THE OPTIMUM VISCOSITY OF ASPHALT CEMENTS WITH REGARD TO ASPHALT PAVING MIXTURES

by

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INTRODUCTION

The Problem

With the growing need for quality pavements brought about by increased traffic volume and increased wheel loads, today's engineer must give reasonable assurance of uniform asphaltic road construction of the highest quality. In order to realize this objective, maximum utilization should be made of one of the basic properties of an asphaltic material - its viscosity.

"Viscosity is that property of a fluid that causes it to resist flow. Fluidity is the inverse of viscosity; the higher the viscosity, the lower the fluidity or ability to flow." (16)

It is the opinion of many of the Asphalt Paving Technologists that for a specific job application there is an optimum asphalt viscosity that will give the best results. (15) This viscosity can be obtained by specifying the temperature range at which the asphalt should be used. The temperature-viscosity relationship for any given asphalt is relatively easy to establish, but the problem remains of determining the optimum viscosity of the asphalt for a given paving mixture under specified conditions.

Approach to the Problem

With this objective, the program of research was undertaken in February, 1960, under the direct supervision of Dr. John W. Shupe, Department of Applied Mechanics, Kansas State University. After conference with Mr. Duane Gagle, Asphalt Consultant of the Phillips Petroleum Company, and Mr. Richard Peyton, Assistant Highway Engineer, Kansas State Highway Commission, it was decided to use six asphalts with widely varying characteristics to test for stability and durability as related to viscosity. To accomplish this, a series of tests was performed on the asphalt as it was received, and also on the asphalt cement recovered from the test specimens. These tests included Penetration; AASHO Designation T 49-53; Loss on Heating; AASHO Designation T 47-52; Thin Film Test; AASHO Designation T 179-57; Viscosity Determination; ASTM Method D-445 T, and Modified Ductility Test on the asphalt cement as received. Penetration, Viscosity Determination and Modified Ductility were also performed on the recovered asphalt cement.

The stability measurements were obtained by the Marshall Method, while the Immersion Compression Test was used in evaluating durability. The stability and durability tests were run at five temperatures: 230, 260, 290, 320, and 350° F. to give a broad viscosity range for the six asphalt cements. These data compiled from the six different asphalts gave an indication of the role of viscosity in designing paving mixtures.

Review of Previous Work

To review all previous work would be virtually impossible because of the magnitude of the research and the many papers dealing with asphalt paving mixtures. Therefore, this discussion shall confine itself to recent research of a similar nature dealing with the viscosity and mixing temperature relationships.

Research was conducted on the effect of asphalt viscosity on the stability of asphalt paving mixtures by Messrs. B. Weetman and D. W. Hurlburt (34), and reported in 1947. The Hubbard-Field Method was used in determining stability and the asphalt cement from the tested specimens was extracted with benzol and recovered by the modified Abson Procedure, ASTM Method D-762-44T. The viscosities of the recovered asphalts versus the punching shear stabilities were plotted on semi-log coordinates at the viscosity temperature. The curves obtained showed a linear relationship between these variables and in addition, that the stability of a mixture made with asphalts from the same crude source is directly related to the absolute viscosity of the asphalt in the mixture.

Directly related to the asphalt viscosity at the mixing temperature is the asphalt film thickness in the paving mixture. Studies (11) in which the film thickness has been evaluated in terms of viscosity indicate that at least a portion of the asphalt in the films of a pavement behaves as a solid. Sudden application and release of a load on paving asphalt has little effect on it; but, if loading is prolonged, deformation may result. The viscous resistance of the pavement is observed to differ with the thickness of the films and viscosity of the asphalt. There appears to be a critical degree of film thickness to achieve optimum mechanical strength or stability (19).

A variety of types and grades of asphalt were investigated by Messrs. D. F. Fink and J. A. Lettier (10). Almost identical stabilities were observed when the different asphaltic mixtures were compacted and tested at equivalent binder viscosities. A plot of log viscosity versus Marshall Stability (at an asphalt content of six per cent) gave a linear relationship. The stability values also showed a direct increase as the compaction temperature increased, and as harder grades of asphalt were used.

The Louisiana Department of Highways, under the direction of Verdi Adam, Bituminous Research Engineer, has been investigating the effects of viscosity of asphalts at several stages of construction on test results and performance of hot mix asphaltic pavements since 1957 (1). In this study, the effects of mixing temperature is compared with the stability of the mixture as determined by the Marshall Method. The comparisons were conducted on specimens prepared from laboratory mixed and from plant mixed samples.

The results for the various asphalts were similar - stability values, when plotted against mixing temperature and viscosity, increased to a peak, dipped somewhat, and then steadily increased. The maximum stability was not reached until the asphalt was viscous enough to envelope the aggregate particles. Then, as the temperature increased, the asphalt became extremely fluid and merely lubricated the aggregate causing the stability to decrease from its peak. The resulting rise of stability may have been caused by a hardening of the asphalt as the temperature reached its maximum (1). As expected, the maximum stability did not occur at the same mixing temperature for each asphalt; but in the viscosity versus stability curves, the maximum stability occured at the same viscosity for each asphalt, 85 Saybolt Furol seconds. It was concluded that for given aggregate characteristics, the viscosity of the asphalt at mixing temperature considerably affects the film thickness of the asphalt and adequate coating of the aggregate.

The effects of temperature on the characteristics of bituminous mixtures was recently studied by Mr. W. H. Gotolski (13). The experiment was designed to provide information concerning temperature effects on the stability characteristics and to determine the temperature at which the rheological properties of the asphalt cement may experience detrimental changes.

The stability was measured by the Marshall Method and the Hveem Stabilometer. The physical properties of the asphalt cement were measured before and after being subjected to the test temperatures.

The asphalt cement was heated in five-gallon lots at each of the temperatures for not less than thirty minutes. It was then sealed until needed for preparing batches, at which time it was heated to $275^{\circ} \pm 5^{\circ}$ F. immediately prior to mixing. The test temperatures for the asphalt cement and the mixing temperatures for the batches were identical: 275°, 350°, 425°, and 500° F.

The results of Gotolski's research indicated that the preheating of asphalt cement caused no significant change in penetration, softening point, and ductility of the asphalt. However, the curves plotted with stability versus asphalt preheat temperature (based on the Marshall Test) show that high temperatures have detrimental effects on the cohesive and viscous properties of the asphalt. In contrast to this, the curves of stability versus mixing temperature show the higher temperatures to be beneficial. To reach a point of optimum temperature the two curves were superimposed, and the point of intersection was determined. The point was approximately 375° F. Previous studies (32), coupled with interpretations of this study (13), indicate the elevated temperature will not affect the durability of finished pavement.

The evaluation of bituminous paving mixtures by the Immersion-Compression Test has also been very effective since the immersion temperature has been raised (19). Mr. J. F. Goode provides a very good discussion of the background of this test and some of the important factors to note in designing bituminous mixtures. The procedure takes into account the four very important design factors; stability, flexibility, and durability of the pavement structure; and anti-skid quality of the pavement surface (19).

Another study by Mr. A. T. Goldbeck compares the Immersion-Compression Test to the laboratory traffic method of testing to determine if a correlation exists between the two (12). The asphalt mixture was first tested by the conventional procedure and then by the laboratory traffic method. This utilized a 7.00 x 20-inch pneumatic tire loaded at 1900 lb, and inflated to 50 to 55 lb. The tire was fastened to a radial arm so that the action simulated a front tire of a bus or truck. The correlation between the two tests was poor; but, nevertheless, it was concluded that the Immersion-Compression test probably gave a good indication of the behavior of bituminous mixtures under water action. However, it would not be too indicative of the serviceability or durability of the pavement other than under unusual conditions (12).

It may be noted in summary that the Asphalt Institute recently recommended that a mixing temperature be selected which will result in an asphalt viscosity of 75 to 150 seconds, Saybolt Furol (15). This should alleviate some of the problems encountered in mixing temperature specifications. It is apparent that substantial differences exist in the viscosity of asphalts that in other respects are basically similar. These differences lead to two basic problems in mixing temperatures:

First, assurance of thorough and uniform coating of the aggregates,

Second, assurance that there will be no draining of the mix as it is being transported.

Over all, it may be concluded from previous work that for a given type and gradation of aggregate, the stability and durability of the pavement will be directly related to the viscosity of the asphalt at mixing temperatures and operating temperatures. This in turn leads to the conclusion that there is an "optimum" viscosity for mixing (15).

MATERIALS, EQUIPMENT, AND PROCEDURE

Materials

The aggregate, St. George Limestone, purchased from Walters Sand Company, Inc., Manhattan, Kansas, was crushed and blended to meet specification limits for Grading B of the Kansas State Highway Commission. This gradation is,

Table 1. Aggregate Gradation

Sieve Size	Actual Per cent Retained	K.S.H.C. Spec. Grad. B, Surface courses of asphaltic concrete. Per cent retained.
3/4"	0	0-5
3/8"	24.2	25-40
No. 4	49.6	40-60
No. 8	59.1	50-68
No. 16	71.8	62-76
No. 30	81.9	70-83
No. 80	89.0	84-91
No. 200	93.4	92-96

The specific gravity of the aggregate is,

Dry bulk specific gravity, ... 2.61
Saturated bulk specific gravity, ... 2.66
Apparent specific gravity, ... 2.74

The aggregate was also tested for resistance to abrasion in accordance with ASTM Designation C 131-51, Grading A. The result was 32.7 per cent wear, which meets K.S.H.C. specification for aggregate to be used in asphaltic concrete.

The loss ratio of the aggregate was determined by freezing and thawing to be 94.8 per cent, which also meets the K.S.H.C. specifications. This test was performed in accordance with AASHO Designation T 103-42.

The aggregate was stored in a bin indoors before crushing. After crushing, it was stored in galvanized barrels to minimize any variables to which the aggregate might be subjected when exposed to the atmosphere.

The six asphalt cements that were used in the study were furnished by the Phillips Petroleum Company. The test results of the asphalt cements are as follows:

Table 2. Initial Test Results

Asphalt Code	1	2	3	4	5	6
Sp. Gr. at 77° F.	1.0120	0.9890	1.0139	0.9940	1.0017	1.0116
Penetration at 77° F.	92	89	91	79	88	110
Ductility at 77° F, cm	100+	100+	100+	100+	100+	100+
Mod. Ductility, cm	50	46	31	39	53	42
Loss of heating 53 hr. %	.04	.002	.78	.70	.50	.10
Pen. on L.O.H.	92	81	66	73	74	98
% of orig. penetration	100	91.0	72.5	92.4	84.1	89.1
Thin Film Test						
L.O.H. Wt. %	.085	+.080	2.62	0.16	.078	.092
Pen. at 77° F.	49	56	32	46	55	71
% of orig. pen.	53.2	62.9	35.1	58.2	62.5	64.5
Viscosity - Centistokes						
180° F.	10,840	16,905	8,025	9,045	8,865	7,860
210° F.	2,665	4,060	2,010	2,265	2,345	1,990
275° F.	314	456	258	291	305.5	257.5

Asphalts Nos. 1 and 2 were supplied in three, 5-gallon cans each. These were heated on an electric hot plate and then transferred to 1-gallon tins. On the day of use, the necessary asphalt for each batch was cut from the 1-gallon tins with a heated spoon. This asphalt was placed in a glass beaker and heated to the mixing temperature in an electric oven. Asphalts Nos. 3, 4, 5, and 6 arrived in 15-gallon drums, and test samples were taken directly from the drum. The lids on the drums were sealed after each sample was taken in order to minimize oxidation.

Equipment and Procedure

In order to establish the role of viscosity, the viscosity of the asphalt cements was measured before mixing and then after being recovered from the tested specimens. A CaLab C 120 Viscosity Bath, as shown in Fig. 1 using rectangular head, cross arm viscometers, operating at 210° F. was used for this purpose. The asphalt cement to be tested was placed in an electric oven for two hours at 220° F. in a four-ounce sample bottle. The asphalt was then transferred to the cross arm viscometers by pouring from the sample bottle, and allowed to remain in the viscometer reservoir for 15 minutes before testing. The tests were all performed in accordance with ASTM Designation D-445 T.

As was mentioned previously, the stability testing was performed using the Marshall Method. The amount of asphalt to be used in the mix for the Marshall Test and the Immersion Compression Test by

FIG. 1 CALAB C-120 VISCOSITY BATH WITH CROSS-ARM VISCOMETERS

running a sample series at 325° F. with asphalt No. 1 at 4.5, 5, 5.5, 6, and 6.5 per cent of asphalt cement by weight of total mix. The optimum asphalt content was found to be 5.5 per cent by total weight of mix.

In preparing the batches for the Marshall specimens, the aggregate is placed in the bowl of a Lancaster Batch Mixer and placed in an electric oven for four hours to allow it to heat to the desired temperature. Two and one-half hours before mixing, the asphalt cement and the molds are placed in the oven. When mixing temperature is reached, the batch is mixed for exactly two minutes in the Lancaster Mixer, after which it is divided into three portions of 1200 grams each. These are placed in an electric oven at 20° F. below mixing temperature for 20 minutes to simulate the time lapse in the field as the batch leaves the mixer and travels to the distributor. It is then placed in a mold and compacted by 50 blows on each side with a standard Marshall mechanical hammer. The specimen is allowed to cool, after which time its specific gravity is determined and voids computed. Approximately 18 hours after compaction, the specimens are tested for stability and flow with the Marshall apparatus. Immediately following this testing, the No. 2 specimen is prepared for recovery. The Faulwetter Extractor, as shown in Fig. 2, is used in separating the asphalt cement and aggregate with benzine as the solvent. The asphalt cement is then recovered from the solution by the Modified Abson Procedure, and tested to determine its penetration, modified ductility, and viscosity. Figure 3 shows the equipment assembled for the recovery by the Modified Abson

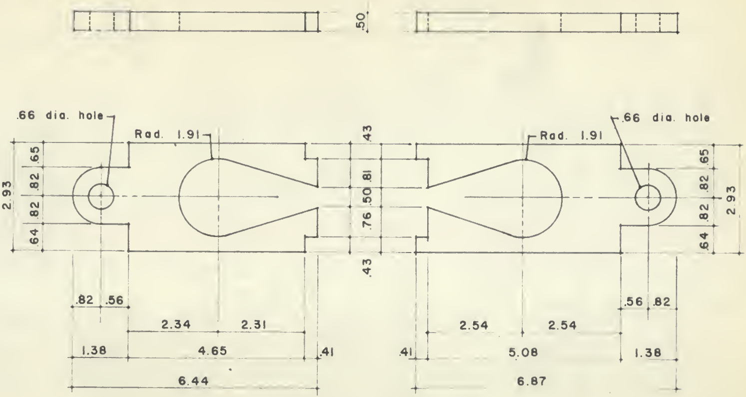
FIG. 2 FAULWETTER EXTRACTOR

FIG. 3 DISTILLATION EQUIPMENT FOR RECOVERY BY MODIFIED ABSON PROCEDURE

Procedure.

The modified ductility referred to in this thesis is performed in accordance with AASHO, T-51-44, except that the mold used is of a smaller design. The throat area is reduced from one square centimeter to 0.25 sq. cm. The other dimensions are as shown in Fig. 4. The new molds are being tried to see if a ductility test can be perfected that will have more meaning. By using a mold with a reduced throat area, the distance required for failure will be reduced which should give a value for ductility that can be used for comparison and identification. With the present molds, it is not uncommon to have values such as 100+ but with the new molds it is hoped a qualitative value will be obtained, thus giving the test values more significance.

The initial preparation of the Immersion-Compression Test specimens, including mixing, was handled in the same manner as the Marshall specimens. After mixing, the batches are divided into three portions of 1950 grams each, and immediately compacted by applying a load of 3000 psi for two minutes. The six specimens are then allowed to cool for two hours after which their specific gravities are determined. The specimens are divided into two groups of three each with average densities as nearly alike as possible. One group is then allowed to cure at room temperature in open air while the other group is placed in a 140° F. water bath for 20 hours. The specimens in the water bath are then transferred to another water bath at room temperature for two hours. After removal of the specimens from the water bath, all six specimens are immediately tested in unconfined compres-



SCALE 1" = 2.54 cm.

FIG. 4 MODIFIED DUCTILITY MOLD

sion, the load being applied at a uniform rate of 0.05 in. per minute per inch of height of the specimen. For the four-inch specimen that is used, this is 0.2 in. per minute. The results are given as per cent of retained strength:

$$\text{Per cent Retained Strength} = 100 \times \frac{\text{Strength Immersed Spec. psi}}{\text{Strength Dry Spec. psi}} .$$

The above procedures were used in the 24 test series. The data from this series, coupled with present knowledge, reveal a relationship which gives an indication of the role of viscosity in asphalt pavement design.

PRESENTATION OF DATA

The data presented in this thesis are divided into the following parts:

1. The Marshall Test values at each mixing temperature,
2. The Immersion-Compression Test values at each mixing temperature,
3. The extracted properties of each asphalt at the different mixing temperatures.

The data is presented in this manner to provide easy comparisons between the asphalts and also between temperatures and viscosities.

Table 3. Properties of extracted asphalts.

	Asphalt Number					
	1	2	3	4	5	6
230° F. Mixing Temp.						
Penetration	85	83	66	70	88	100
Kinematic Viscosity, cs	2832	4250	2809	2571	2571	2014
Modified Ductility, cm.	53	48	49	35	53	51
260° F. Mixing Temp.						
Penetration	90	79	63	79	85	122
Kinematic Viscosity, cs	2751	4669	2851	2650	2519	2030
Modified Ductility, cm	51	44	25	50	49	47
290° F. Mixing Temp.						
Penetration	74	81	60	69	79	101
Kinematic Viscosity, cs	3008	3554	3598	2790	2742	2145
Modified Ductility, cm	64	44	17	32	45	49
320° F. Mixing Temp.						
Penetration	70	68	51	58	72	97
Kinematic Viscosity, cs	3445	5659	4362	3552	2973	2260
Modified Ductility, cm	52	41	10	28	55	50
350° F. Mixing Temp.						
Penetration	61	66	44	56	63	91
Kinematic Viscosity, cs	3870	6165	5724	3677	3335	2408
Modified Ductility, cm	64	45	6	19	49	60

Table 4. Marshall test values.

	Asphalt Number					
	1	2	3	4	5	6
230° F. Mixing Temp.						
Density 1	2.369	2.358	2.352	2.394	2.384	2.378
2	2.350	2.363	2.361	2.398	2.384	2.378
3	2.337	2.348	2.346	2.372	2.374	2.366
Av.	2.352	2.356	2.353	2.388	2.381	2.374
Stability 1	1392	1499	1740	1890	2020	1290
(lb) 2	1480	1570	1724	2070	2000	1724
3	1325	1459	1554	1600	1830	1583
Av.	1399	1509	1673	1853	1950	1532
Flow	13.6	18.7	14.7	14.6	18.0	13.7
% Total Voids	6.12	5.67	6.11	4.45	4.80	5.19
% Voids Filled	67.65	69.90	67.69	74.88	73.10	71.25
260° F. Mixing Temp.						
Density 1	2.411	2.385	2.426	2.417	2.387	2.424
2	2.421	2.389	2.420	2.421	2.390	2.416
3	2.407	2.371	2.415	2.400	2.383	2.400
Av.	2.413	2.382	2.420	2.413	2.387	2.413
Stability 1	2142	1943	2436	2371	1909	2163
(lb) 2	2111	1970	2256	2348	2250	2180
3	1929	1686	1989	2060	2122	1910
Av.	2061	1866	2227	2260	2094	2084
Flow	15	15	14	13	15	13
% Total Voids	3.68	4.60	3.41	3.43	4.56	3.63
% Voids Filled	78.12	74.22	79.38	79.56	74.19	78.19
290° F. Mixing Temp.						
Density 1	2.419	2.380	2.405	2.426	2.425	2.412
2	2.419	2.370	2.416	2.436	2.414	2.423
3	2.394	2.370	2.394	2.428	2.410	2.404
Av.	2.411	2.373	2.405	2.430	2.416	2.413
Stability 1	2285	2190	2234	2464	2309	1979
(lb) 2	2330	1710	2438	2610	2153	2262
3	2035	2035	2050	2172	2285	1970
Av.	2217	1978	2225	2415	2249	2070
Flow	14	17	14	15	13	14
% Total Voids	3.75	5.07	4.18	2.74	3.23	3.66
% Voids Filled	77.74	72.70	75.73	83.08	79.00	78.19

Table 4. (concl.)

		Asphalt Number					
		1	2	3	4	5	6
320° F. Mixing Temp.							
Density	1	2.437	2.425	2.433	2.433	2.422	2.432
	2	2.433	2.428	2.432	2.443	2.435	2.430
	3	2.443	2.419	2.422	2.436	2.429	2.413
	Av.	2.438	2.424	2.429	2.437	2.429	2.425
Stabiliey (lb)	1	2668	2677	2894	2813	2430	2860
	2	2652	2766	2868	3111	2704	2591
	3	2489	2560	2434	2652	2596	2472
	Av.	2603	2668	2732	2857	2577	2641
Flow		16	14	15	15	14	11
% Total Voids		2.67	2.93	3.07	2.49	2.88	3.15
% Voids Filled		83.23	82.19	81.21	84.51	82.19	80.56
305° F. Mixing Temp.							
Density	1	2.444	2.430	2.441	2.445	2.452	2.440
	2	2.446	2.429	2.444	2.441	2.451	2.440
	3	2.440	2.429	2.440	2.438	2.440	2.439
	Av.	2.443	2.429	2.442	2.441	2.448	2.440
Stability (lb)	1	3039	3264	3140	3039	3111	2843
	2	3182	2820	3283	2897	3200	3050
	3	2960	2770	2887	2958	2870	2720
	Av.	3060	2951	3103	2965	3060	2871
Flow		15	13	14	12	15	14
% Total Voids		2.48	2.72	2.55	2.32	2.12	2.56
% Voids Filled		84.37	83.24	83.97	85.45	86.32	83.72

Table 5. Immersion-compression test values.

		Asphalt Number					
		1	2	3	4	5	6
230° F. Mixing Temp.							
Density of Spec.	1	2.372	2.364	2.357	2.338	2.363	2.351
	2	2.347	2.366	2.344	2.354	2.361	2.359
	3	2.355	2.358	--	--	2.361	--
Density of Immersed Spec.	4	2.357	2.371	2.352	2.328	2.371	2.360
	5	2.343	2.364	2.351	2.366	2.361	2.356
	6	2.354	2.367	2.349	2.360	2.358	2.363
Str. of Dry Spec., psi	1	414	414	423	365	412	396
	2	408	406	392	371	430	393
	3	414	377	--	--	398	--
	Av.	412	399	408	368	413	395
Str. of Immersed Spec., psi	4	25	148.1	110	174	58	17
	5	13	98	162	162	57	11
	6	0	121	126	195	75	0
	Av.	13	122	133	177	63	
% Ret. Str.		3.1	30.6	32.6	48.1	15.3	2.3
260° F. Mixing Temp.							
Density of Spec.	1	2.359	2.359	2.374	2.364	2.362	2.371
	2	2.369	2.358	2.375	2.367	2.368	2.367
	3	2.374	2.372	2.386	2.380	2.363	2.370
Density of Immersed Spec.	4	2.367	2.359	2.378	2.367	2.359	2.371
	5	2.371	2.358	2.375	2.380	2.369	2.363
	6	2.374	2.388	2.382	2.379	2.367	2.374
Str. of Dry Spec., psi	1	324	369	412	317	314	226
	2	334	384	373	356	318	248
	3	355	430	408	338	315	246
	Av.	338	394	398	337	316	240
Str. of Immersed Spec., psi	4	124	188	26	287	229	67
	5	143	231	239	244	268	55
	6	174	258	236	318	239	81
	Av.	147	226	246	283	245	68
% Ret. Str.		43.5	57.3	61.8	83.98	77.5	28.33

Table 5. (cont.)

		Asphalt Number					
		1	2	3	4	5	6
290° F. Mixing Temp.							
Density of Spec.	1	2.358	2.362	2.359	2.379	2.368	2.367
	2	2.351	2.367	2.347	2.374	2.385	2.365
	3	2.367	2.360	2.358	2.390	2.386	2.375
Density of Immersed Spec.	4	2.358	2.365	2.359	2.381	2.368	2.369
	5	2.360	2.356	2.347	2.375	2.377	2.366
	6	2.363	2.364	2.356	2.390	2.386	2.370
Str. of Dry Spec., psi	1	409	432	424	373	352	302
	2	361	420	384	336	350	315
	3	424	428	480	378	387	270
	Av.	398	427	429	362	363	296
Str. of Immersed Spec., psi	4	196	240	280	280	231	119
	5	182	251	257	274	221	109
	6	191	278	270	295	288	92
	Av.	190	257	269	283	247	107
% Ret. Str.		47.74	60.19	62.70	78.17	68.04	36.14
320° F. Mixing Temp.							
Density of Spec.	1	2.379	2.370	2.378	2.382	2.370	2.364
	2	2.376	2.379	2.386	2.377	2.372	2.380
	3		2.381	2.383		2.383	2.370
Density of Immersed Spec.	4	2.382	2.372	2.378	2.375	2.372	2.372
	5	2.377	2.378	2.386	2.377	2.380	2.377
	6	2.374	2.382	2.381	2.393	2.387	2.373
Str. of Dry Spec., psi	1	330	370	424	364	336	257
	2	337	361	371	366	359	292
	3		339	396		343	281
	Av.	334	357	397	365	346	277
Str. of Immersed Spec. psi	4	236	314	358	346	341	164
	5	241	279	396	400	346	197
	6	237	297	373	357	287	150
	Av.	238	297	376	368	325	169
% Ret. Str.		71.3	83.2	94.7	100.8	93.9	61.0

Table 5. (concl.)

		Asphalt Number					
		1	2	3	4	5	6
350° F. Mixing Temp.							
Density of Spec.	1	2.377	2.385	2.372	2.373	2.358	2.377
	2	2.379	2.383	2.382	2.384	2.380	2.363
	3	2.384	2.380	2.376	2.383	2.385	2.374
Density of Immersed Spec.	4	2.376	2.380	2.376	2.385	2.380	2.372
	5	2.380	2.381	2.375	2.374	2.378	2.376
	6	2.379	2.390	2.388	2.378	2.385	2.378
Str. of Dry Spec., psi	1	370	404	446	295	291	305
	2	400	407	468	385	416	292
	3	365	341	411	361	406	274
	Av.	378	384	442	347	371	290
Str. Immersed Spec., psi	4	337	354	419	418	373	256
	5	322	335	404	376	330	258
	6	291	356	462	369	397	247
	Av.	317	348	428	388	367	254
% Ret. Str.		83.9	90.6	96.8	111.8	98.9	87.6

INTERPRETATION OF DATA

There are many factors which affect the stability and durability of asphaltic concrete pavement. An attempt was made to hold these factors constant in the tests conducted in this investigation, and to use only the different mixing temperatures and the different asphalt types as variables. The statistical procedure known as "Analysis of Variance" (31) was used to analyze the data. The following is a discussion of the physical properties of the asphalts and how they were affected by the different mixing temperatures.

Effect of Mixing Temperature on the Viscosity of the Recovered Asphalts

The viscosity of a recovered asphalt varies significantly with the different mixing temperature and the different asphalt type. Evidence of this is brought out in the statistical analysis, which gave a probability of .001. Stated in another way, this means that there is less than one chance in one thousand of attaining these results if the viscosity is unaffected by mixing temperature and asphalt type. In Fig. 5 it is observed that for all the asphalt types the viscosity values increase with the mixing temperatures. This is due to oxidation, volatilization, and hardening of the asphalts in thin films as the temperature increases. Also, the viscosity increase may, to some degree, be affected by the aggregates absorbing some of the volatile materials of the asphalts, with volatilization increasing as temperature increases. The slopes of the different curves vary considerably, as illustrated in Fig. 5.

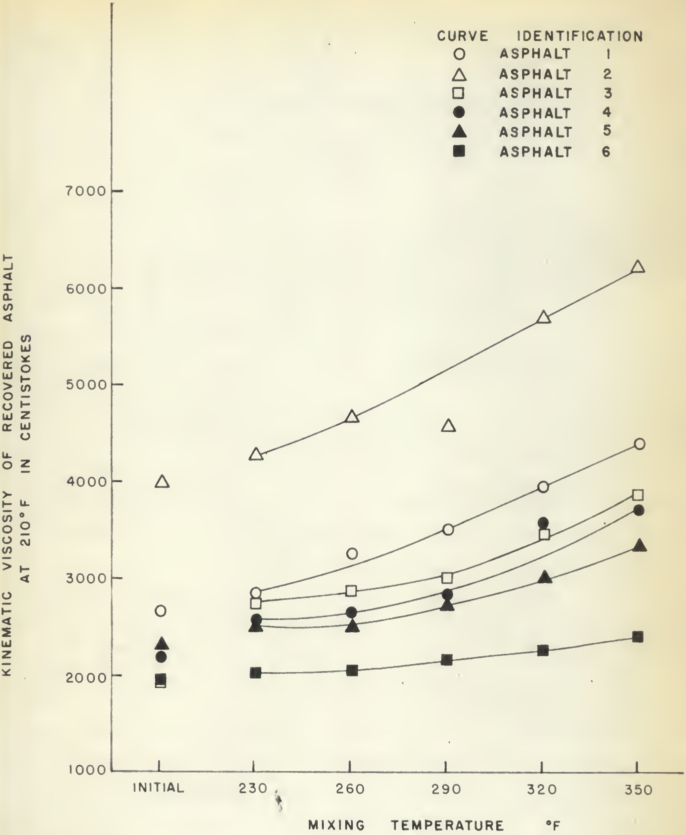


FIG. 5 EFFECT OF MIXING TEMPERATURE ON KINEMATIC VISCOSITY

This can be explained by the difference in the properties of the asphalts caused by their different sources and blending variation.

Effect of Mixing Temperature on Penetration

The penetration tests of the recovered asphalt cement show effects similar to the viscosity tests; as the mixing temperature is increased, the asphalt becomes harder, and the penetration decreases. It may be observed in Fig. 6 that the asphalt with the lowest viscosity also had the highest penetration values, although the asphalt with the highest viscosity values did not have the lowest penetration values as might be expected. At this time, there appears to be no apparent explanation for this phenomenon. Asphalts three and five experienced a decrease in penetration, which, when plotted against mixing temperature, approached a straight line. As mentioned previously, the penetration values indicated that the asphalt was becoming harder as the mixing temperature was increased, much as the viscosity tests had indicated. It is reasonable to assume that the penetration test measured the same change as did viscosity, as a plot of penetration versus viscosity on semi-log paper indicates a straight line relationship. This plot is illustrated in Fig. 7. The apparent irregularity of the slope of the curves could be attributed to the different blending and/or constituents in the asphalt. These constituents may, in addition, be affected at different temperature levels as they are exposed in thin films while mixing.

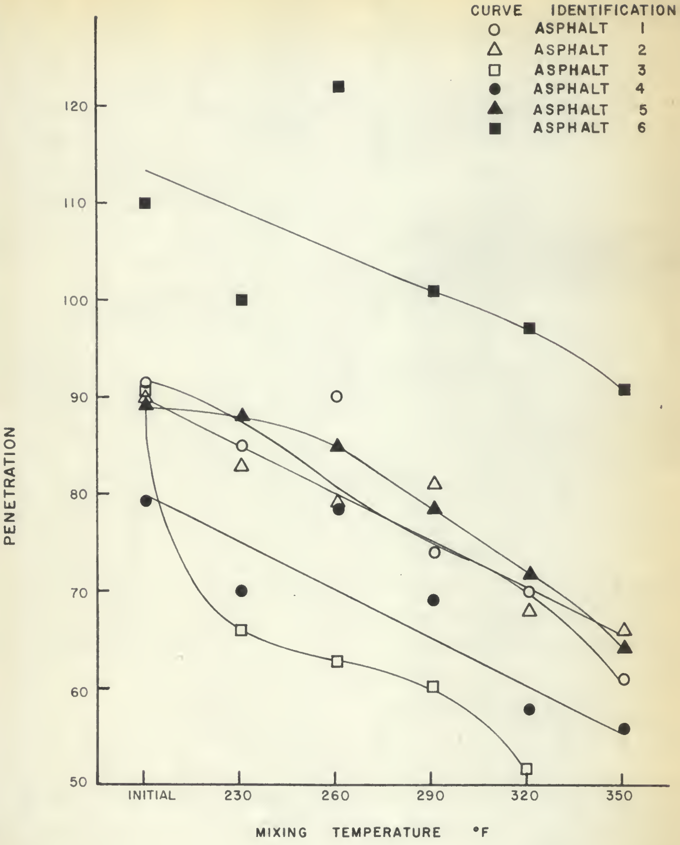


FIG. 6 EFFECT OF MIXING TEMPERATURE ON PENETRATION

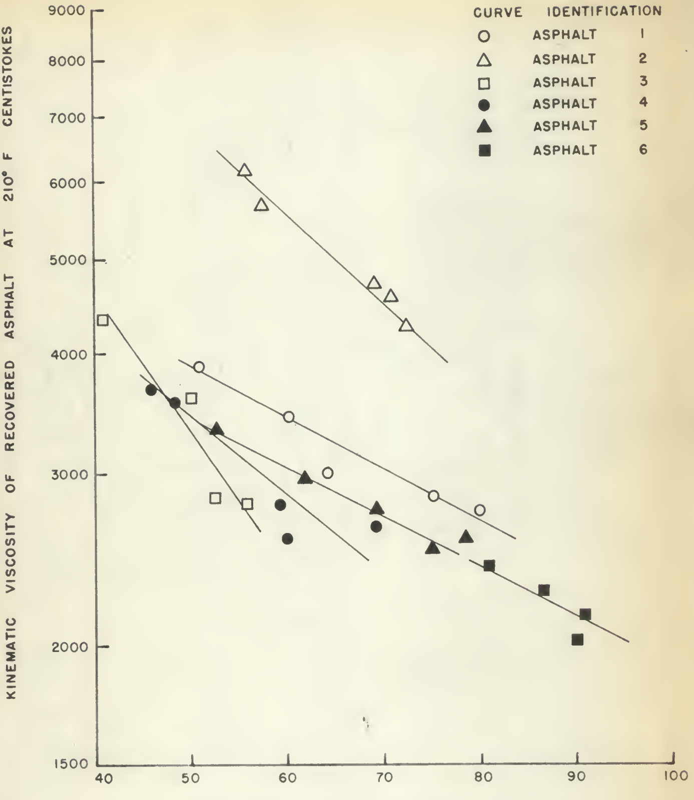


FIG. 7 — CORRELATION BETWEEN PENETRATION AND KINEMATIC VISCOSITY

Effect of Mixing Temperature on Modified Ductility

The effect of mixing temperature on modified ductility exhibits an apparent lack of consistency as the mixing temperature increase appears to influence asphalts three and four, but apparently does not affect the other four asphalts. In Fig. 8 a similarity may be noted between the effects on asphalts three and four as three decreased from 48 cm at 230° F. to 6 cm at 350° F. mixing temperature, and four decreased from 35 cm at 230° F. to 18 cm at 350° F. mixing temperature. The ductility of asphalts two and five remained stable, while asphalts one and six appeared to increase. In comparing the modified ductility tests with the penetration results, it is observed that asphalts three and four behave in much the same way. At this time, it is not known what components or blending differences would cause them to show definite trends. All of the asphalts increased in hardness, but asphalts three and four also became less ductile as the temperature increased. As this was the first use of the new molds, these results must be viewed accordingly, until such time as more data can be gathered.

Effect of Mixing Temperature on Marshall Density

The density of the specimens experienced a slight increase as the temperature increased up to 320° F. mixing temperature; however, the values at 350° F. showed very little increase from 320° F. which would suggest the specimens were approaching maximum compaction with the procedure used. The increase in density as the mixing tem-

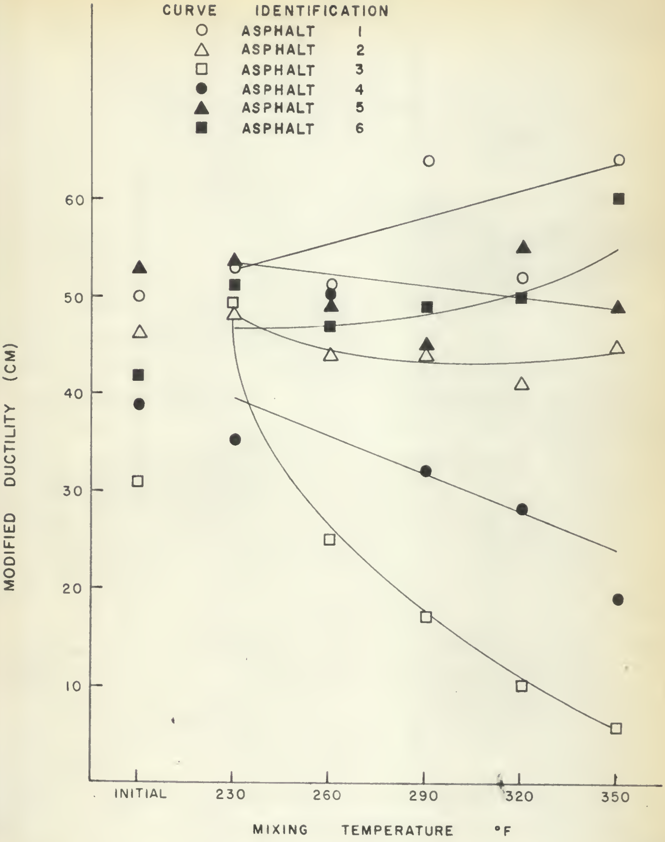


FIG. 8 EFFECT OF MIXING TEMPERATURE ON MODIFIED DUCTILITY

perature was increased was caused by the increasing fluidity of the asphalt. The aggregate particles received increased lubrication and the specimen's resistance to compaction was lowered as the asphalts were mixed and compacted at higher temperatures.

The density increased until the voids in the mixture were essentially filled. In Fig. 9 it is noted that from this point the density levels off. It is also interesting to note the difference in density between asphalts, with asphalt two having the lowest density and also the highest recovered viscosity. This low density can be attributed to the extreme hardening of asphalt two which caused a decrease in the workability of the mix.

Effect of Mixing Temperature on Marshall Stability

The Marshall stability is affected significantly by the mixing temperature and by the asphalt type. The stability increased from below 2,000 lb to approximately 3,000 lb in the six series as the mixing temperature was increased from 230° F. to 350° F. When observing Figs. 10a and 10b, a slight dip is noted in the plot of stability versus mixing temperature at 290° F. in all the asphalts except asphalt five. A possible explanation for this may be that at 230° F. the asphalt was not sufficiently fluid to promote good coating, resulting in low stability. At 260° F. mixing temperature the asphalt was sufficiently fluid for reasonable coating. At 290° F. the asphalt adequately coated the aggregate, but had not started to harden as yet, so that the stability values rose very little, if any. The increase at 320° F. and 350° F.

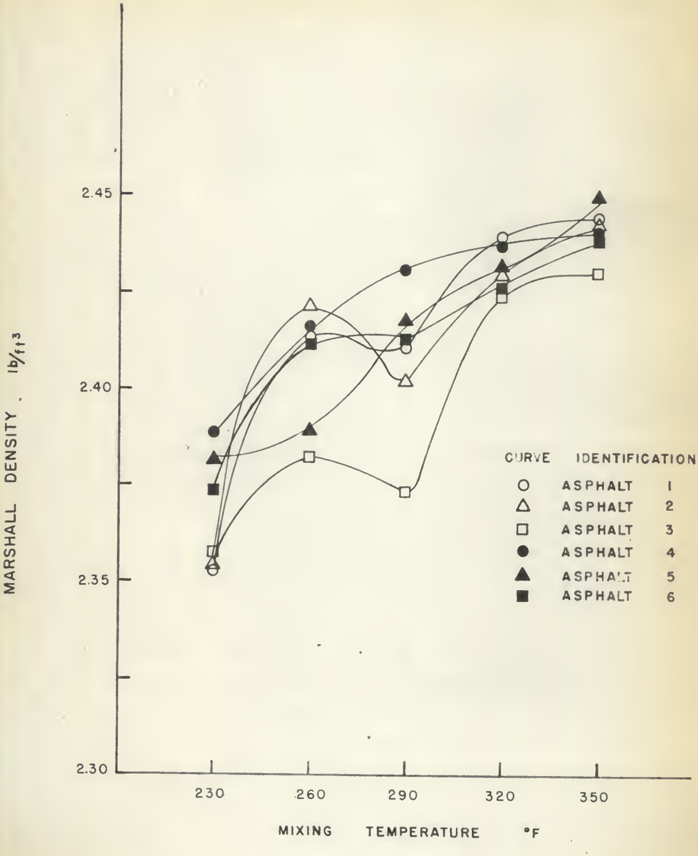


FIG. 9 EFFECT OF MIXING TEMPERATURE ON MARSHALL DENSITY

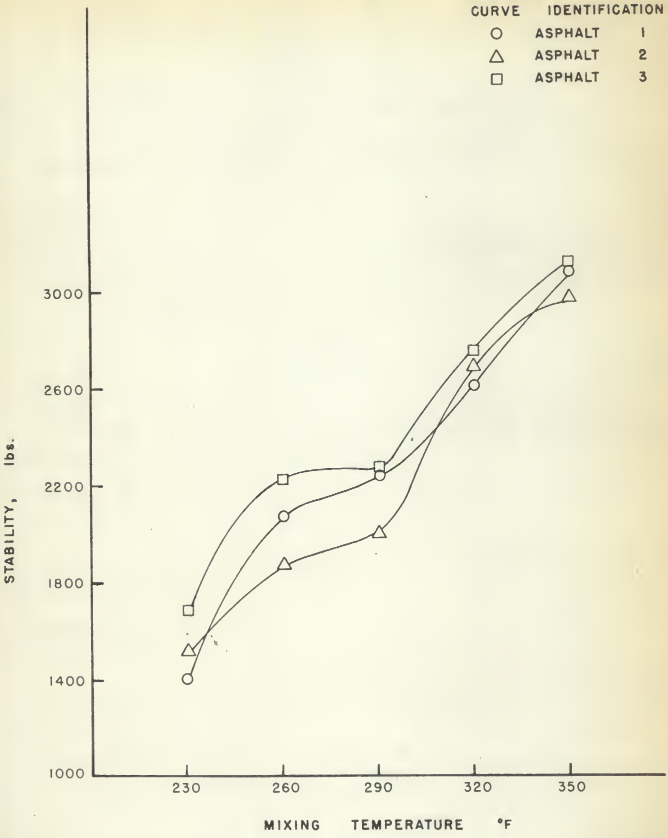


FIG. 10A EFFECT OF MIXING TEMPERATURE ON STABILITY

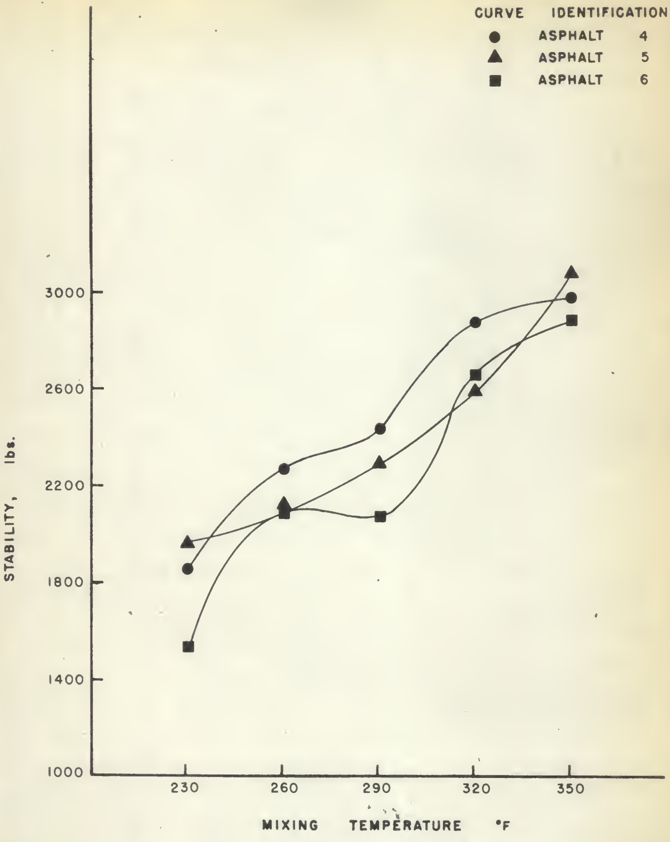


FIG. 10B EFFECT OF MIXING TEMPERATURE ON STABILITY resulted from the rapid coating, with the asphalt in a very fluid state at this temperature, placing the asphalt in very thin films on the aggregate particles. The fractions of the asphalt in these thin films undergo minor changes, resulting in a concentration of the heavier fractions. These changes account for the increased viscosity and penetration caused by an oxidative type hardening. It is observed that asphalt three, which showed very definite effects in penetration and modified ductility tests, also had the highest stability values.

Further reference to the appropriate figures shows that asphalt six was such that its viscosity, penetration and modified ductility were not greatly affected by the increasing mixing temperature. However, asphalt six had the lowest value of strength in the Immersion-Compression test at all temperature levels, and was in approximately fifth position in the Marshall stability tests. From this, it may be surmised that the component of an asphalt contributing to its increasing stability would be the conversion to the heavier fractions which appear at 320° F. A review of previous work (6) (7) indicates that this increase may amount to about two per cent by weight.

The statistical analysis raises the possibility of a linear relationship between stability and mixing temperature. As previously indicated, asphalt five is the only asphalt that does not experience a noticeable dip at 290° F. mixing temperature. Also the extent to which the curves descend varies with the different asphalts, as do the slopes of the curves.

Since attempting to determine an optimum viscosity at which to mix and compact asphalt mixes was of prime interest in this research, the effect of the viscosity of the asphalts at the different mixing temperatures was studied from a plot of the Marshall stability versus the kinematic viscosity on semi-log paper. Because the viscosity of the asphalt is directly related to its temperature, the curves of Fig. 11 are very similar to those of Figs. 10a and 10b. A familiar dip will be noticed at approximately 200 centistokes, but, in general, the stability increases as the viscosity decreases.

Effect of Mixing Temperature on Flow

In the comparison of flow with asphalt mixing temperature, it was found that flow remained relatively unchanged, with a slight decreasing tendency, as illustrated in Fig. 12. Since the flow is said to be an indirect measure of internal friction of the aggregate(5) this would be expected, as the aggregate gradation and source remained the same throughout the research.

Effect of Mixing Temperature on Per cent of Retained Strength as Determined by the Immersion-Compression Test

The results of the Immersion-Compression test are illustrated in Figs. 13a, 13b, and 14, and show a general increase in per cent of retained strength as mixing temperature is increased. The statistical analysis indicates a possible linear or cubic relationship, between per cent of retained strength and mixing temperature. The probability favors a linear, but possibility of a cubic relationship is indicated by the leveling off or slight decline of the asphalts at 290° F. The curves all have the same general form, and appear to have sta-

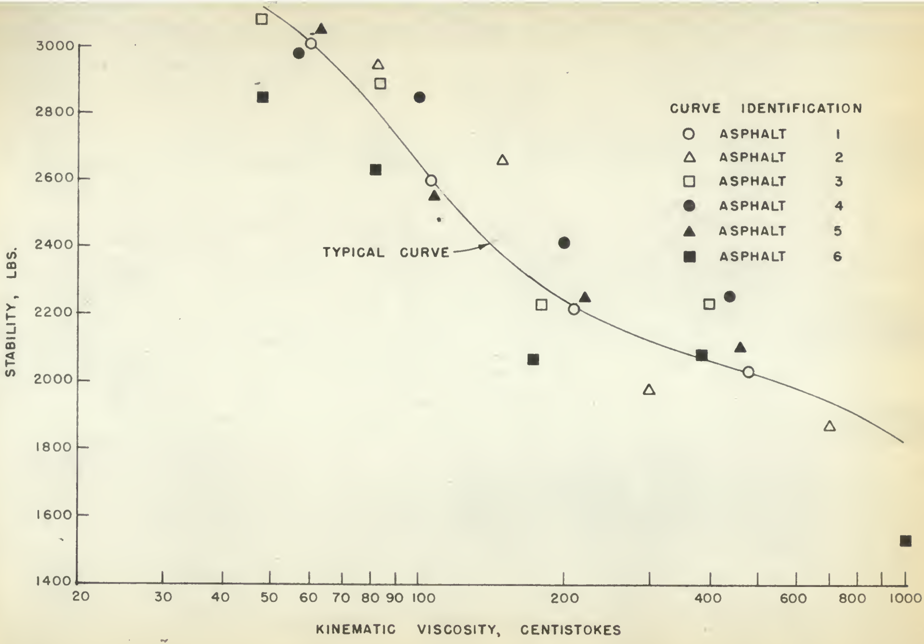


FIG. 11 — VARIATION IN STABILITY WITH KINEMATIC VISCOSITY

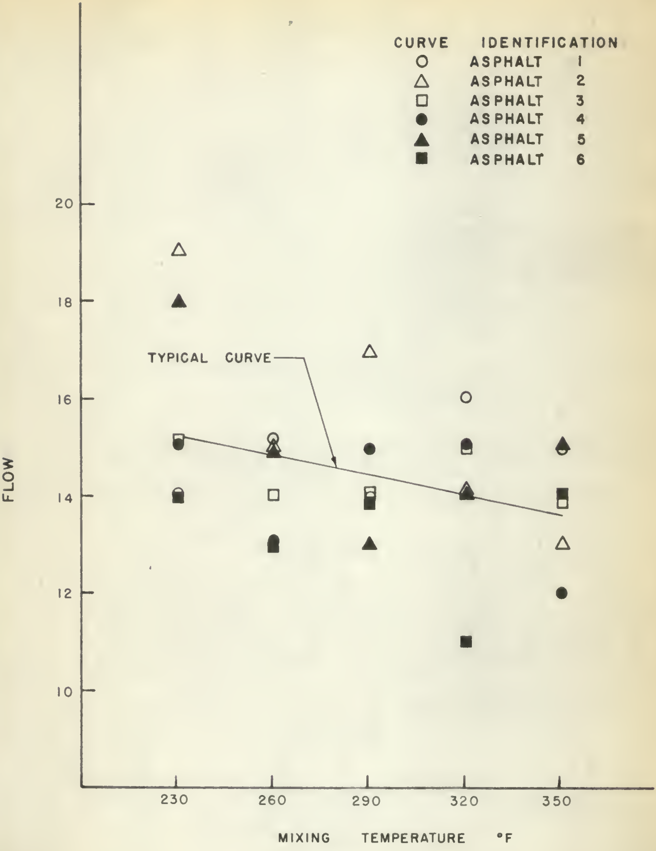


FIG. 12 EFFECT OF MIXING TEMPERATURE ON FLOW

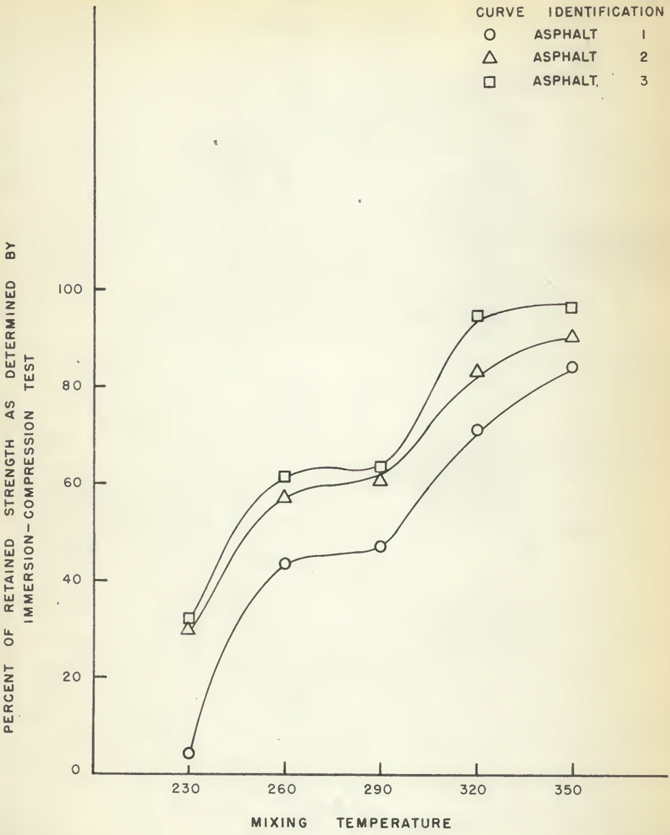


FIG. 13A EFFECT OF MIXING TEMPERATURE ON RETAINED STRENGTH

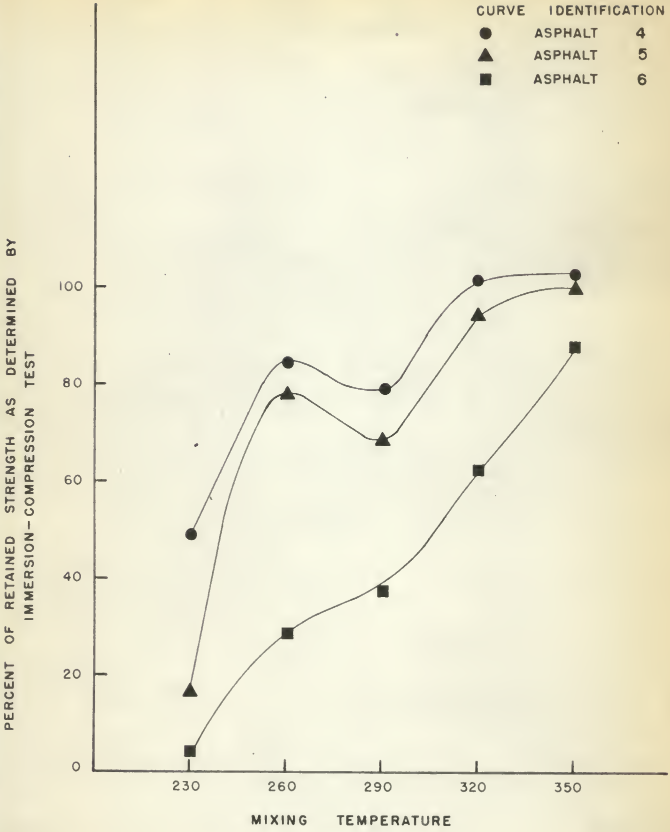


FIG. 13 B EFFECT OF MIXING TEMPERATURE ON RETAINED STRENGTH

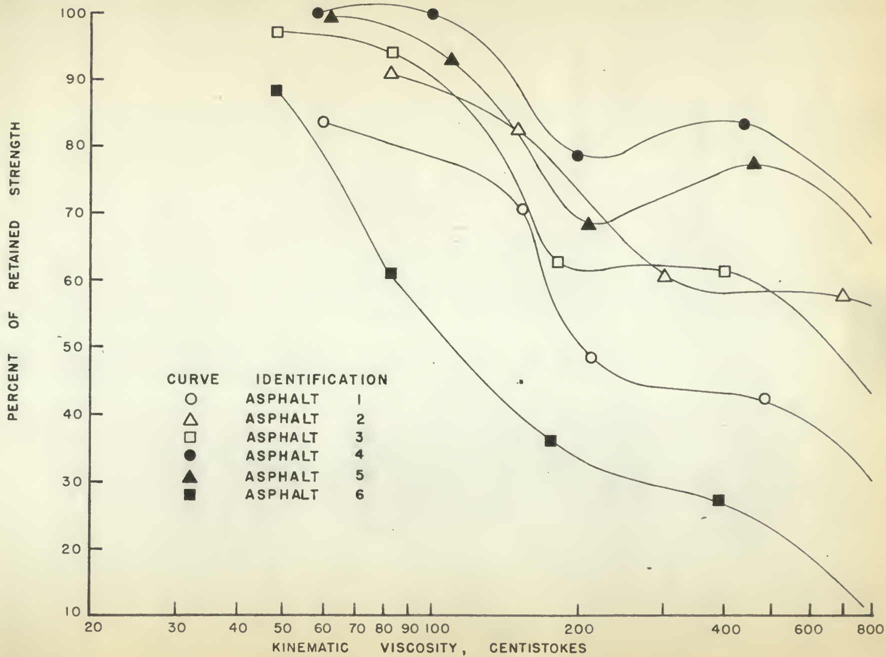


FIG. 14 VARIATION IN RETAINED STRENGTH WITH KINEMATIC VISCOSITY

bilized at 350° F. It may also be noticed that the asphalts having the highest per cent of retained strength at 230° F. also have the highest value at 350° F. This would indicate that the relative waterproofing characteristics of the asphalts are unaffected at different temperatures, but tend to improve as temperature is increased. Two of the reasons for this increase are; first, better coating of the aggregate, and second, increasing density as temperature increases. Another probable reason for this increase is the fact that as the mixing temperature is increased, the aggregate absorbs more of the volatile materials of the asphalt, promoting better bond and adhesion to the aggregate by the asphalt.

The per cent of retained strength was plotted against the kinematic viscosity in centistokes on semi-log paper. These curves of Fig. 14 are similar to the stability curves, with asphalt four having the highest value in each case, and asphalt six the lowest value. In this instance the asphalts that have good stability characteristics also experience high per cent of retained strength values.

DISCUSSION OF RESULTS

The primary objective of this investigation was to determine if a viscosity or viscosity range suitable to all asphaltic cements could be found that would produce maximum stability and durability. The asphalt cements that were used were from three different geographical sources and represented a variety of blends. Unfortunately, no clear indication of the optimum viscosity was observed. A brief summary and analysis is given of the results with recommendations for future investigations of this nature.

Summary of Results

1. The viscosity of the recovered asphalts increased as the mixing temperature was increased for all the asphalts, and the increase varied with the different asphalts.

2. The penetration values for the recovered asphalts increased as temperature was increased. Penetration when plotted against viscosity on semi-log paper appeared to be a straight line relationship.

3. The modified ductility tests were inconclusive, but additional tests are being conducted at this time in order to determine reproducibility of the test.

4. The density of the specimens increased with temperature increase to 320° F., which appeared to be the temperature at which maximum compaction occurred.

5. The stability of the specimens experienced an increase at all temperature levels except 290° F. At this point, the stability remained approximately the same as at the 260° F. level.

6. The Marshall Flow was generally unaffected by the temperature increase, although a slight decreasing trend may be noted.

7. The per cent of retained strength increased at all temperatures except 290° F. Once again, this particular temperature showed approximately the same reaction as the 260° F. level.

Analysis Results

The results of the investigation show the stability and durability of the various asphalt mixes increase as the mixing temperature is increased. However, at this time there must be some reservation regarding the outlook presented by the durability determinations. As stated previously, asphalt six experienced very little change in viscosity, which indicates very little hardening taking place as the temperature is increased. This increase was only 23.5 per cent greater than the original whereas asphalt three showed an increase of almost 200 per cent. The durability of asphalt six may be observed to be rather low as indicated by the Immersion-Compression test. It is believed this may present a distorted picture because in actual pavement the fact that asphalt six does not harden may increase its life considerably. The magnitude of this hardening and its relationship to the other asphalts may best be visualized in the following table:

Table 6. Viscosity Increase.

Asphalt No.	1	2	3	4	5	6
Orig. Vis. (cs)	2666	3979	1957	2196	2336	1950
Vis. of Rec. 350°F. M.T.	3870	6165	5724	3677	3335	2408
Increase	1204	2186	3767	1481	999	458
% Increase	43.5	55.1	193.0	67.4	42.8	23.5

With future testing, it is hoped the effect of this hardening will be clearly defined, and it can be determined at what point it may be detrimental or advantageous, and to what degree.

In analyzing the results, it appears the increase in stability and per cent of retained strength when the mixing temperature was raised from 320° to 350° F. does not warrant endangering the asphalt with this increased temperature. The increased heating causes the asphalt to become harder and thus more susceptible to failure due to brittleness in the pavement. There is no appreciable increase in the density of the specimens after the temperature passes 320° F., so no benefit is gained in this respect. With this in mind, the viscosity range appears to be between 90 and 150 centistokes for this particular aggregate, its gradation and the asphalt types used in this test.

It is the author's contention that many of the current problems will be closer to solution when a method of determining and studying the various components of the asphalts is achieved. When it is possible to determine, with some accuracy, how the components of the asphalts react to different environments, a correlation may be established. Until such time as this is possible, further studies in which records are kept of asphalts used in the field, noting all conditions, and followed by periodic examinations of the pavements should be started. In this way, it may be possible to correlate the physical properties of the asphalts with the behavior of the pavement.

Further research in which a non-absorbing material is used for the aggregate may be of some value, as volatile materials of the asphalt when heated are known to be absorbed by the aggregate.

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BIBLIOGRAPHY

1. Adam, Verdi.
   Viscosity in Hot Mix Construction. Bituminous Research Unit, Louisiana Department of Highways, 1959.

2. Asphalt Handbook.
   The Asphalt Institute Construction Series 81, 1947.

3. Bateman, J. H., and C. Delp.
   The Recovery and Examination of the Asphalt in Asphaltic Paving Mixtures. Louisiana State University Engineering Experiment Station Bulletin 2.

4. Benson, F. J.
   Appraisal of Several Methods of Testing Asphaltic Concrete. Texas Engineering Experiment Station Bull. 126, June, 1952.

5. Bituminous Paving Mixtures.
   Highway Research Board Bulletin 105, 1955.

6. Corbett, L. W., and R. E. Swaibrick.
   "Clues to Asphalt Composition." Assoc. of Asphalt Paving Technologists, Proc. 27:107-123, 1958.

7. Corbett, L. W., and R. E. Swaibrick.
   "Composition Analysis Used to Explore Asphalt Hardening." Assoc. of Asphalt Paving Technologists, Proc. 29:104, 1960.

8. Csanyi, L. H.
   "The Effects of Asphalt Film Thickness on Paving Mixtures." Assoc. of Asphalt Paving Technologists, Proc. 17:50-74, 1948.

9. Dillard, J. H.
   Comparison of Density of Marshall Specimens and Pavement Cores. Virginia Council of Highway Investigation and Research, Feb., 1955.

10. Fink, D. F., and J. A. Lettier.
    "Viscosity Effects in the Marshall Stability Test." Assoc. of Asphalt Paving Technologists, Proc. 20:246-270, 1951.

11. Goetz, W. H., J. F. McLaughlin, and L. E. Wood.
    "Load Deformation Characteristics of Bituminous Mixtures Under Various Conditions of Loading." Assoc. of Asphalt Paving Technologists, Proc. 26, 1957.

12. Goldbeck, A. T.
Immersion-Compression Tests Compared with Laboratory Traffic Tests on Bituminous Concrete. ASTM Special Technical Publication 94: 53-64, 1949.

13. Gofolski, W. H.
"High Temperature Effects on Bituminous Mixes." Am. Soc. of Civil Engineers, Proc. 86:1-28, 1960.

14. Griffith, J. M.
"Effects of Asphalt Cement Viscosity at Mixing Temperature on Properties of Bituminous Mixtures." Highway Research Board, Special Report 54, 7-10.

15. Griffith, J. M.
"How Viscosity at Mixing Temperatures Affects the Mix." Roads and Streets, June, 1959, 162-165.

16. Griffith, John M.
"A Key to Better Asphalt Road Construction." Engineering News-Record, Dec. 4, 1958, 46-48.

17. Hveem, F. N.
Effects of Time and Temperature on Hardening of Asphalts. Highway Research Board, Special Report 54, 13-15.

18. Kimble, F. W.
Effect of Mix Temperature. Highway Research Board, Special Report, 54, 34-36.

19. Krchma, L. C.
"Relationship of Mix Design to Hardening." Assoc. of Asphalt Paving Technologists, Proc. 27: 1958.

20. Krchma, L. C., and T. Groenig.
"Influence of Pavement Voids, Asphalt Cement and Asphalt Grade on Asphalt Performances." Assoc. of Asphalt Technologists, Proc. 28: 1959.

21. Levy, D. F., and others.
Fundamental Viscosity Versus Saybolt Furol Viscosity for Refinery Control of Cut-back Asphalt. A.S.T.M. Special Technical Publication 252. 211-225, 1959.

22. McLaughlin, F. F., and W. H. Goetz.
Comparison of Unconfined and Marshall Test Results. Purdue Engineering Experiment Station Bulletin 87.

23. McLaughlin, J. F., and W. H. Goetz.
Permeability, Void Content, and Durability of Bituminous Concrete. Purdue Engineering Experiment Station Bull. 111.

24. Metcalf, C. T.
Use of Marshall Stability Test in Asphalt Paving Mix Design. Highway Research Board Bull. 235, 12-22.

25. Mix Design Methods for Hot-Mix Asphalt Paving.
The Asphalt Institute Manual Series 2. April, 1956.

26. Oppenlander, J. C., and W. H. Goetz.
"Triaxial Testing of Bituminous Mixtures at High Confining Pressures." Highway Research Board, Proc. 37: 1958.

27. Parker, C. F.
Effect of Mix Temperature. Highway Research Board, Special Report 54, 28-34.

28. Pfeiffer, J. P.
The Properties of Asphaltic Bitumen. Elsevier Publishing Company. 49-76, 155-176, 1950.

29. Rice, J. M.
Effects of Aggregate Temperature on Properties of Bituminous Mixtures. Highway Research Board Special Report 54, 2-3.

30. Shupe, J. W, and W. H. Goetz.
A Laboratory Method for Determining the Skidding Resistance of Bituminous Paving Mixtures. Purdue Engineering Experment Station Bull. 142, 1958.

31. Snedecor, G. W.
Statistical Methods. Ames: Iowa State College Press, 1957. 237-328.

32. Steinbaugh, V. B., and J. D. Brown.
"A Study of Asphalt Recovery Tests and Their Value as a Criterion of Service Behavior." Assoc. of Asphalt Paving Technologists, Proc. 9:138, 1937.

33. Stevens, D. E.
"Fundamentals of Stability Testing of Asphalt Mixes." Assoc. of Asphalt Paving Technologists, Proc. 22:364-383, 1953.

34. Weetman, B., and D. W. Hurlburt.
"The Effect of Asphalt Viscosity on Stability of Asphalt Paving Mixtures." Assoc. of Asphalt Paving Technologists, Proc. 16:249-264, 1947.

35. Welborn, J. Y.
Temperature-Viscosity Relation of Asphalts Used in the United States. Highway Research Board, Special Report 54, 5-6.

36. Wood, P. R.
Rheology of Asphalts and Its Relation to Behavior of Paving Mixtures. Highway Research Board Bull. 192, 20-24.

APPENDIX

Summary of Test Data and Analysis of Variance

In order to determine the number of tests required to insure accuracy in measuring viscosity with the cross-arm viscometers, a series of trial tests were completed on the asphalt cement as received. The results of these tests showed the reproducibility of the procedure to be approximately one per cent of the mean. These factors indicate that the accuracy desired in this investigation could be achieved with two tests on the recovered asphalt. Since only a small amount of asphalt is recovered in each test, it was essential to utilize it fully. The data is shown in tabular form for easy visualization.

Initial Viscosity Tests

	Asphalt Number					
	1	2	3	4	5	6
	2679	3979	1984	2164	2343	1972
	2642	3975	1980	2127	2277	1971
	2658	3918	1969	2142	2263	1996
	2670	3949	1947	2168	2226	1916
	2639	3975	1964	2127	2390	1935
	2631	4010	1960	2291	2412	1940
	2696	4040	1931	2283	2405	1938
	2678	3938	1932	2266	2368	1940
	2675					
	2660					
Av.	2666	3979	1957	2196	2336	1950

Properties of Extracted Asphalt - Viscosity

230° F. Mixing Temp.

	2816	4225	2820	2556	2559	2054
	2849	4285	2798	2586	2582	1974
Av.	2832	4250	2809	2571	2571	2014

Viscosity (cont.)

Asphalt No.	1	2	3	4	5	6
260° F. Mixing Temp.						
	2755	4670	2879	2671	2548	2028
	2774	4667	2823	2683	2489	2048
	2764	4669	2851	2677	2519	2038
290° F. Mixing Temp.						
	3004	4566	3575	2760	2751	2150
	2981	4541	3620	2793	2763	2139
	2993	4554	3598	2775	2755	2145
320° F. Mixing Temp.						
	3428	5625	4345	3545	2968	2259
	3462	5692	4379	3559	2971	2262
	3445	5659	4362	3552	2970	2261
350° F. Mixing Temp.						
	3885	6233	5700	3660	3308	2413
	3856	6197	5720	3694	3362	2432
	3870	6215	5710	3677	3335	2422

Penetration

Asphalt No.	1	2	3	4	5	6
230° F. Mixing Temp.						
	84	83	65	69	88	100
	85	83	66	70	88	100
		85	66	71	87	102
	85	83	66	70	88	100
260° F. Mixing Temp.						
	90	79	64	82	84	122
	89	79	63	78	85	124
	91	79	62	78	86	121
	90	79	63	79	85	122
290° F. Mixing Temp.						
	73	80	60	69	77	100
	74	81	60	69	79	101
	74	81	59	70	81	102
	74	81	60	69	79	101

Penetration (cont.)

Asphalt No.	1	2	3	4	5	6
320° F. Mixing Temp.						
	70	68	51	58	73	97
	71	68	52	57	71	98
	70	70	50	58	71	97
	70	68	51	58	72	97
350° F. Mixing Temp.						
	61	66	44	56	63	91
	61	66	44	56	63	91
	60	65	44	57	63	91
	60	66	44	56	63	91

Modified Ductility

Asphalt No.	1	2	3	4	5	6
230° F. Mixing Temp.						
	42	46	42	33	49	50
	59	50	46	34	49	50
	59	--	59	38	60	54
	53	48	49	35	53	51
260° F. Mixing Temp.						
	47	42	21	48	44	45
	53	44	26	51	46	48
	53	44	27	52	56	49
	51	44	25	50	49	47
290° F. Mixing Temp.						
	59	36	15	31	43	44
	64	41	17	32	46	50
	68	56	17	32	46	52
	64	44	17	32	45	49
320° F. Mixing Temp.						
	48	40	10	27	54	49
	52	41	10	27	55	52
	56	42	11	31	57	--
	52	41	10	28	55	50
350° F. Mixing Temp.						
	61	41	6	17	45	55
	63	45	6	20	48	61
	70	48	7	21	54	65
	64	45	6	19	49	60

Analysis of Variance

Source of Variation	D.F.	Sum of Squares	Mean Squares	F	Significance
		Kinematic Viscosity			
Asphalt Grades	5	24,845,466.67	4,969,093.33	32.49	***
Mixing Temp.	4	8,044,158.00	2,011,039.50	13.15	***
Linear Comp.	1		7,385,743.35	48.29	***
Quadratic Comp.	1		591,864.00	3.87	n.s.
Cubic Comp.	1			.23	n.s.
Quartic	1			.21	n.s.
Expt. Error	20	3,058,710.00			
Total	29	35,948,334.67			
		Penetration			
Asphalt Grades	5	5,745.10	1,149.02	62.72	***
Mixing Temp.	4	2,068.80	517.20	28.23	***
Linear Comp.	1		1,749.60	95.50	***
Quadratic Comp.	1		160.19	8.74	**
Cubic Comp.	1		144.15	7.87	*
Quartic	1		14.86	.81	n.s.
Expt. Error	20	366.40	18.32		
Total	29	8,180.30			
		Ductility			
Asphalt Grades	5	4,426.17	885.23	10.17	***
Mixing Temp.	4	296.34	74.08	.85	n.s.
Linear Comp.	1		248.07	2.85	n.s.
Quadratic Comp.	1		42.86	.49	n.s.
Cubic Comp.	1		3.27	.04	n.s.
Quartic	1		2.14	.02	n.s.
Expt. Error	20	1,741.66	87.08		
Total	29	6,464.17			

Analysis of Variance (cont.)

Source of Variation:	D. F.:	Sum of Squares:	Mean Squares:	F :	Signi-:ficance
		Density			
Asphalt Grades	5	.006702	.001340	3.66	*
Mixing Temp.	4	.057503	.014376	39.28	***
Linear Comp.	1		.053251	145.49	***
Quadratic Comp.	1		.001605	4.39	*
Cubic Comp.	1		.000858	2.34	n.s.
Quartic	1		.001788	4.89	*
Expt. Error	20	.007328	.000366	5.55	***
Sampling Error	60	.003967	.000066		
Total	89	.075500			
		Stability			
Asphalt Grades	5	859,062.22	171,812.44	4.62	**
Mixing Temp.	4	19,872,509.83	4,968,127.46	133.69	***
Linear Comp.	1		19,357,248.80	520.90	***
Quadratic Comp.	1		25,440.57	.68	n.s.
Cubic Comp.	1		62,682.67	1.69	n.s.
Quartic	1		427,137.78	11.49	**
Expt. Error	20	743,220.44	37,161.02	1.23	n.s.
Sampling Error	60	1,806,312.67	30,105.21		
Total	89	23,281,105.16			

Analysis of Variance (concl.)

Source of Variation:	D. F. :	Sum of Squares:	Mean Squares:	F	: Significance
		Flow			
Asphalt Grades	5	17.50	3.50	1.69	n.s.
Mixing Temp.	4	14.67	3.67	1.77	n.s.
Linear Comp.	1		9.60	4.64	*
Quadratic Comp.	1		1.71	.83	n.s.
Cubic Comp.	1		2.40	1.16	n.s.
Quartic	1		.95	.46	n.s
Expt. Error	20	41.33	2.07		
Total	29	73.50			
		Per cent Retained Strength			
Asphalt Grades	5	5,687.5829	1,137.5166	24.57	***
Mixing Temp.	4	19,082.6258	4,770.6564	103.04	**
Linear Comp.	1		17,600.0477	380.14	***
Quadratic Comp.	1		304.6857	6.58	*
Cubic Comp.	1		292.8692	6.33	*
Quartic	1		885.0231	19.12	***
Expt. Error	20	925.9755	46.2988		
Total	29	25,696.1842			

THE OPTIMUM VISCOSITY OF ASPHALT CEMENTS WITH REGARD TO ASPHALT PAVING MIXTURES

by

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B. S. Kansas State University, 1960

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The purpose of this investigation was to determine if a viscosity or viscosity range suitable to all asphaltic cements could be found that would produce maximum stability and durability. If such a viscosity or viscosity range exists, the proper utilization of this range would give reasonable assurance of uniform asphaltic pavements of the highest quality.

With this objective, the asphalt cements that were used were from three different geographical sources and represented a variety of blends. The aggregate, St. George limestone, was crushed and blended to meet specification limits of the Kansas State Highway Commission used in surface courses of asphaltic concrete.

The stability measurements needed to relate stability with viscosity were obtained by the Marshall Method while the Immersion-Compression Test was used in evaluating durability. To insure a broad viscosity range for the investigation, each of the six asphalt types were mixed at five temperatures; 230° F, 260° F, 290° F, 320° F, and 450° F.

In order to establish the role of viscosity in stability and durability of the asphalt pavement, a series of tests was performed on the asphalt cements both prior to mixing and also after recovery from the test specimens. These tests included Penetration, Loss on Heating, Thin Film Tests, Viscosity Determination, and Modified Ductility on the asphalt before mixing. Specimens were then prepared and tested using standard Marshall and Immersion-Compression Test procedures. After testing, the asphalt cement and aggregate were separated using the Faulwetter Extractor with benzine as the solvent. The asphalt cement was then recovered from the solution by the Modified Abson Procedure, and tested to determine its penetration, modified ductility, and viscosity.

The results of the investigation show the stability and durability of the various asphalt mixes increase as the mixing temperature is increased. A brief summary of results follows:

1. The viscosity of the recovered asphalts increased as the mixing temperature was increased for all the asphalts, and the increase varied with the different asphalts.

2. The penetration values for the recovered asphalts increased as temperature was increased.

3. The modified ductility tests were inconclusive.

4. The density of the specimens increased with temperature increase to 320° F., which appeared to be the temperature at which maximum compaction occurred.

5. The stability of the specimens experienced an increase at all temperature levels except 290° F. At this point the stability remained approximately the same as at the 260° F. level.

6. The Marshall Flow was generally unaffected by the temperature increase although a slight decreasing trend may be noted.

7. The per cent of retained strength increased at all temperatures except 290° F. Once again, this particular temperature should be approximately the same reaction as the 260° F. level.

In analyzing the results, it appears that the increase in stability and per cent of retained strength when mixing temperature was raised from 320° to 350° F. does not warrant endangering the asphalt with this increased temperature. The increased heating causes the asphalt to become harder and thus more susceptible to failure due to brittleness in the pavement. There is no appreciable increase in the density of the specimens after the temperature passes 320° F. so no benefit is gained in this respect. With this in mind, the viscosity range appears to be between 90 and 150 centistokes for this particular aggregate, its gradation, and the asphalt types used in this investigation.