HARDENING OF 85-100 PENETRATION ASPHALT CEMENTS DURING SERVICE IN PAVEMENT

by

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Abstract

Report: Progress Report No. 8 - Research Project 2-8-59-9

Title: Hardening of 85-100 Penetration Asphalt Cements During Service in Pavement

Period: May 1, 1963 to May 1, 1965

Objective: To determine changes in hardness that occur in an asphalt cement while the hot paving mixture is being prepared and laid and during the early (one year) service life of the pavement surface.

Experimental: Hot mix surfacing projects using 85-100 penetration grade asphalt cements were located in 13 widely separated Districts of the Texas Highway Department. Asphalts were supplied by 9 different producers in Texas. Samples from each location (including the original asphalt cement) were obtained as the hot mix issued from (1) the plant (2) from the paving machine and from the pavement after (3) one day (4) 2 weeks (5) 4 months and (6) one year of service. The asphalt was extracted from each mixture, recovered and tested for viscosity at 77°, 95°, 140°, and 275°F. The extent of hardening was then calculated by dividing the viscosity of the hardened asphalt by that of the original asphalt at the same temperature (77°F) and rate of shear ($5 \times 10^{-2} sec^{-1}$). The quotient is called the Relative Viscosity. The hardening of the asphalt (Relative Viscosity) obtained from the field samples was compared with the hardening obtained by a laboratory test on the original asphalt. In this test 15-micron films were heated in an air oven at 225°F for 2 hours. This laboratory test is included in the Texas Highway Department specifications for asphalt cements. Data were obtained on the samples removed from the pavement prior to extraction of the asphalt cement and concerning the mineralogical characteristics of the aggregate used in preparing the hot mixture.

Conclusions:

(1) Rates of asphalt hardening are moderate during careful preparation and handling of hot mixes and through the first two weeks of service in the pavements.

(2) The average Relative Viscosities of the extracted asphalts between 2 weeks and 12 months service give a straight line when shown against time on a log-log plot.

(3) Asphaltene contents (n-pentane insolubles) of the asphalts after one year of service are greater than for the original asphalt cements. The increase ranges from 1.4 to 8.3 per cent.

(4) The laboratory hardening test, which is a part of the Texas Highway Department Specifications for asphalt cements, is an indicator of the hardening of the asphalts in service.

(5) Sensitiveness of some asphalts to the effect of mineral matter in the pavement may be one of several causes for the few large and unexplained deviations from the average relationship between laboratory and field hardening.

Recommendations: It is recommended that the results of investigation be publicized in the hope that others will be stimulated to undertake similar and more extensive experiments.

Future Work: The following studies will be made:

(1) From the 13 sites discussed in this report, samples will be recovered and tested after two years service.

(2) Viscosities will be measured on all the asphalts (original and recovered) at temperatures below 77°F.

(3) Microductility tests will be made on all the asphalts (original and recovered) at temperatures from 77° to 45°F.

(4) Microductility tests will be made on asphalts subjected to the laboratory hardening test (15-micron films heated in an air oven at 225°F for 2 hours). These tests will be compared with values obtained on the original asphalts.

(5) Statistical studies will be made on asphalts purchased by the Texas Highway Department using the new viscosity specifications. These data will be used to confirm or adjust the present limits at 140° and 275°F and to establish limits which can be recommended for viscosities at 77°F.

(6) Four field tests established during 1964 will be continued for at least one more year.

TABLES

FIGURES

HARDENING OF 85-100 PENETRATION ASPHALT CEMENTS DURING SERVICE IN PAVEMENT

I. OBJECTIVES OF RESEARCH PROJECT 2-8-59-9

The objectives of this project are to:

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

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

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

This report describes an investigation that has as its objective the determination of changes in hardness that occur in an asphalt cement while the hot paving mixture is being prepared and laid and during the early (one year) service life of the pavement surface.

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

II. HISTORY

Research Project No. 15 (now 2-8-59-9) "Modifications of Properties of Asphalt" was started February 1, 1959. The seven progress reports issued to date are listed in Table A-5 of the Appendix.

The portion of the over-all program discussed in the present report was started in May, 1963, and by February, 1964, hot mix surfacing projects using 85-100 penetration grade asphalt cements were located in thirteen widely separated Districts of the Texas Highway Department. Asphalts were supplied by nine different producers in Texas.

III. CONCLUSIONS

The following conclusions are drawn from the data given this report.

1. Rates of asphalt hardening are moderate during careful preparation and handling of hot mixes and through the first two weeks of service in the pavements.

2. The average Relative Viscosities of the extracted asphalts between 2 weeks and 12 months service give a straight line when shown against time on a log-log plot.

3. Asphaltene contents (n-pentane insolubles) of the asphalts after one year of service are greater than for the original asphalt cements. The increase ranges from 1.4 to 8.3 per cent.

4. The laboratory hardening test, which is a part of the Texas Highway Department Specifications for asphalt cements, is an indicator of the hardening of the asphalts in service.

5. Sensitiveness of some asphalts to the effect of mineral matter in the pavement may be one of several causes for the few large and unexplained deviations from the average relationship between laboratory and field hardening.

IV. RECOMMENDATIONS

It is recommended that the results of this investigation be publicized in the hope that others will be stimulated to undertake similar and more extensive experiments.

V. FUTURE WORK:

The following studies will be made:

1. From the thirteen sites discussed in this report, samples will be recovered and tested after two years service.

2. Viscosities will be measured on all the asphalts (original and recovered) at temperatures below 77°F.

3. Microductility tests will be made on all the asphalts (original and recovered) at temperatures from 77° to 45°F.

4. Microductility tests will be made on asphalts subjected to the laboratory hardening test (15-micron films heated in an air oven at 225° F for 2 hours). These tests will be compared with values obtained on the original asphalts.

5. Statistical studies will be made on asphalts purchased by the Texas Highway Department using the new viscosity specifications. These data will be used to confirm or adjust the present limits at 140° and 275° F and to establish limits which can be recommended for viscosities at 77° F.

6. Four field tests established during 1964 will be continued for at least one more year.

VI. <u>EXPERIMENTAL WORK</u>

1. <u>Field Program</u>

As mentioned above, sites were located in thirteen widely separated Districts of the Texas Highway Department. In each District, a 1-1/4 to 1-1/2 inch thick surfacing (about 125 lbs./sq. yd.) was being laid by the Highway Department. A Particular spot was selected by District [redacted] personnel

TABLE I

GENERAL INFORMATION ON VARIOUS SITES*

Site No.	District	County	Highway	Project	Stations	Asphalt Producer	Date Pavement was Laid	Temperature °F of Fresh Mix
1	9	McLennan	U.S. 84	E55-8-30	755+41to755+66	3	May 26, 1963	320
2	18	Kaufman	S.H. 34	C-173-4	22+00to24+50	3(w)	June 6, 1963	-
3	4	Hartley	U.S. 54	F 608(8)	29+89to30+14	8	June 21, 1963	300
4	11	Sabine	U.S. 96	E 64-6-12	569+75to570+30	11	July 1, 1963	270
6**	5	Hale	U.S. 87	F 546(30)	474+90to475+15	7	July 22, 1963	250
7	24	El Paso	U.S. 62&180	374-2&3,19&13	768+92to768+67	15	July 23, 1963	275
8	8	Taylor	U.S. 83&84	F 90(15)34-1-29	907+00to907+72	7	July 22, 1963	325
9	19	Upshur	U.S. 259	S 75(8)392-2	780+65to781+25	3	July 31, 1963	325
10	12	Montgomery	FM-1314	1986-1-4	908+81to909+06	11	Aug. 6, 1963	270
11	13	Wharton	U.S. 59	C 89-6-19	270to271	6	Aug. 22, 1963	265
12	16	Nueces	I.H. 37	I 137-1(14)001	105+70to106+45	2	Sept. 23, 1963	275
13	20	Hardin	S.H. 105	339-4-10	189+57to189+82	5	Oct. 24, 1963	300
14	14	Williamson	I.H. 35	15-8-43	482+60to482+85	6	Feb. 6, 1964	325

*All asphalts used were 85-100 Penetration Grade.

**Materials from Site No. 5 were not evaluated because of technical difficulties.

for the experiment and before the paving machine arrived, heavy aluminum foil was tacked to the base by roofing nails. This was done to facilitate removing slabs of surfacing material and to prevent contamination of the asphalt cement by primer applied to the base. Slabs taken from the test sections by District personnel were shipped to the Institute in special wooden boxes to prevent breakage during transport.

Pertinent information obtained at each site included District number, County, highway designation, project number, stations, producer, date pavement surfacing was laid, and temperature of the freshly prepared mixture. This information is given in Table 1, facing.

Aggregate samples were taken from each bin at each experimental site. A brief mineralogical description of the contents of each bin is given in Table A-1 of the Appendix.

At each field site the following samples were collected.

(1) Original asphalt as it was supplied to the hot-mix plant.

(2) Asphalt-aggregate mixture as it issued from the plant.

(3) Asphalt-aggregate mixture when it was placed in the paving machine.

(4) A 2x2 foot sample of the surfacing material taken 1 day after the pavement was laid and compacted.

(5) A 2x2 foot sample of the surfacing taken 2 weeks after laying.

(6) A 2x2 foot sample of the surfacing taken 4 months after laying.

(7) A 2x2 foot sample of the surfacing taken 1 year after laying.

2. Extraction of Asphalt Cements

About 25 pounds of asphalt-aggregate mixture or surfacing removed from the road was placed in large Colorado type extractors for removal of the asphalt. A mixture of 6 parts benzene and 1 part ethyl alcohol was used to extract the asphalt from the bituminous mixtures. Alcohol was used to assure complete removal of all asphaltic components from the various aggregate surfaces.

The benzene-alcohol solution was centrifuged to remove any fine mineral that may have passed through the filter paper in the extraction apparatus. The essentially mineral free solution of asphalt was distilled by the standard Abson procedure until a large portion of the benzene-alcohol was removed and the concentrated solution then transferred to a thin film evaporator and the remaining solvent removed at 125°F and 15 mm of mercury pressure. One to 1.5 pounds of asphalt was recovered from each sample delivered from the field.

3. Tests on Surfacings Removed from the Highway.

Hveem Stability and Cohesiometer values were supplied by the District in which the experiment was conducted. Densities were determined on each slab after delivery to the Institute. Measurements were also made using the Air Permeometer developed by the California Research Corporation and sold by Soil Test, Inc.

Data on the various surfacings are shown in Table 2-A of the Appendix.

4. Flow (Rheological) Data on the Original and Extracted Asphalts

Viscosities at 77°, 95°, 140°, and 275° F and ASTM penetration at 77°F, 100 grams, 5 secs were determined on each original and recovered asphalt. Measurement of viscosities at 77° and 95° F were made in the thin film (sliding plate) Hallikainen viscometer. Values were calculated at $5x10^{-2}$ sec^{-1} rate of shear. Kinematic viscosities at 140° and 275° F were determined in Cannon-Manning vacuum capillary tube apparatus.

Relative Viscosity for each recovered asphalt was calculated by dividing the viscosity of the recovered asphalt at 77°F by the viscosity of the original asphalt at the same temperature. The quotient indicates how many fold the asphalt has increased in hardness because of the treatment or service it has encountered.

A laboratory hardening test was also made on each original asphalt. A 15-micron film was placed on 4 cm x 4 cm glass plates and exposed in a dark air oven at 225°F for 2 hours. The cool, hardened films were scraped from the glass by a razor blade, the asphalt placed between the plates used in the sliding plate viscometer and viscosity determined at 77°F and $5x10^{-2}sec^{-1}$ rate of shear. Viscosity of the hardened asphalt was divided by the viscosity of the original asphalt measured at the same temperature and rate of shear. The quotient, called the Relative Viscosity, is considered a measure of the susceptibility of the asphalt to hardening by time, heat and oxidation. Later in this report these laboratory values are correlated with those from the field samples.

All of the above data are given in Table A-3 of the Appendix.

Of the possible seventy-eight samples of recovered asphalts, nine were defective for one reason or another and data for them are not included in Table A-3. For the record the missing values are:

Site 1: Paver and 2 week samples.

Site 2: Plant sample.

Site 3: One year sample.

Site 11: Paver and one day samples.

Site 13: One day sample.

Site 14: Paver and 2 week samples.

TABLE II

RELATIVE VISCOSITIES OF THE 13 ASPHALTS HARDENED
UNDER VARIOUS CONDITIONS AND TIMES

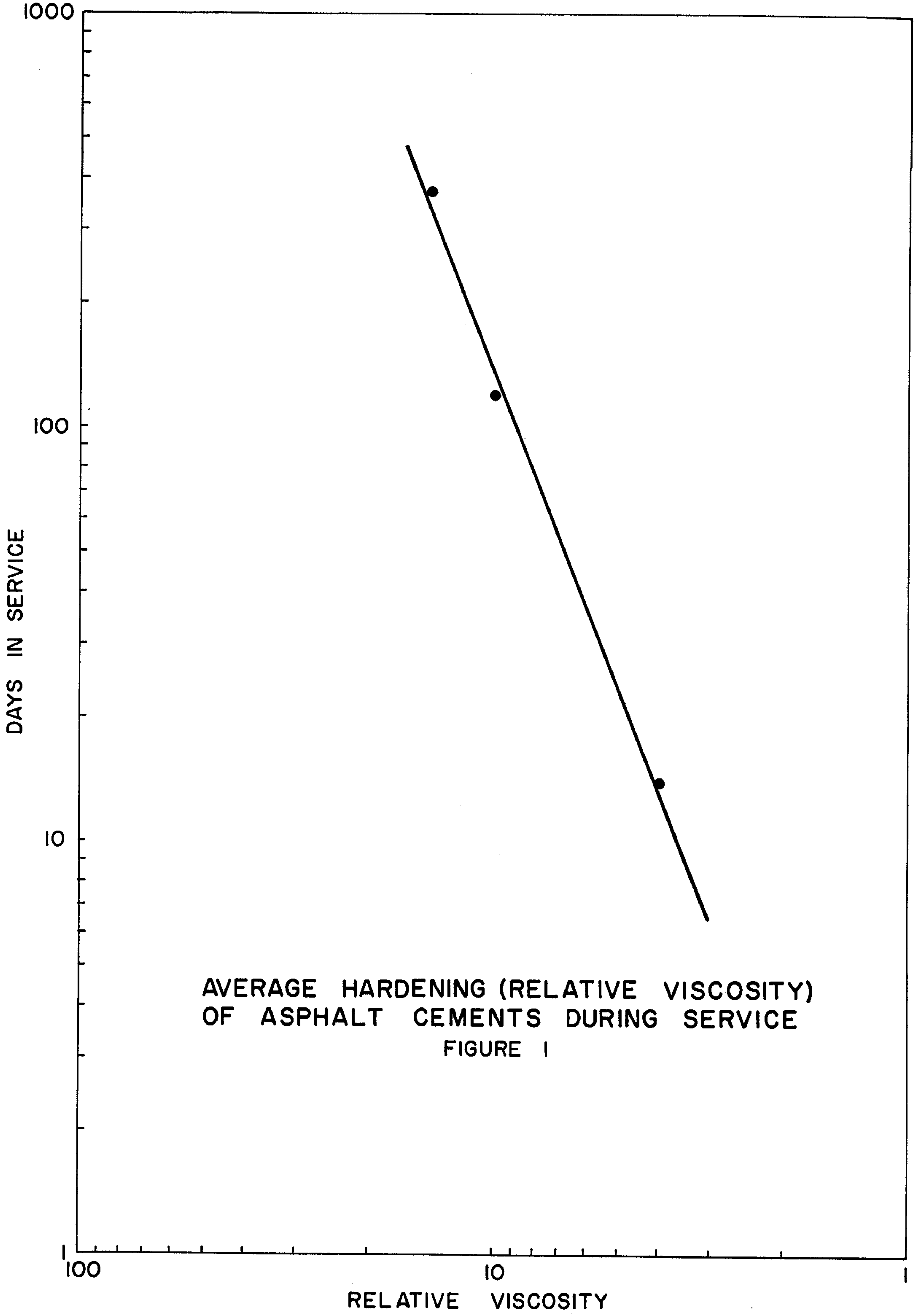
Site	1	2	3	4	6	7	8	9	10	11	12	13	14	Range	Average
Laboratory Test	4.2	2.7	2.7	2.7	6.35	3.2	5.1	4.7	2.7	3.2	3.2	2.55	2.8	2.55 to 6.35	3.55
Plant	1.65	-	2.3	1.7	2.6	1.75	2.7	2.4	1.15	2.6	1.4	2.2	1.8	1.15 to 2.7	2.00
Paver	-	2.1	2.7	1.75	2.7	1.85	2.8	2.3	1.55	-	1.6	2.5	-	1.55 to 2.8	2.20
1 Day	2.7	3.1	2.8	2.0	3.1	2.85	3.25	2.3	1.9	-	2.4	-	1.9	1.9 to 3.25	2.60
2 Weeks	-	3.6	3.6	2.2	5.6	4.35	7.6	4.7	2.85	3.6	2.6	2.8	-	2.2 to 7.6	3.95
4 Months	8.95	9.3	6.0	9.7	21.5	13.2	14.3	7.4	8.3	15.2	5.7	5.75	3.3	3.3 to 21.5	9.90
1 Year	9.1	13.3	-	10.65	25.0	14.5	17.5	10.2	13.8	22.0	15.3	9.85	10.6	9.1 to 25.0	14.30

5. Hardening of the Asphalt During Handling and Service

One of the important objectives of the investigation discussed in this report was to determine the rate of hardening of different commercial asphalt cements during mixing with hot aggregate, transport to the paving site, handling in the paving machine, compaction on the road and during service. Data obtained are reported in Table A-3 of the Appendix.

In order to simplify the presentation of the progress of asphalt hardening during the preparation and service of a bituminous surfacing, the absolute viscosity of the bitumen at 77°F is not used. The viscosities of the thirteen original 85-100 penetration asphalts varied from 0.565×10^6 to 1.18×10^6 poises at 77° F. The relative viscosity of each hardened asphalt was calculated by dividing its viscosity at 77°F by the viscosity of the original asphalt at the same temperature. Thus, the variability caused by the differences in original viscosity was eliminated. A comparison of the relative viscosities gives a clearer picture of the rates of hardening that were encountered.

Table II, facing, first shows the relative viscosity obtained for each of the thirteen asphalts by heating a 15-micron film in air at 225°F for 2 hours in a laboratory oven. Next, the relative viscosities are shown for the asphalt recovered from (a) the mixture issuing from the plant, (b) a sample taken from the paver, (c) a sample removed one day after laying and compaction, (d) after 2 weeks service, (e) after 4 months service and (f) after 1 year of service. The table also shows



AVERAGE HARDENING (RELATIVE VISCOSITY) OF ASPHALT CEMENTS DURING SERVICE

FIGURE I

the range of relative viscosity values for a particular type of sample and finally, the average RV for each situation to the nearest 0.05. This last column in the table shows gradual hardening as the aging continues. Figure 1, is a log RV versus log time (days) for average values of RV at 2 weeks to one year.

TABLE III

ASPHALTENE AND PETROLENE CONTENTS OF ORIGINAL ASPHALTS
USED IN 1963-64 PROGRAM
AND VISCOSITIES OF PETROLENES

Lot No.	Producer No.	Asphaltenes,%	Petrolenes,%	Viscosity of Petrolenes, Poises, at 60°F	77°F	Log. Vis. 60° / Log. Vis. 77°
1	3	22.6	77.4	29,800	5,220	1.204
9	3	25.8	74.2	57,600	9,780	1.193
2	3(w)	12.2	87.8	516,000	57,600	1.200
4	11	19.5	80.5	53,800	4,780	1.286
10	11	20.5	79.5	37,800	4,040	1.269
6	7	14.4	85.6	126,000	17,000	1.206
8	7	20.0	80.0	142,000	10,800	1.277
11	6	4.9	95.1	680,000	47,600	1.247
14	6	2.0	98.0	680,000	75,000	1.196
3	8	0.01	99.99	26,000,000	2,780,000	1.151
7	15	13.3	86.7	61,000	16,700	1.133
12	2	13.7	86.3	328,000	29,800	1.233
13	5	9.4	90.6	700,000	70,000	1.206

6. Asphaltene and Petrolene Content of the Asphalts

Petrolenes were extracted from the original asphalts by means of n-pentane. Alundum Extraction Thimbles (RA 84 Dense) were filled with glass wool and about 2.5 grams of molten asphalt poured over the fibrous mass. The alundum thimbles were placed in slightly larger paper thimbles which fitted into a Soxhlet Extractor. About 150 ml of n-pentane was refluxed through the asphalt coated glass wool for 22 to 23 hours.

The resulting solution of petrolenes was stripped of solvent, the residue cooled and weighed to determine the amount of extracted material (petrolenes). This subtracted from the weight of the original sample gave the amount of n-pentane insoluble material (asphaltenes). This procedure avoided the weighing of asphaltenes in air thereby precluding errors caused by the rapid oxidation of unprotected asphaltenes.

Values obtained for the original asphalts are given in Table III, facing. Also shown are the viscosities of the petrolenes at 60° and 77°F for each original asphalt, and the quotient obtained by dividing log viscosity at 60° F by log viscosity at 77°F. The viscosities were determined on the sliding plate viscometer at a rate of shear of $5x10^{-2} sec^{-1}$.

Asphaltene contents were also obtained on the asphalts extracted from the pavements after one year of service. As would be expected, these harder, extracted asphalts all had somewhat higher

TABLE IV

ASPHALTENE CONTENT OF ORIGINAL
ASPHALTS AND OF THOSE RECOVERED AFTER ONE YEAR OF SERVICE

Site No.	Asphalt Producer	Percent Asphaltenes Original	Percent Asphaltenes After one year	During 1 year asphaltene content increased by %
1	3	22.6	24.0	1.4
9	3	25.8	30.6	4.8
2	3(w)	12.2	20.4	8.2
4	11	19.5	23.5	4.0
10	11	20.5	24.1	3.6
6	7	14.4	22.1	7.7
8	7	20.0	25.4	5.4
11	6	4.9	8.2	3.3
14	6	2.0	6.8	4.8
3	8	0.01	0.93	0.92
7	15	13.3	19.9	6.6
12	2	13.7	22.0	8.3
13	5	9.4	11.5	2.1

asphaltene contents than the original bitumen (see Table IV, facing). However, the increase of asphaltenes in the asphalts (excluding asphalt from producer 8) varied from 1.4 to 8.3 percent for the materials used at the various sites. A brief discussion of these data is given on pages 22 to 23.

TABLE V

HIGH TEMPERATURE VISCOSITIES AND RELATIVE VISCOSITIES ON ORIGINAL ASPHALTS AS COMPARED WITH 1964 THD SPECIFICATIONS

Site	Asphalt Producer	Penetration at 100 gms, 5secs, 77°F	Viscosity (1) Stokes 140°	Viscosity (1) Stokes 275°F	Relative Viscosity (2) by Laboratory Test
12	2	77	1190	2.55	3.2
1	3	84	1830	4.35	4.2
9	3	81.5	1870	4.00	4.7
2	3 (w)	86	1410	3.35	2.7
13	5	90	940	2.60	2.55
11	6	99.5	1110	2.70	3.2
14	6	98.5	1280	3.55	2.8
6	7	79	1150	2.45	6.35
8	7	80	1160	2.40	5.1
3	8	77	2650	9.95	2.7
4	11	85	1620	2.60	2.7
10	11	88.5	1660	2.85	2.7
7	15	92.5	1165	2.75	3.2
New THD Specification			2000-3000	3.0 min.	5.0 max.

(1) Determined by vacuum capillary tube viscometer.

(2) 15 micron film heated in air at 225°F for 2 hours. Viscosity of hardened and original asphalt determined at 77° F in sliding plate thin film viscometer at 5×10^{-2} sec $^{-1}$.

$$RV = \frac{\text{viscosity of hardened material}}{\text{viscosity of original asphalt}}.$$

VIII. CORRELATIONS AND DISCUSSIONS

1. Viscosities of Original Asphalts Compared with 1964 Texas Highway Department Specifications for Asphalt Cements

Table V, facing, gives penetration values, viscosities at 140° and 275°F and Relative Viscosities, as determined in the laboratory, for the thirteen original asphalts. Where asphalts from one producer were supplied to more than one site, the asphalts are grouped together in the tabulation.

Values meeting the new Texas Highway Department specifications are underscored. Asphalt used at Site 3 passed both viscosity specifications and the proposed relative viscosity of 5.0 maximum. Four other asphalts passed viscosity requirements at 275°F and the relative viscosity. Only one asphalt (used at sites 6 and 8) failed all three of the new items listed.

The 1964 Texas Highway limits are shown at the bottom of the tabulation. Table A-4 in the Appendix gives the complete new THD specifications for asphalt cements. It will be noted there that the penetration tests have been deleted.

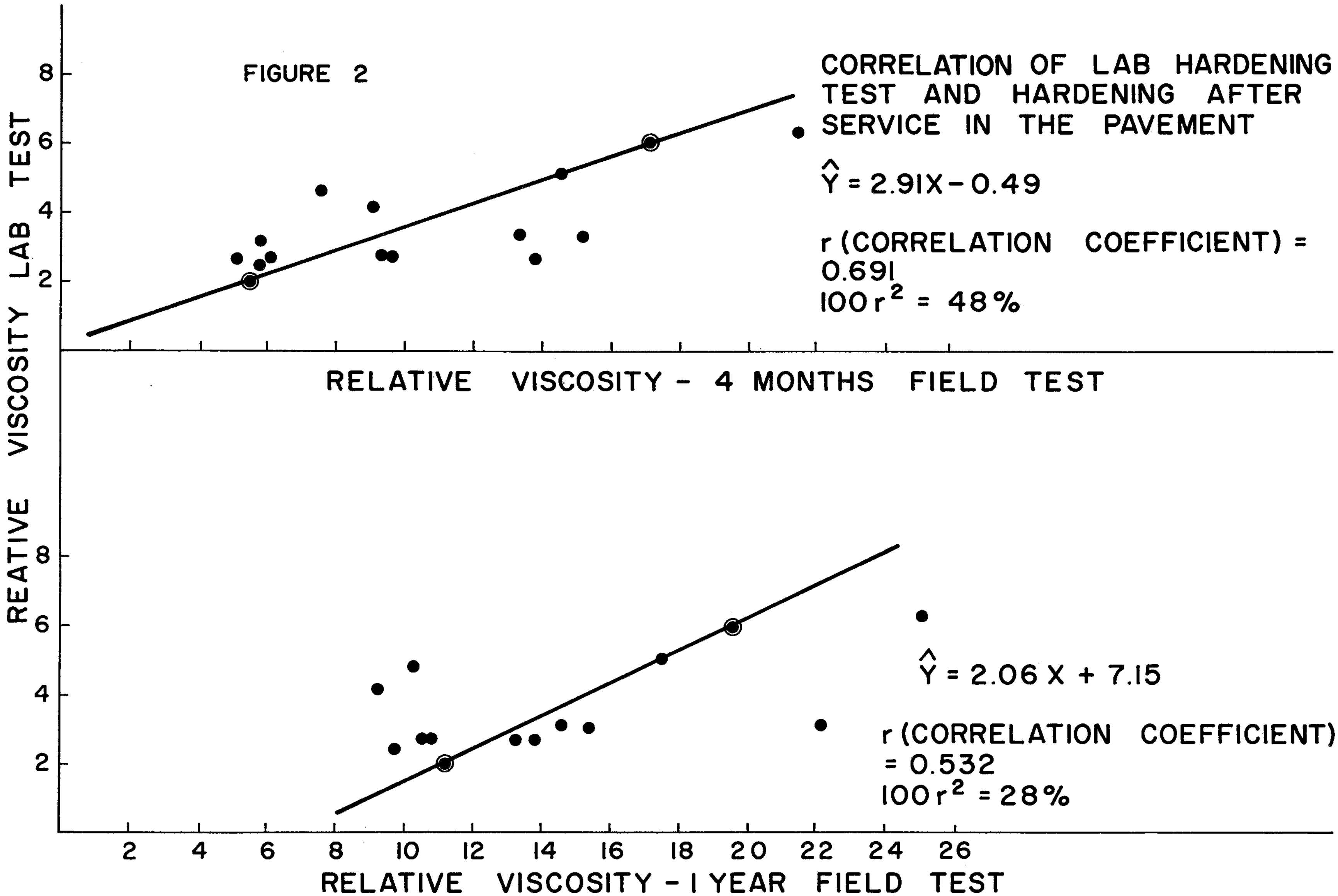


FIGURE 2
CORRELATION OF LAB HARDENING TEST AND HARDENING AFTER SERVICE IN THE PAVEMENT
$\hat{Y} = 2.91X - 0.49$
r (CORRELATION COEFFICIENT) = 0.691
$100 r^2 = 48\%$
RELATIVE VISCOSITY - 4 MONTHS FIELD TEST
REATIVE VISCOSITY LAB TEST
$\hat{Y} = 2.06X + 7.15$
r (CORRELATION COEFFICIENT) = 0.532
$100 r^2 = 28\%$
RELATIVE VISCOSITY - 1 YEAR FIELD TEST
2
4
6
8
10
12
14
16
18
20
22
24
26

2. <u>Correlation Between Relative Viscosity by Laboratory Tests and Those for Asphalts Recovered after Handling and Service</u>

Figure 2, facing, shows the correlation between Relative Viscosity by the laboratory test (as ordinate) and RV's of recovered asphalt after 4 and 12 months service (as abscissa). The straight lines shown on the graphs were determined by the method of least squares. If a perfect correlation existed between hardening by the laboratory test and hardening in the pavement, the points for all the samples would fall on or near the straight lines.

The 12-month sample from Site 3 was discarded because it was contaminated presumably from crank case or some other oil. Data on the asphalts after 12 months service are of more practical importance than those for 4 months, thus the former will be discussed here.

Referring to Table A-3 of the appendix, the asphalt extracted from Site 6 (supplied by Producer No. 7) had hardened much more than would be expected from the laboratory test. The same producer supplied the asphalt cement used at Site 8 which falls on the straight line shown in Figure 2. Sites 6 and 8 were laid on July 22, 1963, the first in Hale County and the second in Taylor County (both in Northwest Texas). The weather was hot during the construction of the pavements.

It will be noted from Table IV, page 16, that the asphalt recovered after one year at Site 6 showed a 7.7 percent increase in asphaltene whereas the sample of the same age from Site 8 (which fell on the straight line) increased in asphaltene content by only 5.4 percent. It is well known that an increase in asphaltene content results in an increase in viscosity.

What could have caused the increase in asphaltene content and hardening at Site 6? Data in Table A-1 of the appendix shows that an aggregate of considerable mineralogical variety was used at Site 6 whereas that used at Site 8 was predominately limestone. The variable miscellaneous type of aggregate used at Site 6 may be one reason for the excessive hardening of the asphalt during service for one year.

Now let us review the behavior of the asphalt No. 6 used at Sites 11 and 14 as shown in Table A-3. Site 11 was laid in Wharton County (South Texas) on August 22, 1963. The asphalt after one year of service had hardened much more than would be expected from the laboratory test. The aggregate in this case was about 80% rounded river gravel and 20% oyster shell. Site 14 was constructed during cold weather (February 6, 1964) in Williamson County (Central Texas). After one year the Relative Viscosity approached the straight line. The aggregate used was mainly a porous limestone. The difference in behavior of the same asphalt used at Sites 11 and 14 after one year of service are difficult to explain but may have been caused by the difference in temperature of the two pavements during their early life and to the effects of the different aggregates on this particular asphalt.

The pavements at Sites 1 and 9 were made with asphalt cement supplied by Producer No. 3. The asphalts recovered after 12 months service had not hardened as much as would be expected from the laboratory tests. Aggregate used at Site 1 was more than 60% limestone, while that at Site 9 was predominately iron ore slag with a small amount of field sand. The natures of the aggregates at these two sites did not appear to have much effect on the hardening of this particular asphalt. It should be pointed out that asphalt No. 3 originally has the highest asphaltene content of the nine different asphalts used in this investigation. We must conclude that the asphalt supplied by Producer No. 3 is relatively stable in respect to hardening effects operating during the preparation of the hot mixture and service in the pavement.

The few situations where there is not reasonable correlation between hardening of an asphalt determined by the laboratory test and its hardening in service do not invalidate the laboratory test. On the contrary, these situations should be taken as indications of the pressing need for more extensive research concerning the reactions which take place between asphalt and aggregate during preparation and service of the pavement.

VIII. APPENDIX

INDEX

Table A-1

IDENTIFICATION AND DESCRIPTION OF AGGREGATES USED AT THE 13 SITES

Lot #1 -- three cans.

Information from Labels: - All 3 cans labelled alike except for Bin Number. District: 9. County: McLennan. Control: 55-8. Project: E-55-8-30. Highway: U.S. 84. Limits: 5.0 miles W. of Waco C.L., W. 1.2 miles. Contractor: Dean Word (Young Bros.). Type of Aggregate: Siliceous gravel.

Hot Bin #3 (coarsest): - Entirely gravel -- more or less rounded; a few pebbles broken -- all are dusty from thin coating of yellow-brown clay-- washed to aid examination.

60% or more is limestone, white, gray, yellow-brown -- also brown, red, and black chert; red quartzite; milky quartz; fossil shells.

"Siliceous gravel" therefore must not be understood too literally.

Hot Bin #2 (intermediate): - Same gravel as in Hot Bin #3, except for smaller size -- also dusty.

Hot Bin #1 (finest): -- Quartered down to about 1/16 of original sample -- this portion then sieved dry, yielding:

> 1.000 mm. (plus 16 mesh) : -	Estim. 2 volumes or 11%
< 1.000 >0.500 mm. (minus 16, plus 32 mesh):-	Estim. 2 volumes or 11%
< 0.500 >0.246 mm. (minus 32, plus 60 mesh):-	Estim. 4 volumes or 22%
< 0.246 >0.124 mm. (minus 60, plus 115 mesh):-	Estim. 1 volume or 6%
< 0.124 >0.062 mm. (minus 115, plus 250 mesh):-	Estim. 8 volumes or 44%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 volume or 6%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

> 1.000 mm. Fraction: - Perhaps 40-50% is much coarser, up to about 5 mm. diam. -- composition similar to that of Hot Bin #3, except that this fraction contains more red quartzite -- still more than 50% limestone -- grains show some clay coating, which is not very adherent, however.

< 1.000 >0.500 mm. Fraction: - Washed to remove clay (dust) and aid examination) -- most grains more or less rounded, but range from angular to well rounded -- much colorless and some milky and reddish quartz, most of it rounded -- also white limestone; red, gray, and brown chert; red quartzite; other rocks; a little microcline; a few fossil fragments.

<0.500 >0.246 mm. Fraction: - Washed to aid examination -- much higher proportion of quartz than in next preceding fraction -- colorless, milky, and reddish quartz, most of it rounded, but some showing crystal faces -- also some white and pink limestone, red chert, dark rocks.

< 0.246 > 0.124 mm. Fraction: - Washed -- reddish sand -- chiefly (at least 80%) quartz -- colorless, milky, orange, and reddish quartz -- also a little white and pink limestone, a little red chert, a little red quartzite, unknown black rocks, 2 or 3 flakes of mica.

<0.124 >0.062 mm. Fraction: - Washed -- fine reddish sand -- chiefly quartz, colorless, orange, and red, angular to subrounded -- some black grains and other colors -- a very few grains of white limestone -- no mica seen -- the washed sand still shows considerable effervescence with cold dilute HCl.

< 0.063 Fraction: - Very fine red silt and clay -- washed to remove clay --remainder is angular quartz, colorless, orange, and red -- a very few black grains -- no mica seen -- only one or two grains of white limestone seen, but the washed sample effervesces freely, though briefly, with cold dilute HCl.

Table A-1 continued

Lot #2 -- four cans.

Information from Labels: - All four cans labelled alike except for Bin Number. District: 18. County: Kaufman. Control: C173 - 3&4-10 & 18. Project: Same as control. Highway: SH34. Limits: Kaufman city limits to Terrell city limits. Contractor: Uvalde Constr. Co. Type of Agregate: Not stated.

Hot Bin #4 (coarsest):- All pieces coated with yellow-brown silt, which clings rather tightly, but can be washed off -- washed for examination. Entirely limestone -- white, yellow, and light brown -- some pieces are lighter color inside than on surface, as if oxidized since crushing -- all pieces angular, with conchoidal fracture -- texture lithographic to sub-lithographic -- fairly pure limestone; leaves only a little yellow clay on solution in HCl -- hard and tough.

Hot Bin #3:- Pieces from about 1/8" to 1"; most about 1/2" across-- even dirtier than in Hot Bin #4, with same clinging yellow-brown silt-- same limestone as in Hot Bin #4, except smaller size -- no other material added.

Hot Bin #2 :- Pieces from about 1/16" to 1/2"; most about 1/4" across -- very dirty with same yellow-brown silt, very fine sand, and clay. --washing reveals mixture of crushed limestone and small gravel, with a little fine sand -- the limestone is white to pink -- the gravel contains milky quartz; red, brown, and black chert; yellow limestone; one or two fossil shells -- gravel mostly subrounded, but some pebbles are crushed.

Hot Bin #1 :- Quartered down to about 1/16 of original volume -- this 1/16 then sieved, yielding:

> 1.000 mm. (plus 16 mesh):-	Estim.	4	volumes	or 14%
< 1.000 >0.500 mm. (minus 16, plus 32 mesh):-	"	3	"	or 10%
< 0.500 >0.246 mm. (minus 32, plus 60 mesh):-	"	9	"	or 30%
< 0.246 >0.124 mm. (minus 60, plus 115 mesh):-	"	10	"	or 33%
< 0.124 >0.062 mm. (minus 115, plus 250 mesh):-	"	3	"	or 10%
< 0.062 mm. (minus 250 mesh):-	"	1	"	or 3%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

All fractions are very dirty; have dull brown appearance due to adhering silt and clay -- all were washed before examination -- a little oily matter appeared on some of the wash water.

> 1.000 mm. Fraction:- Some grains up to 5 mm., but most are 1 to 2mm. across -- washing reveals mixture of limestone chips, fine gravel, and coarse sand, similar in composition to Hot Bin #2 -- Limestone chips are white to cream colored -- gravel subangular to rounded -- gravel consists of colorless and milky quartz; yellow to brown limestone; brown chert; limonite-cemented sandstone; limonite nodules; a very few bundles of $CaCO_3$ prisms from fossil shells.

< 1.000 > 0.500 mm. Fraction:- much well-rounded, colorless quartz-- also less-rounded, colored quartz; red and brown chert; chips of white limestone; sand-limonite; limonite nodules; a very few $CaCO_3$ prisms.

< 0.500 > 0.246 mm. Fraction: - Chiefly quartz, subangular to well rounded -- colorless to reddish -- also red and brown chert, white limestone fragments, limonite, a few $CaCO_3$ prisms.

< 0.246 > 0.124 mm. Fraction: - Chiefly quartz; more quartz than in next coarser fraction -- angular to subrounded -- colorless to reddish -- very little chert -- a few white limestone fragments, a little limonite, a very few $CaCO_3$ prisms.

< 0.124 > 0.062 mm. Fraction:- Effervesces with cold dilute HCl before washing -- after washing nearly all quartz -- angular to subrounded-- colorless to reddish -- a very little limonite -- a few $CaCO_3$ prisms.

< 0.062 mm. Fraction:- Effervesces with cold dilute HCl before washing--after washing nearly all is quartz -- angular and subangular -- colorless to reddish -- a very little limonite -- a very few $CaCO_3$ prisms.

Table A-1 continued

Lot #3 -- four cans.

Information from Labels: - District: 4. County: Hartley. Control: 238-2-16. Project: F 608 (8). Highway: U.S. 54. Limits: Dallam C/L SW to FM 694. Producer, also Contractor: Gilvin & Terrill. Location: Local. Type of Aggregate: Limestone rock, mostly siliceous fines. (This label on Bin #1.)

Hot Bin #1 (inside slip marked "Coarse Rock") (coarsest of the four):- Angular pieces of rock, ranging from 1/8 to 1/2" across; most about 3/8" -- all pieces coated with adherent dust -- washed for examination.

All limestone, of 2 types -- the one pink, somewhat banded, very fine grained to lithographic, hard, compact-- the other white, hard, but porous and spongy -- both look as if they might be secondary, as if derived from caliche or travertine -- both react freely with cold, dilute HCl; no indication of dolomite -- both are impure; the pink in HCl leaves residue of reddish-brown silt; the white in HCl leaves a pink, flaky, gelatinous residue, apparently of silicic acid.

Hot Bin #2 (marked "Smaller rock") :- Same limestone as in Hot Bin #1, except for smaller size -- range 1/8 to 3/8"; most about 1/4" across -- pieces coated, as in Bin #1.

Hot Bin #3 (marked "Fine rock");- Same linestone as in Hot Bins nos. 1 and 2 -- range 1/16 to 3/8"; most about 1/4" across -- almost identical with Bin #2 except for a larger percentage of smaller sizes.

Hot Bin #4 (finest) (marked "Sand Bin"):- Quartered down to about 1/16 of original volume -- this 1/16 then sieved, yielding:

> 1.000 mm. (plus 16 mesh):-	Estim.	6	volumes	or 20%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	"	6	"	or 20%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	"	7	"	or 24%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	"	6	"	or 20%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	"	4	"	or 13%
< 0.062 mm. (minus 250 mesh):-	"	1	"	or 3%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope, after washing to remove adherent dust.

>1.000 mm. Fraction:- Ranges up to 5 mm., with a considerable proportion in the 2 and 3 mm. sizes -- quite a little white clay(?) coating comes off grains when rubbed in water -- washed materials is pink and white limestone, like that in Hot Bins nos. 1, 2, and 3; plus colorless, milky, and rusty quartz, limonite-cemented sandstone, $CaCO_3$ - cemented sandstone, and a very few other rocks -- nearly all grains angular.

< 1.000 > 0.500 mm. Fraction:- Colorless, milky, rusty, and red quartz; about 10-15% spongy white limestone; a little quartzite -- test for gypsum negative.

< 0.500 > 0.246 mm. Fraction:- Sand, angular to subrounded -- chiefly quartz, colorless, milky, & reddish -- also some spongy white limestone, a few limonite cementations, a very few green rocks, a very few muscovite flakes, a very few grains of black mineral (hornblende?).

< 0.246 > 0.124 mm. Fraction:- Sand, angular to rounded -- chiefly quartz, colorless, milky, & reddish -- also a little spongy white limestone, a little muscovite, a very few limonite cementations, a very few hornblende(?) grains.

< 0.124 > 0.062 mm. Fraction:- Original fraction effervesces strongly in cold, dilute HCl -- negative test for sulphate in this HCl solution -- washed sand is angular to subrounded -- colorless to reddish quartz -- also considerable spongy white limestone -- a little muscovite, a few black grains, a very few limonites.

< 0.062 mm. Fraction:- Original fraction effervesces strongly in cold, dilute HCl -- washed by decantation, thus losing much fine flaky silt and brownish clay -- residue is silt, angular to subrounded -- colorless to reddish quartz, quite a lot of spongy white limestone (rounded), a little limonite, a few black grains, a very little colorless mica.

Lot #4 -- three cans.

Information from Labels :- All three cans labeled alike except for Bin No.; Station numbers on Bin #1 can only.

District: 11. County Sabine. Control: 64-6-12 Project: E-64-6-12. Highway: U.S.96. Limits: 1.0 mile south of Pineland to Jasper County line. Contractor: Uvalde Constr. Co. Type of Aggregate: Not stated.

Bin #1 (coarsest):- Rounded gravel, with a few split pebbles-- range from about 3/16" to 1/2" diam. mostly 1/4" to 1/2" -- well sorted -- all pebbles coated with gray-brown dust and clay, and require washing for idenfification -- chert (perhaps 50%), gray, brown, and reddish -- quartz, milky and reddish -- pegmatite, microcline, a little limestone, a little calcareous sandstone.

Bin #2 (intermediate):- Gravel -- range about 1/9" to 3/8" diam., mostly about 3/16"--similar to that in Bin #1, but even dirtier -- contains quite a little dark brown mud, which includes a little sand as well as much clay -- requires washing for identification.

Bin #3 (finest) :- Quartered down to about 1/16 of original bulk-- this 1/16 then sieved dry, yielding:

> 1.000 mm. (plus 16 mesh)	Estim. 2 vols. or 8%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 4 vols. or 15%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 12 vols. or 45%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 5 vols. or 19%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim 2-1/2 vols. or 9%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 4%

All sieving done by hand and in the dry--therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

All fractions were very dirty -- all grains look alike because coated with dark brown mud, which comes off only after much rubbing in water -- all fractions washed in this way for examination.

>1.000 mm. Fraction:- Grains range up to about 6x10 mm. --larger grains are chiefly gray, brown, & reddish chert -- most grains of the 1 to 2 mm. size are colorless to milky quartz, which makes up perhaps 60% of sample--also microcline, a very few black grains, a little organic matter, a little limestone, a very little limonite and hematite--also quite a little fine sand, which must have come from disintegration of composite grains during washing and drying.

< 1.000 >0.500 mm. Fraction:- Chiefly colorless to milky quartz-- angular to rounded -- also a little brown chert, a little kaolinized feldspar, a very little limonite, a very few black grains-- trace of limestone by HCl test.

< 0.500 > 0.246 mm. Fraction:- Chiefly quartz, colorless, milky, and a few reddish -- angular to rounded, mostly angular-- also some kaolinized feldspar, a very little brown chert, a very few black grains--slight trace of limestone by HCl test.

< 0.246 > 0.124 mm. Fraction:- Requires much rubbing in water to remove dark brown clay and black organic matter -- after washing chiefly quartz, colorless, milky, pink -- angular to rounded, mostly subangular, also a little kaolinized feldspar (?), a few quartz grains coated with adherent silt, a few yellow-brown chert grains, a very few black grains -- mere trace of carbonate by HCl test.

< 0.124 > 0.062 mm. Fraction: - Requires much rubbing to remove black, granular organic matter as well as clay -- washed sample chiefly quartz, mostly colorless to milky, some yellowish to reddish -- mostly angular, but ranges to subrounded -- also some chalky grains (kaolinized feldspar?), a few grains coated with shiny black pustular material (goethite?, dried organic matter?) a very few black grains, a very little limonite -- mere trace of carbonate by HCl test.

< 0.062 mm. Fraction:- Largely dark brown clay and black specks of organic matter, both of which were washed out by decantation -- remaining silt is chiefly quartz, colorless, milky, orange, and pink -- mostly angular-- also some brown grains (limonite?) and some black grains.

Table A-1 continued

Lot # 6 --three cans.

Information from Labels:- All 3 cans labeled alike except for Bin Number. District: 5. County: Hale. Control: 67-6-15. Project: F 546 (30). Highway: U.S. 87. Limits: From Abernathy to Hale Center. Producer: Panhandle S. & G. Location: 12 mi. N. of Amarillo. Type of Aggregate: Gravel.

Hot Bin #3 (coarsest):- Gravel -- angular to subrounded--wide variety of rocks, including calcareous sandstone (caliche-cemented sand, 5 to 10%), brown and black chert, gray and milky quartz, brownish quartzite, a little microcline -- some pebbles show tightly cemented additions of caliche and/or sand -- pebbles are coated with loose yellow dust; washed for examination.

Hot Bin #2 (intermediate):- Similar in every way to Hot Bin #3 except fro smaller size -- dusty -- not studied in more detail.

Hot Bin #1 (finest):- Quartered down to about 1/16 of original sample -- this portion then sieved dry, giving:

>1.000 mm. (plus 16 mesh):-	Estim. 9 volumes or 28%
<1.000 >0.500 mm. (minus 16, plus 32 mesh):-	Estim. 3-1/2 volumes or 11%
<0.500 >0.246 mm. (minus 32, plus 60 mesh):-	Estim. 4 volumes or 13%
<0.246 >0.124 mm. (minus 60, plus 115 mesh):-	Estim. 10 volumes or 32%
<0.124 >0.062 mm. (minus 115, plus 250 mesh):-	Estim. 4 volumes or 13%
<0.062 mm. (minus 250 mesh):-	Estim. 1 volume or 3%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

>1.000 mm. Fraction:- Many grains much coarser, ranging up to about 5 mm. diam. -- assorted minerals and rocks, as in Hot Bin #3--quartz, chert, calcareous sandstone (caliche-cemented), aplite, calcite, quartzite-- most grains, except the larger ones, are high angular --grains thinly coated with a little loose dust.

< 1.000 >0.500 mm. Fraction:- Highly angular sand -- washed to remove yellow-brown dust -- contains much colorless quartz -- also white and brown calcareous sandstone, yellow sandstone, pink quartzite, pink gypsum(?), a little chert, a few dark rocks.

< 0.500 >0.246 mm. Fraction:- Washed to remove dust -- much angular colorless quartz -- also rounded quartz; red, yellow, & brown sandstone and quartzite; pink gypsum (?); white calcium carbonate; a very few flakes of mica; a little of a black shiny mineral, some of it enclosed in quartz, resembling tourmaline or ilmenite.

< 0.246 > 0.124 mm. Fraction:- Contains much reddish-brown very fine silt and clay, removed as far as possible by washing prior to examination -- sand is chiefly quartz, colorless, orange, red -- angular to rounded, mostly subangular -- also a little white $CaCO_3$, a few shiny black grains, a very few flakes of mica, some of which may have been lost by washing.

< 0.124 >0.062 mm. Fraction:- Washed to remove reddish-brown very fine silt and clay -- sand is chiefly quartz, colorless, orange, some red-- angular to subrounded -- also quite a little white $CaCO_3$, a few black grains, a very few mica flakes.

<0.062 Fraction:- Effervesces strongly with cold, dilute HCl -- contains much reddish-brown clay -- after this is removed by washing and decanting, residue is angular to subrounded silt -- colorless, orange, and a few red quartz; many milky-white $CaCO_3$ grains; a few black grains; a very few mica flakes.

Table A-1 continued

Lot #7 -- four cans.

Information from Labels:- District: 24. County: El Paso. Control: 374 - 2&3- 19 & 13. Highway: U.S. 62 and 180. Limits: From Trowbridge Street in El Paso to Hudspeth C/L. Contractor: Hugh McMillan, Inc. Type of Aggregate: Lime Stone. All four cans labeled alike except for size designation.

3/8" CRS Agg. sample, from the hot bin (coarsest):- Crushed limestone --angular pieces -- range from about 1/8" to 5/8" in greatest dimension, but most are about 3/8" to 1/2" -- have thin, non-adherent dust coating, but generally fairly clean -- washing reveals gray to pink to white limestone -- very fine-grained to lithographic--hard, strong, and non-porous, except for a few weathered chips -- some chips are dolomitic judged by behavior in HCl (reaction begins again on heating after ceasing in cold), but few if any are 100% dolomite.

Contains perhaps 10-15% of chert -- mostly black; some white -- sharp chips and flakes.

N/4 Intermed. Agg. sample, from the hot bin: Ranges from about 1/16" to 3/8"; mostly 1/4" in greatest dimension -- similar to the 3/8" can, but with much more dust, which however washes off easily -- same gray, pink, and white hard limestone, with black, brown, and white chert -- one crinoid stem seen.

N/10 Crs. Screenings sample, from the hot bin:- Intimate mixture of coarse and fine particles, all the way to dust -- quartered down to about 1/16 original volume -- this 1/16 then sieved, yielding:

> 1.000 mm. (plus 16 mesh):-	Estim. 7 volumes or 24%
< 1.000 >0.500 mm. (minus 16, plus 32 mesh):-	Estim. 4 volumes or 13%
< 0.500 >0.246 mm. (minus 32, plus 60 mesh):-	Estim. 5 volumes or 17%
< 0.246 >0.124 mm. (minus 60, plus 115 mesh):-	Estim. 7 volumes or 23%
< 0.124 >0.062 mm. (minus 115, plus 250 mesh):-	Estim. 6 volumes or 20%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 volume or 3%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

> 1.000 mm. Fraction:- Ranges up to 5 mm., with a considerable proportion of the larger sizes -- all is crushed limestone, with nothing else added -- same gray, pink, and white limestone as in preceding cans, - with a little black and gray chert -- all angular chips and flakes -- only slightly dusty -- not washed for examination.

< 1.000 > 0.500 mm. Fraction:- Same crushed limestone and chert; nothing added -- angular chips, thinly coated with dust, which washes off easily.

< 0.500 > 0.246 mm. Fraction:- Washed and dried to remove adhering dust and a little organic matter -- washed material is same white, pink, and dark gray limestone and chert -- sharp, angular chips and flakes -- also perhaps 10 to 20% of a white, micro-sugary limestone or silica, perhaps from weathering of the other limestone -- no added sand.

< 0.246 > 0.124 mm. Fraction:- Washed and dried to remove dust -- angular chips of white limestone -- also large percentage of quartz grains; colorless, milky, and orange; subangular to rounded -- also micro-sugary white limestone and/or silica -- some chert, a very few black grains -- some sand has been added to the crushed limestone.

< 0.124 > 0.062 mm. Fraction:- Washed and dried to remove dust and considerable gray clay -- residue largely quartz; colorless, milky, orange -- mostly angular, ranging to subrounded -- also quite a little white micro-sugary limestone and/or silica -- also chips of white limestone -- quite a few dark brown to black grains, a very little calcite.

< 0.062 mm. Fraction:- Largely gray clay -- on washing and decanting this leaves a little brown silt -- mostly angular quartz, colorless, milky, orange -- quite a lot (perhaps 10% of the silt) of dark brown to black grains, most of which are magnetite (attracted by magnet) -- also some carbonate by dilute HCl test.

<u>N/10 Fine Screenings sample, from the hot bin</u>:- Intimate mixture of coarse and fine particles, in appearance very much the same as the N/10 coarse screenings can, except perhaps for more dust -- quartered down to about 1/16 original volume -- this 1/16 then sieved, yielding:

> 1.000 mm. (plus 16 mesh):-	Estim. 2-1/2 vols. or 26%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 1-1/4 vols. or 13%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 1-1/4 vols. or 13%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 2 vols. or 20%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim. 1-3/4 vols. or 18%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 10%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

> 1.000 mm. Fraction:- Ranges up to about 5 mm. in greatest dimension --same white, pinkish, and dark gray limestone as in Coarse Screenings can, with a little black to white chert -- a little dust coating, which washes off easily -- no added sand.

< 0.254 > 0.124 mm. Fraction:- Sample of this fraction heated with dilute HCl to destroy all carbonate -- a little organic matter floats up during effervescence -- brown clay flocculates and settles out on top of sand--behavior also suggests some dolomite in the limestone.

After washing out acid and clay the residue is sand, chiefly quartz--angular to rounded, mostly subangular -- colorless, milky, orange -- also a little white and dark chert, quite a little micro-sugary silica, a few black grains, a very few limonite grains.

It seems evident that there is no essential difference between the N/10 Coarse Screenings can and the N/10 Fine Screenings can; therefore the analysis was not carried farther.

Table A-1 continued

Lot # 8, three cans.

Information from Labels:- District: 8. County: Taylor. Control: 34-1-29. Project: F (90) (15). Highway: U. S. 83. Limits: Abilene south to U.S. 84 junction. Contractor: J. H. Strain & Sons. Type of Aggregate: Crushed Limestone.

Hot Bin #3 (coarsest):- Limestone--chiefly white, but with 5-10% blue-gray--also a little colorless calcite, one quartz pebble, one root fragment--considerable dust from abrasion, which tends to coat the rock chips and to obscure their character.

The white limestone is quite pure, fine-grained, hard--composed chiefly of microscopic fossils with interstitial fine-grained carbonate--contains many minute pores where fossils have dissolved; most of these openings are lined with tiny calcite crystals--a few veins and masses of colorless calcite fill former larger openings--the rock is a recrystallized biomicrite or micro-coquina, probably from the Edwards formation.

The blue-gray limestone is similar to the white, but contains many dark-gray to brown crystalline grains, and a little glauconite--less pure; solution in dilute HCl leaves residue of dark silt and clay.

No indication of dolomite in either limestone.

Hot Bin #2 (intermediate):- Limestone--same as Hot Bin #3 except for smaller size (about 1/8" to 1/2")--some yellow-brown weathered limestone--dust from abrasion coats all pieces.

Hot Bin #1 (finest):- Quartered down to about 1/16 of original sample--this portion then sieved, yielding:

> 1.000 mm. (plus mesh):-	Estim. 2 vols. or 15%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh:-	Estim. 2 vols. or 15%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh:-	Estim. 2 vols. or 18%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh:-	Estim. 4 vols. or 30%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh:-	Estim. 2 vols. or 15%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 7%

All sieving done by hand and in the dry--therefore finer fractions may be incompletely separated--all percentages are merely visual estimates; fractions were not weighed--fractions examined under binocular microscope.

1.000 Fraction:- Almost entirely the white limestone described under Hot Bin #3--a very few grains of the blue-gray--no sand.

< 1.000 > 0.500 mm. Fraction: - Chiefly white limestone, with some blue-gray, some weathered brown and yellow, some colorless calcite--contains a little admixed sand, composed of colorless quartz plus pink and red minerals or rocks -- quite a little adherent dust, so that grains require washing.

< 0.500 > 0.246 mm. Fraction:- After washing to remove adherent dust, material is about 2/3 limestone and 1/3 sand -- limestone is white, bluish, and weathered reddish, also colorless calcite--sand is chiefly rounded to well-rounded colorless quartz, plus orange and red grains.

< 0.246 > 0.124 mm. Fraction:- After washing to remove dust, material is perhaps 15-20% crushed limestone, 80-85% sand -- limestone chiefly white with a little blue, and quite a little colorless calcite as cleavage pieces--Sand is chiefly subrounded to well-rounded, colorless quartz, plus some orange and red grains.

< 0.124 > 0.062 mm. Fraction:- After washing to remove dust, material looks to be about 50-50 crushed limestone and sand, but proportions are difficult to judge -- limestone practically all white, with a little colorless calcite --sand chiefly colorless quartz, angular to rounded, with numerous orange to red grains.

< 0.062 Fraction:- Looks to be merely white limestone powder, which is fluffy and tends to aggregate -- but removal of all carbonate with HCl leaves a small residue of brown clay and silt -- after washing and decantation of most of the clay, the silt consists chiefly of angular, colorless quartz, plus many reddish grains and quite a few black grains.

Table A-1 continued.

Lot #9, four cans.

Information from Labels: Upshur County. Project S 75 (8). Highway U.S. 259, 6.5 miles north of Ore City to Gregg County line. Aggregate Type: Crushed iron ore slag and field sand.

Hot Bin #4 (coarsest):- All slag -- gray to blue-gray, with a very few reddish pieces -- most pieces at least partly vesicular (full of gas cavities), with surfaces showing broken spherical cavities of all sizes from 0.1 mm. to 1 cm. diam. -- most pieces aphanitic (stony) texture, but quite a few show glassy luster -- a few are dark gray and non-vesicular; these resemble limestone but do not react for it.

With cold, dilute HCl the slag, including the non-vesicular pieces, bubbles slightly and gives off a little H_2S, which soon ceases -- on boiling this reaction speeds up, and then the entire liquid gelatinizes -- even on standing in the cold dilute HCl some decomposition of the silicate occurs, as shown by opalescence in the liquid.

If used as concrete aggregate this slag should certainly be expected to react with alkalis in cement.-- might also be useful as a pozzolan.

Hot Bin #3 :- All slag, similar to Hot Bin #4, except for smaller size of pieces.

Hot Bin #2 :- All slag -- similar to nos. 3 and 4 except for smaller size.

Hot Bin #1 (finest):- Quartered down to about 1/16 of its original bulk -- this 1/16 then sieved, giving:

> 1.000 mm. (plus 16 mesh):-	Estim. 4 vols. or 20%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 1-1/2 vols. or 7%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 6 vols. or 30%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 6 vols. or 30%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim. 2 vol. or 9%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 4%

All sieving done by hand and in the dry; therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

> 1.000 Fraction:- All slag.

< 1.000 > 0.500 Fraction:- All slag.

< 0.500 > 0.246 Fraction:- Sand, with a little slag -- sand highly angular, with a very few subrounded grains -- chiefly quartz -- most grains dirtied by what looks like very fine, crystalline silt adhering to them.

< 0.246 > 0.124 Fraction:- All fine sand -- little or no slag -- general pinkish-brown color -- sand similar to that in preceding fraction, but contains larger proportion of rounded grains -- most grains dirty with adhering silt, as before.

< 0.124 > 0.062 Fraction:- Very fine sand, similar to that in preceding fraction -- no visible slag -- general pinkish-brown color -- grains dirty with silt, as before.

< 0.062 Fraction:- Silt -- pinkish-brown--angular -- quartz, with a little mica -- much dust (in water, a little white clay).

Table A-1 continued

Lot #10, three cans.

Information from Labels:- District 12. County:Montgomery. Control: 1986-1-4. Project:C. Highway: FM 1314. Limits: SH 105 at Conroe to US 59 at Porter. Material: HMAC. Producer: Gaylord Const. Co. Location: Willis, Tex. Type of Aggregate: Iron ore topsoil.

Hot Bin #3 (coarsest):- Iron ore concretions -- spheroids, ovoids, and irregularly rounded -- Mostly brown, some red and some black -- diameter 1/4 to 1/2 inch -- these concretions consist of very fine sand and silt cemented with limonite, hematite, or both -- some can be broken in fingers; all with light tap of a hammer -- nevertheless nearly all of concretions in sample are unbroken -- all somewhat friable and have dusty surface -- sample contains some very fine sand, silt, and dust from their abrasion -- also a few roots --no gravel or crushed rock.

When heated in dilute HCl the black concretions show a very little carbonate (siderite) -- after heating in 1::;1 HCl plus oxalic acid to dissolve all the iron, the residue is colorless, fine grained quartz, held together in small lumps by white clay, or possibly silicic acid.

Hot Bin #2 (intermediate):- Same concretions as in Hot Bin #3, but smaller size -- 1/8 to 3/8 inch diam. -- no gravel, but considerable very fine sand, silt, and dust.

Hot Bin #1 (finest):- Quartered down to about 1/16 of original volume -- this portion then sieved, yielding:

>1.000 mm. (plus 16 mesh):-	Estim. 1-1/2 vols. or 9%
<1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 1 vol. or 6%
<0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 5 vols. or 32%
<0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 5 vols. or 32%
<0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim 2 vols. or 13%
<0.062 mm. (minus 250 mesh):-	Estim. 1-1/4 vols. or 8%

All sieving done by hand and in the dry; therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates-- fractions were not weighed -- fractions examined under binocular microscope.

>1.000 mm. Fraction:- Limonite-hematite concretions like those in Hot Bin #3, but up to only about 4 mm. diameter. -- all well rounded-- nothing else except a few fragments of roots.

< 1.000> 0.500 mm. Fraction:- Mostly quartz grains, subrounded to well rounded, partly to entirely coated with adherent pink silt -- also some fragments of limonite concretions -- a few carbonized root fragments -- most, but not all of the adherent silt comes off the grains on vigorous shaking with water.

< 0.500 >0.246 mm. Fraction:- Similar to next coarser fraction-- mostly quartz grains, subangular to well rounded, coated with fine silt-- about 10% of the grains coated with black hematite (?) -- a few silt aggregates -- a few limonite-silt root casts.

< 0.246 >0.124 mm. Fraction:- Same as next coarser fraction--angular to well rounded quartz grains, most of them coated with yellow-brown silt-- some black-coated grains -- a few root casts.

< 0.124 >0.062 mm. Fraction:- Chiefly quartz, angular to rounded--colorless, orange, and yellow grains, much less coated than in preceding fractions --significant amount of red and black grains, probably iron oxides-- a few root casts -- no mica.

<0.062 mm. Fraction:- Chiefly quartz, angular to rounded -- colorless, orange, and yellow grains -- some red and some black grains, probably iron oxides -- no mica -- dilute HCl shows no reaction in cold but gives slight effervescence on heating (siderite) -- shaking and settling in water shows a little brownish clay or clay-size limonite.

Table A-1 continued

Lot # 11, three cans.

Information from Labels:- District 13, Wharton County. Project C-89-6-19. Highway U.S. 59, from Jackson County line to west city limits of El Campo. Producer (of asphalt) : Humble. Location: Houston. Contractor: Worth Constr. Co. Type of Aggregate not mentioned.

Hot Bin #3 (coarsest):- Estimated about 20% shells and shell fragments, mostly of oysters, but other types present.

Estimated about 80% river gravel, mostly rounded, which contains:

Quartz, white, well rounded,
Quartz, gray, rough ,
Quartz, reddish, rounded,
Chert, brown, rounded,
Chert, gray, flaky and sharp, apparently from crushing of larger pebbles.
Miscellaneous dark chert and rocks, rounded,
Microcline, pink, subrounded,
A little sand.

Hot Bin #2 (intermediate):- Material practically identical to that in Hot Bin #3, except that average size is smaller -- not well sorted-- size ranges from about 3/8 inch gravel to sand size -- contains a little sand.

Hot Bin #1(finest):- Halved down to about 1/16 of original sample --this portion then sieved, giving:

> 1.000 mm. (plus 16 mesh)	Estim. 5 vols. or 32%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 1-1/2 vols. or 10%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 1 vol. or 6%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 3 vols. or 19%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim. 4 vols. or 26%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 7%

All sieving done by hand and in the dry; therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

\> 1.000 mm. Fraction:- Composition much the same as that of Hot Bins Nos. 2 and 3, but shell fragments make up 50% or more of the fraction -- also large proportion (perhaps 20-25%) of thin splinters and flakes of gray chert, almost certainly derived from crushing of larger pebbles -- these plus the shell give an unusually high proportion of flat fragments-- also small rounded grains of chert and quartz -- a little microcline.

< 1.000 > 0.500 mm. Fraction:- Same constituents as in > 1.000 mm. fraction -- somewhat fewer shell fragments, and more and better-rounded grains of quartz -- still a great many flakes and splinters of chert.

< 0.500 > 0.246 mm. Fraction:- About 50% thin, flat shell fragments-- remainder rounded to subangular, colorless, orange, and reddish quartz, with perhaps 10-15% of thin flakes and splinters of gray-brown chert -- no microcline observed.

< 0.246 > 0.124 mm. Fraction:- Chiefly rounded to angular, colorless, orange, and reddish quartz grains -- small (estim. 5% or less) proportion of shell splinters and flakes -- very few if any chert flakes (identification uncertain in this size) -- a very few black grains -- very fine silt adheres to some of the grains.

< 0.124 > 0.062 mm. Fraction:- Almost entirely very fine quartz sand-- subrounded to angular, colorless, pink, and reddish quartz -- a few (< 1%) shell splinters -- no chert flakes observed -- no other identifiable minerals --most grains look clean; some have adhering silt.

< 0.062 Fraction:- Silt -- almost all angular, colorless to pinkish quartz --a very few shell splinters (or possibly mica) -- an occasional black mineral --grains look fairly clean, but shaking and settling in water discloses a very little white clay -- effervescence in cold dilute HCl reveals some carbonate content (from shells?).

Table A-1 continued

Lot # 12, three cans.

Information from Labels:- District: 16. County: Nueces. Control: 74-6-44. Project: 137-'(14)001. Highway: IH 37. Limits: Peabody Street to Upriver Road in Corpus Christi, 1.4 miles. Contractor: So. Texas Const. Co. Type of Aggregate: Shell.

Hot Bin #3 (coarsest):- Composed entirely of crushed oyster shells -- from about 3/16 to 3/4 inch across -- plus considerable dust from them.

Hot Bin #2 (intermediate):- Similar to Hot Bin #3 -- chiefly crushed shell -- most chips from 1/8 to 1/4 inch, but considerable fines and dust -- the fines contain some white-coated sand, like that described below in Hot Bin #1.

Hot Bin #1 (finest):- Quartered down to about 1/16 of original sample -- this portion then sieved, yielding:

> 1.000 mm. (plus 16 mesh):-	Estim. 7-1/2 vols. or 19%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 7 vols. or 18%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 12 vols. or 30%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 10 vols. or 25%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim. 2-1/2 vols. or 6%
< 0.062 mm. (minus 250 mesh):-	Estim. 1 vol. or 2%

All sieving done by hand and in the dry -- therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed. -- fractions examined under binocular microsope.

> 1.000 Fraction:- Entirely shell fragments -- thin and flat--from about 1 mm. across to about 4x8 mm.

< 1.000 > 0.500 mm. Fraction:- Entirely shell fragments, mostly thin and flat.

< 0.500 > 0.246 mm. Fraction:- About 40% thin shell fragments -- about 60% sand, subangular to rounded -- nearly all sand grains are coated with white silt or clay or calcium carbonate -- some grains appear to be aggregates -- a few resemble foraminiferal tests.

Removal of $CaCO_3$ with hot dilute HCl shows residue to be about half sand and half gray-brown clay -- the sand, after washing out the clay, is chiefly colorless to milky quartz, angular to well rounded, with about 5% or more of orange to brown grains, and a very few opague grains resembling oxidized pyrite.

< 0.246 > 0.124 mm. Fraction:- Very similar to the next coarser fraction --30 or 40% thin flakes of shell, and the remainder white-coated sand.

< 0.124 > 0.062 mm. Fraction:- Similar to the last two next coarser fractions -- perhaps 25% splintery and platy shell fragments, and the remainder fine, white-coated sand.

Removal of $CaCO_3$ with hot dilute HCl shows residue to be about one third sand and two thirds (by volume after settling) gray-brown clay -- after washing out clay remainder is chiefly colorless to milky quartz -- angular to subrounded -- a few orange, brown, and black grains.

< 0.062 mm.:- White silt -- chiefly white-coated silt grains, with some splintery shell fragments -- removal of $CaCO_3$ with hot dilute HCl gives residue of gray-brown silt and clay.

Table A-1 continued

Lot # 13, three cans.

Information from Labels:- District 20. County: Hardin. Control: 339-4-10- Project: 339-4-10. Highway: State 105.

3 cans, marked respectively Rock, Screenings, Sand. Further information differs with each can.

Rock can:- Material: Rock. Producer: TCM, Burnet, Tex. Location: Burnet, Texas. Type of Aggregate: Rock. No hot bin mentioned.

Screenings can:- Material: Screenings. Producer: TCM, Helms, Tex. Location: Not shown. Type of Aggregate: Screenings. Remarks:- Hot bin sample.

Sand can:- Material: Sand. Producer: Jones pit. Location: Beaumont, Tex. Type of Aggregate: Sand. Remarks: Hot bin sample.

Rock Can:- (Coarsest):- Chiefly dolomite -- hard, fine to medium grained, pinkish -- angular pieces -- probably from Ellenburger formation.

A significant amount (possibly 5%) of flakes and splinters of gray chert, almost certainly from crushing of larger pieces.

A little (not over 1%)quartz -- rounded pebbles up to about 3/8" diam.

A few (less than 1%)pieces of limestone, -- white -- lithographic to sublithographic.

A little dust.

Screenings Can:- Chiefly dolomite, with a little lithographic limestone, as in the Rock Can -- somewhat higher proportions of chert flakes and of small gravel (rounded; contains both quartz and chert) -- considerable admixed sand.

Sand Can:- Quartered down to about 1/16 or original volume -- this portion then sieved, giving:

>1.000 mm.	(plus 16 mesh):-	Estim. 2 vols. or 10%
<1.000 >0.500 mm.	(minus 16, plus 32 mesh):-	Estim. 3 vols. or 15%
<0.500>0.246 mm.	(minus 32, plus 60 mesh):-	Estim. 7 vols. or 35%
<0.246 >0.124 mm.	(minus 60, plus 115 mesh):-	Estim. 4 vols. or 20%
<0.124 >0.062 mm.	(minus 115, plus 250 mesh):-	Estim. 3 vols. or 15%
<0.062 mm.	(minus 250 mesh):-	Estim. 1 vol. or 5%

All sieving done by hand and in the dry; therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed -- fractions examined under binocular microscope.

> 1.000 Fraction:- Contains

Dolomite, in sizes up to about 1/4 inch
Much chert, white, gray, brown, and red -- all flaky and splintery from crushing;
Quartz, angular, colorless,
Quartz, a few rounded grains, colorless to pink,
Microcline, occasional grains.

< 1.000 > 0.500 Fraction: - 50% or more is quartz, angular to well rounded, mostly colorless -- much of remainder is flakes and splinters of chert, gray to brownish -- also dolomite, pink to white, and a little limestone by cold HCl test -- no microcline observed.

< 0.500 > 0.246 Fraction:- Mostly quartz sand, subangular to well rounded, colorless to pinkish -- also a few chert flakes -- also a little dolomite by HCl test -- mostly clean sand, but fine silt adheres to some of the quartz grains.

< 0.246 > 0.124 Fraction:- Chiefly quartz, angular to well rounded, colorless, pink reddish -- also a very few chert flakes -- a little dolomite by HCl test -- a very few black grains -- no microcline observed-- mostly clean, but fine silt or dust adheres to some grains.

< 0.124 > 0.062 Fraction: - Nearly all quartz, angular to subrounded, colorless, white, orange, red -- a very few chert (?) flakes (identification uncertain in this size) -- a few black grains -- a little carbonate (apparently dolomite) by HCl test -- no mica observed -- some grains dusty.

< 0.062 Fraction:- chiefly quartz, mostly angular, some rounded; colorless, white, orange, red -- a few black grains -- no mica observed -- some carbonate shown by effervescence in cold, dilute HCl, increasing sharply on warming (dolomite) -- suspension in water shows a very little white clay or dust.

Table A-1 continued

Lot #14, four cans.

Information from Labels:- District 14, Williamson County. Project 8. Highway IH 35, 7.7 miles south of Bell County line to 3.3 miles north of Georgetown. Type of Aggregate: Limestone. Producer: Cecil Ruby Co., Inc. from Logan Pit. Date Sampled: 2/6/64.

Hot Bin #4 (coarsest):-

Chiefly limestone--moderately hard, white, fine grained, partly crystalline--a calcarenite composed of minute fossils (foraminifera), oolites, etc. cemented with calcite--minutely porous (absorbs water slowly) -- much dust from abrasion.

A few pieces of secondary calcite -- white to orange -- fine grained -- spongy and porous -- probably from small caverns in the rock.

A few pieces of lithographic limestone -- gray.

A few pieces of chert -- light gray to dark gray-probably from nodules in the limestone.

A small proportion (possibly 5%) of river gravel, more or less rounded-- brown chert, quartz, limestone, feldspar, and igneous and metamorphic rocks.

Hot Bin #3:- Essentially the same as Hot Bin #4, except for size-- contains only a little gravel -- some chert observed.

Hot Bin #2:- Essentially same composition as Hot Bins #3 and #4, but with higher proportion of river gravel than either -- gravel and chert together make up perhaps 15% of the sample.

Hot Bin #1:- (finest; contains much dust):- Label says "Field sand used in this mix from Colorado River in Austin".

Mixture of gray and brown particles, with much fines and dust -- reduced by quartering to about 1/16 of original volume -- this 1/16 then sieved, giving:

> 1.000 mm. (plus 16 mesh):-	Estim. 1-1/2 vols. or 20%
< 1.000 > 0.500 mm. (minus 16, plus 32 mesh):-	Estim. 1-1/2 vols. or 20%
< 0.500 > 0.246 mm. (minus 32, plus 60 mesh):-	Estim. 1-1/4 vols. or 17%
< 0.246 > 0.124 mm. (minus 60, plus 115 mesh):-	Estim. 1 vol. or 13%
< 0.124 > 0.062 mm. (minus 115, plus 250 mesh):-	Estim. 1 vol. or 13%
< 0.062 mm. (minus 250 mesh):-	Estim. 1-1/4 vols. or 17%

All sieving done by hand and in the dry; therefore finer fractions may be incompletely separated -- all percentages are merely visual estimates; fractions were not weighed --- fractions examined under binocular microscope.

> 1.000 mm. Fraction: - About 50% is same limestone as in Hot Bins nos. 2, 3, and 4 -- about 50% is fine river gravel, consisting of quartz, feldspar, chert, and rock fragments.

< 1.000 >0.500 Fraction: - Same as the preceding fraction except for size -- proportions of limestone and sand about the same (50-50) -- sand is more rounded than in > 1.000 fraction, but many grains show fresh splits as if they had been run through a crusher.

< 0.500 > 0.246 Fraction:- Composition nearly the same as the coarser fractions -- perhaps a little higher proportion of the river sand, which is more rounded than in the coarser fractions -- limestone dust adhering to the grains, especially to the limestone grains.

< 0.246 >0.124 Fraction: - Essentially the same -- so much limestone dust that character hard to determine -- after washing by decantation a small sample shows perhaps 30-40% of limestone grains -- more quartz in the river sand -- no mica.

<0.124 >0.062 Fraction: - Full of limestone dust -- after washing by decantation the very fine sand shows perhaps 60% of limestone grains, plus quartz, other minerals or rocks, and a few particles of black organic matter (it floats) -- no mica.

< 0.062 Fraction:- Very fine, dark gray silt and dust--treatment with dilute HCl and water shows much carbonate, some tarry organic matter, a little dark clay, and a fine silt of reddish and black minerals and quartz -- not magnetic -- no mica.

The mineralogical evaluations were made by Dr. Horace R. Blank, Professor of geology, Texas A&M University.

TABLE A-2

Tests on Samples of Surfacings
Removed from the Highways

Site	Age of Sample	Density gm/ml 77°F	Hveem Stability	Hveem Cohesion	Permeability to air,ml/in/min
1	Original Mix	-	32	156	-
	1 day	2.311	-	-	103.
	4 months	2.366	-	-	Impermeable
	1 year	2.358	-	-	"
2	Original Mix	-	41	154	-
	1 day	2.355	-	-	36.3
	2 weeks	2.390	-	-	2.1
	4 months	2.385	-	-	Impermeable
	1 year	2.410	-	-	"
3	Original Mix	-	50	389	-
	1 day	2.130	-	-	200.
	2 weeks	2.160	-	-	41.
	4 months	2.231	-	-	0.4
	1 year	2.235	-	-	Impermeable
4	Original Mix	-	31	63	-
	1 day	2.290	-	-	1.12
	2 weeks	2.296	-	-	0.53
	4 months	2.314	-	-	0.61
	1 year	2.326	-	-	Impermeable
6	Original Mix	-	36	90	-
	1 day	2.255	-	-	160.
	2 weeks	2.293	-	-	65.
	4 months	2.325	-	-	4.5
	1 year	2.326	-	-	Impermeable
7	Original Mix	-	42	134	-
	1 day	2.155	-	-	1820.
	2 weeks	2.240	-	-	272.
	4 months	2.269	-	-	46.
	1 year	2.264	-	-	Impermeable
8	Original Mix	-	50	214	-
	1 day	2.172	-	-	2260.
	2 weeks	2.206	-	-	473.
	4 months	2.239	-	-	49.
	1 year	2.245	-	-	10.9
9	Original Mix	-	32	287	-
	1 day	2.300	-	-	236.
	2 weeks	2.295	-	-	164.
	4 months	2.336	-	-	40.6
	1 year	2.355	-	-	Impermeable

Table A-2, Continued

Site	Age of Sample	Density gm/ml, 77°F	Hveem Stability	Hveem Cohesion	Permeability to air, ml/in/min
10	Original Mix	-	38	116-158	-
	1 day	2.282	-	-	129.
	2 weeks	2.322	-	-	61.5
	4 months	2.337	-	-	35.
	1 year	2.327	-	-	39.
11	Original Mix	-	36	126	-
	1 day	2.209	-	-	158.
	2 weeks	2.254	-	-	36.
	4 months	2.271	-	-	8.
	1 year	2.274	-	-	8.
12	Original Mix	-	51	159	-
	1 day	1.952	-	-	269.
	2 weeks	2.005	-	-	132.
	4 months	2.009	-	-	39.
	1 year	2.096	-	-	Impermeable
13	Original Mix	-	34	-	-
	1 day	2.245	-	-	14.
	2 weeks	2.264	-	-	Cracked
	4 months	2.258	-	-	41.
	1 year	2.305	-	-	13.
14	Original Mix	-	58	-	-
	1 day	2.128	-	-	1033.
	2 weeks	2.145	-	-	1380.
	4 months	2.159	-	-	588.
	1 year	2.183	-	-	1240.

TABLE A-3

RHEOLOGICAL PROPERTIES OF ORIGINAL AND RECOVERED ASPHALTS

				Sliding Plate Viscometer				Vacuum Capillary Tube				
Site	Producer	Age of Sample	Pen. @ 77°F	Vis. @ 77°F $S=5x10^{-2}sec^{-1}$	R.V.	Vis. @ 95°F $S=5x10^{-2}sec^{-1}$	R.V.	Vis. @ 140°F	R.V.	Vis. @ 275°F	R.V.	Lab. Oxid. R. V.
1	3	Original	84	$1.15x10^6$	-	$0.15x10^6$	-	1830	-	4.35	-	4.2
		Plant	66	$1.90x10^6$	1.65	$0.20x10^6$	1.35	2040	1.1	4.80	1.1	-
		1 day	52	$3.15x10^6$	2.7	$0.36x10^6$	2.4	3610	2.0	5.35	1.2	-
		4 months	39	$10.30x10^6$	8.95	$0.55x10^6$	3.7	6120	3.3	6.20	1.5	-
		1 year	36	$10.40x10^6$	9.1	$0.67x10^6$	4.5	7070	3.9	6.05	1.4	-
2	3(w)	Original	86	$0.90x10^6$	-	$0.09x10^6$	-	1410	-	3.35	-	2.7
		Paver	52	$1.90x10^6$	2.1	$0.24x10^6$	2.7	2450	1.75	4.15	1.25	-
		1 day	44.5	$2.80x10^6$	3.1	$0.31x10^6$	3.4	3200	2.3	4.35	1.3	-
		2 weeks	40.5	$3.20x10^6$	3.6	$0.39x10^6$	4.3	3340	2.4	4.65	1.4	-
		4 months	35	$8.35x10^6$	9.3	$0.45x10^6$	5.0	4510	3.2	4.90	1.45	-
		1 year	32	$12.00x10^6$	13.3	$1.06x10^6$	11.8	8210	5.8	6.00	1.8	-
3	8	Original	77	$0.98x10^6$	-	$0.13x10^6$	-	2650	-	9.95	-	2.7
		Plant	66	$2.30x10^6$	2.3	$0.30x10^6$	2.3	4340	1.6	12.85	1.3	-
		Paver	60	$2.65x10^6$	2.7	$0.35x10^6$	2.7	4930	1.8	12.70	1.3	-
		1 day	58.5	$2.78x10^6$	2.8	$0.34x10^6$	2.6	4980	1.9	12.30	1.2	-
		2 weeks	53	$3.50x10^6$	3.6	$0.54x10^6$	4.1	6690	2.5	13.55	1.35	-
		4 months	47	$5.94x10^6$	6.0	$0.59x10^6$	4.5	7865	3.0	14.40	1.45	-
		1 year*	-	-	-	-	-	-	-	-	-	-
4	11	Original	85	$1.17x10^6$	-	$0.13x10^6$	-	1620	-	2.60	-	2.7
		Plant	66	$1.96x10^6$	1.7	$0.23x10^6$	1.75	2270	1.4	3.20	1.2	-
		Paver	64	$2.06x10^6$	1.75	$0.26x10^6$	2.0	2400	1.5	3.35	1.3	-
		1 day	59	$2.36x10^6$	2.0	$0.28x10^6$	2.15	2520	1.55	3.85	1.5	-
		2 weeks	59	$2.56x10^6$	2.2	$0.38x10^6$	2.9	2790	1.7	3.60	1.4	-
		4 months	40.5	$11.40x10^6$	9.7	$0.98x10^6$	7.5	6130	3.8	4.25	1.6	-
		1 year	39.5	$12.40x10^6$	10.65	$1.06x10^6$	8.2	7570	4.7	4.40	1.7	-
6	7	Original	79	$0.96x10^6$	-	$0.11x10^6$	-	1150	-	2.45	-	6.35
		Plant	54.5	$2.50x10^6$	2.6	$0.22x10^6$	2.0	1955	1.7	3.10	1.25	-
		Paver	51	$2.60x10^6$	2.7	$0.23x10^6$	2.1	2010	1.75	3.20	1.3	-
		1 day	49	$3.00x10^6$	3.1	$0.25x10^6$	2.3	2215	1.9	3.25	1.35	-
		2 weeks	47	$5.35x10^6$	5.6	$0.46x10^6$	4.2	2500	2.2	3.35	1.4	-
		4 months	27	$20.80x10^6$	21.5	$1.06x10^6$	9.6	5820	5.1	4.40	1.8	-
		1 year	24.5	$23.60x10^6$	25.0	$1.52x10^6$	10.4	7650	6.6	4.70	2.0	-
7	15	Original	92.5	$1.00x10^6$	-	$0.11x10^6$	-	1165	-	2.75	-	3.2
		Plant	75	$1.75x10^6$	1.75	$0.17x10^6$	1.55	1660	1.4	3.35	1.2	-
		Paver	66	$1.85x10^6$	1.85	$0.24x10^6$	2.2	2060	1.75	3.55	1.3	-
		1 day	58	$2.85x10^6$	2.85	$0.31x10^6$	2.8	2430	2.1	3.70	1.35	-
		2 weeks	54	$4.35x10^6$	4.35	$0.33x10^6$	3.0	2960	2.5	3.75	1.35	-
		4 months	36.5	$13.20x10^6$	13.2	$0.86x10^6$	7.8	5370	4.6	4.45	1.6	-
		1 year	33.5	$14.50x10^6$	14.5	$1.28x10^6$	11.6	8100	6.9	5.00	1.8	-
8	7	Original	80	$0.86x10^6$	-	$0.11x10^6$	-	1160	-	2.40	-	5.1
		Plant	50.5	$2.35x10^6$	2.7	$0.34x10^6$	3.1	1990	1.7	3.00	1.25	-
		Paver	48	$2.40x10^6$	2.8	$0.22x10^6$	2.0	2040	1.8	3.00	1.25	-
		1 day	47	$2.80x10^6$	3.25	$0.38x10^6$	3.5	2200	1.9	3.10	1.3	-
		2 weeks	38.5	$6.56x10^6$	7.6	$0.47x10^6$	4.3	3320	3.0	3.45	1.4	-
		4 months	30.5	$12.40x10^6$	14.3	$0.73x10^6$	6.6	4560	3.9	3.90	1.6	-
		1 year	26	$15.00x10^6$	17.5	$1.04x10^6$	9.5	7390	6.4	4.46	1.85	-

* Contaminated sample

(w) This sample came from a different plant than did the other two samples from Producer No. 3.

TABLE A-3 (Cont.)

RHEOLOGICAL PROPERTIES OF ORIGINAL AND RECOVERED ASPHALTS

				Sliding Plate Viscometer				Vacuum Capillary Tube				
Site	Producer	Age of Sample	Pen. @ 77° F	Vis. @ 77°F $S=5x10^{-2}sec^{-1}$	R.V.	Vis. @ 95°F $S=5x10^{-2}sec^{-1}$	R.V.	Vis. @ 140°F	R.V.	Vis. @ 275°F	R.V.	Lab. Oxid. R. V.
9	3	Original	81.5	$1.18x10^6$	-	$0.17x10^6$	-	1870	-	4.00	-	4.7
		Plant	53.5	$2.85x10^6$	2.4	$0.34x10^6$	2.0	3860	2.1	5.30	1.3	-
		Paver	54.0	$2.82x10^6$	2.3	$0.43x10^6$	2.5	4090	2.2	5.55	1.4	-
		1 day	55.0	$2.80x10^6$	2.3	$0.41x10^6$	2.4	3910	2.1	5.60	1.4	-
		2 weeks	54.5	$5.56x10^6$	4.7	$0.48x10^6$	2.8	4970	2.7	5.95	1.5	-
		4 months	44.5	$8.76x10^6$	7.4	$0.84x10^6$	7.1	6710	3.6	6.40	1.6	-
		1 year	36.5	$12.00x10^6$	10.2	$1.44x10^6$	8.5	10,400	5.5	8.83	2.2	2
10	11	Original	88.5	$1.12x10^6$	-	$0.13x10^6$	-	1660	-	2.85	-	2.7
		Plant	82	$1.28x10^6$	1.15	$0.16x10^6$	1.2	2060	1.25	3.15	1.1	-
		Paver	71	$1.76x10^6$	1.55	$0.20x10^6$	1.55	2370	1.4	3.45	1.2	-
		1 day	68.5	$2.10x10^6$	1.9	$0.22x10^6$	1.7	2630	1.6	3.75	1.3	-
		2 weeks	56	$3.20x10^6$	2.85	$0.38x10^6$	2.9	3560	2.15	4.20	1.5	-
		4 months	41	$9.30x10^6$	8.3	$0.76x10^6$	5.8	6255	3.7	4.45	1.55	-
		1 year	33	$15.40x10^6$	13.8	$1.84x10^6$	14.1	16,690	10.0	6.10	2.1	-
11	6	Original	99.5	$0.565x10^6$	-	$0.53x10^6$	-	1110	-	2.70	-	3.2
		Plant	62.5	$1.45x10^6$	2.6	$0.14x10^6$	2.6	2020	1.8	3.45	1.25	-
		2 weeks	54	$2.05x10^6$	3.6	$0.20x10^6$	3.8	2440	2.2	3.80	1.4	-
		4 months	41	$8.60x10^6$	15.2	$0.34x10^6$	6.4	3570	3.2	4.20	1.55	-
		1 year	29.5	$12.40x10^6$	22.0	$0.63x10^6$	11.9	5610	5.1	4.75	1.75	-
12	2	Original	77	$0.86x10^6$	-	$0.088x10^6$	-	1190	-	2.25	-	3.2
		Plant	68	$1.20x10^6$	1.4	$0.116x10^6$	1.3	1430	1.2	2.80	1.1	-
		Paver	62	$1.40x10^6$	1.6	$0.130x10^6$	1.5	1780	1.5	2.95	1.15	-
		1 day	55	$2.05x10^6$	2.4	$0.196x10^6$	2.2	1995	1.7	3.15	1.25	-
		2 weeks	53.5	$2.20x10^6$	2.6	$0.210x10^6$	2.4	2175	1.8	3.17	1.25	-
		4 months	39.5	$4.95x10^6$	5.7	$0.400x10^6$	4.5	3340	2.8	3.70	1.45	-
		1 year	25.5	$13.20x10^6$	15.3	$0.690x10^6$	7.8	8775	7.4	5.16	2.0	-
13	5	Original	90	$0.81x10^6$	-	$0.074x10^6$	-	940	-	2.6	-	2.55
		Plant	59	$1.78x10^6$	2.2	$0.200x10^6$	2.7	1590	1.7	3.3	1.25	-
		Paver	57.5	$1.98x10^6$	2.5	$0.200x10^6$	2.7	1920	2.0	3.4	1.3	-
		2 weeks	52	$2.26x10^6$	2.8	$0.244x10^6$	3.3	1990	2.1	3.5	1.35	-
		4 months	48	$4.66x10^6$	5.75	$0.250x10^6$	3.4	2200	2.3	3.65	1.4	-
		1 year	30	$7.96x10^6$	9.85	$0.660x10^6$	8.9	5690	6.0	4.35	1.65	-
14	6	Original	98.5	$0.58x10^6$	-	$0.075x10^6$	-	1280	-	3.55	-	2.8
		Plant	76.5	$1.03x10^6$	1.8	$0.096x10^6$	1.3	1780	1.4	4.05	1.1	-
		1 day	70.5	$1.10x10^6$	1.9	$0.118x10^6$	1.55	1910	1.5	4.25	1.2	-
		4 months	52.5	$2.92x10^6$	5.0	$0.168x10^6$	2.25	2740	2.1	4.55	1.3	-
		1 year	37.5	$6.20x10^6$	10.6	$0.304x10^6$	4.05	3905	3.0	5.55	1.6	-

TABLE A-4

TEXAS HIGHWAY DEPARTMENT SPECIFICATIONS FOR ASPHALT CEMENTS - 1964

The material shall be homogeneous, shall be free from water, shall not foam when heated to 347°F and shall meet the following requirements:

SUGGESTED APPLICATION	Distributor		Plant Mix (Light)		Plant Mix (Heavy)		Plant Mix (Very Heavy)	
TYPE-GRADE	AC-5		AC-10		AC-20		AC-40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity at 275°F, stokes	1.5	---	2.0	---	3.0	---	4.0	---
Viscosity at 140°F, stokes	500	750	1000	1500	2000	3000	4000	6000
Solubility in CCl_4, %	99.5	---	99.5	---	99.5	---	99.5	---
Flash Point C.O.C., F	375	---	425	---	450	---	450	---
Ductility, 77°F, 5 cm.min, cm	100*	---	100	---	100	---	100	---
Relative Viscosity (after oxidation, 15μ films for 2 hours at 225°F, viscosities determined at 77°F)	---	4.0	---	4.5	---	5.0	---	6.0

*For AC-5 grade only, a minimum ductility value of 60 cm. at 60°F. will be acceptable in lieu of 100 cm. at 77°F.

TABLE A-5

RESEARCH REPORTS ISSUED FOR
PROJECT NO. 51 (NOW PROJECT 2-8-59-9)
FROM FEBRUARY, 1961, THROUGH AUGUST, 1965

Report No. 1 "Hardening of Paving Asphalts and Relation to Composition," February, 1961

Report No. 2 "Temperature-viscosity Data on Asphalt Cements," September, 1962

Report No. 3 "Antioxidants for Paving Asphalts," September, 1962

Report No. 4 "Susceptibility of Paving Asphalts to Hardening by Heat, Oxygen and Sunlight," October, 1962

Report No. 5 "Correlation of Composition with Rheology and Durability of Asphalts," December, 1962

Report No. 6 "Viscosity Data for Asphalts Used by the Texas Highway Department," July, 1963

Report No. 7 "Oxidation (Durability) Tests on Asphalts Used by the Texas Highway Department," August, 1963

Report No. 8 "Hardening of 85-100 Penetration Asphalt Cements During Service in Pavement," May, 1965