3 and 4 show the increase in Absolute Viscosity with time in the oven.

TABLE IV

BRAND A

60-70 PENETRATION GRADE

	Original Asphalt Cement	Period of Heating				
		2 Hours	5 Hours	12 Hours	18 Hours	24 Hours
Change in Weight, Grams	----	+0.0124	+0.0387	+0.0856	+0.1182	+0.1427
Penetration at 77°F.	60	52	48	35	27	24
Percent of Original Penetration Lost	----	14	21	41	55	60
Ductility at 77°F. Centimeters	150+	150+	150+	107	30	11
Penetration at 45°F.	14.2	12.7	12.0	9.6	8.4	7.6
Percent of Original Penetration Lost	----	10	16	32	41	46
Ductility at 45°F. Centimeters	8.1	6.5	5.4	4.4	3.6	3.0
Percent of Original Ductility Lost	----	20	33	46	55	63

TABLE V

BRAND A

85-100 PENETRATION GRADE

	Original Asphalt Cement	Period of Heating				
		2 Hours	5 Hours	12 Hours	18 Hours	24 Hours
Change in Weight, Grams	----	+0.0046	+0.0458	+0.0925	+0.1283	0.1547
Penetration at 77°F.	92	81	68	50	38	32
Percent of Original Penetration Lost	----	13	26	46	59	65
Ductility at 77°F. Centimeters	150+	150+	150+	150+	150+	150+
Penetration at 45°F.	14.3	12.8	11.8	9.2	8.2	7.5
Percent of Original Penetration Lost	----	10	18	36	43	48
Ductility at 45°F. Centimeters	20.8	19.8	15.9	6.6	4.9	4.1
Percent of Original Ductility Lost	----	5	23	68	76	80

TABLE VI

BRAND B

60-70 PENETRATION GRADE

	Original Asphalt Cement	Period of Heating				
		2 Hours	5 Hours	12 Hours	18 Hours	24 Hours
Change in Weight, Grams	----	-0.0003	+0.0137	+0.0460	+0.0797	+0.1018
Penetration at 77°F.	60	53	45	36	31	28
Percent of Original Penetration Lost	----	11	25	40	47	52
Ductility at 77°F. Centimeters	150+	145	100	32	19	10
Penetration at 45°F.	14.7	14.2	13.3	10.2	9.6	8.5
Percent of Original Penetration Lost	----	3	10	24	35	42
Ductility at 45°F. Centimeters	6.3	5.2	4.7	4.0	3.8	3.1
Percent of Original Ductility Lost	----	18	26	37	40	51

TABLE VII

BRAND B

85-100 PENETRATION GRADE

	Original Asphalt Cement	Period of Heating				
		2 Hours	5 Hours	12 Hours	18 Hours	24 Hours
Change in Weight, Grams	----	-0.0007	+0.0172	+0.0650	+0.0970	+0.1202
Penetration at 77°F.	88	72	65	50	44	38
Percent of Original Penetration Lost	----	18	26	43	50	56
Ductility at 77°F. Centimeters	150+	150+	150+	150+	92	40
Penetration at 45°F.	19.4	17.8	16.8	14.8	13.1	10.6
Percent of Original Penetration Lost	----	8	13	24	32	45
Ductility at 45°F. Centimeters	15.3	8.2	7.7	5.1	4.8	4.5
Percent of Original Ductility Lost	----	46	50	67	68	71

TABLE VIII

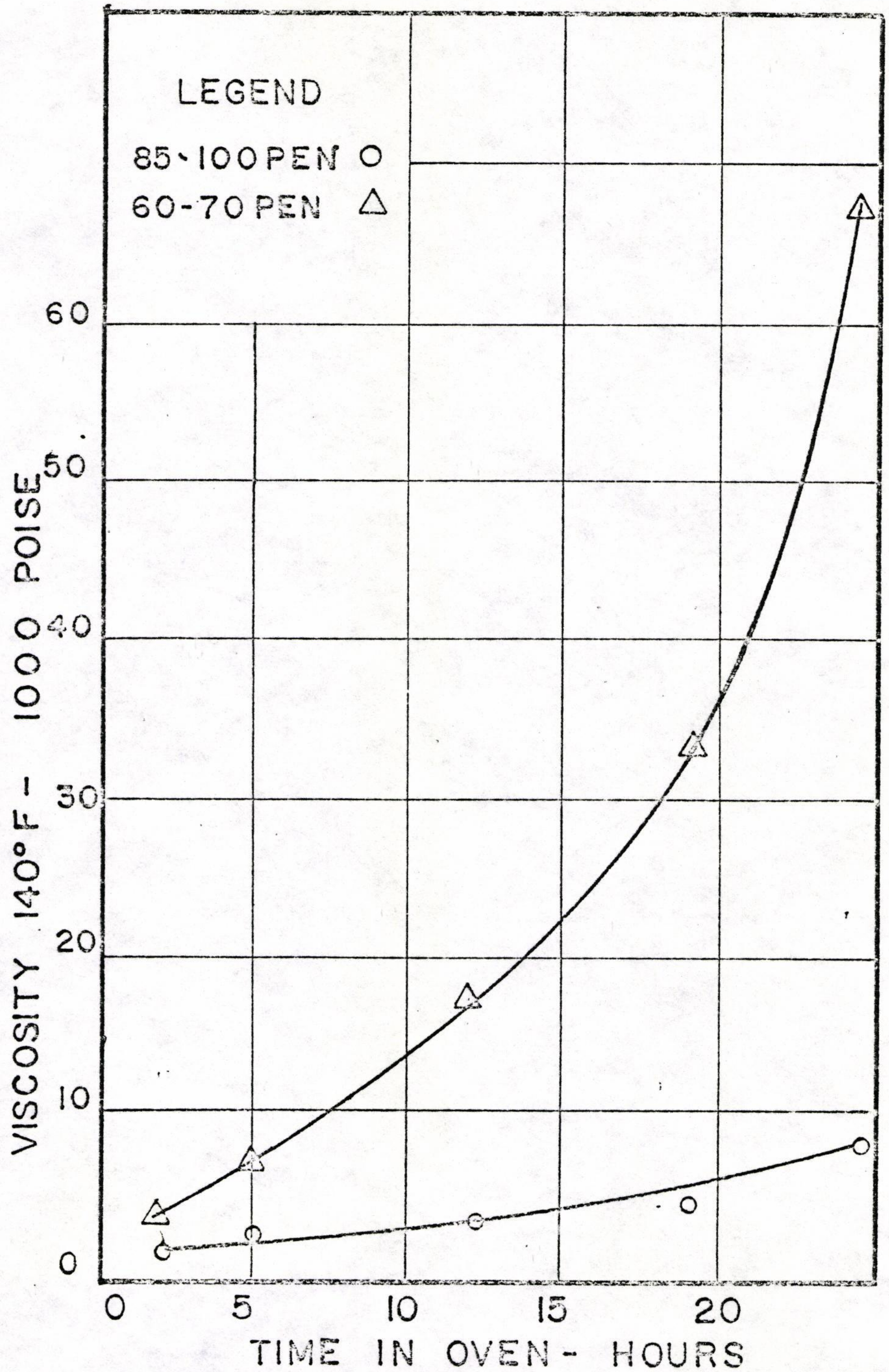
RESULTS OF THIN FILM OVEN TEST

BRAND A

Time	Penetration				Ductility				Absolute Viscosity
In Oven Hours	77°F 100g	% Loss	60°F 200g	% Loss	77°F	60°F 5 cm/m	% Loss	45°F 1 cm/m	140°F, Poise
0	60		27		150+	37		5.5	3,150
2	52	14	27	0	150+	12.0	68	5.3	4,030
5	48	21	23	15	150+	10	73	4.8	6,720
12	35	41	23	15	107	88		3.6	16,110
18	27	55	21	22	10.0	89		3.1	33,100
24	24	60	19	30	5.8	91		2.8	66,300

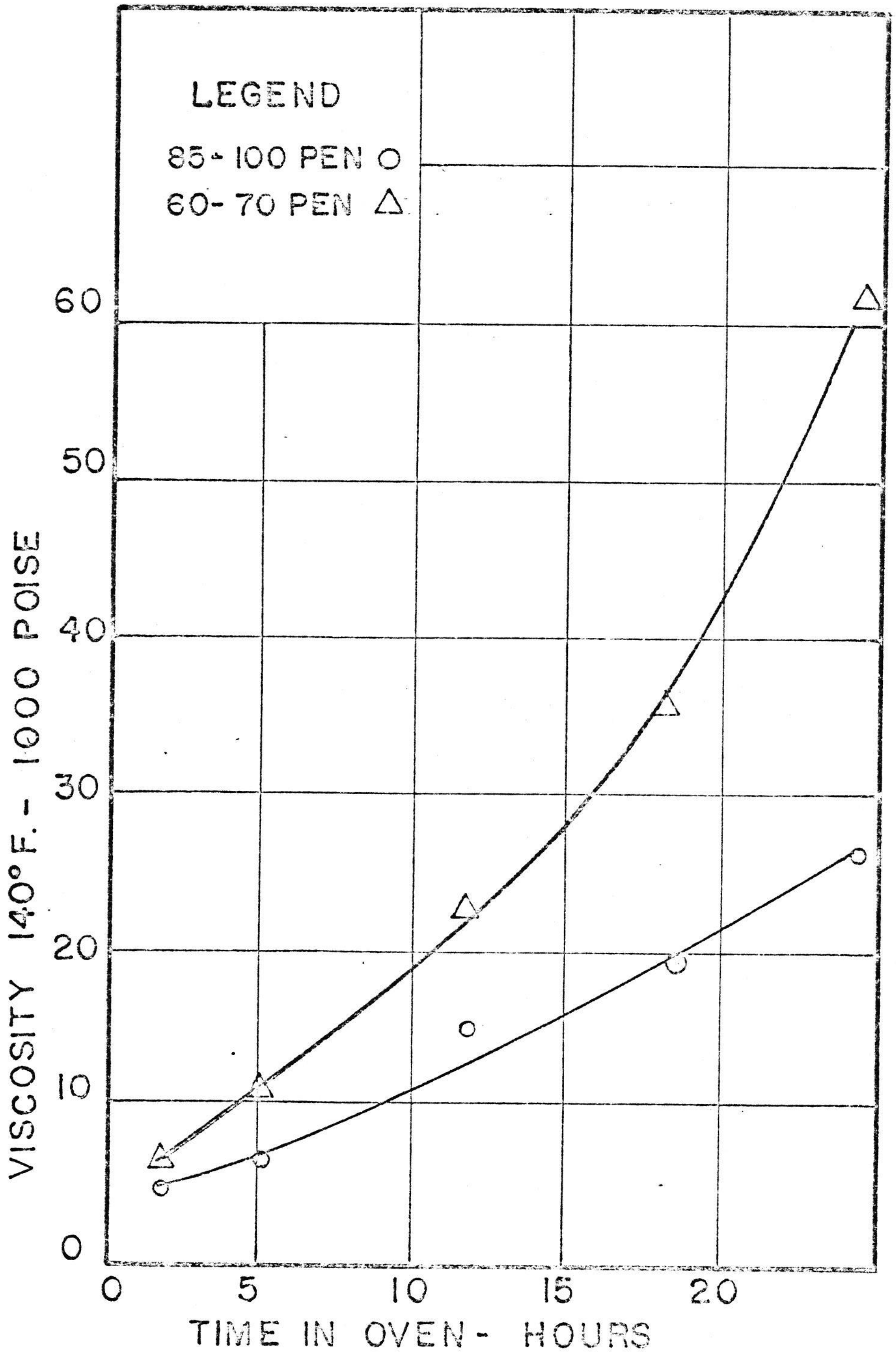
BRAND B

Time	Penetration				Ductility				Absolute Viscosity
In Oven Hours	77°F 100g	% Loss	60°F 200g	% Loss	77°F	60°F 5 cm/m	% Loss	45°F 1 cm/m	140°F, Poise
0	60		35		150+	35		6.3	5,240
2	53	11	29	15	145	6.0	83	4.6	10,828
5	45	25	28	18	100	9	74	4.5	19,400
12	36	40	24	29	32	4.3	88	3.6	22,370
18	31	47	23	32	19	3.5	90	3.0	34,890
24	28	52	22	35	10	3.5	90	3.0	61,630



CHANGE IN VISCOSITY
THIN FILM OVEN TEST
BRAND A

FIGURE 3



CHANGE IN VISCOSITY
THIN FILM OVEN TEST
BRAND B

FIGURE 4

PRESENT PAVEMENT CONDITION

JOB 4473
State Highway 22, Logan County

Sample location number one. There are no cracks and the surface is very dense. There are numerous signs of incipient bleeding in the inside wheel path. The outside wheel path is very black and there are many evidences of bleeding. The mix appears to be very fat. Sample location number two. The surface is in excellent condition at this location. There are a few fine black lines indicating incipient bleeding in the outside wheel path but none in the inside wheel path. The pavement does not appear to be as fat at this location. Sample location number three. The surface is excellent, very dense and smooth. A few evidences of incipient bleeding in the outside wheel path but no evidence of bleeding in the inside wheel path. Sample location number four. There are a few fine black lines indicating incipient bleeding in the inside wheel path, but none in the outside wheel path. The surface is in excellent condition. Sample location number five is inside the city near a street intersection and at a driveway to a service station. There are many indications of oil dripping at this location.

JOB 2-509
State Highway 11, Arkansas County

The surface of this project is generally in excellent condition. There are a few small cracks in the outer wheel path. At sample number one location map-cracking appears at one place in an area of about two feet square. There are two or three transverse cracks eight inches long. There is one very small transverse crack eighteen inches long at the location of sample number two and there is one longitudinal crack twenty-four inches long and about three feet from the edge of the pavement near the end of the location where sample number three was placed. No cracking is evident at all at sample location number four.

JOB 1370
State Highway 36, Faulkner County

Sample location number one is on a steep ascending grade and there are evidences of oil drippings in the pavement where some of the samples were cut from the pavement. The surface is in excellent condition and no cracks are evident. There is one small longitudinal crack at sample location number six. This crack is approximately six feet long. At the same location there are two transverse cracks beginning at the center line and extending into the traffic lane from one to one and one-half feet. These are the only defects in the surface of this job. The surface is excellent in texture and seems to be well sealed.

JOB 2661
State Highway 130, Arkansas County

The surface of this job is generally in excellent condition. No cracks were evident in the locations of samples number one, three and four. There was a single longitudinal crack in the outer wheel path for about fifty feet at sample number two location. This longitudinal crack in the outer wheel path was in short lengths varying from twelve to forty-eight inches long.

JOB 2-528
Highway US 79, Jefferson County

There are no cracks in this pavement. The surface is in excellent condition. There is, however, a small amount of bleeding evident. The fine black longitudinal lines are numerous in both wheel paths. There are a few spots where actual bleeding is beginning to occur. Sample location numbers three, four and five indicate that bleeding is beginning. There are actual black spots indicating bleeding at sample location number one in both inner and outer wheel paths.

JOB 2-534
State Highway 81, Jefferson County

The surface of the pavement at all six sample locations is in excellent condition. There are some thin black lines in a longitudinal direction in each wheel path indicating incipient bleeding. The outer wheel path shows more of these lines than does the inner wheel path, however, both wheel paths are somewhat darker than the pavement between the wheel paths.

JOB 9-518
Highway US 6265, Boone County

The aggregate has polished badly. Both wheel paths are very slick and have the appearance of terazzo. There are numerous transverse cracks usually beginning at the center line or crossing the center line. Most of them do not extend to the edge of the pavement. These cracks appear at sample locations one, two, five and six. This is side-hill location part on filled and part in cut. The cracks seem to be associated with the fill and may be due to movement of the side-hill fill section. There are twelve cracks at sample location number two. These cracks are transverse and vary in length from one to four feet beginning at the center line and extending out into the center lane. There are no cracks near the edge of the pavement. There is one longitudinal crack at sample location number two. This crack is about ten feet long and about the middle of the traffic lane. There are three transverse cracks beginning at the center line in sample location number one. One of these cracks is about twelve inches long, the other one is about three feet long. One longitudinal crack is twelve feet long.

JOB 2-536
State Highway 81, Lincoln County

The surface at all sample locations was in excellent condition. The surface is well sealed and there are no signs of deterioration.

JOB 2-527
Highway US 82, Ashley County

The surface at sample locations two, three, four and five is excellent. There are no signs of distress of any kind. A short single longitudinal crack appears at about the end of test location number six. This crack appears as though it might be a cold joint or a reflection crack from some defect below the surface.

JOB 9432
Highway US 71, Washington County

This job was resurfaced in the summer of 1968 with one-half inch of hot sand asphalt. There were no signs of distress and the pavement was in excellent condition at the time resurfacing began. There was some polishing of the aggregate and motorists were complaining of a very slick surface. The slick surface was the reason for adding the hot sand asphalt surfacing. An inspection was made just prior to the resurfacing and there were no signs of deterioration at any of the locations at that time.

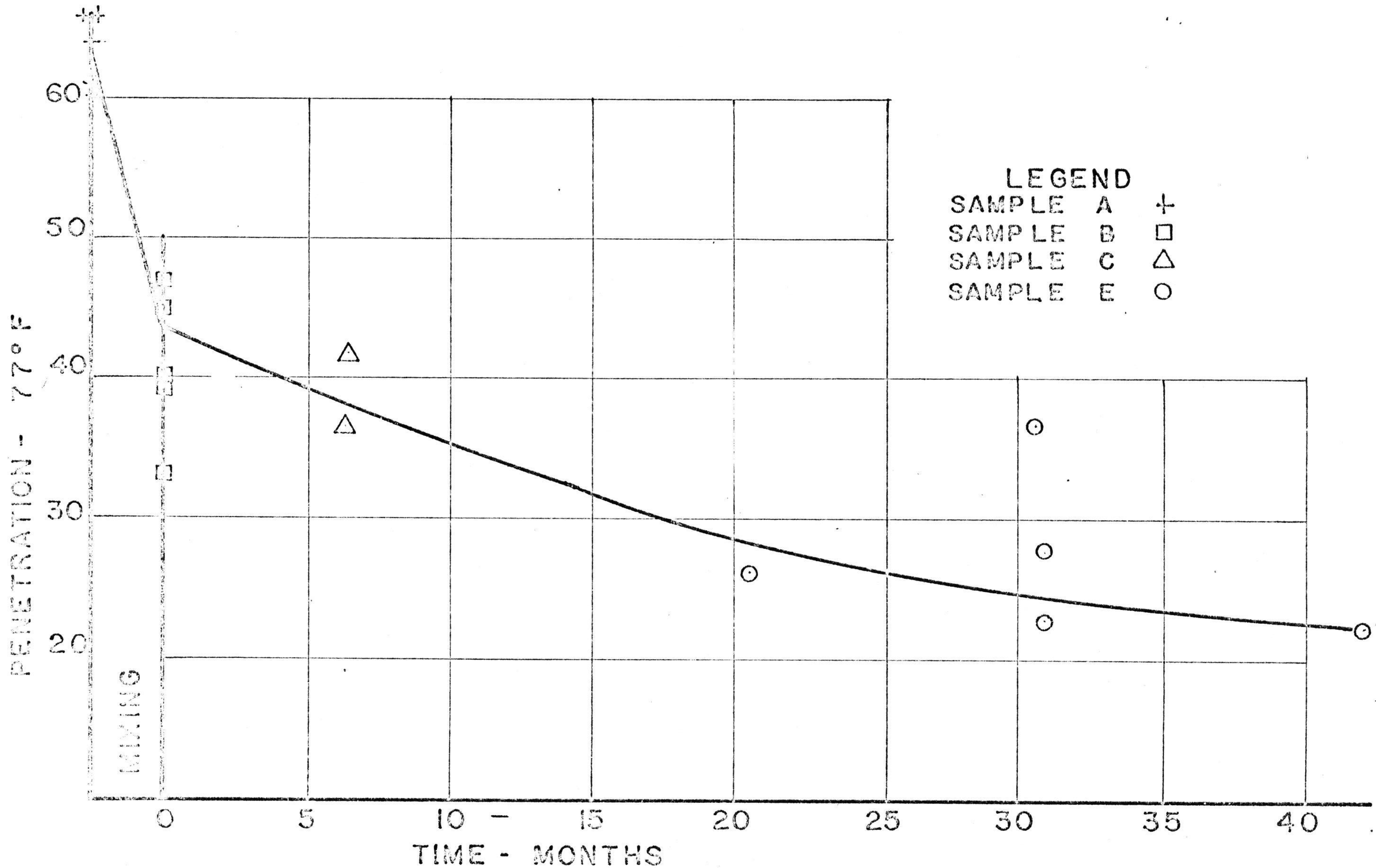
The original sample locations have been preserved and are available for future sampling.

JOB 11-681
Highway US 49, Phillips County

This pavement is in excellent condition. There are no cracks or other signs of distress at any of the sample locations.

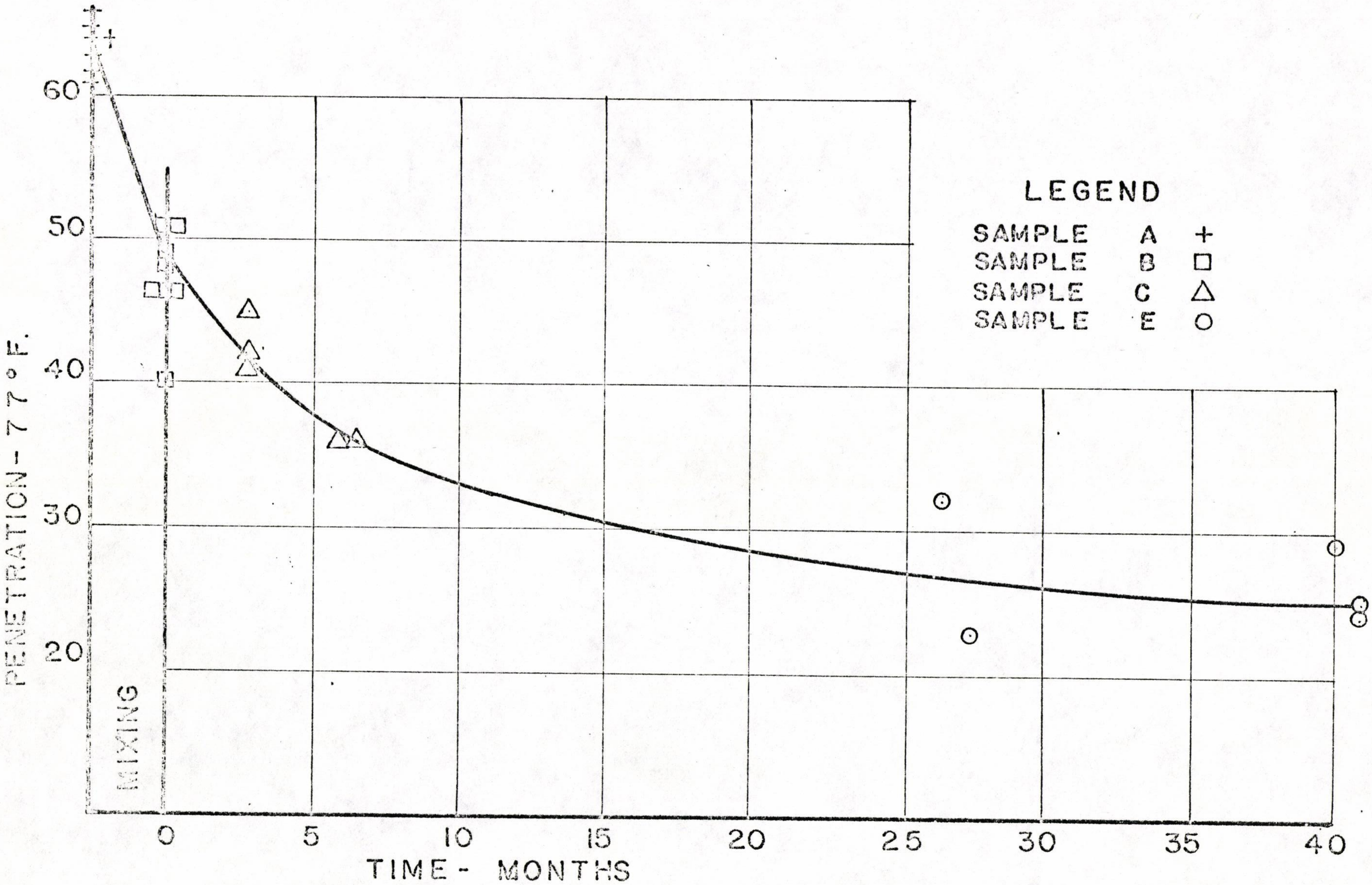
RESULTS

The penetration of asphalt cement Brand A decreased more during mixing than did the penetration of Brand B. Figure 5 indicates that the average decrease of penetration for five samples of Brand A was 32 percent. Seven samples of Brand B decreased an average of 24 percent as in Figure 6. The decrease in penetration of Brand A varied from 20 percent to 35 percent except that a fifth sample showed a decrease in penetration of 50 percent. There is nothing to indicate why there is so much variation in this particular job. The mixing temperature varied from 290°F to 300°F with most of the batches running about 295°F. Brand B showed a decrease in penetration of 77°F of 24 percent with a variation between 19 percent and 29 percent for the seven jobs. The six samples from one job using Brand C showed an average decrease of 22 percent in penetration. The penetrations of the asphalt cement extracted from mixes immediately after mixing showed a penetration of 40 for Brand A and 48 for Brand B. The penetration of Brand B decreased more rapidly than did that of Brand A during the first few months of service. However, at the end of 40 months there is very little difference in the penetration of the asphalt cement extracted from the samples. The average penetration of



CHANGE IN PENETRATION WITH TIME
BRAND A

FIGURE 5



CHANGE IN PENETRATION WITH TIME
BRAND B
FIGURE 6

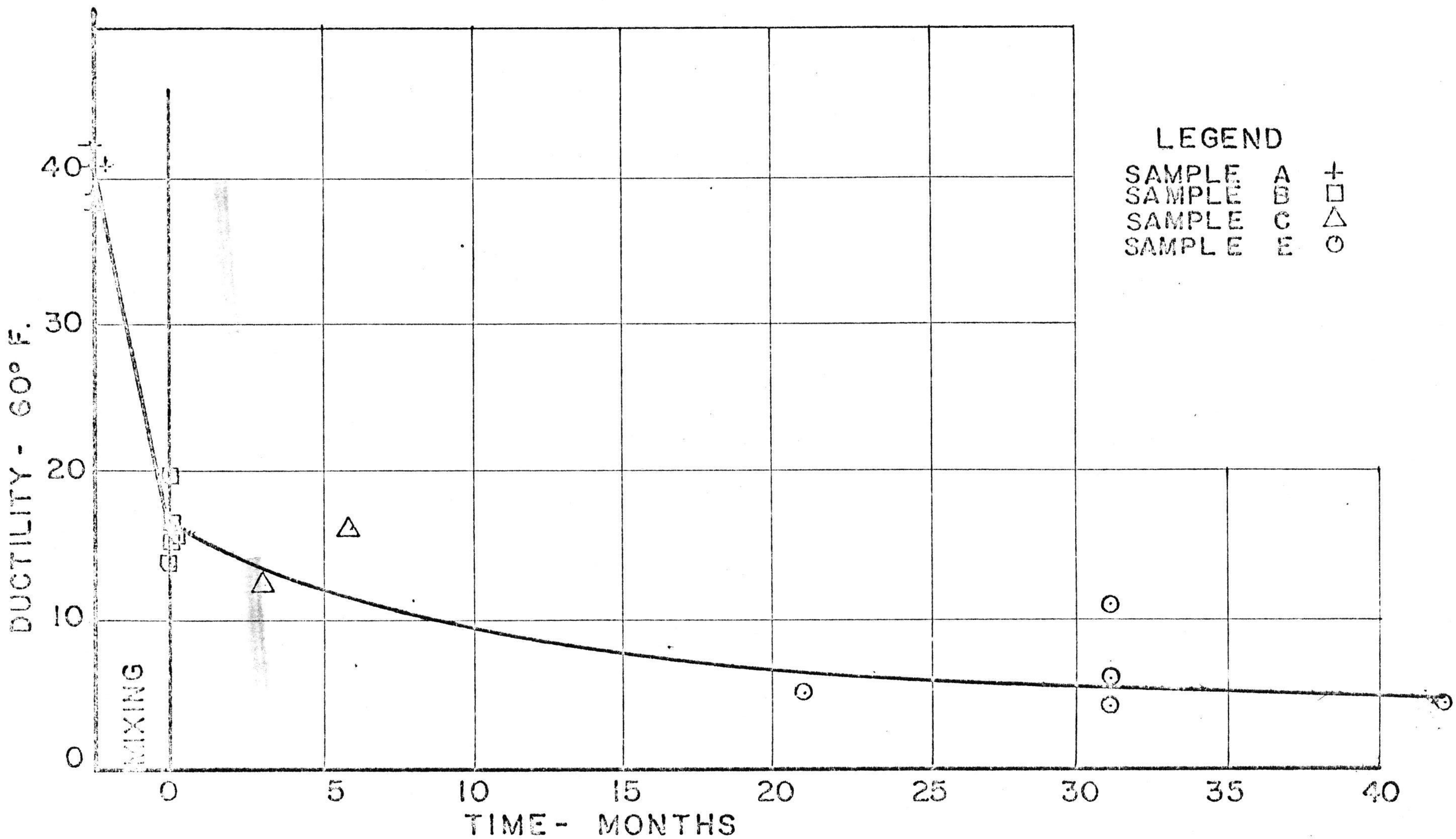
the samples from Brand A had a penetration at the end of 40 months of 24 where Brand B had an average penetration of 26.

Ductility of the asphalt cement extracted from the samples immediately after mixing of Brand A had an average loss of 60 percent in ductility during mixing. The variation in these were from a low of 53 percent to a high of 66 percent.

The asphalt cement Brand B lost an average of 58 percent ductility during mixing. The variation between the different jobs was from a low of 52 percent to a high of 69 percent. The five samples from one job using Brand C showed a loss in ductility during mixing of 44 percent.

Figure 7 indicates that Brand A continued to lose ductility during service, but at a rather slow rate. The ductility decreased from 15 cm. at the time the pavement was placed to a ductility of about 5 cm. at the end of 42 months. There appears to be very little change in ductility during the last several months of service.

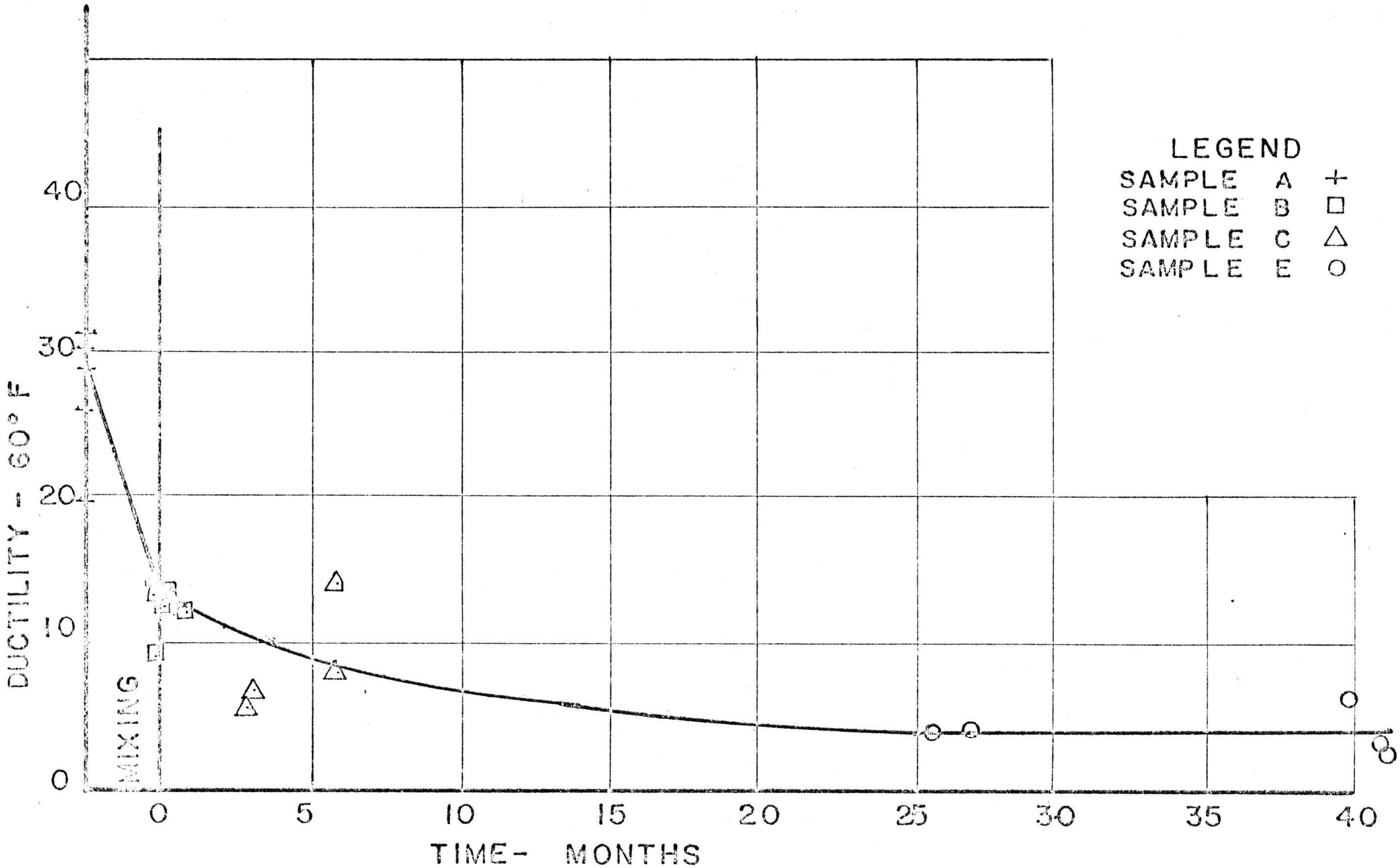
The same general trend was indicated for Brand B. However, the original ductility at 60°F for Brand B was somewhat below that of Brand A. The ductility of Brand B at the time of placing was approximately 13. At the end of 42 months this ductility had decreased to an average of 4. Again there seems to be very little change in the ductility of the asphalt during the last 18 months of service.



CHANGE IN DUCTILITY WITH TIME

BRAND A

FIGURE 7



CHANGE IN DUCTILITY WITH TIME

BRAND B

FIGURE 8

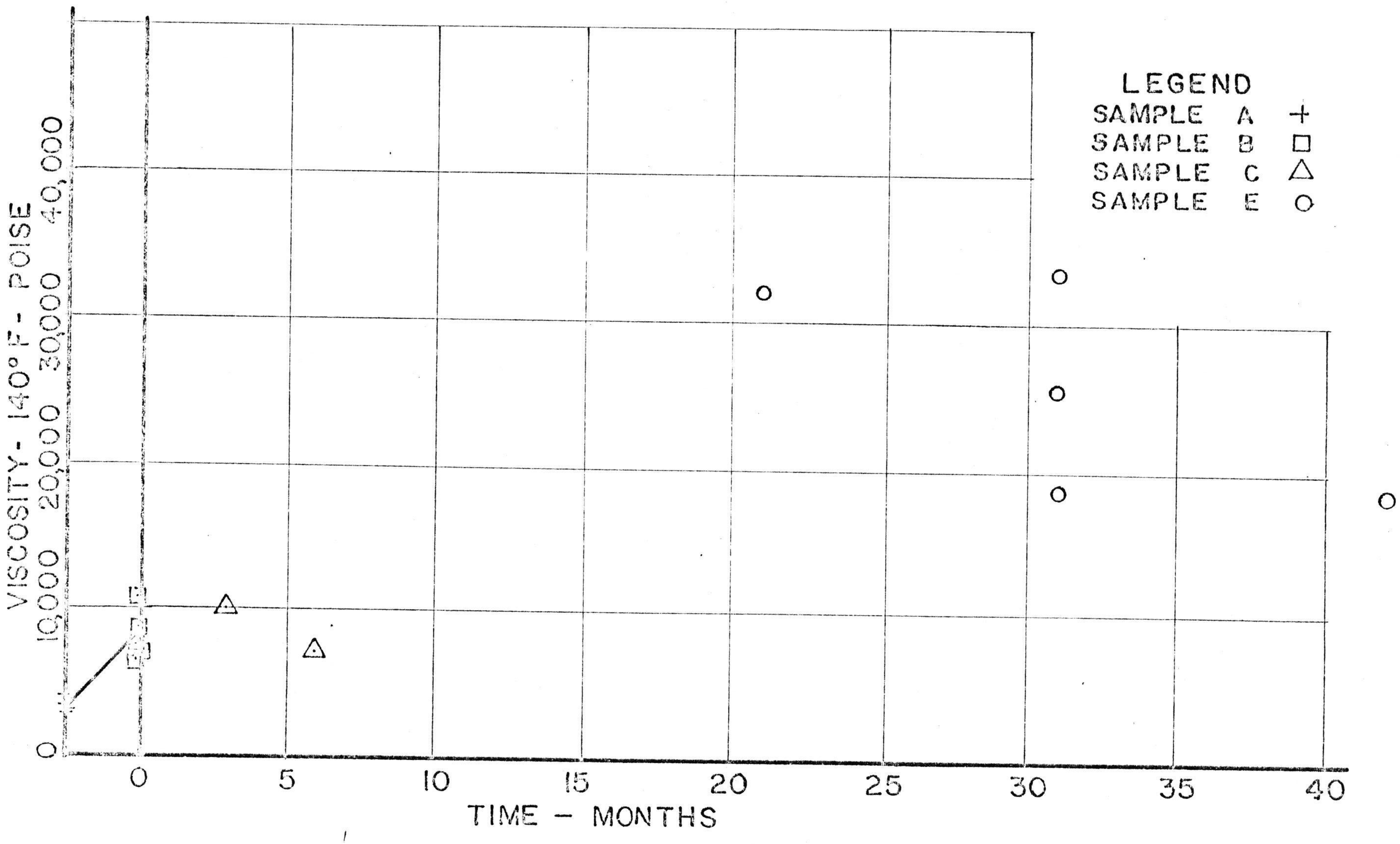
Figures 9 and 10 show the changes in the absolute viscosity during mixing and under service conditions. The absolute viscosity of asphalt cement Brand A was about 3,300 poises. The absolute viscosity increased to 8,000 poises or an increase of 242 percent during mixing. This viscosity increased during the service life of the pavement to about 25,000 poises at the end of 30 months.

The average absolute viscosity of the asphalt cement Brand B as received on the job was 5,300 poises. The viscosity of the various samples varied from a low of 4,600 poises to a high of 5,900 poises.

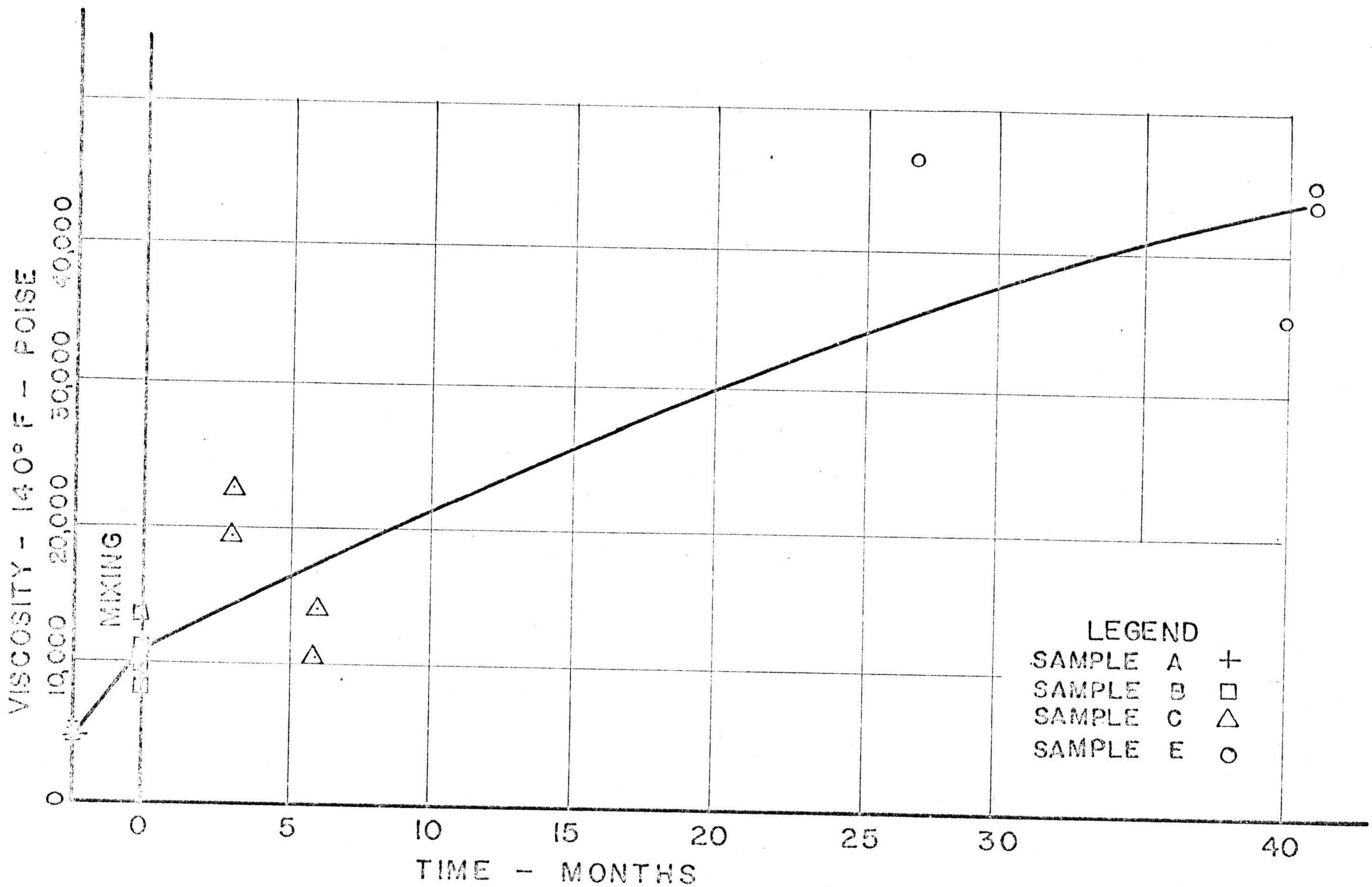
Asphalt cement Brand B increased in absolute viscosity from an average of 5,300 as received on the job to 11,050 poises during the mixing process. This amounted to an increase of 207 percent. After 42 months of service in the pavement, the absolute viscosity had increased to about 43,000 poises. This amounts to about 390 percent increase after 42 months service. There are not enough data to indicate whether this increase during service is a straight line or whether the slope of the curve begins to flatten out after a period.

Figure 11 shows the relationship between the change in viscosity and change in penetration for both brands A and B. These two curves are very nearly parallel.

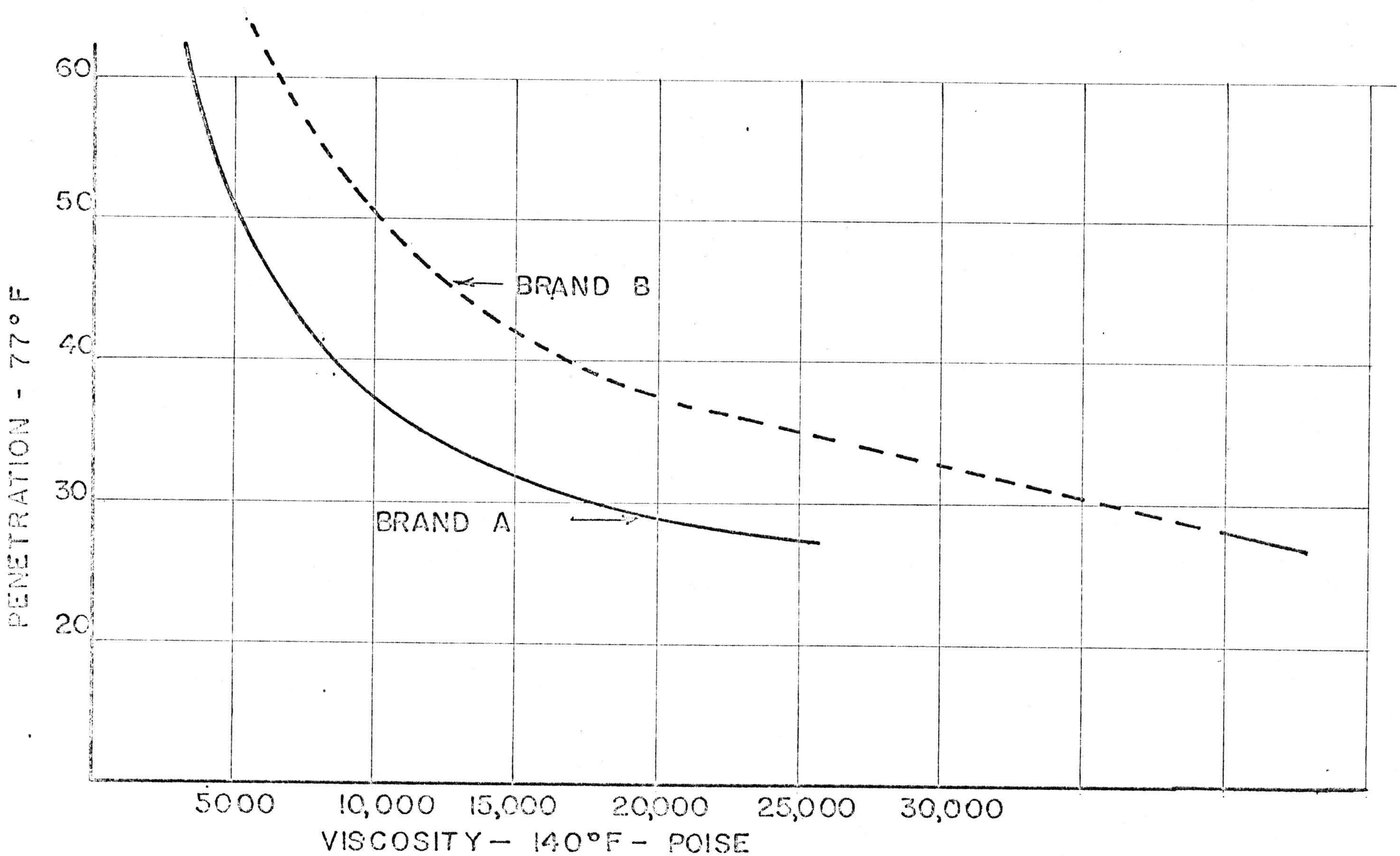
Cores were taken for the entire thickness of the pave-



CHANGE IN VISCOSITY WITH TIME
BRAND A
FIGURE 9



CHANGE IN VISCOSITY WITH TIME
BRAND B
FIGURE 10



PENETRATION VS VISCOSITY

FIGURE 11

ment but the asphalt cement was extracted from the surface course only. It was observed in the laboratory that in many cases there was some excess of tack coat between the surface course and the binder course. This undoubtedly had some effect on the change in consistency of the asphalt cement in the surface course itself.

Penetration tests were made at several temperatures and two different weights on the needle. Observations of the actual testing procedures in the laboratory indicate that the penetration of 77°F and 100 grams weight is better than those at lower temperatures. This is expecially true of the temperatures of 45°F and 39.2°F. It was observed in many cases that the needle only dimpled the surface of the asphalt cement at these lower temperatures. In other cases, the needle penetrated the surface but only for a very small distance and then no asphalt cement adhered to the needle. The high surface tension of some of the samples appeared to materially affect the results. Original ductilities at 77°F were not usable because the original asphalt cement as received on the job had a ductility of over 150 cm. which was the limit of the testing machine. Ductilities at 60°F were used for comparisons. There was not a wide enough range in ductilities at lower temperatures to make the changes meaningful. Figure 11 indicates that the change in viscosity with change in penetration of the two brands of asphalt cement are parallel, but some appreciable distance apart. For instance, Brand B has a penetration of 41 at 60°F and 200 grams for a viscosity of 5,000, whereas the penetration of Brand A would be about 33 for the same viscosity.

In observing the testing prodecures and the results obtained for the penetration, ductility, and viscosity it appears that both the penetration test and the ductility test are not sensitive enough at lower values. On the other hand it appears that the absolute viscosity test by the Cannon-Manning method may be too sensitive. However, for research purposes it has considerable value and does give indication of any variations in the samples.

Mr. Baber's investigation confirms that the thin film oven test is a good indicator of the changes in the physical properties of asphalt cement during mixing and pavement life. Brand A lost 32 percent of its penetration during mixing whereas the loss in the thin film oven test at 5 hours was 21 percent, 12 hours in the thin film oven shows a loss of 41 percent.

Brand B lost 24 percent of its penetration during mixing and 25 percent of its penetration after five hours in the thin film oven test.

The viscosity of 9,000 poises after five hours in the thin film oven test compares favorably with the viscosity of 9,000 poises after mixing for Brand A. Brand B shows an absolute viscosity of 11,000 poises after mixing and a viscosity of 10,000 poises after five hours in the thin film oven test. The viscosity of the asphalt cement extracted from pavements that were 42 months old was 43,000 poises whereas the viscosity after 18 hours in the thin film oven test for Brand B was 34,890.

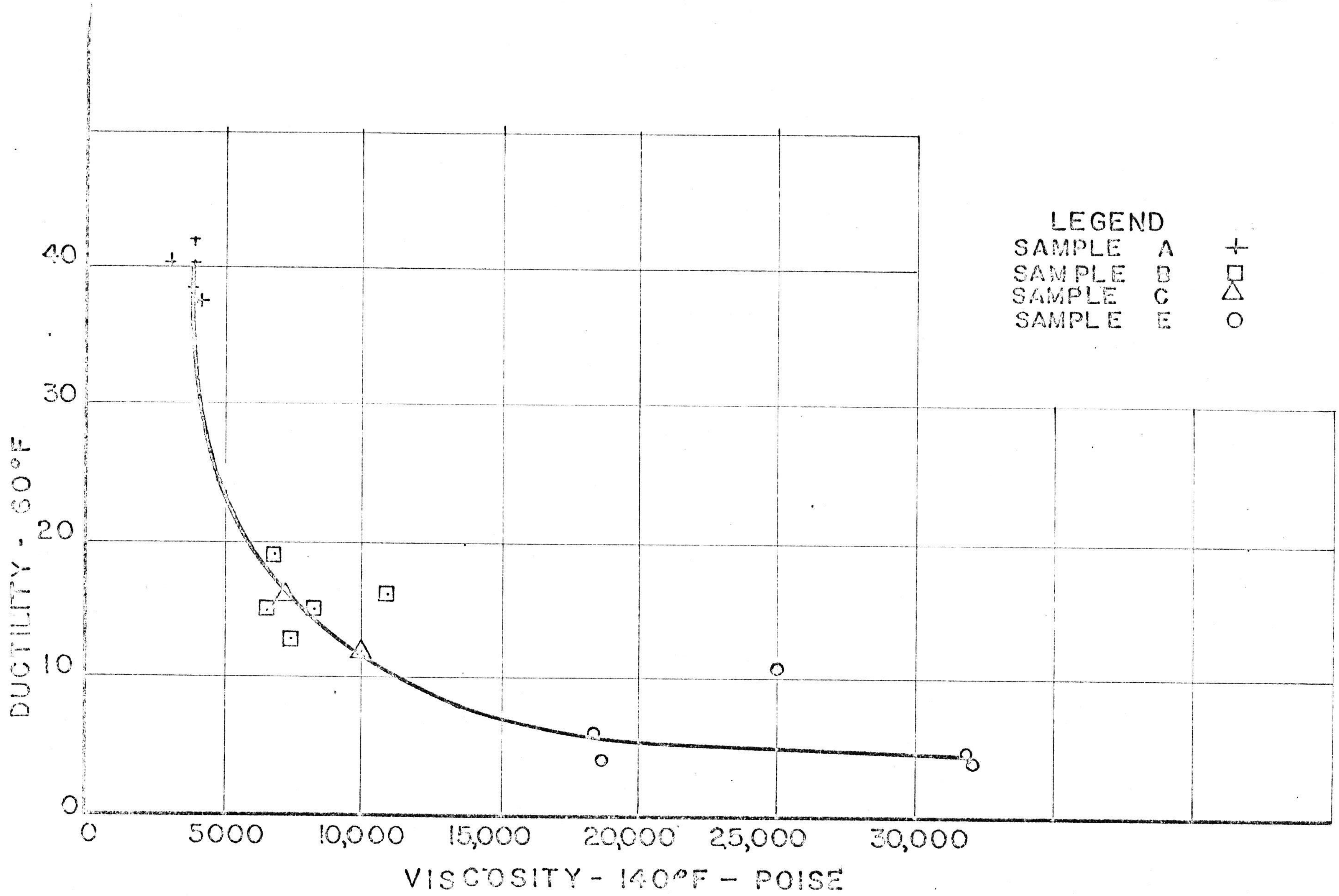
On the basis of these tests the change in viscosity during the thin film oven test compares very closely with the changes in viscosity under service conditions.

Two of the thirteen jobs tested in the original investigation are no longer available for study. These are jobs 8-516 and 11-524. Some sections of these two jobs were resurfaced and the A and B samples were taken at the time this resurfacing was done. Later the Highway Department placed a new surface over the entire length and the location of the other tests were lost, therefore no further sampling was done on these jobs.

Job 9432 has been resurfaced with one-half inch of hot sand asphalt, however, this was done after the E samples were taken on this job. The resurfacing on this job was done to increase the skid resistance and not because of any sign of distress in the pavement. The locations of the research sections were preserved and are available if further investigations are desired.

The extraction of the asphalt cement from the samples was a "team effort". Several laboratory assistants worked together to recover the asphalt cement and prepare for the tests. Each test was made in duplicate by different workers. In every case where the results varied more than the pertinent specification permitted additional samples were checked. Ductility and penetration tests by different operators checked very closely when the measurements were high. Some difficulty was experienced when the penetrations and ductilities were low. As an example, the same operator would have penetration results for the same sample that varied as much as 40% when the numbers were low. Typical variations might be from 5 to 7. The variations in ductilities below 20 cm. was also wide.

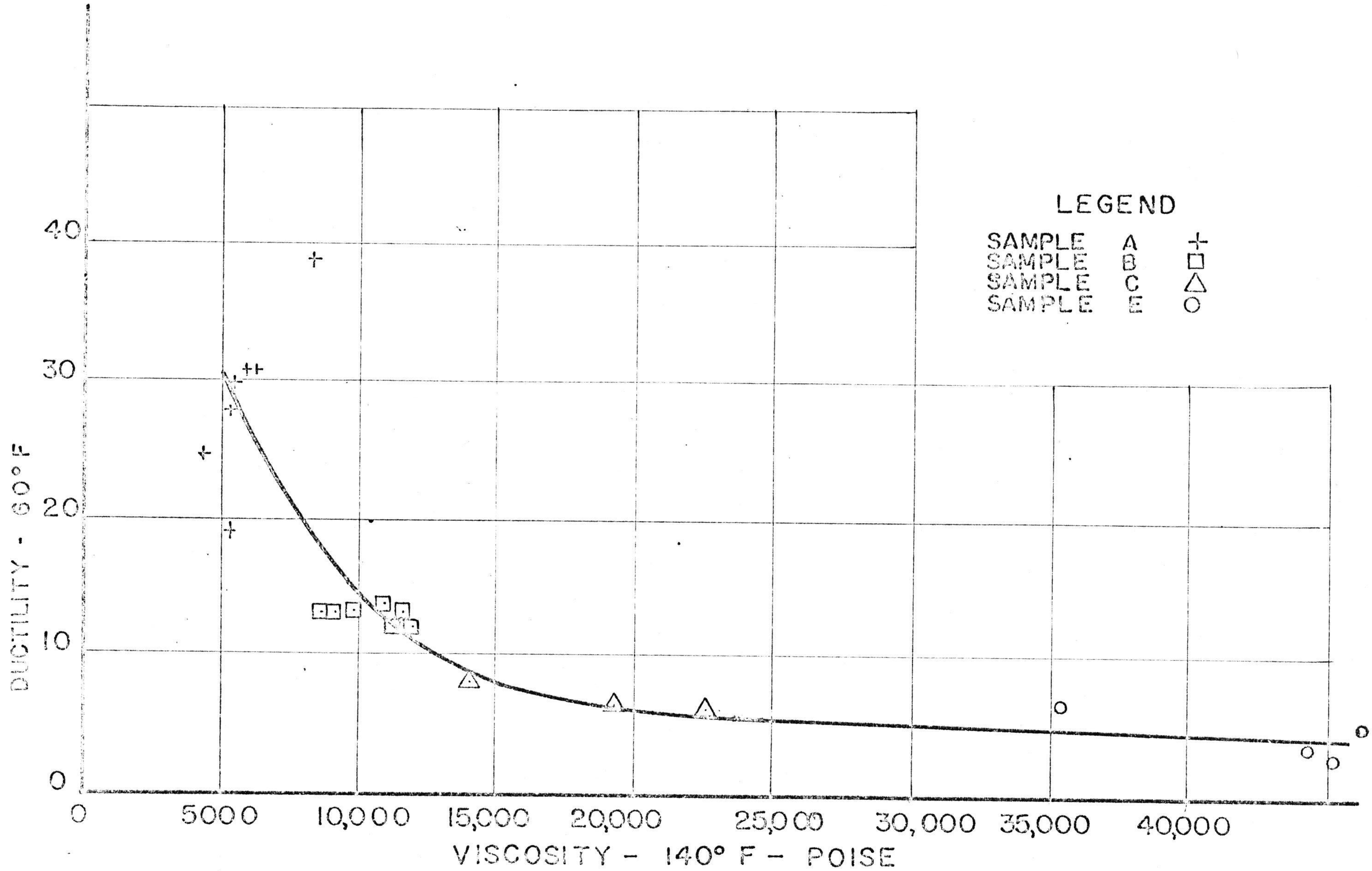
There was good agreement of results on the viscosity tests however it was early observed that the test was very sensitive and reheating a sample for a second test increased the viscosity.



DUCTILITY VS VISCOSITY

BRAND A

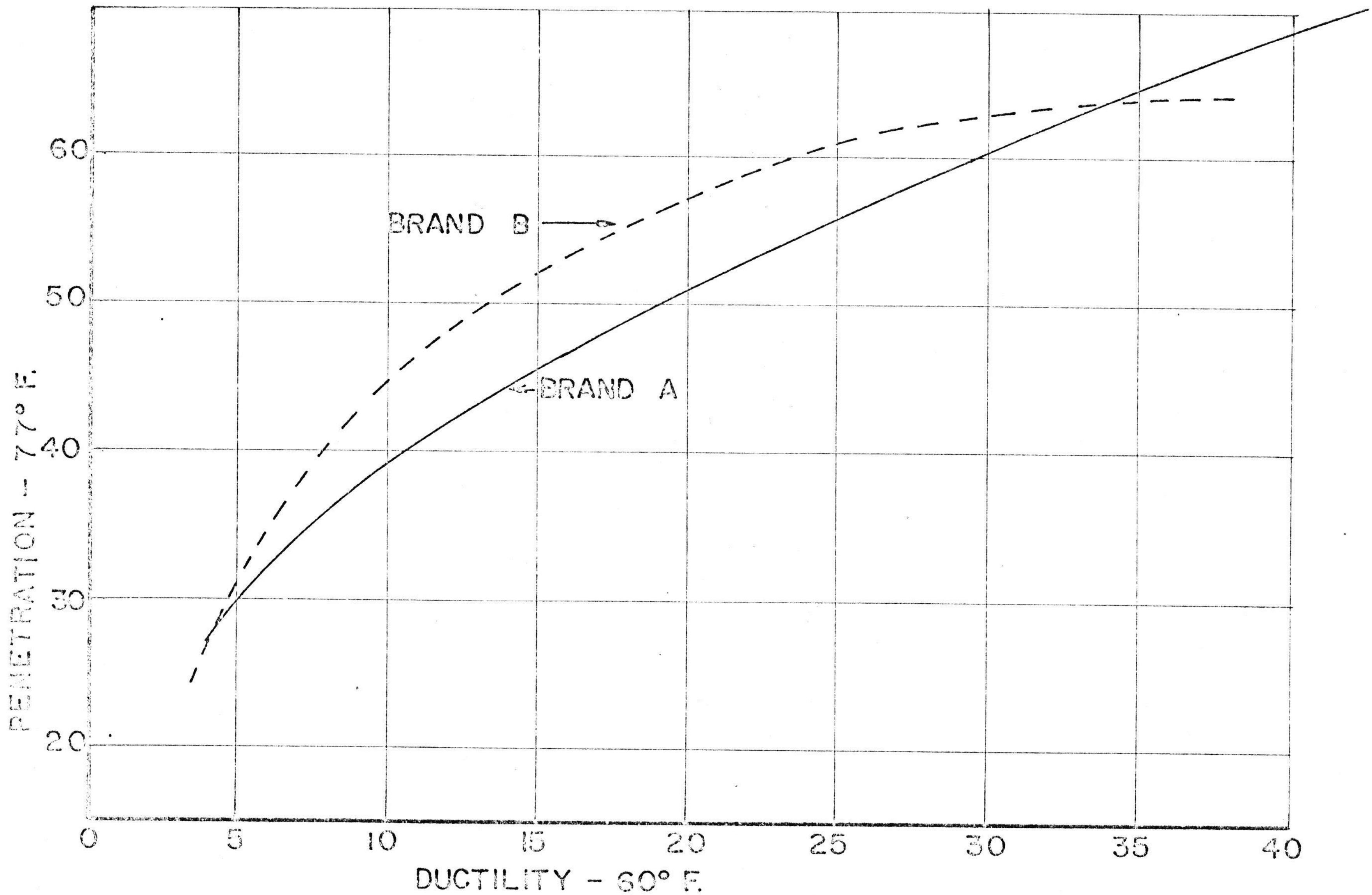
FIGURE 12



DUCTILITY VS VISCOSITY

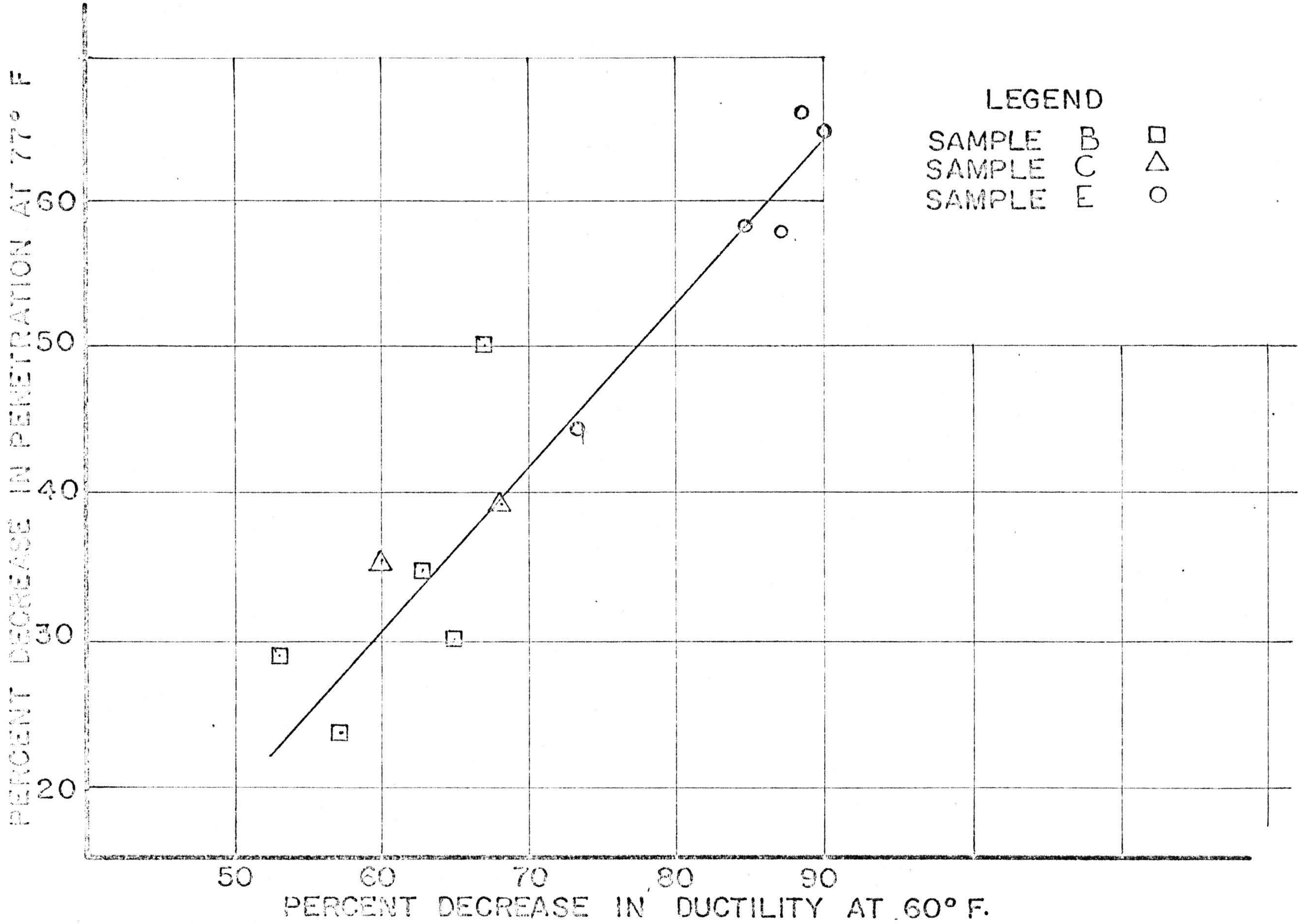
BRAND B

FIGURE 13



PENETRATION DUCTILITY RELATIONSHIP

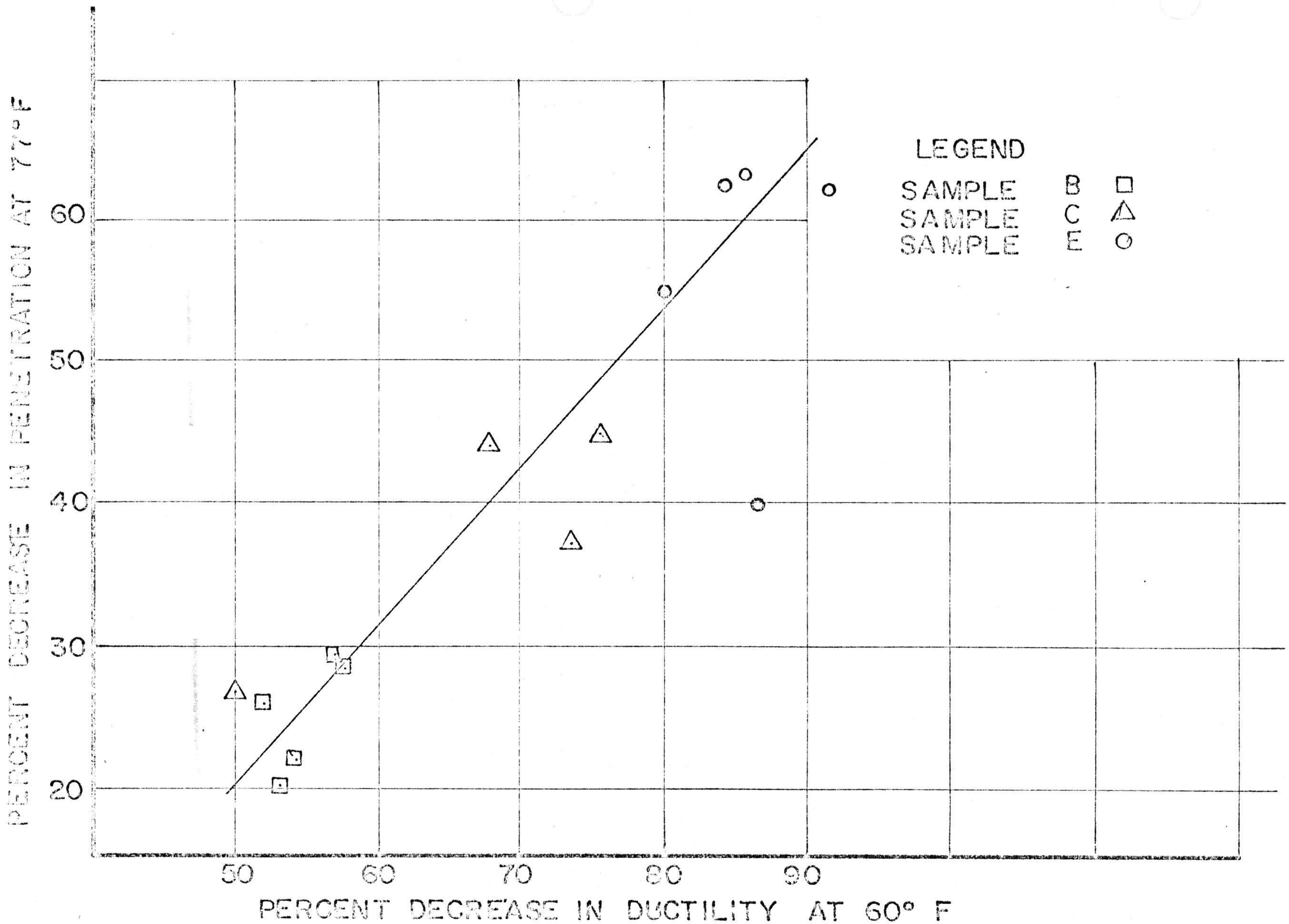
FIGURE 14



RELATIONSHIP BETWEEN PENETRATION AND DUCTILITY

BRAND A

FIGURE 15



RELATIONSHIP BETWEEN PENETRATION AND DUCTILITY

BRAND B

FIGURE 16

JOB 4473

Asphalt Cement Brand	-- A	Coarse Aggregate	-- Crushed Sandstone
Fine Aggregate	-- Local Sand	Mineral Filler	-- Balesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	61		86		21		32		10		15		6		10	
B	40	34	65	24	18	14	28	12	8	20	13	13	6	0	10	0
C	37	39	55	36	18	14	27	16	8	20	13	13	6	0	10	0
DL	32	47	49	43	13	38	23	37	8	20	15	0	-		--	
DM	31	49	46	46	12	43	19	41	8	20	14	7	-		--	
E	22	64	38	56	11	48	18	44	4	60	10	33	-		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	37		7		11		10	
B	150+	16	57	5	29	5	55	5	50
C	150+	12	68	5	29	6	45	5	50
DL	150+	10	73	6	14	4	64	--	--
DM	55	7	81	1	86	4	64	--	--
E	10	4	89	0	100	4	64	--	--

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	3,653	
B	10,999	201
C	10,006	174
DL	11,746	226
DM	17,107	368
E	18,623	410

JOB 2-509

Asphalt Cement Brand -- B
Fine Aggregate -- Local Sand
Coarse Aggregate -- Crushed Syenite
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	64		92		25		38		13		21		10		16	
B	51	20	73	21	20	20	33	13	11	15	17	19	9	10	14	13
C	36	44	54	41	17	32	27	29	10	23	16	24	7	30	11	31
DL	31	52	39	58	14	44	22	42	8	38	15	28	--		--	
DM	25	61	38	59	14	44	22	42	7	46	12	43	--		--	
E	24	62	39	58	12	52	20	47	6	54	10	52	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	19		--		17		7	
B	120	9	53	--		7	59	4	42
C	50	6	68	--		7	59	4	42
DL	10	5	74	3		4	76	--	--
DM	10	4	79	2		3	82	--	--
E	5	3	84	0		2	88	--	--

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	5,196	
B	13,966	169
C	22,557	334
DL	19,293	271
DM	46,140	788
E	44,129	750

JOB 1370

Asphalt Cement Brand -- B
Fine Aggregate -- Arkansas River Sand
Coarse Aggregate -- Crushed Limestone
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	66		95		25		38		14		22		10		16	
B	49	26	72	24	17	32	28	26	11	21	18	18	9	10	15	6
C	36	45	53	44	16	36	24	37	8	43	14	36	7	30	--	
DL	33	50	50	47	16	36	27	29	8	43	15	32	--		--	
DM	40	39	59	38	19	24	31	18	9	36	17	23	--		--	
E	25	62	39	59	12	52	21	45	6	57	11	50	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	25		8		6		9	
B	125	12	52	7	12	--		5	44
C	38	6	76	4	50	--		3	67
DL	13	4	84	3	62	4	33	--	
DM	56	3	88	3	62	4	33	--	
E	8	2	92	2	75	3	50	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	4,647	
B	12,145	161
C	19,431	318
DL	29,901	543
DM	17,251	271
E	45,115	871

JOB 2661

Asphalt Cement Brand -- B
Fine Aggregate -- Fine Local Sand
Coarse Aggregate -- Crushed Syenite
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	65		95		28		41		14		24		10		15	
B	46	29	68	28	21	25	33	20	12	14	19	20	10	0	15	0
C	41	37	57	40	20	28	31	24	11	21	16	33	9	10	14	7
DL	38	42	56	41	20	28	32	22	10	28	17	29	--	--	--	-
DM	32	51	37	61	18	36	27	34	9	36	16	33	--	--	--	-
E	29	55	44	54	15	46	26	36	7	50	15	38	--	--	--	-

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	30				11		8	
B	134	13	57	--		8	27	5	38
C	82	8	73	--		6	45	5	38
DL	39	7	77	4		5	54	--	
DM	22	5	83	2		4	64	--	
E	13	6	80	2		4	64	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	5,663	
B	11,857	109
C	14,090	149
DL	16,928	199
DM	26,424	367
E	35,388	525

JOB 8-516

Asphalt Cement Brand -- B
Fine Aggregate -- Local Sand
Coarse Aggregate -- Crushed Limestone
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	63		93		26		42		15		21		12		18	
B	51	13	75	19	20	23	32	24	14	7	19	10	9	25	14	22
C	--		--		--		--		--		--		--		--	
DL	36	43	57	39	18	31	29	31	10	33	16	24	--		--	
DM	35	44	55	41	20	23	32	24	11	27	17	19	--		--	
E	--		--		--		--		--		--		--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	39				15		9	
B	115	12	69			8	47	6	33
C	--	--		--		--		--	
DL	24	6	85	4		3	80	--	
DM	40	7	82	4		3	80	--	
E	--	--		--		--		--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Decrease
A	5,351	
B	11,447	114
C	--	
DL	15,801	195
DM	16,668	211
E	--	

This job was resurfaced before "E" Samples could be obtained.
The resurfacing was not due to any distress in the pavement.

JOB 2-528

Asphalt Cement Brand -- A
Fine Aggregate -- Local Sand

Coarse Aggregate -- Crushed Syenite
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	66		96		26		44		12		18		8		11	
B	47	29	69	28	20	23	32	27	10	17	16	11	7	12	10	9
C	42	36	63	34	20	23	31	30	10	17	15	17	7	12	11	0
DL	31	53	48	50	13	50	23	48	5	58	11	39	-		--	
DM	38	42	57	30	14	46	24	45	6	50	12	33	-		--	
E	37	44	57	30	16	38	25	43	6	50	13	28	-		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	40				33		7	
B	150+	19	53			9	73	5	28
C	150+	16	60			8	76	6	14
DL	149	8	80	3	--	3	91	--	
DM	120	8	80	3	--	4	88	--	
E		11	73	3	--	4	88	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	3,503	
B	6,838	95
C	7,183	105
DL	10,679	205
DM	11,268	222
E	24,968	613

JOB 2-534

Asphalt Cement Brand -- C
Fine Aggregate -- Local Sand

Coarse Aggregate -- Crushed Syenite
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	64		92		24		38		13		22		10		14	
B	50	22	73	20	20	17	32	16	11	15	20	9	9	10	14	0
C	46	28	68	26	18	25	27	29	10	23	18	18	--	--	--	-
DL	28	56	41	55	12	50	22	42	7	46	13	41	--	--	--	-
DM	17	73	50	46	15	38	26	31	8	38	15	32	--	--	--	-
E	27	57	43	53	15	38	27	29	8	38	14	36	--	--	--	-

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	32				36		--	
B	150+	18	44			16		7	
C	--	16	50			10		9	
DL	28	5	84	2		3			
DM	66	8	75	2		3			
E	36	5	84	3		4			

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	3,950	
B	7,093	79
C	9,864	150
DL	32,033	711
DM	16,435	316
E	16,969	330

JOB 11-524

Asphalt Cement Brand -- B	Coarse Aggregate -- Crushed Limestone
Fine Aggregate -- Local Sand	Mineral Filler -- Limestone Dust

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	61		91		24		35		12		19		10		15	
B	46	25	69	24	20	17	32	9	11	9	18	5	9	10	13	13
C	--		--		--		--		--		--		--		--	
DL	23	62	38	58	12	50	20	43	7	42	13	32	--		--	
DM	28	54	44	51	13	46	24	31	8	33	14	26	--		--	
E	--		--		--		--		--		--		--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	31				14		9	
B	110	12	61			7	50	5	44
C	--	--		--		--		--	
DL	12	4	87	2		3	78	--	
DM	10	4	87	3		3	78	--	
E	--	--		--		--		--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Decrease
A	5,103	
B	9,828	93
C	--	
DL	21,584	323
DM	33,725	561
E	--	

This job was resurfaced before "E" Samples could be obtained.
The resurfacing was not due to any distress in the pavement.

JOB 9-518

Asphalt Cement Brand -- A
Fine Aggregate -- Pyatt Sand
Coarse Aggregate -- Crushed Limestone
Mineral Filler -- Limestone Dust

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	66		82		22		33		9		15		8		12	
B	33	50	48	41	19	19	31	6	9	0	14	7	7	13	11	8
C	--		--		--		--		--		--		--		--	
DL	22	67	36	56	10	54	18	45	6	33	11	27	--		--	
DM	19	71	33	60	10	54	15	54	6	33	12	20	--		--	
E	28	58	43	48	15	32	22	33	6	33	12	20	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	38				19		9	
B	150+	13	66			8	58	6	33
C	--	--		--		--		--	
DL	15	4	89	0		1	95	--	
DM	22	4	89	1		2	89	--	
E	41	6	84	1		2	89	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	3,285	
B	7,309	122
C	--	
DL	34,943	964
DM	--	
E	18,130	452

JOB 2-536

Asphalt Cement Brand -- B Coarse Aggregate -- Crushed Syenite
Fine Aggregate -- Local Sand Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	62		90		25		37		14		20		9		16	
B	48	22	72	20	24	4	34	8	13	7	19	5	8	11	15	6
C	45	27	73	18	19	24	31	16	10	28	16	20	--		--	
DL	27	72	42	53	14	44	24	35	7	50	15	25	--		--	
DM	--		--		--		--		--		--		--		--	
E	23	63	37	59	11	56	19	49	7	50	13	35	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	28		--		12		10	
B	140	13	54	--		9	25	7	30
C	142	14	50	--		9	25	--	
DL	10	4	86	--		3	75	--	
DM	--	--		--		--		--	
E	6	4	86	--		2	83	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	5,415	
B	8,993	66
C	11,069	104
DL	38,307	607
DM	--	
E	46,871	766

JOB 2-527

Asphalt Cement Brand -- A
Fine Aggregate -- Local Sand
Coarse Aggregate -- Crushed Granite
Mineral Filler -- Batesville Lime

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	64		92		24		37		11		15		7		12	
B	45	30	71	23	18	25	28	24	8	27	13	13	6	14	12	0
C	--		--		--		--		--		--		--		--	
DL	26	59	41	55	10	58	19	48	6	45	11	26	--		--	
DM	--		--		--		--		--		--		--		--	
E	23	64	37	60	11	54	19	48	7	36	12	19	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	42		--		30		10	
B	150+	15	64	--		10	67	5	50
C	--	--	--	--		--	--	--	--
DL	27	5	88	--		4	87		
DM	--	--	--	--		--	--	--	--
E	17	4	90	--	--	3	90		

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	3,442	
B	6,684	94
C	--	
DL	22,393	551
DM	--	
E	33,016	859

JOB 9432

Asphalt Cement Brand -- A
Fine Aggregate -- Arkhola Sand
Coarse Aggregate -- Crushed Limestone
Mineral Filler -- Local Limestone Dust

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	60		82		23		36		11		17		6		11	
B	39	35	58	29	17	26	26	28	10	9	17	0	5	17	10	9
C	--		--		--		--		--		--		--		--	
DL	27	55	42	49	11	52	20	44	6	45	11	35	--		--	
DM	--		--		--		--		--		--		--		--	
E	26	57	42	49	13	43	22	39	7	36	12	29	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	40		--		22		12	
B	150+	15	62	--		11	50	5	58
C	--	--		--		--		--	
DL	33	5	87	--		3	86	--	
DM	--	--		--		--		--	
E	22	5	87	--		4	82	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	2,620	
B	8,107	209
C	--	
DL	20,812	694
DM	--	
E	31,806	1113

JOB 11681

Asphalt Cement Brand -- B
Fine Aggregate -- Local Sand

Coarse Aggregate -- Crushed Limestone
Mineral Filler -- Limestone Dust

PENETRATION

Sample No.	77°F 100g	% Decr	77°F 200g	% Decr	60°F 100g	% Decr	60°F 200g	% Decr	45°F 100g	% Decr	45°F 200g	% Decr	39.2°F 100g	% Decr	39.2°F 200g	% Decr
A	64		82		25		39		12		20		11		17	
B	46	28	67	18	21	16	33	15	11	8	18	10	9	18	16	6
C	--		--		--		--		--		--		--		--	
DL	24	62	37	55	12	52	21	46					--		--	
DM	--		--		--		--		--		--		--		--	
E	32	40	48	41	15	40	26	33	7	40	13	35	--		--	

DUCTILITY

Sample No.	77°F 5cm/min	60°F 5cm/min	% Decr	45°F 5cm/min	% Decr	45°F 1cm/min	% Decr	39.2°F 1cm/min	% Decr
A	150+	31		--		7		6	
B	134	13	58	--		5	28	4	33
C	--	--		--		--		--	
DL	5	3	90	--		3	57	--	
DM	--	--	--	--		--		--	
E	13	4	87	--		3	57	--	

ABSOLUTE VISCOSITY
Poises at 140°F

Sample No.	Poises at 140°F	Percent Increase
A	5,988	
B	9,073	52
C	--	
DL	30,940	417
DM	--	
E	--	

TABLE IX

SAYBOLT - FUROL VISCOSITY - SECONDS

BRAND A

Job No.	Temperature At 250°F	275°F	325°F
2-527	710	297	75
9432	553	240	65
9-518	698	296	73
2-528	881	269	72
4473	762	302	76

BRAND B

Job No.	Temperature At 250°F	275°F	325°F
2-509	794	379	92
1370	887	373	92
2661	858	373	89
8-516	907	378	90
11-524	915	381	92
2-536	932	357	91
11-681	825	361	92

BRAND C

Job No.	Temperature At 250°F	275°F	325°F
2-534	720	309	85

TABLE X

TYPICAL GRADATIONS

From Extracted "C" Samples

SCREEN	PERCENT PASSING					
	Job 9432			Job 2-536		
3/8	94	95	96	97	97	98
No. 4	72	73	73	77	78	80
10	51	52	51	29	54	55
40	27	28	29	25	29	26
80	14	15	16	7	10	10
200	5.6	6.9	7.1	4.2	5.6	6.9
%AC	5.9	6.0	5.8	6.0	5.8	5.8
% Voids	4.8	4.9	4.9	4.1	5.0.	5.6

	Job 2-528			Job 2-534		
3/8	96	97	97	97	97	98
No. 4	70	72	74	73	73	72
10	46	47	47	49	48	48
40	22	22	23	23	21	23
80	15	15	13	13	9	12
200	6.4	6.6	7.0	8.2	5.9	7.8
%AC	6.1	6.2	6.0	6.0	6.0	
% Voids	1.0	0.9	1.3	4.8	5.0	

	Job 4473
3/8	92
No. 4	63
10	47
40	27
80	13
200	6.4
%AC	5.8
% Voids	0.8

CONCLUSIONS

The revised work plan posed seven questions for this investigation. These questions and the answers produced by this investigation are as follows.

1. What effect does the variation in mixing temperature have on physical properties?

   The variation in mixing temperatures on the various jobs was not wide in range but there was no indication of change in the physical properties due to different mixing temperatures. See Table III. The laboratory investigations of mixing temperatures ranging from 250°F to 325°F did not show any significant changes of the physical properties. See Table II.

2. Does viscosity vary for different brands of asphalt cement that have the same penetration?

   The different brands of asphalt with the same penetration have decidedly different viscosities. Four samples of asphalt cement Brand A had an average viscosity of 3470 poises at 140°F. The variation in the individual samples was from 3285 to 3653. The absolute viscosity of Brand B varied from 4647 poises to 5988 poises with an average of 5340 poises. The one sample of asphalt cement Brand C had an absolute viscosity of 3950 poises. The penetration of these samples varies from 60 to 64. See Figures 11, 12 and 13.

3. Is there any relation between the ductility and viscosity of the asphalts?

Figures 12 and 13 show this relationship. It appears that the ductility is not very definitive at low lengths.

4. Do aggregates and mineral fillers affect the physical properties?

There was no changes in the physical properties due to the different aggregates. Batesville limestone dust was used in most of the mixes and there was no detectable difference in the physical properties of the asphalt cements where other mineral fillers were used. Likewise there was no indication of any aggregate effects on any of the mixes either in pavement samples or the mixes studied in the laboratory.

5. What is the total effect on asphalt cement of mixing and placing?

Overall results indicate that from 25 to 30 percent of the penetration of the asphalt was lost during mixing. The ductility loss during the same process was about 60 percent and the increase in viscosity varied from 207 to 240 percent. The curves of Figures 5 and 6 indicate that the loss in penetration during mixing approximates the loss during the first three years of pavement life if penetration is to be used as a criterion of life. The loss of ductility during mixing was much greater than the loss during the first three years of pavement life. The loss in ductility during mixing was about twice as great as the decrease during the first forty months of pavement life.

The viscosity of both Brands A and B seems to increase much more rapidly during service life than during mixing.

6. What changes take place in asphalt cements during the first two or three years in the pavement?

The penetration and ductility decrease very slowly during service life. There was a rapid increase in absolute viscosity. The time in service has not been sufficient to indicate what the end point is.

7. What changes take place in the same mix if it is compacted into specimens and stored for the same period?

There seems to be very little difference in the physical changes that take place in the asphalt cements. Whether they are stored in the laboratory or if they are in the pavements. It should be remembered that all of these pavements were dense graded and the surfaces are very tight. Thus only the surface is subject to very serious weathering.

Stability and void content tests were not made on the samples stored in the laboratory. There was no stripping and the compacted specimens appeared to be as firm as when placed in the distilled water. The loose mix stored in distilled water was firm and required heating to loosen sufficient to place in the extractors.

It did not prove feasible to carry out Part VII of the Work Plan which contemplated that the mixing temperature of actual jobs would be varied from the minimum to maximum tempatures permitted by the specifications. There was not a sufficient number of paving jobs being constructed. Also the Highway Department's methods of job control did not provide for an easy method of changing the temperatures during the operations.

The loss of penetration during mixing of the samples in the laboratory compared very closely with that loss during mixing in the pugmills on the job. The average loss in penetration on the jobs using Brand B asphalt was 24 percent, whereas, the loss from mixing in the laboratory varied from 21 to 23 percent.

The loss in ductility during mixing was much more pronounced in the laboratory pugmill than in the commercial pugmills. The ductility of the asphalt cement Brand B decreased about 80 percent during mixing in the laboratory pugmill, whereas, the loss in ductility during mixing in the field varied from 55 to 65 percent.

Viscosities were measured only at 140°F. It was decided that it would be a duplication of Highway Research Project 21, Rheology of Asphalt Cements to make the determinations at other temperatures.

RECOMMENDATIONS

Recommendation one.

It is recommended that the Materials and Tests Division and the Construction Division of the Highway Department make an investigation of the mixing time and other conditions surrounding the placing of hot-mix pavements. The results reported here show that 24 to 32 percent of the life of the pavement is lost during mixing if penetration is a measure of pavement life. The loss in life is still more if ductility is used as a measure.

There was not one instance in this entire study where it was observed that mixing was not adequate. If the mixing procedures were barely adequate, an occasional uncoated particle or other evidence of poor mixing would appear. It thus seems that the present mixing procedures may be more than adequate and that the time and possibly the temperature of mixing could be reduced.

Recommendation two.

The Highway Department should take additional samples of the pavements of these jobs as long as they are in service, to determine the actual life of the pavement and what the indications of life are. These samples could be taken at intervals of two to three years or any time that one of the jobs is to be resurfaced. Much valuable information has been obtained but a continued observation of these pavements will yield much more information with very little additional effort.

Recommendation three.

The penetration test and the ductility test are not good indicators of the condition of the asphalt cement when the quantities measured are low. Other tests such as viscosity and perhaps a simple chemical test should be used as check tests for research and aging purposes.

REFERENCES

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