TESTS FOR AGGREGATES AND MINERAL FILLER

SPECIFIC GRAVITY AND ABSORPTION TESTS OF COARSE AND FINE AGGREGATES FOR USE IN THE DESIGN OF ASPHALT CONCRETE MIXTURES.

Reference - ASTM Designations: C 127 and C 128.

A. Purpose: Determine the bulk, apparent, and effective specific gravities, and absorption of coarse and fine aggregates. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body. The effective specific gravity was determined since the absorption of asphalt cement is an important factor in asphalt mixtures.

B. Equipment and Materials: Balance, wire basket, 500 ml. Flask, conical metal mold 1-1/2" in diameter at the top, 3" in diameter at the bottom, and 2-7/8" in height, metal tamping rod with a flat circular tamping face 1" in diameter, weighing 12 ounces, suitable balance and apparatus for suspending sample in water. 5 Kg. of coarse aggregates, where the nominal maximum size is 1-1/2 inches or less and all material is retained on the No. 4 sieve; 3 Kg. of fine aggregates, all particles passing the No. 4 sieve.

C. Test Procedure:

1. Coarse Aggregate:
   a. Select by quartering or use of a sample splitter approximately 5 Kg. of aggregate. Reject all material passing a No. 4 sieve.

   b. Thoroughly wash the sample to remove all dust or other coatings from the particles.

   c. Dry the sample to a constant weight at a temperature of 100^0 to 110°C (212° to 230°F). Cool at room temperature for about 15 minutes and then immerse in water at room temperature for approximately 1/2 hour.

   d. Remove sample from water and wipe the particles until all surface films are removed. Weigh the sample in this saturated surface dry condition to the nearest 0.5 grams.

   e. Immediately after weighing, place the sample in a wire basket, suspend in water, and obtain the bouyant weight.

   f. Dry the sample to a constant weight at a temperature of 100^0 to 110^0C(212^0 to 230^0F). Cool at room temperature for at least 1/2 hour and weigh.

g. Computations

A = weight of oven-dry sample in air, grams
B = weight of saturated-surface-dry sample in air, grams
C = weight of saturated sample in water, grams

i) Bulk Specific Gravity = $\frac{A}{B - C}$

ii) Apparent Specific Gravity = $\frac{A}{A - C}$

iii) Absorption in Percent = $\frac{(B - A) \times 100}{A}$

2. Fine Aggregate:

a. Obtain by sample splitting or quartering 3,000 grams of aggregate, including equal quantities of all fractions.

b. Dry to a constant weight at a temperature of 100^0 to 110^0C (212^0 to 230^0F).

c. Allow to cool and cover with water for about 1/2 hour.

d. Remove excess water and spread on a flat surface. Expose to a gentle moving flame until test sample approaches a free-flowing condition.

e. Place a portion of the fine aggregate sample loosely into the mold. Tamp lightly 25 times and lift the mold vertically. If surface moisture is present, the fine aggregate will maintain its molded share. Continue drying and testing until upon removal of the mold, the aggregate slumps slightly. This indicates that the saturated, surface-dry condition has been reached.

f. Immediately introduce into the flask <u>500.0 grams</u> of the fine aggregate. Fill the flask almost to capacity and eliminate the air bubbles by agitation. Determine the total weight of the flask, including the sample, and the water.

g. Carefully remove the fine aggregate and dry to a constant weight at 100^0 to 110^0C (212^0 to 230^0F). Cool for at least 1/2 hour and weigh.

h. Computations:

A = weight of oven-dry sample in air, grams
B = weight of pycnometer filled with water, grams
C = weight of pycnometer with sample and water, grams

i) Bulk Specific Gravity = $\frac{A}{B + 500 - C}$

ii) Apparent Specific Gravity = $\frac{A}{B - C + A}$

iii) Absorption, Percent = $\frac{(500 - A) \times 100}{A}$

3. Special Instructions:
   a. Determine the specific gravities for three samples of both the the coarse and fine aggregates. Test the fourth sample, if necessary, in order to obtain three sets of results that vary from each other by no more than 2%. If these precisions are not met, rerun the entire test.

   b. Effective Specific Gravity, determined in the design of asphalt concrete mixtures, should approximately equal

$$\frac{\text{Bulk Specific Gravity} + \text{Apparent Specific Gravity}}{2}$$

   Because of the greater viscosity of liquid asphalt cement in comparison to water, less of the aggregate voids are filled. For a more complete explanation see Equation 2 on page 155.

D. Explanation of Computations and Data Sheets:

1. Computations: these were explained separately under Section C: Test Procedure, for both the coarse and fine aggregates.

2. Data Sheet: Specific Gravity Data Sheet, Page 16 - for both the fine and course aggregates the last value obtained in the laboratory will be A) the weight of the Oven Dry Sample. Once the saturated surface dry condition is obtained and weighed, value C) is determined which is in effect a measure of bouyancy. In the case of the coarse aggregate, C) is obtained directly. To get the value A), the aggregates are placed in an oven and dried to a constant weight. B, the saturated-surface-dry condition of the aggregates, is determined according to the procedures outlined in Section C.1.d. for coarse aggregates and Section C.2.e. for fine aggregates. The four values, bulk, apparent, and effective specific gravities and absorption are then computed for each sample. Based upon the results a decision needs to be made as whether or not to test the fourth sample for either or both of the aggregates. The final step is to determine the accepted results by averaging the values of those samples that fall within the guideline criteria as explained in Section C.3.a.. These values will then be used in the various mix design computations. It is for this reason that obtaining accurate specific gravities is so important. Do not hesitate to redo the entire procedure if the results are questionable.

COARSE and FINE AGGREGATES SPECIFIC GRAVITY DATA SHEET
ASTM Designations: C 127 and C 128

<table>
<tr><td colspan="5">Coarse Aggregates - ASTM Designation: C 127</td></tr>
<tr><td>Passing ____ Sieve & Retained on ____ Sieve</td><td>Sample 1</td><td>Sample 2</td><td>Sample 3</td><td>Sample 4</td></tr>
<tr><td>A) Wt. Oven Dry Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B) Wt. SSD Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C)Wt. Saturated Sample in Water, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bulk Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Apparent Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Effective Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Absorption, %</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Average Values: Bulk Sp Gr. = ; Apparent Sp. Gr. = ;
Effective Sp. Gr. = ; Absorption = .</td></tr>
<tr><td colspan="5">Fine Aggregates - ASTM Designation: C 128</td></tr>
<tr><td>A) Wt. Oven Dry Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B) Wt. Pycnometer+Water to Calibration Mark, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C) Pycnometer+Water+Sample to Calibration Mark, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bulk Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Apparent Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Effective specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Absorption, %</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Average Values: Bulk Sp. Gr. = ; Apparent Sp. Gr. = ;
Effective Sp. Gr. = ; Absorption = .</td></tr>
</table>

RESISTANCE to DEGRADATION of SMALL-SIZE COARSE AGGREGATE by ABRASION and IMPACT in the LOS ANGELES MACHINE

Reference - ASTM Designation: C 131

A. Purpose: The test is to determine the ability of coarse aggregate smaller than 37.5mm (1-1/2") to resist abrasion, using the Los Angeles Testing Machine.

B. Equipment and Materials: Los Angeles Testing Machine (details shown on the next page), sieves following specifications in ASTM Designation: E 11, abrasive charge in accordance with the table below, and test samples in accordance with the table below.

C. Test Procedure: Select the proper amount of aggregate and abrasive charge in accordance with the following tables:

Table of Abrasive Charge

Grading	Number of Spheres	Weight of Charge in Grams
A	12	5,000 ± 25
B	11	4,584 ± 25
C	8	3,330 ± 20
D	6	2,500 ± 15

The abrasive charge consists of steel spheres approximately 47.6mm (1-7/8") in diameter, each ball weighing between 390 and 445 grams.

Table Showing the Grading of Test Samples

Sieve Sizes from ASTM Designation: E 11		Weight of Indicated Size in Grams Aggregate Grading			
Passing	Retained On	A	B	C	D
37.5mm(1.5")	25.0mm(1")	1,250±25			
25.0mm(1")	19.0mm(3/4")	1,250±25			
19.0mm(3/4")	12.5mm(.5"	1,250±25	2,500±10		
12.5mm(1/2")	9.5mm(3/8"	1,250±25	2,500±10		
9.5mm(3/8")	6.3mm(1/4")			2,500±10	
6.3mm(1/4")	4.75mm(#4)			2,500±10	
4.75mm(#4)	2.36mm(#8)				5,000±10
	Total	5,000±10	5,000±10	5,000±10	5,000±10

Test Procedure Continued: Place the test sample and the abrasive charge in the Los Angeles Abrasion Machine. The machine should rotate at a speed of 30 to 33 rpm for 500 revolutions. After the prescribed number of revolutions, the material shall be discharged from the machine. Separate the aggregates on a 1.7mm (No.12) sieve. Carefully weigh the material retained on the 1.7mm (No.12) sieve to the nearest whole gram.

D. Explanation of Computations and Data Collection:

1. Calculate the difference between the original sample weight and that retained on the 1.7mm (No.12) sieve. Express that value as a percentage of the original sample weight. This value is considered as the percentage of wear.

2. There are no special data sheets. Simply follow the instuctions in the Procedure for Data Collection.

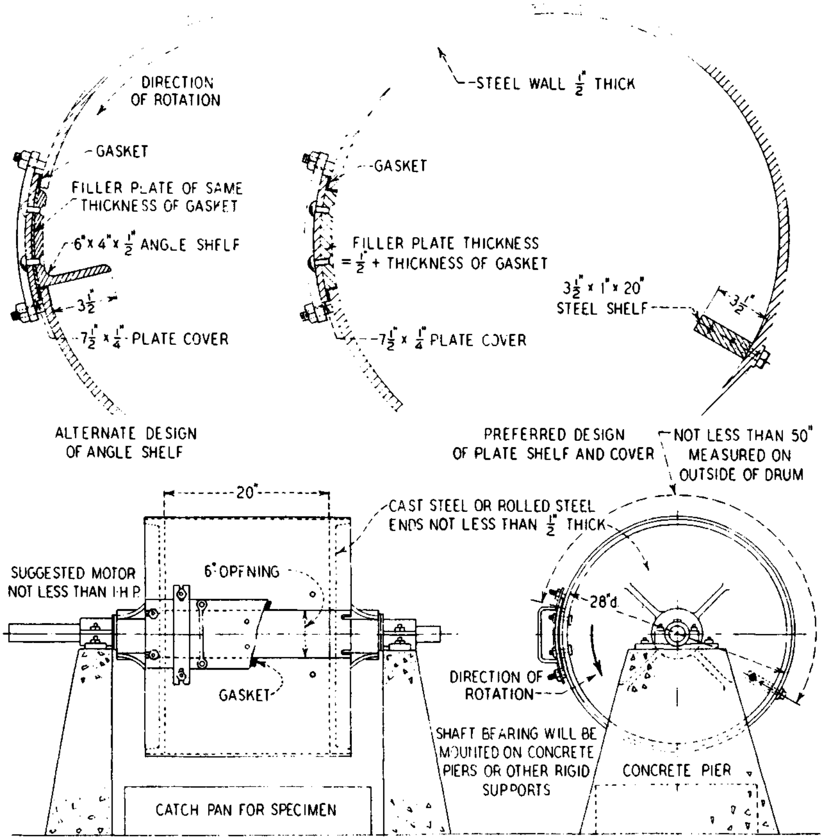

Figure 3 - Los Angeles Testing Machine
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SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES
Reference - ASTM Designation: C 136
and
MATERIAL FINER THAN #200 by WASHING
Reference - ASTM Designation: C 117

A. Purpose: Determination of the particle size distribution of fine and coarse aggregates by sieving.

B. Equipment and Materials: Balance, sensitive to within 0.1 per cent of the weight of the sample to be tested; standard sieves for grading of fine agregates - No. 4, 8, 16, 30, 50, & 100; standard sieves for grading coarse aggregates 2, 1-1/2, 1, 3/4, and 3/8 inch, plus a No. 4 sieve; fine (0.5 kg) and coarse (2 to 20 kg depending upon maximum size from 3/8" to 2") aggregate samples.

C. Test Procedure:

1. Samples - Use dry aggregates from the specific gravity and absorption tests of coarse and fine aggregates.

2. Continue the sieving until not more than 1% by weight of the residue passes any sieve during 1 minute.

3. For the wet analysis procedure (ASTM C 117), after weighing the dry aggregates, cover with water, agitate, and pour off the wash water containing suspended particles. Repeat until the wash water is clear. Dry the aggregates a second time at $110^0 \pm 5^0$ C ($230^0 \pm 9^0$ F) and weigh.

D. Explanation of Computations and Data Sheets:

1. Computations: On page 20, Sieve Analysis for Fine and Coarse Aggregate, calculate percentages on the basis of the total weight of the sample. Compute the per cent of material retained on each sieve and the per cent of material finer than for each sieve size for both the coarse and the fine aggregates. Follow the procedure at the bottom of the table on page 21 for the determination of all minus #200 mineral aggregates by the wet analysis. Plot the results on the Gradation Charts, Page 22 which is a semilog scale and/or Page 23 which are the sieve sizes raised to the 0.45 power. Both graphs are commonly used to help select the best aggregate blend. On both graphs the ordinate is the total percent by weight passing a given size on an arithmetic scale. If you are blending an asphalt concrete mix design from several aggregate sources, compute the combined gradation by following the form on Page 24. The 0.45 exponent FHWA graph is very convenient for determining the maximum density line and then adjusting the aggregate gradation accordingly. The maximum density lines can easily be obtained by drawing a straight line

from the origin at the lower left hand corner to the 100 percent passing point of the maximum nominal size aggregate. Plot the midband gradation line on this graph. It is generally considered best when this gradation line is parallel to the maximum density line and a few percentages above or below it in order for the asphalt mix to have sufficient air voids. VMA increases as the gradation line moves away from the maximum density line. A poor aggregate gradation will adversely affect almost all the critical properties of a hot mixed asphalt concrete.

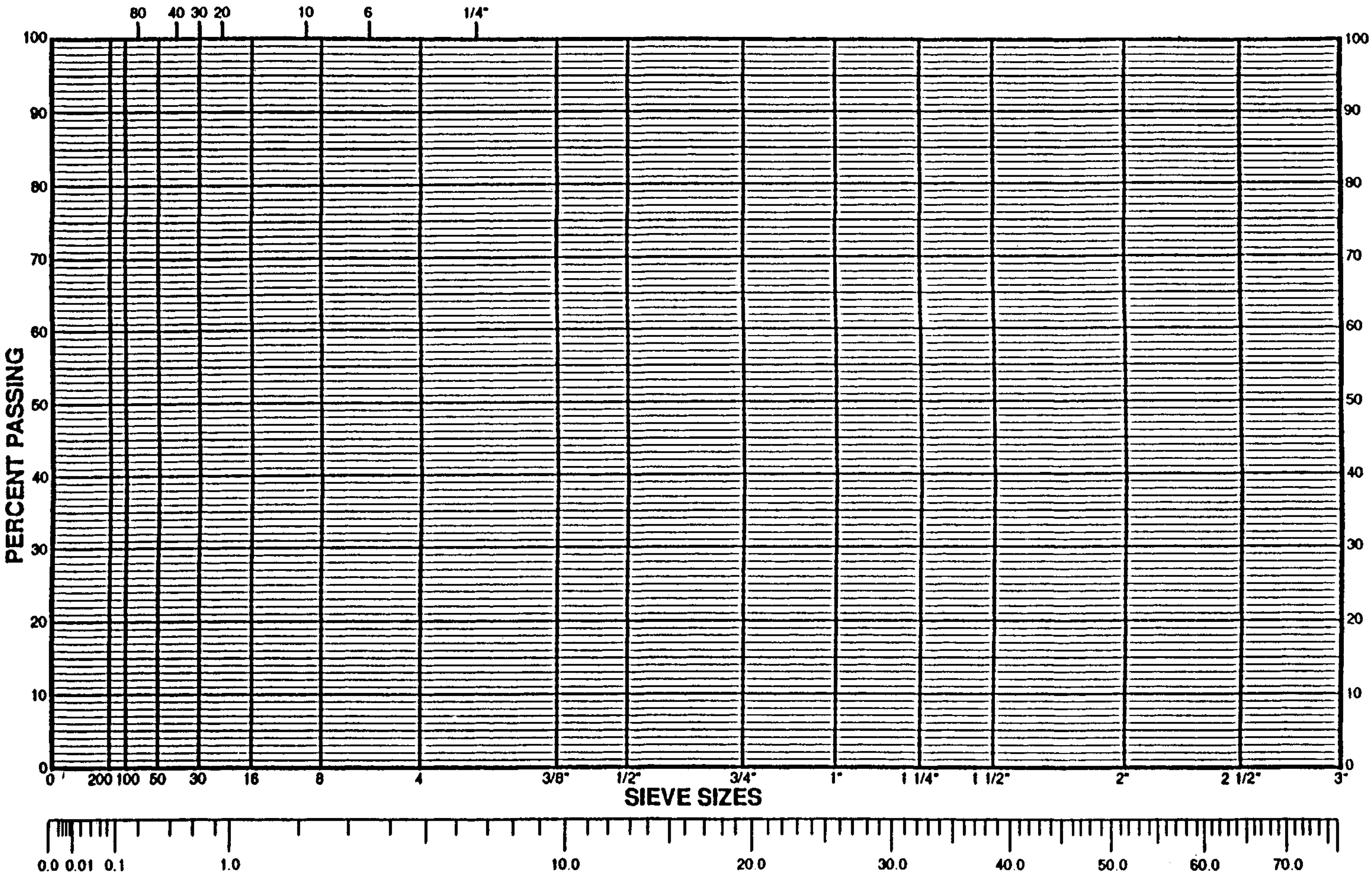
2. Data Sheets: for dry Sieve Analysis for Fine and Coarse Aggregate use the data sheet below; for the wet sieve analysis use the data sheet on Page 21; Gradation Charts, Pages 22 and 23; and Aggregate Blend Design for Bituminous Paving Mixtures, Page 24.

SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)

DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			

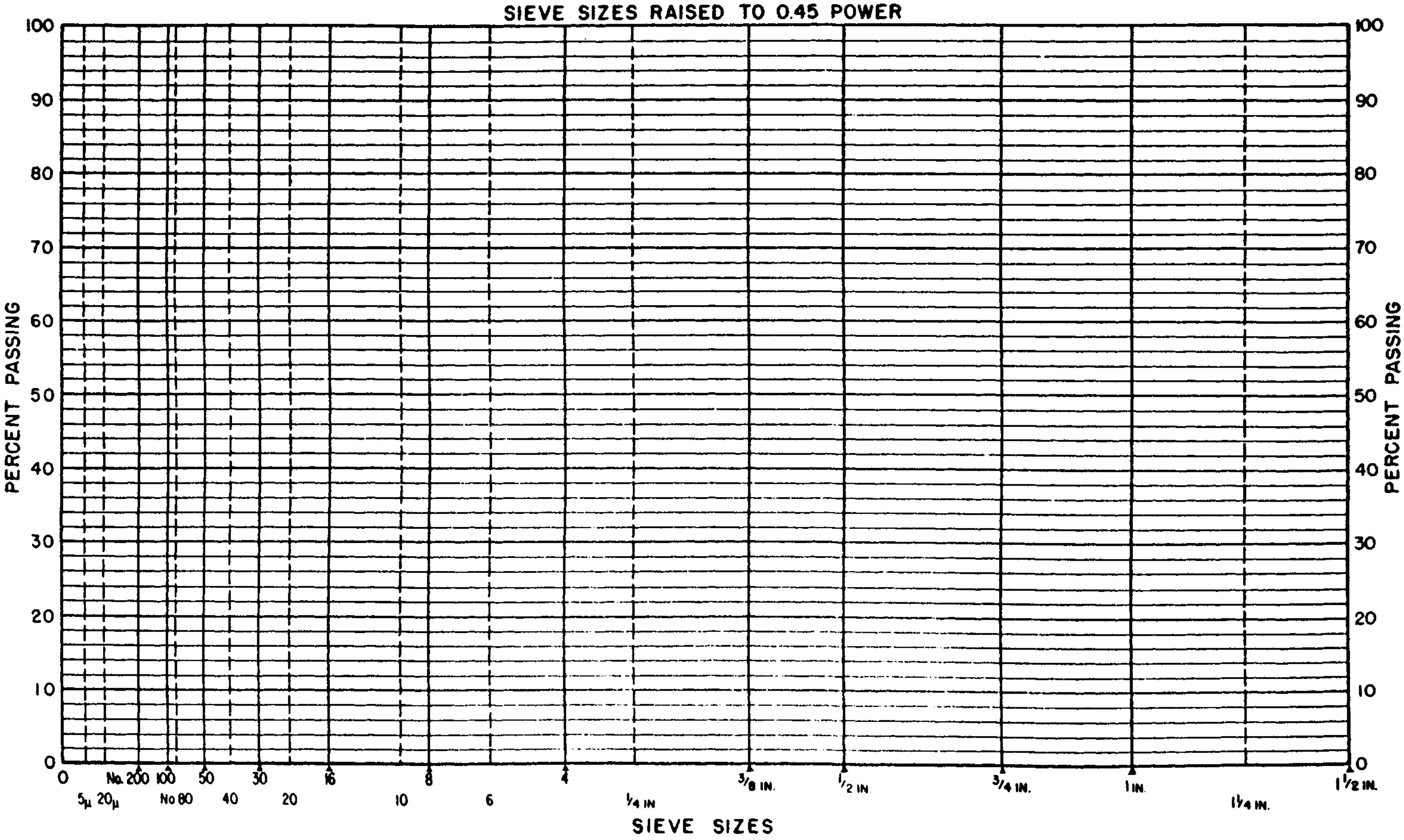
SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)
and
MINERAL AGGREGATES by WASHING (ASTM C 117)

WASH and DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			
a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -				a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -			



Millimeter Gradation Chart.

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



COMBINED GRADATION FORM

Material	No. 1		No.2		No.3		No.4		Combined Gradation	Target Value	Specification Limits
% in Mix											
U. S. Sieves	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch			
2											
1 1/2											
1											
3/4											
1/2											
3/8											
No. 4											
No. 8											
No. 16											
No. 30											
NO. 50											
No. 100											
No. 200											

Aggregate Blend Design for Bituminous Paving Mixtures.

CLAY LUMPS and FRIABLE PARTICLES in AGGREGATES

Reference - ASTM Designation: C 142

A. Purpose: Clay and friable particles may be present in the form of lumps in natural aggregates. If they are near the surface, these lumps can cause pitting under the influence of traffic. Specifications frequently limit these particles to a maximum of 1 percent

B. Apparatus and Materials: weighing device accurate to 0.1%, flat pans for speading the test specimens in a thin layer, sieves as called for in the Testing Procedure, drying oven capable of maintaining a free circulating air temperature of 110 ± 5^0C (230 ± 9^0F), and test samples as called for.

C. Testing Procedure:

1. Test samples shall be prepared in accordance with ASTM Designation: C 117 and after oven drying at 110 ± 5^0C (230 ± 9^0F), shall consist of the following quantities:

Fine aggregates shall consist of particles retained on a 1.18 mm (No.16) sieve and weigh at least 25 grams.

Coarse aggregate sizes and minimum quantites per sample are as follows:

Size of Particles Making up Test Sample	Minimum Weight of Test Sample in grams
4.75 to 9.5 mm (No.4 to 3/8 inch sieves)	1,000
9.5 to 19.0 mm (3/8 to 3/4 inch sieves)	2,000
19.0 to 37.5 mm (3/4 to 1 1/2 inch sieves)	3,000
Retained on 37.5 mm (1 1/2 inch sieve)	5,000

where the test sample consists of both fine and coarse aggregates, the material is separated on a 4.75 mm (No.4) sieve. The fine and coarse fractions are then handled as above.

2. The weighed specimens are spread in a thin layer on the bottom of a container and covered with distilled water for about 24 hours.

3. Roll and squeeze the individual particles between the thumb and forefinger. Try to break down the particles but only with the thumb and forefinger. Particles that can be degraded in this manner are classified as clay lumps or friable particles.

4. The detritus is separated from the remainder of the sample by wet sieving in the manner prescribed in the table below:

Size of Particles Making up Test Sample	Size of Sieve for Removing Residue Particles
Fine Aggregate	850-μm (No.20)
4.75 to 9.5 mm (No.4 to 3/8 inch)	2.36 mm (No.8)
9.5 to 19.0 mm (3/8 to 3/4 inch)	4.75 mm (No.4)
19.0 to 37.5 mm (3/4 to 1 1/2 in.)	4.75 mm (No.4)
Over 37.5 mm (1 1/2 inches)	4.74 mm (No.4)

Agitate the sieve during the wet sieving operation to assure removal of all undersized particles.

5. Remove the retained particles and dry to a constant weight in the oven at a temperature of 110 ± 5^0C (230 ± 9^0F). Allow the aggregates to cool and weigh to nearest 0.1%.

D. Explanation of Computations and Data Collection:

1. Computation: $P = [(W - R)/W] \times 100$

P = % of clay lumps and friable particles.

W = weight of the test sample.

R = weight of particles retained on the designated sieve in wet sieving.

For coarse aggregates P shall be based upon the weighted average of the clay lumps and friable particles in each sieve size fraction. Any coarse aggregate fraction that is less than 5% of the total gradation shall not be tested separately. That coarse aggregate fraction shall be assumed to contain the same % of clay lumps and friable particles as that found in the next larger or smaller coarse aggregate fraction.

2 Data Collection: there is no prescribed format for data collection. Simply follow the instructions for recording the data in the Test Procedure.

DENSITY of HYDRAULIC CEMENT

Reference - ASTM Designation: C 188

A. Purpose: Determination of the density of mineral filler in connection with the design of asphalt concrete mixtures.

B. Apparatus and Materials: Standard Le Chatelier Flask, heavy rubber pad about 12" x 12" square, lead-ring weight to fit around stem of the flask, funnel, thermometer, Portland Cement or other mineral filler, and kerosene.

C. Testing Procedure:

1. Fill the flask with kerosene to a mark on the stem between the 0 and the 1 cm mark. Dry the inside of the flask if there are any drops above the liquid level.

2. Place the flask in a constant temperature bath and record the initial height of the kerosene in the flask. The constant-temperature bath should be maintained at a temperature such that its temperature variation between the initial and final readings within the flask should not vary by more than 0.2^0C.

3. Carefully introduce about 64 grams of cement, weighed to the nearest 0.1 grams. Try to avoid the cement adhering to the inside of the flask or sticking to the neck. The cement should be introduced slowly through a funnel. Place the stopper on the flask.

4. Remove the flask from the bath and place it on the rubber mat. Take off the lead weight and manipulate the flask on the mat so as to remove all air bubbles from the flask.

5. Return the flask to the bath and check the temperature within the flask. If it is within 0.2^0 C of the original temperature inside the flask, take the final reading.

D. Explanation of Computations and Data Sheet:

1. Computations: Density, p = mass of cement/displaced volume

Conduct the density determination on two samples of cement. If they do not differ by more than 0.03 gr/cm, take the average. Otherwise run 3 additional determinations until a pair of valves are obtained within 0.03gr/cm^3.

2. Data Sheet: record the readings and complete the data sheet, shown on the next page.

DATA SHEET for DETERMINATION of PORTLAND CEMENT SPECIFIC GRAVITY (ASTM C 188)

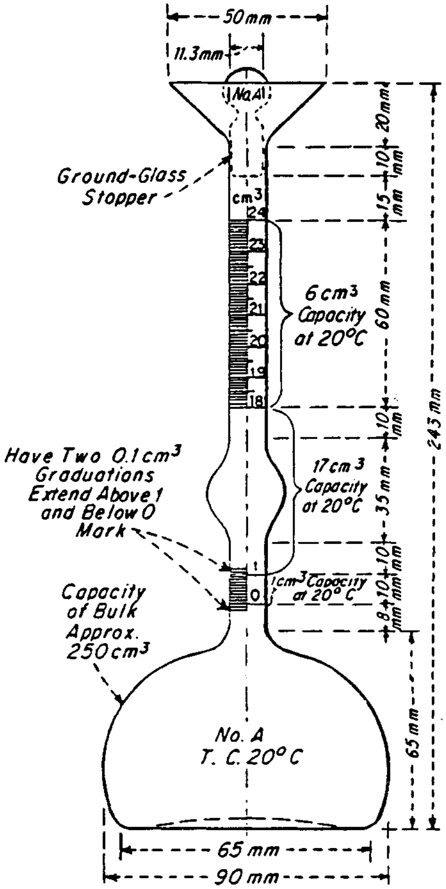
	Specimen Numbers				
	1	2	3	4	5
Initial Bath Temp., ^0C					
Final Height, cm					
Initial Height, cm					
Displaced Volume, cm^3					
Final Bath Temp., ^0C					
Specific Gravity = 64 grams/displacement, cm^3					

Average Specific Gravity of accepted specimen results =

DATA SHEET for DETERMINATION of PORTLAND CEMENT SPECIFIC GRAVITY (ASTM C 188)

	Specimen Numbers				
	1	2	3	4	5
Initial Bath Temp., ^0C					
Final Height, cm					
Initial Height, cm					
Displaced Volume, cm^3					
Final Bath Temp., ^0C					
Specific Gravity = 64 grams/displacement, cm^3					

Average Specific Gravity of accepted specimen results =



NOTE—Variations of a few millimetres in such dimensions as total height of flask, diameter of base, etc., are to be expected and will not be considered sufficient cause for rejection.

Figure 4 - Le Chatelier Flask for Density Determination of Mineral Filler.
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SAND EQUIVALENT VALUE of FINE AGGREGATE

Reference - ASTM Designation: D 2419

A. Purpose: To determine the percent of undesirable particles in the fine aggregate fraction used in the design of asphalt or Portland Cement concrete mixtures. The method is also applicable for determining the relative proportions of detrimental fine dust or clay-like material in soils.

B. Equipment and Materials: The Sand Equivalent test kit consists of a graduated plastic cylinder, a rubber stopper, an irrigation tube, a weighted foot assembly and a siphon assembly, 3.78-liters (1-gallon) bottle, four measuring tins having a diameter of approximately 57 mm (2 1/4 inches) and a capacity of 85 ± 5 ml., funnel, stop watch, mechanical sand equivalent shaker, stock calcium chloride solution, 4.75-mm (No.4) sieve, and fine aggregate.

C. Test Procedure:

1. Prepare fine aggregate passing a 4.75-mm (U.S. standard No.4) sieve, oven dried and room temperature condition, before testing. Quarter by splitting approximately 1,500 grams. Moisten each specimen slightly to prevent loss of fines and mix each specimen thoroughly. Place each of the four specimens in a closed can.

2. Siphon 101.6 ± 2.54 mm (4 ± 0.1 inch) of working calcium chloride solution into the plastic cylinder. Pour one of the prepared specimens into the plastic cylinder, using the funnel to avoid spillage. Tap the bottom of the cylinder sharply by hand to release any air bubbles. Allow the material to stand for about 10 minutes.

3. Place the stopper on the cylinder and vigorously shake it manually to loosen the material. Place the cylinder in the mechanical sand equivalent shaker, set the timer and allow the machine to run for 45 seconds. Remove the cylinder from the mechanical shaker, remove the stopper, and set it upright on the table.

4. Insert the irrigator tube in the cylinder and rinse material from the inside surface as it is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle, stabbing, and twisting action, while the working solution flows from the irrigator tip. This action flushes the fine particles into the suspension above the coarser sand sizes. Continue this irrigation process until the cylinder is filled to the 381 mm (15-inch) mark.

5. Raise the irrigator slowly without shutting off the flow so that the liquid level is maintained at about 381 mm (15 inches) while the irrigator is being withdrawn. Regulate the flow just before the irrigation is entirely withdrawn and adjust the final level to 381 mm (15 inches).

6. The flow is supplied through the siphon assembly to a 3.78-liters (1 gallon) bottle of working calcium chloride solution placed on a shelf about 1 meter (3 feet ± 1) inch above the work surface. Allow the cylinder to now stand undisturbed for 20 minutes. Start the timing immediately after withdrawing the irrigator tube. At the end of the 20-minute sedimentation, read and record the top of the clay suspension. This is referred to as the "clay reading. If no clear line of demarcation has formed at the end of the 20-minute period, allow the cylinder to stand undisturbed until a clay reading can be obtained. Immediately read and record the level of the top of the clay suspension and the total suspension time. If the total sedimentation time exceeds 30 minutes, rerun the test on the other prepared samples of the same material. Read and record the clay column height of the specimen requiring the shortest sedimentation period only.

7. After the clay reading has been taken, place the weighted foot assembly into the cylinder and lower it gently until it comes to rest on the top of the sand. Be careful not to hit the mouth of the cylinder with the weighted foot assembly. Tip the assembly toward the graduations on the cylinder until the indicator touches the inside wall of the cylinder. Subtract 254 mm (10 inches) from the level indicated by the extreme top edge of the indicator and record this as the "sand reading". Do not apply pressure to the assembly at any time.

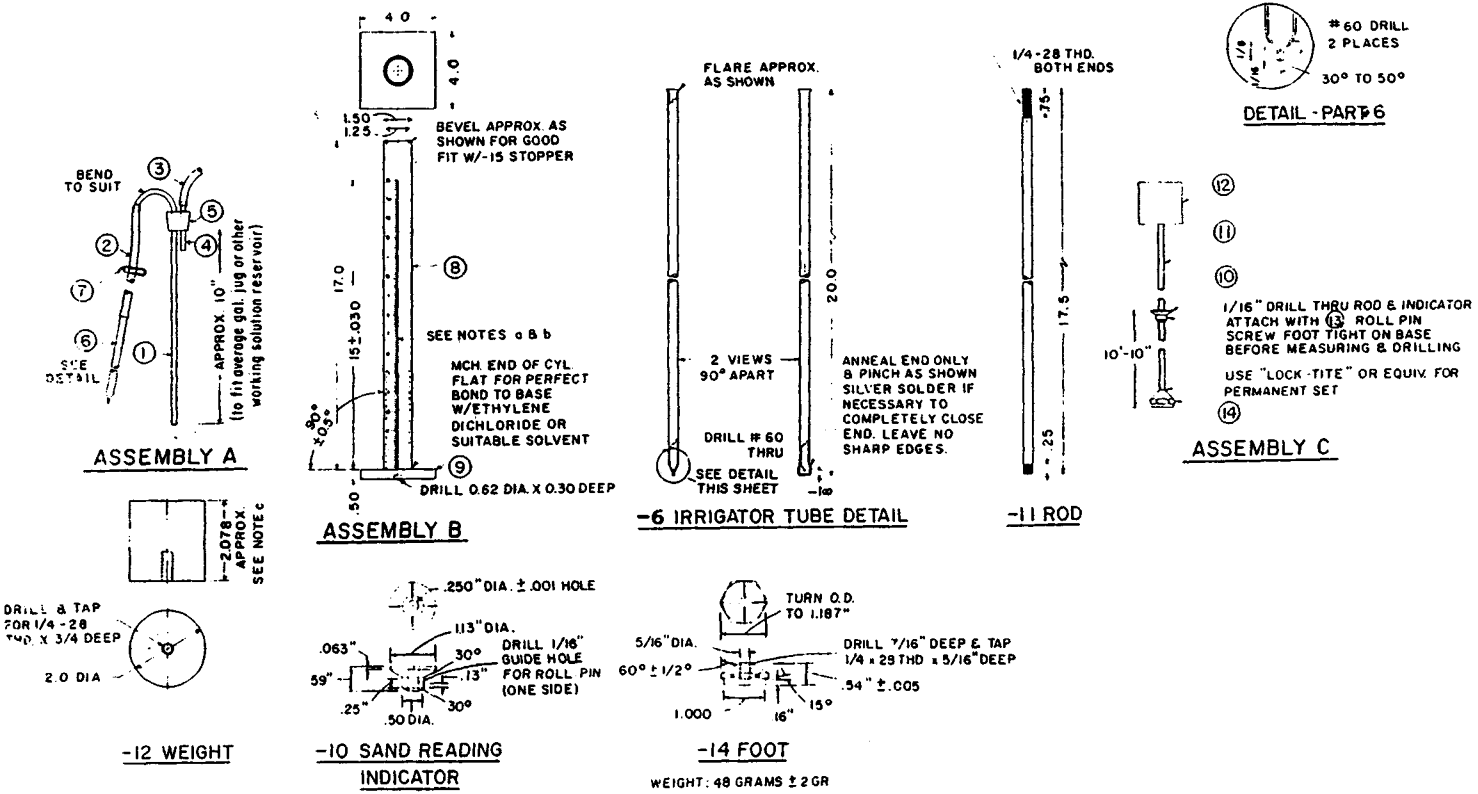
D. Explanation of Computations and of Data Sheet:

1. Computations: Report the result in %, always carrying the SE up to the next higher whole number (do not use any decimals). If more than one SE test is made, take the average of each whole number value for each test specimen to the next higher whole number. Use 2.5 mm (one-tenth of an inch) as the smallest unit for the readings and always use the higher graduation if the readings fall between one-tenth inch marks. Calculate the sand equivalent to the nearest 0.1% using the following formula:

$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100\%$$

Cleaner aggregates will have a higher SE value. Specifications generally call for a minimum SE in the order of 25 to 35 percent.

2. Data Sheet: no special data sheet has been devised for this test.



NOTE—The sand reading indicator and foot specified by ASTM Method D 2419 - 69. Fig. 1, may be used where this equipment is previously available

Figure 5 - Sand Equivalent Test Apparatus.
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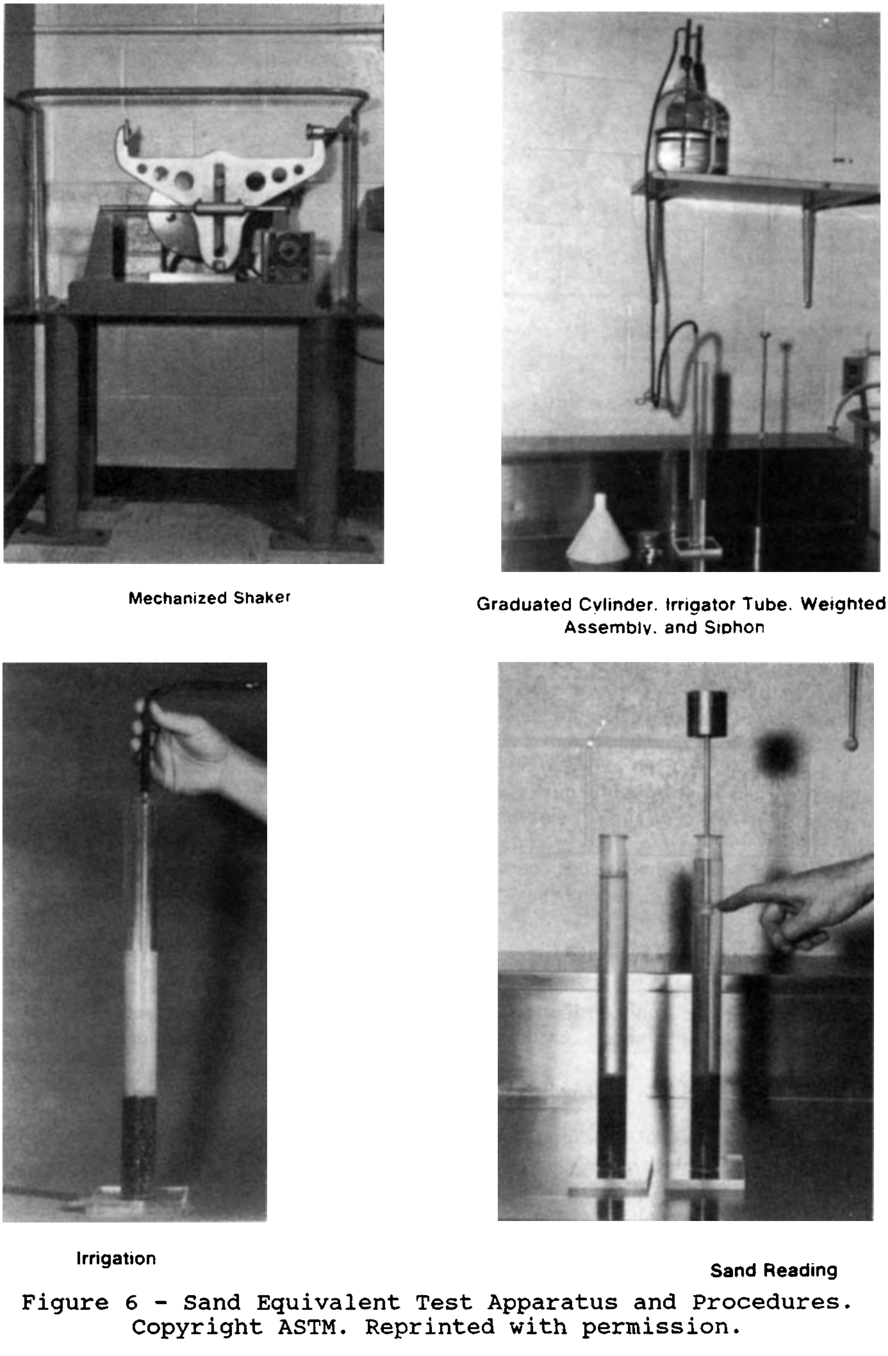

Mechanized Shaker

Graduated Cylinder, Irrigator Tube, Weighted Foot Assembly, and Siphon

Irrigation

Sand Reading

Figure 6 - Sand Equivalent Test Apparatus and Procedures. Copyright ASTM. Reprinted with permission.

INDEX of AGGREGATE PARTICLE SHAPE and TEXTURE

Reference - ASTM Designation: D 3398

A. Purpose: This method covers the determination of the particle index of aggregate as an overall measure of particle shape and texture. The procedure, as described below, applies to aggregates with a maximum size of 19.05 mm (3/4 inch). For larger particle sizes bigger molds of approximately the same diameter to height ratios should be used. Also there should be a proportional increase in the number of rodding strokes used so that the compaction energy per volume of material is approximately constant. For testing of fine aggregate, that is material passing the 4.75 mm (No.4), a smaller mold of proportional dimensions and rodding stokes per layer may be used.

B. Equipment and Materials:

1. Cylindrical Mold, made of a sufficient steel thickness to withstand rough usage, with an inside diameter of 152 ± 0.13 mm (6.000 ± 0.005 inches) and an inside height of 177.80 ± .013 mm (7.000 ± 0.005 inches) as shown in Figure 7.

2. Steel Tamping Rod of 15.88 ± 0.25 mm (0.625 ± 0.01 inches) in diameter and approximately 610 mm (24 inches) in length. The tamping end should be rounded to a hemispherical tip.

3. Scale of at least 15-kg capacity, accurate to within 4 grams.

C. Test Procedure:

1. Carefully determine the volume of the cylindrical mold by filling with water and weighing.

2. Obtain a quantity of aggregate sample such that at least 6 kg (13 lbs.) of each size as shown in the table below is available for testing. Aggregate sizes which are less than 10% of the total gradation need not be tested.

Passing	Retained
19.0 mm (3/4 inch)	12.5 mm (1/2 inch)
12.5 mm (1/2 inch)	9.5 mm (3/8 inch)
9.5 mm (3/8 inch)	4.75 mm (No.4)
4.75 mm (No.4)	2.36 mm (No.8)
2.36 mm (No.8)	1.18 mm (No.16)
1.18 mm (No.16)	600 µm (No.30)
600 µm (No.30)	300 µm (No.50)
300 µm (No.50)	150 µm (No.100)
150 µm (No.100)	75 µm (No.200)

3. Determine the bulk specific gravity of each aggregate size to be tested in accordance with ASTM Methods C 127 and C 128. The determination of the saturated surface dry condition in C 128 is established by the use of hard-finished paper towels. This is a departure from the procedure in C 128 for fine aggregates.

4. Using oven-dry materials, determine the Percent of voids for each aggregate size to be tested at two compaction levels. First conduct two tests for each size, three layers, at 10 tamps per layer. Then rerun the test, using the same aggregates at 50 tamps per layer. The method of filling the mold and tamping is as follows:

   a. Fill the molds in three equal lifts, leveling each lift with the fingers.
   b. Compact each layer, with the required number of tamps, by holding the tamp about 50 mm (2 inches) above the surface of the aggregate, and releasing the tamp so that it falls freely with the rounded end of the tamp penetrating the aggregate layer. Repeat for each layer. After the final lift has been properly tamp, add individual pieces of aggregate so that the top surface is as even as possible with no projections above the rim of the mold.

5. Use the average weight of two compaction tests for each aggregate size for both compactive efforts. The two results should agree within approximately 0.5%. Otherwise rerun the tests.

D. Explanation of Computations and Data Collection:

1. Computations: calculate the percent of voids for each aggregate size as follow:

$$V_{10} = [1 - (W_{10}/sv)] \times 100$$
$$V_{50} = [1 - (W_{50}/sv)] \times 100$$

V_{10} = voids in aggregate compacted at 10 tamps per layer, %.
V_{50} = voids in aggregate compacted at 50 tamps per layer, %.
W_{10} = average net weight of aggregates in mold compacted at 10 tamps per layer.
W_{50} = average net weight of aggregates in mold compacted at 50 tamps per layer.
s = bulk specific gravity of the aggregate size fraction.
v = volume of the cylindrical mold, ml.

The particle index (I_o) is computed as follows:

$$I_o = 1.25V_{10} - 0.25V_{50} - 32.0$$

Calculate the weighted particle index for the mix of particle sizes tested based upon the % of each size in the aggregate sample in accordance with the following equation:

$$\text{Weighted } I_o = \frac{I_1 x\% + I_2 x\% + I_3 x\% + \text{etc}}{100\%}$$

2. Data Collection Form: shown on the next page. For those aggregate sizes that represent less than 10% of the total aggregate sample, use the average particle index of the next size higher and the next size lower, which were determined. This is shown in the illustrative example on the next page.

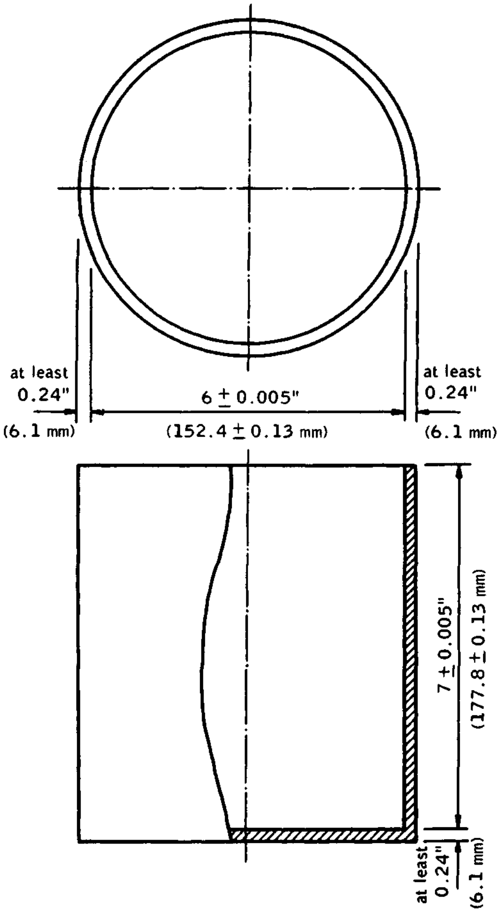

Figure 7 - Cylindrical Mold
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DATA SHEET for DETERMINATION of INDEX of AGGREGATE PARTICLE SHAPE and TEXTURE (D 3398)

Sieve Size		Aggregate Grading %	Particle Index of Each Size Group	Weighted Average of Aggregate Grading X Particle Index÷100
Passing	Retained			
19.0 mm	12.5 mm	3	17.2[a]	0.5
12.5 mm	9.5 mm	42	17.2[b]	7.2
9.5 mm	4.75 mm	36	15.8[b]	5.7
4.75 mm	2.36 mm	7	15.2[c]	1.1
2.36 mm	1.18 mm	10	14.6[b]	1.5
1.18 mm	600 μm	2	14.6[a]	0.3
Totals		100		16.3
[a] Use particle index for the adjacent size since less than 10%.				
[b] Particle index measured for these sizes since $\geq$ 10%				
[c] Use average particle index for the 2.36 mm to 4.75 mm size of the particle indices above and below since less than 10%.				

Illustrative Example.

DATA SHEET for DETERMINATION of INDEX of AGGREGATE PARTICLE SHAPE and TEXTURE (D 3398)

Sieve Size		Aggregate Grading %	Particle Index of Each Size Group	Weighted Average of Aggregate Grading X Particle Index÷100
Passing	Retained			

FLAT or ELONGATED PARTICLES in COARSE AGGREGATE

Reference: ASTM Designation: D 4791

A. Purpose: Determination of the percentages of flat or elongated particles in coarse aggregates.

B. Equipment and Materials: Proportional Caliper Device as shown on Figure 8; scales accurate to 0.5% of the mass to be weighed; suitable coarse aggregate sample splitters.

C. Test Procedure:

1. Samples - the size of the coarse samples should be in accordance with the following table:

Maximum Nominal Aggregate Size mm (inch)	Approximate Minimum Mass of Samples from ASTM D 75 kg (lb)
9.5 (3/8)	10 (25)
12.5 (1/2)	15 (35)
19.0 (3/4)	25 (55)
25.0 (1)	50 (110)
38.1 (1 1/2)	75 (165)
50 (2)	100 (220)
63 (2 1/2)	125 (275)
75 (3)	150 (330)
90 (3 1/2)	175 (385)

Place the thoroughly mixed samples in apprpriate size splitters (the individual chutes shall have a minimum individual width of approximately 50% greater than the largest size of aggregate). Reintroduce the split sample into the splitter as many times as necessary to reduce the sample size either to that specified or until approximately 100 particles are obtained.

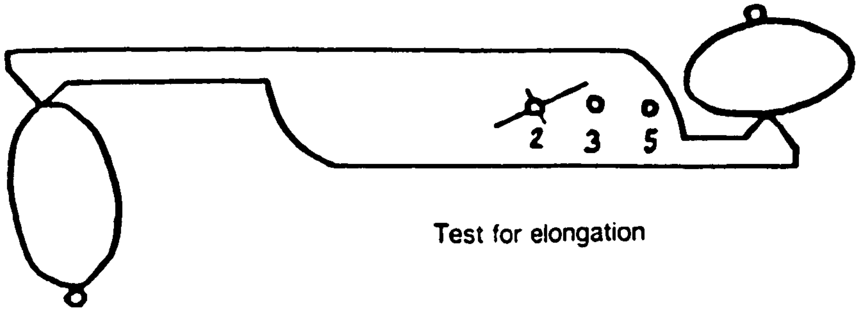
2. Sieve the sample in accordance with ASTM Designation: C 136.

3. Test the particles in each size fraction that is present in the amount of 10% or more into one of three categories; flat, elongated, or rhombic. When a particular sieve size represents less than 10% of the sample, use the same percentage of flat

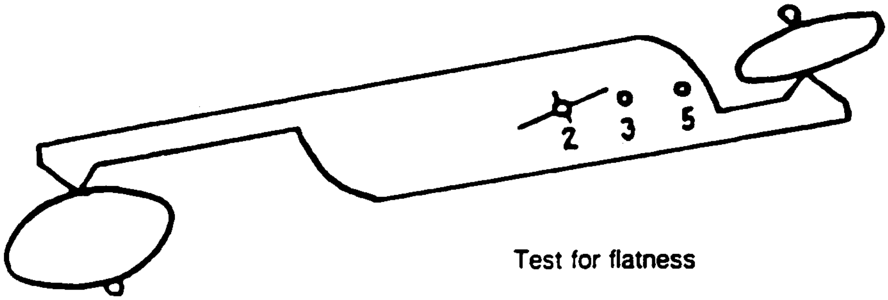
and/or elongated particles as the next smaller or the next larger size, or the average of the next smaller and next larger sizes, if both are present.

4. Use the proportional caliper device as shown below for determining the percentage present of flat or elongated particles in each significant size (representing >10% of the sample). Dimension ratios of less than 1:2 are considered rhombic, 1:2 is defined as slightly flat or elongated and is not considered in the evaluation, 1:3 is flat or elongated, and 1:5 or greated as being very flat and elongated.

5. Method of testing for flat or elongated - the sketches below indicate the way the proportional caliper device is used to determine the elongation or flatness of a particle. To test for elongation set the larger opening equal to the length of the particle. The particle is elongated if the width can be placed within the smaller opening. To test for flatness a similar procedure is followed except that the particle width is used instead of the length. Consider both the elongation or flatness ratio in identifying how the particle is to be rated. Therefore, an particle may be rated for both elongation and flatness. For example, if the measure of its elongation is 1:2 or rhombic and the flatness ratio is 1:3, the overall shape of the particle should be considered in both categories in the table. Only particles with a ratio of 1:3 or greater will be considered elongated and/or flat, unless specifications require otherwise.



Test for elongation



Test for flatness

Use of the Proportional Calipers in Testing for Particle Shape.

D. Explanation of Computations and Data Sheet:

1. Computations: the weighted average of the combined elongated and flat particles is generally based upon dimension ratios equal or greater than 3:1. In the illustrative example taken from the data sheet on page 42, the computation would be as follows:

Weighted Average Percent of Elongated and Flat Coarse partcles =

$$\frac{(25.0+5.0)0.05+(25.0+5.0)0.10 + (10.0+3.4)0.15 + (20.0+6.7)0.15 +}{1.00}$$

$$\frac{(15.4+0)0.13 + (9.7+9.7)0.18 + (9.5+11.9)0.11 + (9.5+11.9)0.09}{1.00} =$$

$$23.86\%$$

Report to the nearest percent = 24% elongated and flat particles for the sample in the illustative example.

Specifications may require a different criteria for evaluating elongated and flat particle shape. What is recommended here is to combine the ratios $\geq 3:1$. However, other data is readily available from the illustrative problem, shown on the data sheet, on the next page.

Particle Shape Composition in a Representative Coarse Aggregate Sample (ASTM D 4791)

Sieve Sizes		Sample Wt. Gm. - % of Total	Rhombic		Slightly Flat/ Elongated, 1:2		Flat or Elongated, 1:3		Very Flat or Elongated, 1:5	
Pass	Retain		Wt.Gm	%Total	Wt.Gm	%Total	Wt.Gm	%Total	WtGm	%Total
mm(Inch)	mm(Inch)									
100 (4)*	90(3 1/2)	500-5.0		40.0		30.0		25.0		5.0
90(3 1/2)	75 (3)	1000-10	400	40.0	300	30.0	250	25.0	50	5.0
75 (3)	63(2 1/2)	1500-15	800	53.3	500	33.3	150	10.0	50	3.4
63(2 1/2)	50 (2)	1500-15	600	40.0	500	33.3	300	20.0	100	6.7
50 (2)	38(1 1/2)	1300-13	700	53.8	400	30.8	200	15.4	0	---
38(1 1/2)	25 (1)	1800-18	1000	55.6	450	25.0	175	9.7	175	9.7
25 (1)	12.5(1/2)	1100-11	473	43.0	391	35.6	105	9.5	131	11.9
12.5(1/2*	9.5 (3/8)	900-9.0		43.0		35.6		9.5		11.9
9.5 (3/8)	Pan	400-4.0		---		---		---		---
Total		10,000								

*Since the percentage of these sizes are less than 10% of the total mass of the aggregate sample, the percentage of the various shape ratios are taken from the adjacent aggregate sizes. The % of elongated and flat particles are computed to the nearest 0.1% for each size greater than 9.5mm (3/8 inches), based upon the combined weight for each dimension ratio.

% Elongated and Flat Particles = 24%. See computations on Page 41.

Particle Shape Composition in a Representative Coarse Aggregate Sample (ASTM 4791)

Sieve Sizes		Sample	Rhombic		Slightly Flat/ Elongated, 1:2		Flat or Elongated, 1:3		Very Flat or Elongated, 1:5	
Pass	Retain	Wt.Gm.	Wt.Gm	%Total	Wt.Gm	%Total	Wt.Gm	%Total	WtGm	%Total
mm(Inch)	mm(Inch)									

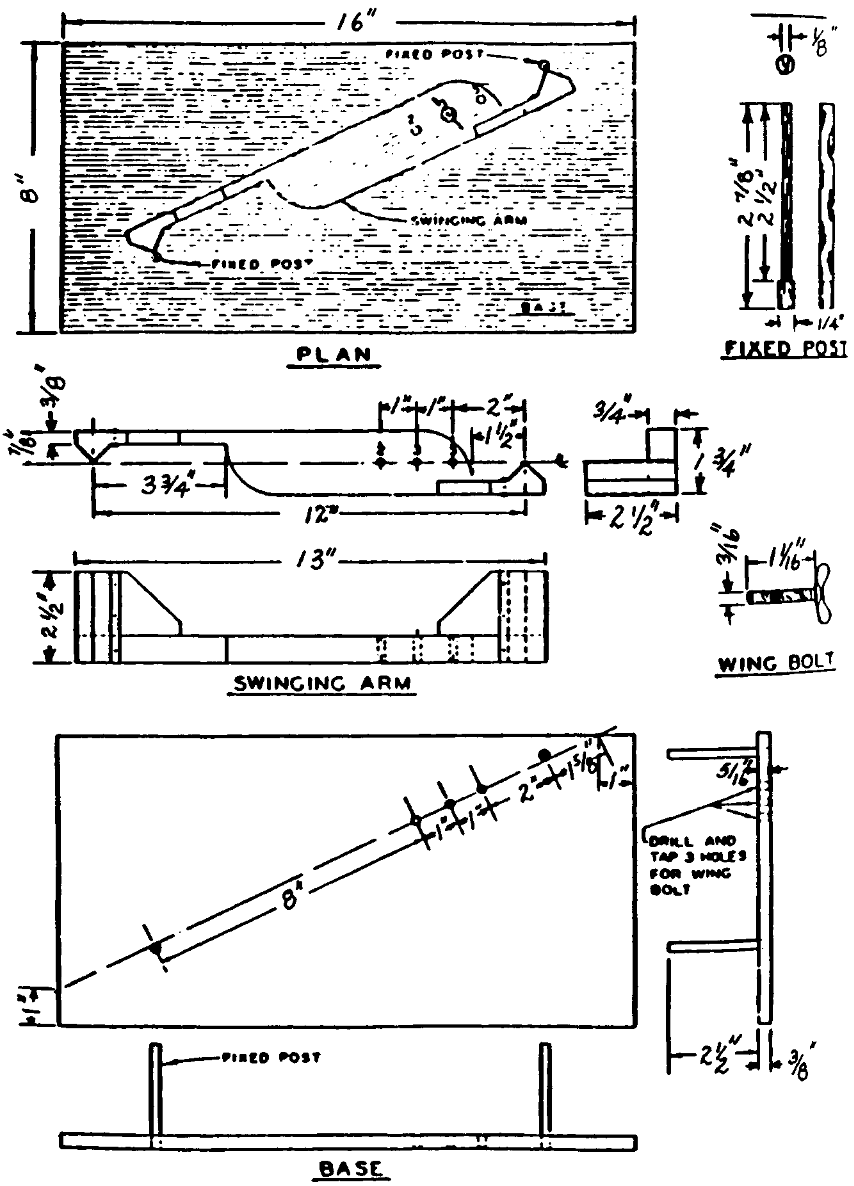


Figure 8 - Details of the Proportional Caliper.
Drawings are not to Scale.

STANDARD SPECIFICATIONS for WIRE CLOTH and SIEVES for TESTING PURPOSES

Reference - ASTM Designation: E 11

A. Purpose: E 11 covers the requirements for the design and construction of various types of testing sieves. However, the only purpose in introducing E 11 into this MANUAL is to present the specifications that govern the openings in testing sieves, used for aggregate size classification. These are covered in Table 1 on the following page. If the details of the design and construction of these sieves are required, the reader is directed to ASTM Designation: E 11 in the applicable ASTM publication. The table covers all standard sieve sizes used the U.S. Standard System of Measurements and their approximate equivalent S.I. dimensions (soft conversion). Please take cognizance of the six notes, A through F, at the bottom of Table 1, on the next page.

Sieve Designation		Nominal Sieve Opening, in.[B]	Permissible Variation of Average Opening from the Standard Sieve Designation	Opening Dimension Exceeded By Not More Than 5 % of the Openings	Maximum Individual Opening	Nominal Wire Diameter, mm[C]
Standard[A]	Alternative					
(1)	(2)	(3)	(4)	(5)	(6)	(7)
125 mm	5 in.	5	±3.70 mm	130.0 mm	130.9 mm	8.00
106 mm	4.24 in.	4.24	±3.20 mm	110.2 mm	111.1 mm	6.30
100 mm[D]	4 in.[D]	4	±3.00 mm	104.0 mm	104.8 mm	6.30
90 mm	3½ in.	3.5	±2.70 mm	93.6 mm	94.4 mm	6.30
75 mm	3 in.	3	±2.20 mm	78.1 mm	78.7 mm	6.30
63 mm	2½ in.	2.5	±1.90 mm	65.6 mm	66.2 mm	5.60
53 mm	2.12 in.	2.12	±1.60 mm	55.2 mm	55.7 mm	5.00
50 mm[D]	2 in.[D]	2	±1.50 mm	52.1 mm	52.6 mm	5.00
45 mm	1¾ in.	1.75	±1.40 mm	46.9 mm	47.4 mm	4.50
37.5 mm	1½ in.	1.5	±1.10 mm	39.1 mm	39.5 mm	4.50
31.5 mm	1¼ in.	1.25	±1.00 mm	32.9 mm	33.2 mm	4.00
26.5 mm	1.06 in.	1.06	±.800 mm	27.7 mm	28.0 mm	3.55
25.0 mm[D]	1.00 in.[D]	1	±.800 mm	26.1 mm	26.4 mm	3.55
22.4 mm	⅞ in.	0.875	±.700 mm	23.4 mm	23.7 mm	3.55
19.0 mm	¾ in.	0.750	±.600 mm	19.9 mm	20.1 mm	3.15
16.0 mm	⅝ in.	0.625	±.500 mm	16.7 mm	17.0 mm	3.15
13.2 mm	0.530 in.	0.530	±.410 mm	13.83 mm	14.05 mm	2.80
12.5 mm[D]	½ in.[D]	0.500	±.390 mm	13.10 mm	13.31 mm	2.50
11.2 mm	7/16 in.	0.438	±.350 mm	11.75 mm	11.94 mm	2.50
9.5 mm	⅜ in.	0.375	±.300 mm	9.97 mm	10.16 mm	2.24
8.0 mm	5/16 in.	0.312	±.250 mm	8.41 mm	8.58 mm	2.00
6.7 mm	0.265 in.	0.265	±.210 mm	7.05 mm	7.20 mm	1.80
6.3 mm[D]	¼ in.[D]	0.250	±.200 mm	6.64 mm	6.78 mm	1.80
5.6 mm	No. 3½[E]	0.223	±.180 mm	5.90 mm	6.04 mm	1.60
4.75 mm	No. 4	0.187	±.150 mm	5.02 mm	5.14 mm	1.60
4.00 mm	No. 5	0.157	±.130 mm	4.23 mm	4.35 mm	1.40
3.35 mm	No. 6	0.132	±.110 mm	3.55 mm	3.66 mm	1.25
2.80 mm	No. 7	0.110	±.095 mm	2.975 mm	3.070 mm	1.12
2.36 mm	No. 8	0.0937	±.080 mm	2.515 mm	2.600 mm	1.00
2.00 mm	No. 10	0.0787	±.070 mm	2.135 mm	2.215 mm	0.900
1.7 mm	No. 12	0.0661	±.060 mm	1.820 mm	1.890 mm	0.800
1.4 mm	No. 14	0.0555	±.050 mm	1.505 mm	1.565 mm	0.710
1.18 mm	No. 16	0.0469	±.045 mm	1.270 mm	1.330 mm	0.630
1.00 mm	No. 18	0.0394	±.040 mm	1.080 mm	1.135 mm	0.560
850 µm[F]	No. 20	0.0331	±35 µm	925 µm	970 µm	0.500
710 µm	No. 25	0.0278	±30 µm	775 µm	815 µm	0.450
600 µm	No. 30	0.0234	±25 µm	660 µm	695 µm	0.400
500 µm	No. 35	0.0197	±20 µm	550 µm	585 µm	0.315
425 µm	No. 40	0.0165	±19 µm	471 µm	502 µm	0.280
355 µm	No. 45	0.0139	±16 µm	396 µm	426 µm	0.224
300 µm	No. 50	0.0117	±14 µm	337 µm	363 µm	0.200
250 µm	No. 60	0.0098	±12 µm	283 µm	306 µm	0.160
212 µm	No. 70	0.0083	±10 µm	242 µm	263 µm	0.140
180 µm	No. 80	0.0070	±9 µm	207 µm	227 µm	0.125
150 µm	No. 100	0.0059	±8 µm	174 µm	192 µm	0.100
125 µm	No. 120	0.0049	±7 µm	147 µm	163 µm	0.090
106 µm	No. 140	0.0041	±6 µm	126 µm	141 µm	0.071
90 µm	No. 170	0.0035	±5 µm	108 µm	122 µm	0.063
75 µm	No. 200	0.0029	±5 µm	91 µm	103 µm	0.050
63 µm	No. 230	0.0025	±4 µm	77 µm	89 µm	0.045
53 µm	No. 270	0.0021	±4 µm	66 µm	76 µm	0.036
45 µm	No. 325	0.0017	±3 µm	57 µm	66 µm	0.032
38 µm	No. 400	0.0015	±3 µm	48 µm	57 µm	0.030
32 µm	No. 450	0.0012	±3 µm	42 µm	50 µm	0.028
25 µm[D]	No. 500	0.0010	±3 µm	34 µm	41 µm	0.025
20 µm[D]	No. 635	0.0008	±3 µm	29 µm	35 µm	0.020

[A] These standard designations correspond to the values for test sieve openings recommended by the International Standards Organization, Geneva, Switzerland, except where noted.

[B] Only approximately equivalent to the metric values in Column 1.

[C] The average diameter of the wires in the x and y direction, measured separately, of any wire cloth shall not deviate from the nominal values by more than ±15 %.

[D] These sieves are not in the standard series but they have been included because they are in common usage.

[E] These numbers (3½ to 635) are the approximate number of openings per linear in. but it is preferred that the sieve be identified by the standard designation in millimetres or micrometres.

[F] 1000 µm—1 mm.

Table 1 - Nominal Dimensions,“Permissible Variations for Wire Cloth of Standard Test Sieves (U.S.A.) Standard Series. Copyright ASTM. Reprinted with Permission.

Previous Page

COARSE and FINE AGGREGATES SPECIFIC GRAVITY DATA SHEET
ASTM Designations: C 127 and C 128

<table>
<tr><td colspan="5">Coarse Aggregates - ASTM Designation: C 127</td></tr>
<tr><td>Passing _____ Sieve &
Retained on _____ Sieve</td><td>Sample 1</td><td>Sample 2</td><td>Sample 3</td><td>Sample 4</td></tr>
<tr><td>A) Wt. Oven Dry Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B) Wt. SSD Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C) Wt. Saturated Sample in Water, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bulk Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Apparent Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Effective Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Absorption, %</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Average Values: Bulk Sp Gr. = ; Apparent Sp. Gr. = ;
Effective Sp. Gr. = ; Absorption = .</td></tr>
<tr><td colspan="5">Fine Aggregates - ASTM Designation: C 128</td></tr>
<tr><td>A) Wt. Oven Dry Sample, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B) Wt. Pycnometer+Water to Calibration Mark, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C) Pycnometer+Water+Sample to Calibration Mark, gm.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bulk Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Apparent Specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Effective specific Gravity</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Absorption, %</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Average Values: Bulk Sp. Gr. = ; Apparent Sp. Gr. = ;
Effective Sp. Gr. = ; Absorption = .</td></tr>
</table>

COARSE and FINE AGGREGATES SPECIFIC GRAVITY DATA SHEET
ASTM Designations: C 127 and C 128

Coarse Aggregates - ASTM Designation: C 127				
Passing ____ Sieve & Retained on ____ Sieve	Sample 1	Sample 2	Sample 3	Sample 4
A) Wt. Oven Dry Sample, gm.				
B) Wt. SSD Sample, gm.				
C) Wt. Saturated Sample in Water, gm.				
Bulk Specific Gravity				
Apparent Specific Gravity				
Effective Specific Gravity				
Absorption, %				
Average Values: Bulk Sp Gr. = ; Apparent Sp. Gr. = ; Effective Sp. Gr. = ; Absorption = .				
Fine Aggregates - ASTM Designation: C 128				
A) Wt. Oven Dry Sample, gm.				
B) Wt. Pycnometer+Water to Calibration Mark, gm.				
C) Pycnometer+Water+Sample to Calibration Mark, gm.				
Bulk Specific Gravity				
Apparent Specific Gravity				
Effective specific Gravity				
Absorption, %				
Average Values: Bulk Sp. Gr. = ; Apparent Sp. Gr. = ; Effective Sp. Gr. = ; Absorption = .				

SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)

DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			

SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)

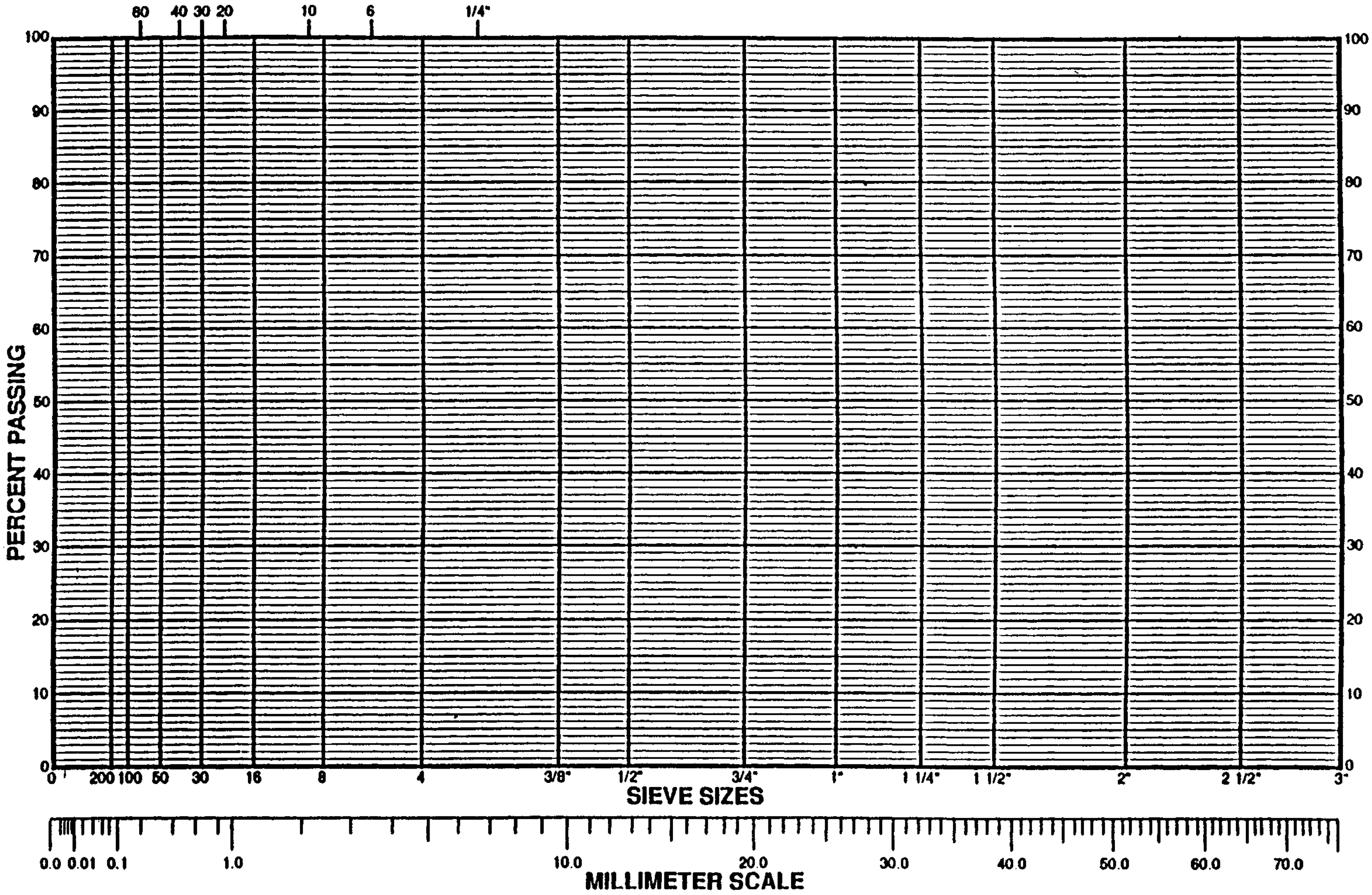
DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			

SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)
and
MINERAL AGGREGATES by WASHING (ASTM C 117)

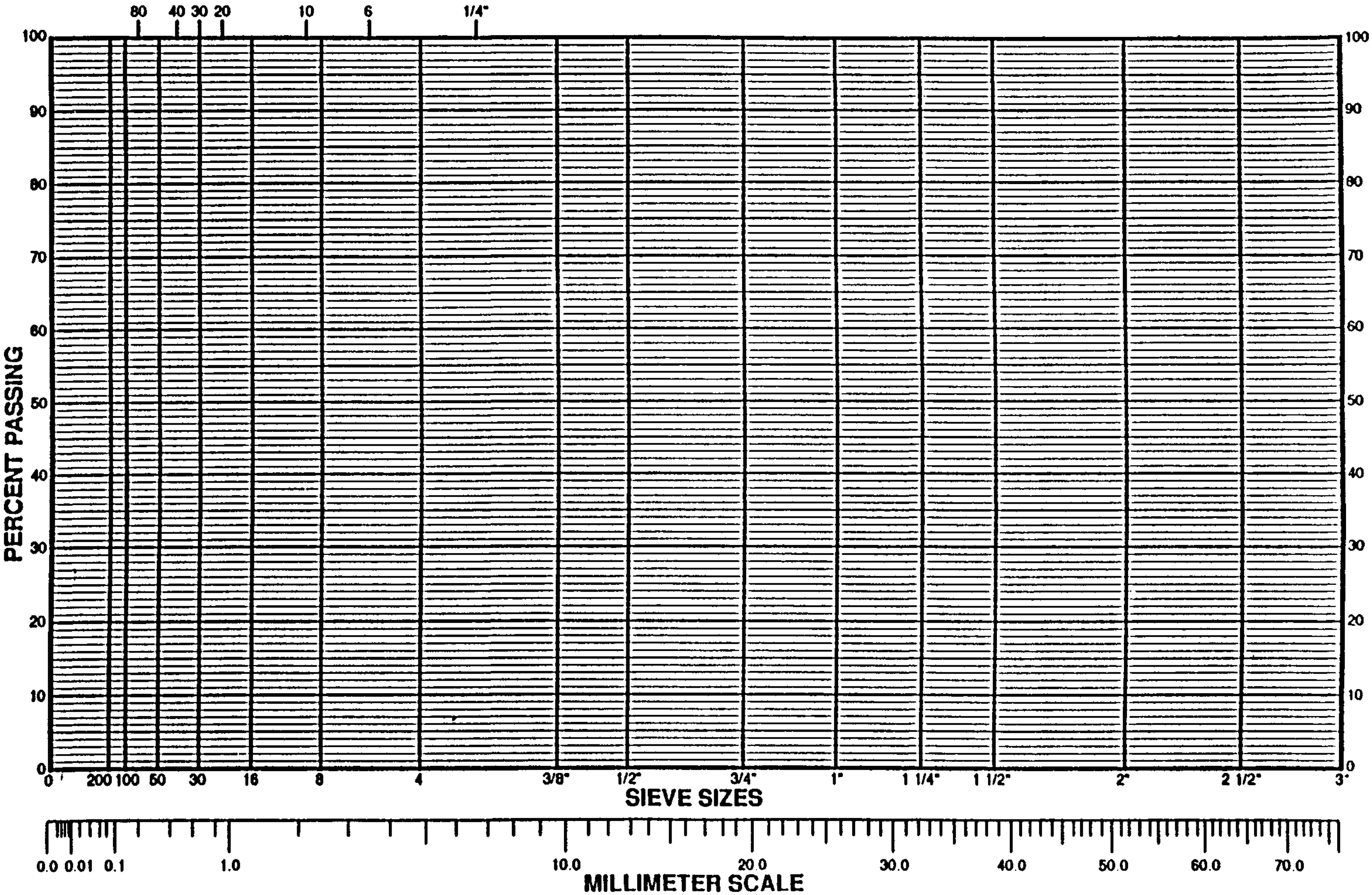
WASH and DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			
a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -				a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -			

SIEVE ANALYSIS for FINE and COARSE AGGREGATE (ASTM C 136)
and
MINERAL AGGREGATES by WASHING (ASTM C 117)

WASH and DRY SIEVE ANALYSIS							
Sample Number				Sample Number			
Sieve Size	Weight Retained (gm)	% Retained	% Passing	Sieze Size	Weight Retained (gm)	% Retained	% Passing
2				2			
1 1/2				1 1/2			
1				1			
3/4				3/4			
1/2				1/2			
3/8				3/8			
4				4			
8				8			
16				16			
30				30			
50				50			
100				100			
200				200			
-200				-200			
Total				Total			
a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -				a. Wt. of Sample, grams - b. Wt. of Sample after Washing, grams - c. Loss in Washing, (a - b), grams - d. -200 from Dry Sieve, grams - Total-200, (c+d), grams -			

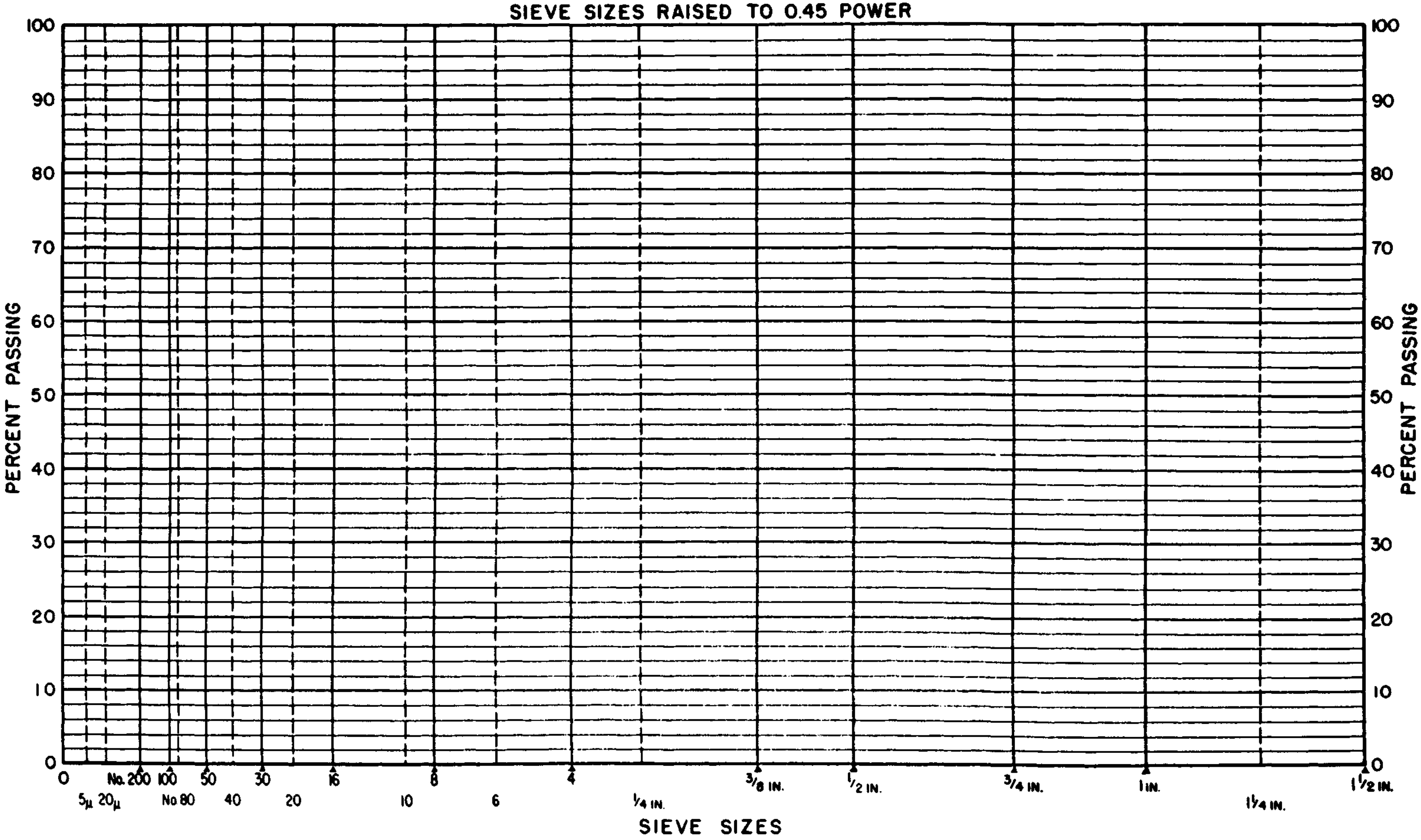


Millimeter Gradation Chart.

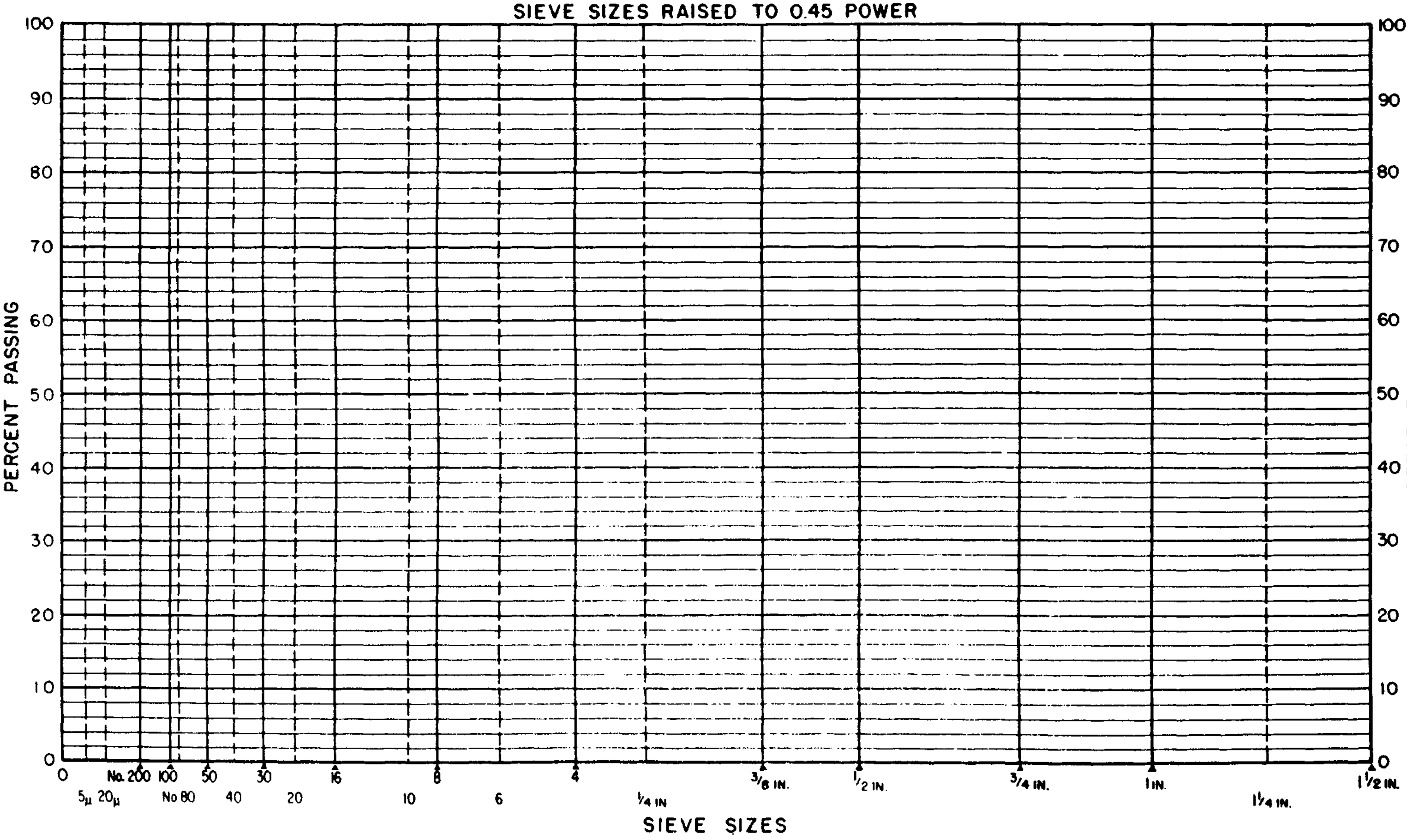


Millimeter Gradation Chart.

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



COMBINED GRADATION FORM

Material	No. 1		No.2		No.3		No.4		Combined Gradation	Target Value	Specification Limits
% in Mix											
U. S. Sieves	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch			
2											
1 1/2											
1											
3/4											
1/2											
3/8											
No. 4											
No. 8											
No. 16											
No. 30											
NO. 50											
No. 100											
No. 200											

COMBINED GRADATION FORM

Material	No. 1		No.2		No.3		No.4		Combined Gradation	Target Value	Specification Limits
% in Mix											
U. S. Sieves	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch	% Passing	% in Batch			
2											
1 1/2											
1											
3/4											
1/2											
3/8											
No. 4											
No. 8											
No. 16											
No. 30											
NO. 50											
No. 100											
No. 200											

DATA SHEET for DETERMINATION of PORTLAND CEMENT SPECIFIC GRAVITY (ASTM C 188)

	Specimen Numbers				
	1	2	3	4	5
Initial Bath Temp., ^{0}C					
Final Height, cm.					
Initial Height, cm.					
Displaced Volume, cm^3					
Final Bath Temp., ^{0}C					
Specific Gravity = 64 grams/displacement,cm^3					

Average Specific Gravity of accepted specimen results =

DATA SHEET for DETERMINATION of PORTLAND CEMENT SPECIFIC GRAVITY (ASTM C 188)

	Specimen Numbers				
	1	2	3	4	5
Initial Bath Temp., ^{0}C					
Final Height, cm.					
Initial Height, cm.					
Displaced Volume, cm^3					
Final Bath Temp., ^{0}C					
Specific Gravity = 64 grams/displacement,cm^3					

Average Specific Gravity of accepted specimen results =

DATA SHEET for DETERMINATION of INDEX of AGGREGATE PARTICLE SHAPE and TEXTURE (ASTM D 3398)

Sieve Size		Aggregate Grading %	Particle Index of Each Size Group	Weighted Average of Aggregate Grading X Particle Index÷100
Passing	Retained			

DATA SHEET for DETERMINATION of INDEX of AGGREGATE PARTICLE SHAPE and TEXTURE (ASTM D 3398)

Sieve Size		Aggregate Grading %	Particle Index of Each Size Group	Weighted Average of Aggregate Grading X Particle Index÷100
Passing	Retained			

Particle Shape Composition in a Representative Coarse Aggregate Sample (ASTM 4791)

Sieve Sizes		Sample	Rhombic		Slightly Flat/ Elongated, 1:2		Flat or Elongated, 1:3		Very Flat or Elongated, 1:5	
Pass	Retain	Wt.Gm.	Wt.Gm	%Total	Wt.Gm	%Total	Wt.Gm	%Total	WtGm	%Total
mm(Inch)	mm(Inch)									

Particle Shape Composition in a Representative Coarse Aggregate Sample (ASTM 4791)

Sieve Sizes		Sample	Rhombic		Slightly Flat/ Elongated, 1:2		Flat or Elongated, 1:3		Very Flat or Elongated, 1:5	
Pass	Retain	Wt.Gm.	Wt.Gm	%Total	Wt.Gm	%Total	Wt.Gm	%Total	WtGm	%Total
mm(Inch)	mm(Inch)									

PENETRATION TEST (ASTM D 5)

1. Material identification ______________________________
2. Date ____________ Air Temperature ______________________________ ^{0}F
3. Date of preparation of test Specimens ______________________________
4. Depth of sample in container (specified to be at least 10 mm. greater than depth of penetration of needle). ______________________________ mm
5. Length of air cooling period before placing in controlled water bath (specified to be between 1 1/2 and 2 hr.) ______________________________ hr.
6. Clock time specimen placed in controlled water bath ______________________________ hr.
7. Clock time specimen removed from controlled water bath ______________________________ hr.
8. Interval in controlled water bath (specified to be between 1 1/2 and 2 hr.) ______________________________ hr.
9. Weight of load on needle ______________________________ g
10. Time of applicaton of needle to specimen ______________________________ sec.
11. Temperature of controlled water bath ______________________________ ^{0}F

Penetrometer Readings

Take readings until 3 penetration values are secured whose average meets the tolerance requirements. Circle the 3 penetration values used in computing the penetration value recorded on line 12. Report penetration value as the nearest whole number.

Trial	1	2	3	4	5	6	7	8
Final								
Initial								
Penetration Value								

12. Penetration value for material ______________________________

13. Grade of material based on penetration value secured ______________________________

PENETRATION TEST (ASTM D 5)

1. Material identification ______________________
2. Date____________Air Temperature ______________________ ^{0}F
3. Date of preparation of test Specimens ______________________
4. Depth of sample in container (specified to be at least 10 mm. greater than depth of penetration of needle). ____________________mm
5. Length of air cooling period before placing in controlled water bath (specified to be between 1 1/2 and 2 hr.) ____________________hr.
6. Clock time specimen placed in controlled water bath ____________________hr.
7. Clock time specimen removed from controlled water bath ____________________hr.
8. Interval in controlled water bath (specified to be between 1 1/2 and 2 hr.) ____________________hr.
9. Weight of load on needle ______________________g
10. Time of applicaton of needle to specimen ____________________sec.
11. Temperature of controlled water bath ______________________ ^{0}F

Penetrometer Readings

Take readings until 3 penetration values are secured whose average meets the tolerance requirements. Circle the 3 penetration values used in computing the penetration value recorded on line 12. Report penetration value as the <u>nearest whole number.</u>

Trial	1	2	3	4	5	6	7	8
Final								
Initial								
Penetration Value								

12. Penetration value for material ______________________

13. Grade of material based on penetration value secured ______________________

SOFTENING POINT TEST -- Ring and Ball Method (ASTM D 36)

1. Material identification ____________________

2. Date ______________ Air Temperature ____________________ ^{0}C

3. Clock time sample poured into ring ____________________

4. Clock time ring transferred to 5^{0}C water bath ____________________

5. Interval test specimen cooled in air ______________ minutes

6. Clock time test specimen removed from 50C water bath for trimming ____________________

7. Interval test specimen in 5^{0}C water bath ____________________

8. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval.

Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C	Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C
0			8		
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		

9. Temperature indicated by thermometer when material touches bottom ____________________ ^{0}C

10. Softening point ____________________ ^{0}C

11. Grade of material tested based upon the softening point test result according to the current specification requirements of the Illinois Division of Highways ____________________

SOFTENING POINT TEST -- Ring and Ball Method (ASTM D 36)

1. Material identification ____________________

2. Date ______________ Air Temperature ____________________ ^{0}C

3. Clock time sample poured into ring ____________________

4. Clock time ring transferred to 5^{0}C water bath ____________________

5. Interval test specimen cooled in air ______________ minutes

6. Clock time test specimen removed from 50C water bath for trimming ____________________ hr.

7. Interval test specimen in 5^{0}C water bath ____________________

8. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval.

Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C	Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C
0			8		
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		

9. Temperature indicated by thermometer when material touches bottom ____________________ ^{0}C

10. Softening point ____________________ ^{0}C

11. Grade of material tested based upon the softening point test result according to the current specification requirements of the Illinois Division of Highways ____________________

DATA SHEET FOR SPECIFIC GRAVITY OF ASPHALT (ASTM D 70)

ASPHALT______________________DATE________TEMP.______________

ASPHALT CEMENT

	Pycnometer No.	________	________	________
(1)	Weight of Pycnometer Filled With Water	______gm	______gm	______gm
(2)	Weight of Empty Pycnometer	______gm	______gm	______gm
(3)	Weight of Water (Line 1 - Line 2)	______gm	______gm	______gm
(4)	Weight of Pycnometer + Asphalt Cement	______gm	______gm	______gm
(5)	Weight of Empty Pycnometer (Line 2)	______gm	______gm	______gm
(6)	Weight of Asphalt Cement (Line 4 - Line 5)	______gm	______gm	______gm
(7)	Weight of Pycnometer + Asphalt Cement + Water	______gm	______gm	______gm
(8)	Weight of Pycnometer + Asphalt Cement (Line 4)	______gm	______gm	______gm
(9)	Weight of Water (Line 7 - Line 8)	______gm	______gm	______gm
(10)	Weight of Water Displaced by AC (Line 3 - Line 9)	______gm	______gm	______gm

$\text{Specific Gravity} = \frac{\text{Weight of A.C.}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 10}}$ _______ _______ ______

Average __________

LIQUID ASPHALT - ASPHALT CUTBACK AND EMULSIFIED ASPHALT

	Pycnometer No.	________	________	________
(1)	Weight of Pycnometer Filled With Water	______gm	______gm	______gm
(2)	Weight of Empty Pycnometer	______gm	______gm	______gm
(3)	Weight of Water (Line 1 - Line 2)	______gm	______gm	______gm
(4)	Weight of Pycnometer Filled With Asphalt	______gm	______gm	______gm
(5)	Weight of Pycnometer (Line 2)	______gm	______gm	______gm
(6)	Weight of Asphalt (Line 4 - Line 5)	______gm	______gm	______gm

$\text{Specific Gravity} = \frac{\text{Weight of Asphalt}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 3}}$ ______ ______ _____

Average __________

DATA SHEET FOR SPECIFIC GRAVITY OF ASPHALT (ASTM D 70)

ASPHALT______________________ DATE________ TEMP.______________

ASPHALT CEMENT

Pycnometer No.	_________	_________	_________
(1) Weight of Pycnometer Filled With Water	_______gm	______gm	_______gm
(2) Weight of Empty Pycnometer	_______gm	______gm	_______gm
(3) Weight of Water (Line 1 - Line 2)	________gm	______gm	_______gm
(4) Weight of Pycnometer + Asphalt Cement	_______gm	______gm	_______gm
(5) Weight of Empty Pycnometer (Line 2)	_______gm	______gm	_______gm
(6) Weight of Asphalt Cement (Line 4 - Line 5)	________gm	______gm	_______gm
(7) Weight of Pycnometer + Asphalt Cement + Water	_______gm	______gm	_______gm
(8) Weight of Pycnometer + Asphalt Cement (Line 4)	_______gm	______gm	_______gm
(9) Weight of Water (Line 7 - Line 8)	_______gm	______gm	_______gm
(10) Weight of Water Displaced by AC (Line 3 - Line 9)	_______gm	______gm	_______gm

Specific Gravity = $\frac{\text{Weight of A.C.}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 10}}$ _______ _______ ______

Average __________

LIQUID ASPHALT - ASPHALT CUTBACK AND EMULSIFIED ASPHALT

Pycnometer No.	________	_________	_________
(1) Weight of Pycnometer Filled With Water	_______gm	_______gm	______gm
(2) Weight of Empty Pycnometer	_______gm	________gm	_______gm
(3) Weight of Water (Line 1 - Line 2)	_______gm	________gm	_______gm
(4) Weight of Pycnometer Filled With Asphalt	_______gm	________gm	_______gm
(5) Weight of Pycnometer (Line 2)	_______gm	________gm	_______gm
(6) Weight of Asphalt (Line 4 - Line 5)	_______gm	________gm	_______gm

Specific Gravity = $\frac{\text{Weight of Asphalt}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 3}}$ ______ ______ _____

Average ______________

SAYBOLT VISCOSITY TEST DATA SHEET (ASTM D 88)

1. Material identification ______________________________

2. Date _______________ Air Temperature __________________________

3. Outlet tube used ______________________________

4. Designated test temperature ______________________________ ^{0}F

5. Exact temperature of material when cork was snapped ______________________________ ^{0}F

6. Time for material to flow from oil tube through outlet tube _________________________ min.

7. Saybolt-Furol viscosity value (SFS) ____________________ sec.

8. Temperature record. Record below the temperature of the bath when the cork is snapped (0 time) and at the end of each minute thereafter.

Time - Minutes	Temperature ^{0}F	Time - Minutes	Temperature ^{0}F
0		6	
1		7	
2		8	
3		9	
4		10	
5		11	

SAYBOLT VISCOSITY TEST DATA SHEET (ASTM D 88)

1. Material identification ______________________________

2. Date _______________ Air Temperature __________________________

3. Outlet tube used ______________________________

4. Designated test temperature _____________________________ ^{0}F

5. Exact temperature of material when cork was snapped ____________________________ ^{0}F

6. Time for material to flow from oil tube through outlet tube
_______________________ min.

7. Saybolt-Furol viscosity value (SFS) ____________________ sec.

8. Temperature record. Record below the temperature of the bath when the cork is snapped (0 time) and at the end of each minute thereafter.

Time - Minutes	Temperature ^{0}F	Time - Minutes	Temperature ^{0}F
0		6	
1		7	
2		8	
3		9	
4		10	
5		11	

FLASH AND FIRE POINTS TEST DATA (ASTM D 92)

1. Material identification ______________________________

2. Date ____________________ Air Temperature __________________

3. Apparatus used ____

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minutes.	Temperature, ⁰F.	Temperature, ⁰F.	Timer Reading Minutes.	Temperature, ⁰F.	Temperature, ⁰F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point,⁰F.______________. Fire point,⁰F. ________________.

6. Were the heating requirements met, as outlined in paragraph C of the instruction sheet? (a)_______________________________, (b)___________________________, (c)________________________________.

FLASH AND FIRE POINTS TEST DATA (ASTM D 92)

1. Material identification ______________________________

2. Date ____________________ Air Temperature __________________

3. Apparatus used ____

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minutes.	Temperature, ^{0}F.	Temperature, ^{0}F.	Timer Reading Minutes.	Temperature, ^{0}F.	Temperature, ^{0}F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point,^{0}F.______________. Fire point,^{0}F. ________________.

6. Were the heating requirements met, as outlined in paragraph C of the instruction sheet? (a)__________________________________,
(b)__________________________, (c)________________________________.

FLASH POINT TEST by PENSKY-MARTENS APPARATUS (ASTM D 93)

1. Material identification ______________________________

2. Date ___________ Air Temperature ______________________________

3. Apparatus used ______________________________

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minute.	Temperature, ^{0}F.	Temperature, ^{0}F.	Timer Reading, Minute.	Temperature, ^{0}F.	Temperature, ^{0}F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point, ^{0}F. ______________.

6. Were the heating requirements met, as outlined in Section C of the Test Procedure?

(a) ______________________________

(b) ______________________(c) ______________________________.

FLASH POINT TEST by PENSKY-MARTENS APPARATUS (ASTM D 93)

1. Material identification ______________________________

2. Date __________ Air Temperature ______________________________

3. Apparatus used ____

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minute.	Temperature, ^{0}F.	Temperature, ^{0}F.	Timer Reading, Minute.	Temperature, ^{0}F.	Temperature,^{0}F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point,^{0}F.______________.

6. Were the heating requirements met, as outlined in Section C of the Test Procedure?

(a)______________________________

(b)______________________(c)______________________________.

DUCTILITY TEST (ASTM D 113)

1. Material Identification ______________________________

2. Date __________ Room Temperature ____________________ °F

3. Temperature of Sample during heating ____________________ °F

4. Time sample poured ____________________________

5. Time placed in bath ____________________________

6. Elapsed time cooling __________________________ min.

7. Temperature of Water bath ______________________ °F

8. Time: Start Test (Mold removed) ______________________________

9. Curing Period in bath
________________________ min.

10. Setting of Controller for speed ____________________ rate

11. Distant of Specimen to:

Top of Water ____________________________ cm

Bottom of Water ____________________________ cm

12. Test results

Specimen	Ductility, cm
A	
B	
C	
D	
Sum	______________________
Average	

Remarks ____

____

____

____

DUCTILITY TEST (ASTM D 113)

1. Material Identification ____________________

2. Date ________ Room Temperature ____________ ^{0}F

3. Temperature of Sample during heating ____________ ^{0}F

4. Time sample poured ____________________

5. Time placed in bath ____________________

6. Elapsed time cooling ____________________min.

7. Temperature of Water bath ____________________ ^{0}F

8. Time: Start Test (Mold removed) ____________________

9. Curing Period in bath ____________________min.

10. Setting of Controller for speed ____________________rate

11. Distant of Specimen to:

    Top of Water ____________________cm

    Bottom of Water ____________________cm

12. Test results

Specimen	Ductility, cm
A	
B	
C	
D	
Sum	
Average	

Remarks ______________________________

____

____

____

KINEMATIC VISCOSITY DATA SHEET USING REVERSE-FLOW VACUUM CAPILLARY VISCOMETERS (ASTM D 2170)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, cSt	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			C				
			J				
			C				
			J				
			C				
			J				

Viscometer Type:

Type of Asphalt:

Average Viscosity:

Asphalt Grade:

KINEMATIC VISCOSITY DATA SHEET USING REVERSE-FLOW VACUUM CAPILLARY VISCOMETERS (ASTM D 2170)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, cSt	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			C				
			J				
			C				
			J				
			C				
			J				

Viscometer Type:

Type of Asphalt:

Average Viscosity:

Asphalt Grade:

ABSOLUTE VISCOSITY DATA SHEET BY VACUUM CAPILLARY VISCOMETER (ASTM D 2171)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, Poises	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				

Viscometer Type:

Type of Asphalt:

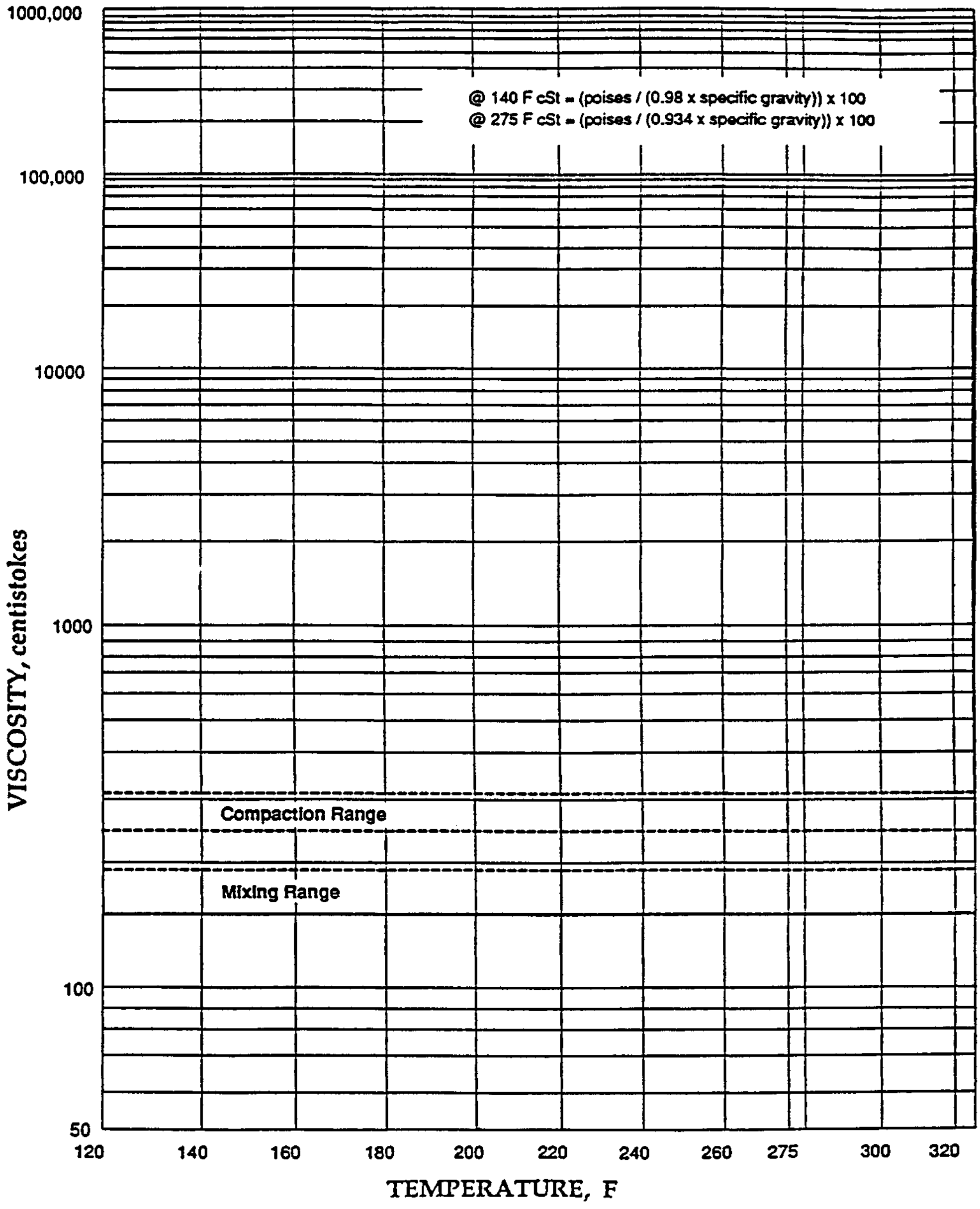
Average Viscosity:

Asphalt Grade:

ABSOLUTE VISCOSITY DATA SHEET BY VACUUM CAPILLARY VISCOMETER (ASTM D 2171)

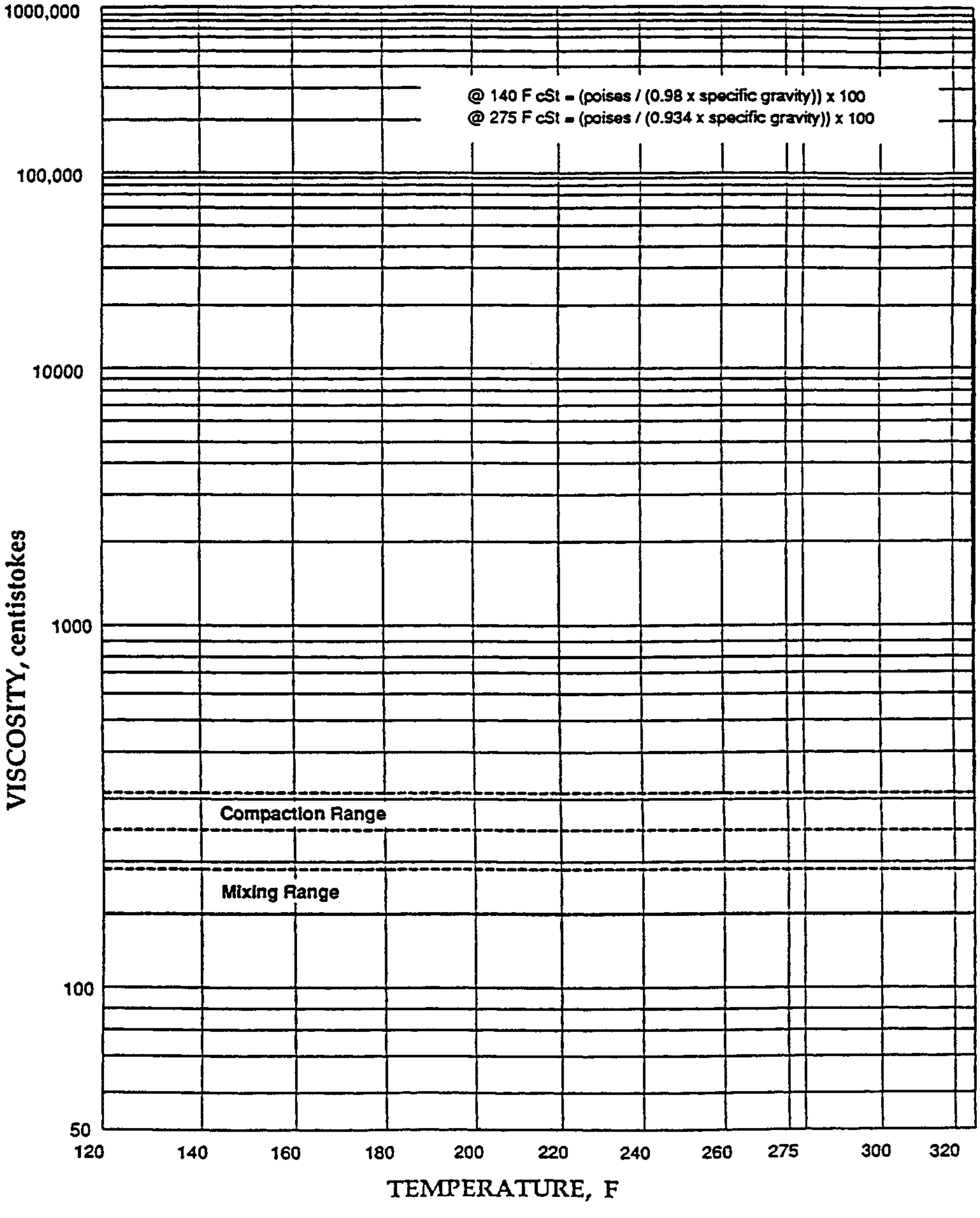
Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, Poises	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				
Viscometer Type:							
Type of Asphalt:							
Average Viscosity:							
Asphalt Grade:							

VISCOSITY VS TEMPERATURE



@ 140 F cSt = (poises / (0.98 x specific gravity)) x 100
@ 275 F cSt = (poises / (0.934 x specific gravity)) x 100

VISCOSITY VS TEMPERATURE



BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1559)

Specimen Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1559)

Speci-men Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

MARSHALL METHOD STABILITY and FLOW
Data Sheet (ASTM D 1559)

Specimen Number	% AC by Wt. of Mix	Ht. of Specimen Inches	Marshall Stability Lbs.	Stability Corr. Ratios	Corrected Marshall Stability	Marshall Flow 0.01 Inches

MARSHALL METHOD STABILITY and FLOW Data Sheet (ASTM D 1559)

Specimen Number	% AC by Wt. of Mix	Ht. of Specimen Inches	Marshall Stability Lbs.	Stability Corr. Ratios	Corrected Marshall Stability	Marshall Flow 0.01 Inches

RICE METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (ASTM D 2071)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C G_{mm}

Note: All weights measured in grams.

Rice Method Computation Data Sheet.

RICE METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (ASTM D 2071)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C G_{mm}

Note: All weights measured in grams.

Rice Method Computation Data Sheet.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1559)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate			P_1					
Fine Aggregate			P_2					
Mineral Filler			P_3					
Total Aggregate			P_4					
Asphalt Cement			P_5					
Bulk Sp.Gr.(G_{mb}),compacted mix,(ASTM D 2726)								
Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1								
Effective Sp.Gr.(G_{se}), total aggregates, Equation 2								
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3								
Absorbed Asphalt (P_{ba}),% by wt. of aggregate, Equation 4								
Effective Asphalt Content(P_{be})% by wt.of total mix, Equation 5								
Percent Voids Mineral Aggregate (VMA), Equation 6								
% Air Voids (P_a), Equation 8								
Percent Voids Filled with Asphalt (VFA), Equation 9								

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Marshall Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

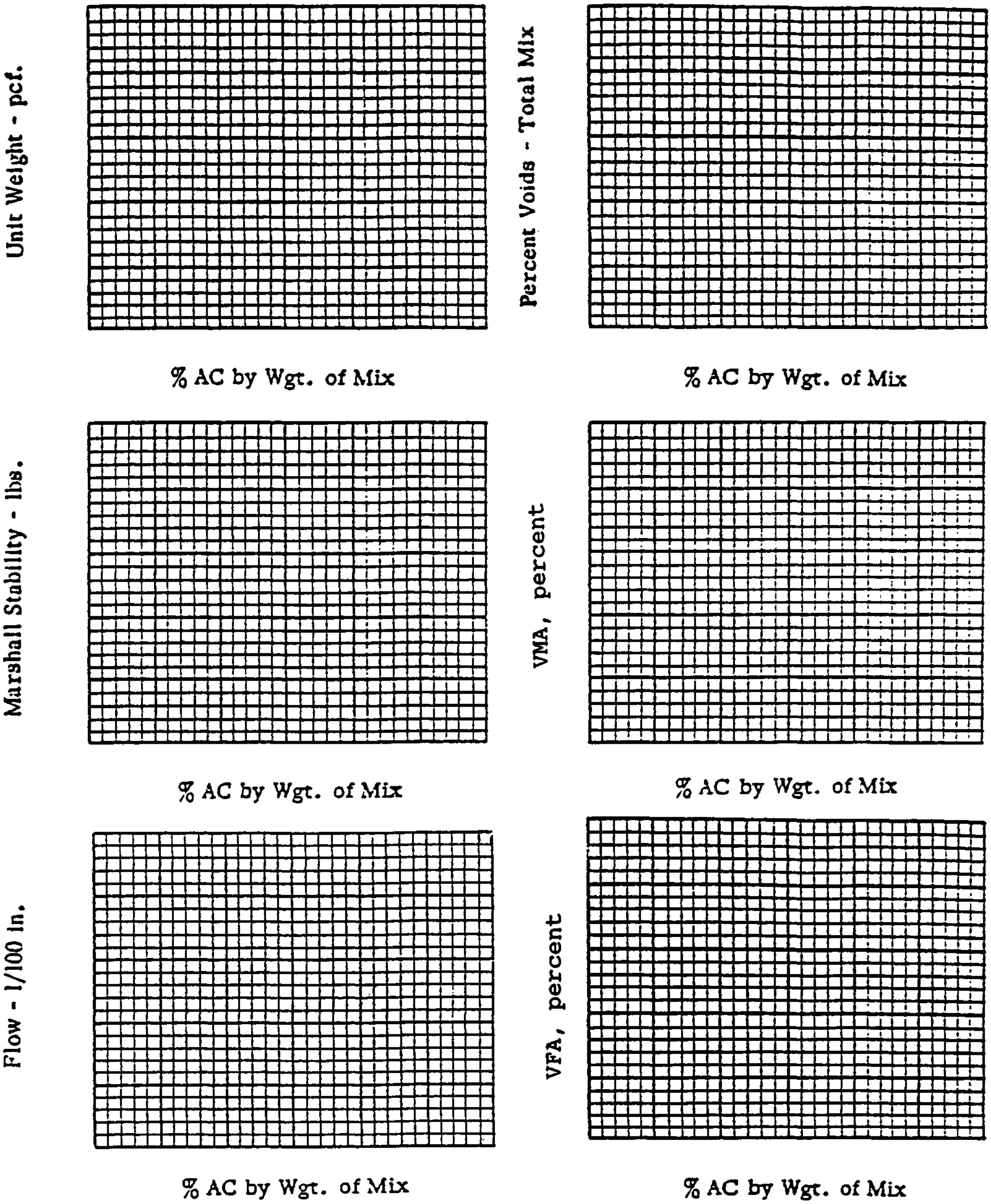
COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1559)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate			P_1					
Fine Aggregate			P_2					
Mineral Filler			P_3					
Total Aggregate			P_4					
Asphalt Cement			P_5					
Bulk Sp.Gr.(G_{mb}),compacted mix,(ASTM D 2726)								
Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1								
Effective Sp.Gr.(G_{se}), total aggregates, Equation 2								
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3								
Absorbed Asphalt (P_{ba}),% by wt. of aggregates, Equation 4								
Effective Asphalt Content(P_{be})% by wt.of total mix, Equation 5								
Percent Voids Mineral Aggregate (VMA), Equation 6								
% Air Voids (P_a), Equation 7								
% Voids Filled with Asphalt (VFA), Equation 9								

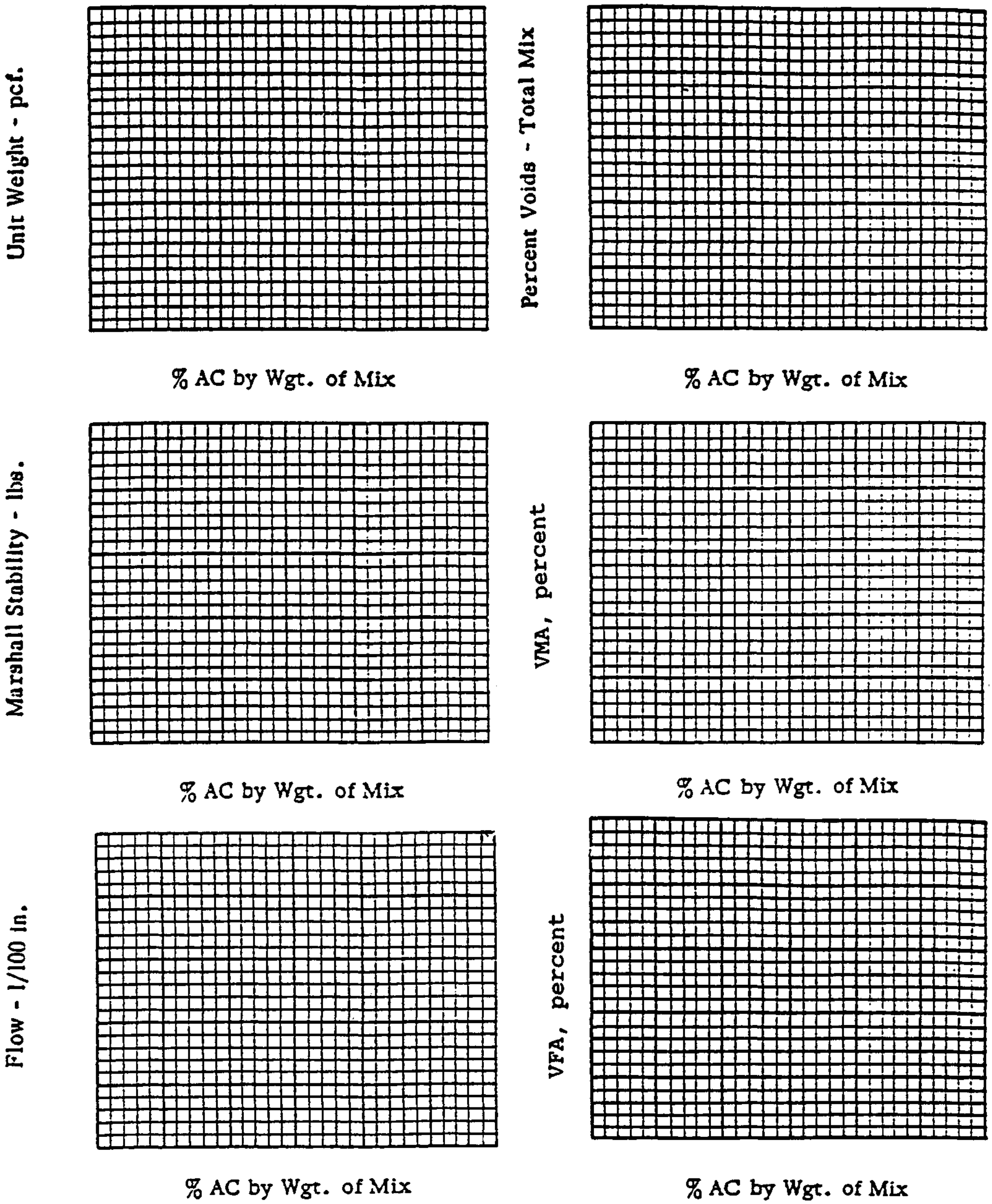
Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Marshall Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.



Test Property Curves for a Hot Mix Asphalt
Paving Mixture by the Marshall Method: Six Graphs.



Test Property Curves for a Hot Mix Asphalt Paving Mixture by the Marshall Method: Six Graphs.

DETERMINATION of OPTIMUM ASPHALT CONTENT by C.K.E. PROCEDURE
(ASTM D 1560 and D 1561)

1. Surface Area of Aggregates:

Sieve No.	% Passing	S.A. Constant	Surface Area
3/8 inch & above	100	(0.41) 2	(0.41) 2
4		(0.41) 2	
8		(0.82) 4	
16		(1.64) 8	
30		(2.87) 14	
50		(6.14) 30	
100		(12.29) 60	
200		(32.77) 160	

Total S.A.: _____ ft.^{2}/lb.
Surface Area: S.I. System in Brackets _____ (m^2/kg.)

2. Bulk Specific Gravity of Aggregates:

Fine (passing No. 4 Sieve), not including M.F. ______
Coarse (retained on No. 4) ______
Weighted Average of Fine and Coarse Aggregates ______

3. % Fine Aggregate _____ ; % Coarse Aggregate _____ .

4. C.K.E. of 2 Fine Aggregates Specimens: _____ ______
Average C.K.E., corrected for Specific Gravity: ______

5. % Oil Retained of 2 Coarse Aggregate Specimens: ______ _____
Average % Oil Retained, corrected for Specific Gravity: _____

6. Determination of Optimum Asphalt Content:

Type of Asphalt and Aged Residue Viscosity: ______________

K_f: _____ K_c: _____ K_m: _____ Oil Ratio: _____

Optimum % AC by weight of Aggregates: _____

Optimum % AC by Weight of Total Mix: _____

DETERMINATION of OPTIMUM ASPHALT CONTENT by C.K.E. PROCEDURE
Data Sheet (ASTM D 1560 and 1561)

1. Surface Area of Aggregates:

Sieve No.	% Passing	S.A. Constant	Surface Area
3/8 inch & above	100	(0.41) 2	(0.41) 2
4		(0.41) 2	
8		(0.82) 4	
16		(1.64) 8	
30		(2.87) 14	
50		(6.14) 30	
100		(12.29) 60	
200		(32.77) 160	

Total S.A.: _____ ft.^{2}/lb.
Surface Area: S.I. System in Brackets _____ (m^2/kg.)

2. Bulk Specific Gravity of Aggregates:

Fine (passing No. 4 Sieve), not including M.F. ______
Coarse (retained on No. 4) ______
Weighted Average of Fine and Coarse Aggregates ______

3. % Fine Aggregate _____ ; % Coarse Aggregate _____ .

4. C.K.E. of 2 Fine Aggregates Specimens: _____ ______
Average C.K.E., corrected for Specific Gravity: ______

5. % Oil Retained of 2 Coarse Aggregate Specimens: ______ _____
Average % Oil Retained, corrected for Specific Gravity: _____

6. Determination of Optimum Asphalt Content:

Type of Asphalt and Aged Residue Viscosity: ______________

K_f: _____ K_c: _____ K_m: _____ Oil Ratio: _____

Optimum % AC by weight of Aggregates: _____

Optimum % AC by Weight of Total Mix: _____

HOT MIX DESIGN by the HVEEM METHOD Data Sheet

(ASTM D 1560 & 1561)

Specimen Nos.							
% AC by Wt. Mix							
Total Load pounds	Unit Load - P_v(psi)	Stabilometer Pressure Gauge Readings - P_h Horizontal Pressure					
500	40						
1,000	80						
2,000	160						
3,000	240						
4,000	320						
5,000	400						
6,000	480						
Displacement Turns - D_2							
Uncorrected Hveem Stabilometer Value - S							
Ht. of Specimen mm. or Inches							
Corrected Hveem Stabilometer Value* - S							
Swell - nearest 0.001 inches (0.025mm)		2 specimens tested at middle AC %					

$$\text{Stabilometer Value, } S = \cfrac{22.2}{\cfrac{P_h D_2}{P_v - P_h} + 0.222}$$

S = stabilometer value

D_2 = displacement on specimen

P_v = vertical pressure

P_h = horizontal pressure (Hveem Stabilometer Gauge Reading)

*See Figure 36 for correcting stabilometer values for specimen height.

HOT MIX DESIGN by the HVEEM METHOD Data Sheet
(ASTM D 1560 & 1561)

Specimen Nos.							
% AC by Wt. Mix							
Total Load pounds	Unit Load - P_v(psi)	Stabilometer Pressure Gauge Readings - P_h Horizontal Pressure					
500	40						
1,000	80						
2,000	160						
3,000	240						
4,000	320						
5,000	400						
6,000	480						
Displacement Turns - D_2							
Uncorrected Hveem Stabilometer Value - S							
Ht. of Specimen mm. or Inches							
Corrected Hveem Stabilometer Value* - S							
Swell - nearest 0.001 inches (0.025mm)		2 specimens tested at middle AC %					

$$\text{Stabilometer Value, } S = \frac{22.2}{\dfrac{P_h D_2}{P_v - P_h} + 0.222}$$

S = stabilometer value
D_2 = displacement on specimen
P_v = vertical pressure
P_h = horizontal pressure (Hveem Stabilometer Gauge Reading)
*See Figure 36 for correcting stabilometer values for specimen height.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1560 and D 1561)

Specimen Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt.in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1560 and D 1561)

Specimen Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C

Note: All weights should be measured in grams.

Rice Method Computation Sheet.

METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C

Note: All weights should be measured in grams.

Rice Method Computation Sheet.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1560 and D 1561)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate			P_1					
Fine Aggregate			P_2					
Mineral Filler			P_3					
Total Aggregate			P_4					
Asphalt Cement			P_5					
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Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1								
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Absorbed Asphalt (P_{ba}),% by wt. of aggregate., Equation 4								
Effective Asphalt Content(P_{be})% by wt.of total mix, Equation 5								
Percent Voids Mineral Aggregate (VMA), Equation 6								
% Air Voids (P_a), Equation 8								

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Hveem Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1560 and D 1561)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
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Total Aggregate			P_4					
Asphalt Cement			P_5					
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Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1								
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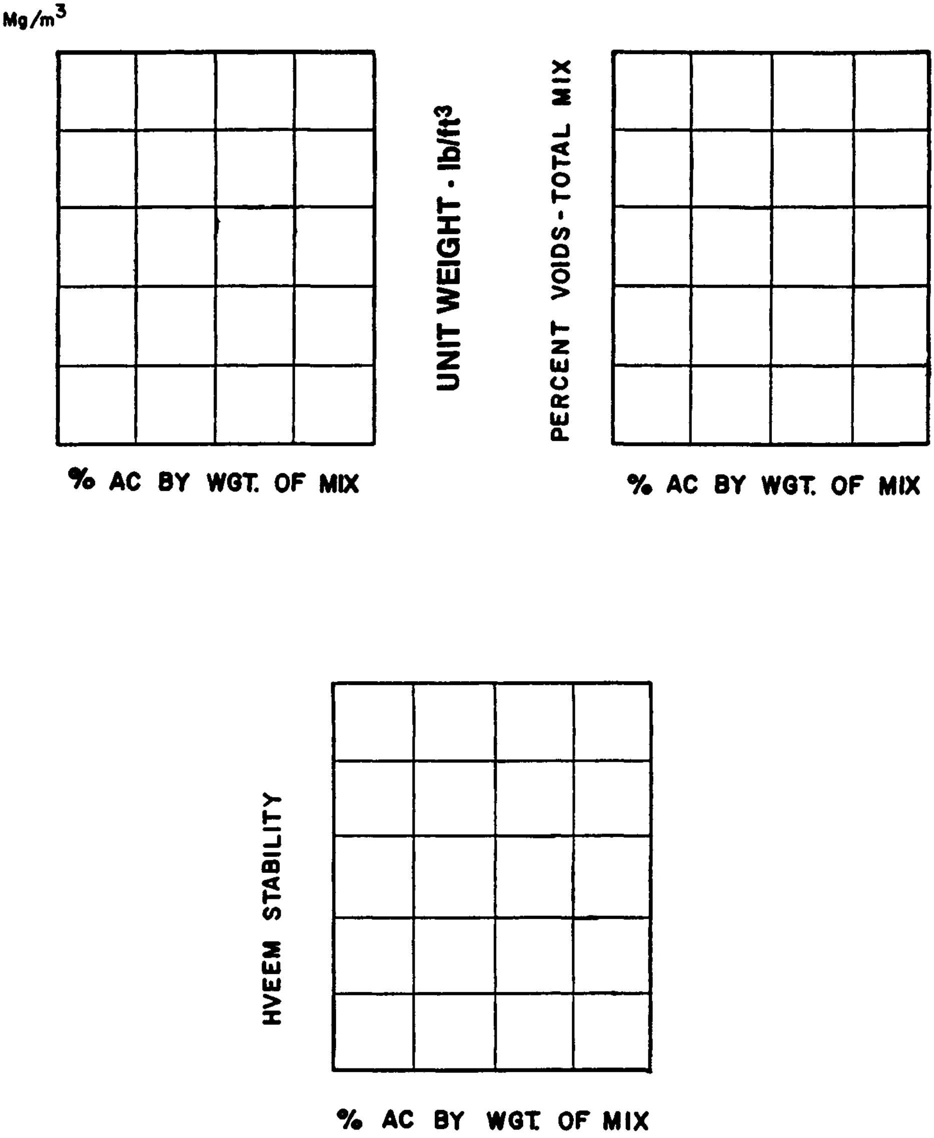
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3								
Absorbed Asphalt (P_{ba}),% by wt. of aggregates, Equation 4								
Effective Asphalt Content(P_{ba})% by wt.of total mix, Equation 5								
Percent Voids Mineral Aggregate (VMA), Equation 6								
% Air Voids (P_a), Equation 8								

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Hveem Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.



Three Graphs of Physical Properties for Hveem Mix Design.
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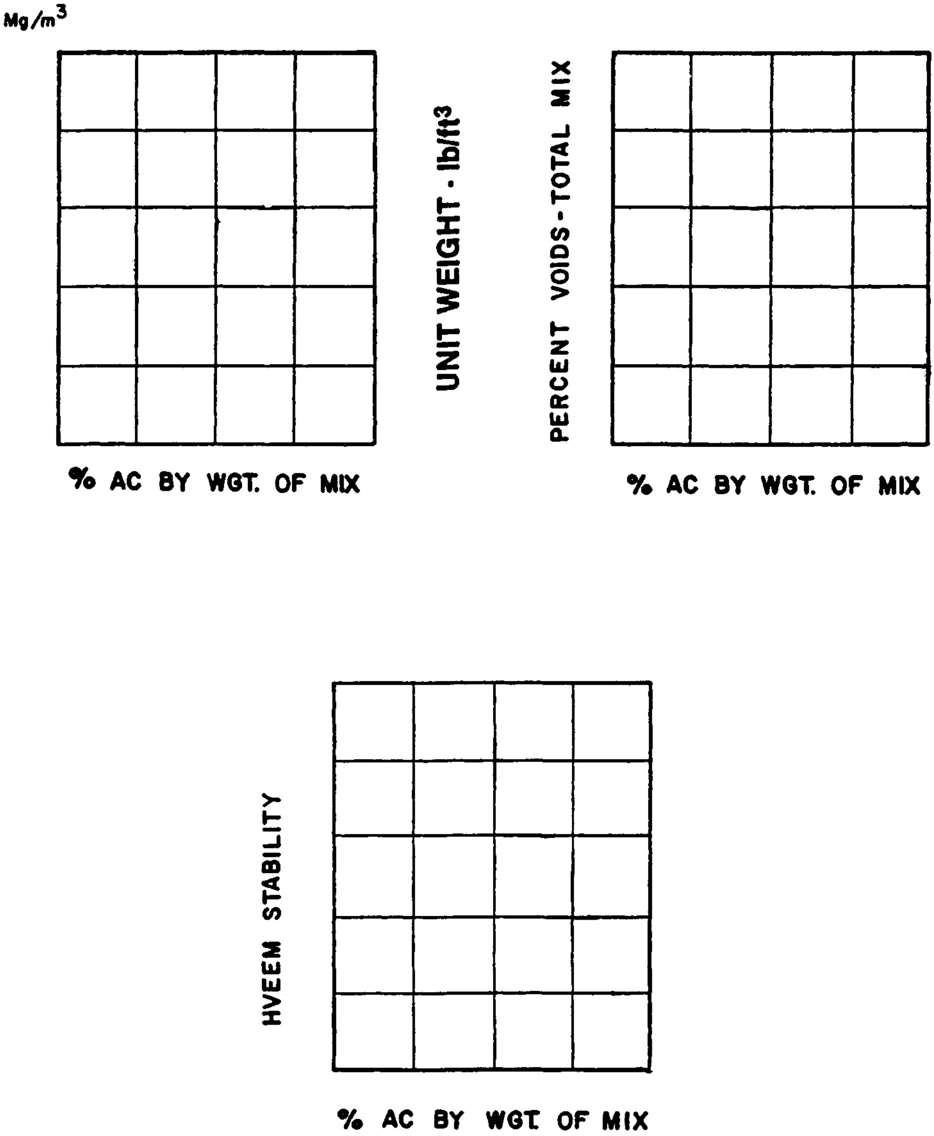

Three Graphs of Physical Properties for Hveem Mix Design. Reprinted with Permission of The Asphalt Institute.

TESTS FOR
ASPHALT MATERIALS

PENETRATION TEST

Reference - ASTM Designation: D 5

A. Purpose: A weighted needle is allowed to bear on the surface of a dish of asphalt at standard test temperature for a given length of time. The depth of penetration of the needle measured in 1/10 mm is the basis for the classification of standard penetration ranges of most asphalt cements for their consistency.

B. Equipment and Materials: Penetration apparatus with a standard needle, two 3-oz. metal containers (55 mm in diameter and 35 mm deep), constant-temperature water bath, thermometers, stop watch, and asphalt cement.

C. Test Procedure: Heat the sample with care to prevent local overheating until it has become fluid. Then with constant stirring raise the temperature of the asphalt sample 80^{0}C (77^{0}F) to 90^{0}C (194^{0}F) above its softening point. Pour it into the sample container to a depth such that, when cooled to the temperature of test, the depth of the sample is at least 10 mm greater than the depth to which the needle is expected to penetrate. Cover the container loosely to protect from dust and allow to cool in an atmosphere at a temperature between 21.1 to 29.5^{0}C (70^0 to 85^{0}F) for 1 to 1-1/2 hr. Place the 50 gm weight above the needle, making the nominal total load 100 gm. Place the container in the bath and keep it completely submerged under water at temperature 25^{0}C (77^{0}F) during the entire period of test. If the tests are made with the penetration apparatus mounted in the bath, place the sample container directly on the submerged stand of the penetration apparatus. If tests are made with the sample in the bath and the penetration apparatus outside the bath, place the container on the shelf provided in the bath. If tests are made using the transfer dish with the penetration apparatus outside the bath, place the sample in a dish filled with water from the bath to a depth to cover completely the sample container. Then place the transfer dish containing the sample on the stand of the penetration apparatus and penetrate immediately. In each case, adjust the needle to just make contact with the surface of the sample (watch the contact of the actual needle point with its image). Note the dial reading or adjust it to zero. See the sketches on page 50.

1. 50 gr., 50.8 mm (2 inches) long, 1.00 - 1.02 mm in diameter, forming a truncated cone at one end with 0.14 to 0.16 mm in diameter. The tapering angle is 8^{0}40′ to 9^{0}40′. Rockwell hardness C57 to C60 stainless steel.

2. Unless specified, the test conditions are assumed to be at 25^0C (77^0F), 100 g load and 5 sec. duration time. Then quickly release the needle for the specified period of time, 5 sec., and adjust the instrument to measure the distance penetrated. Hold the container tight. If it moves during the test the result should be discarded.

3. Make at least 3 penetrations at points on the surface of the sample not less than 1 cm (3/8 inch) from the side of the container and not less than 1 cm (3/8 inch) apart. If the transfer dish is used, return the dish and sample to the water bath after each penetration. Before each test, clean the needle with a clean cloth moistened with a suitable solvent to remove all adhering bitumen and then wipe with a clean dry cloth. For penetration values greater than 225, use at least three needles, leaving them in the sample until completion of the entire test.

D. Explanation of Computations and Data Sheet:

1. Computations: submit to the nearest whole unit the average of at least 3 least three penetrations whose values do not differ by more than the amount shown below. Average only those results that meet that criterion for determining the penetration value of the test specuimen.

Penetration	0 to 49	50 to 149	150 to 249	250 or over
Maximum difference between highest and lowest determinations.	2	4	6	8

2. Data Sheet: the Penetration Test data sheet is shown on the next page. Complete the data called for and carefully follow the instructions just above the table for Penetrometer Readings. The Penetration Grade of the asphalt on line 13, shown on the data sheet, is obtained from the Appendix , Table 7. If grading is based on aged residue asphalt, make reference to the Appendix, Table 14, for the percent of original penetration retained. The average penetration for the AC may not fall within specification limits. In those instances select the nearest applicable grade and note the discrepancy.

PENETRATION TEST (ASTM D 5)

1. Material identification ______________________
2. Date____________Air Temperature ______________________⁰F
3. Date of preparation of test Specimens ______________________
4. Depth of sample in container (specified to be at least 10 mm. greater than depth of penetration of needle). ______________________mm
5. Length of air cooling period before placing in controlled water bath (specified to be between 1 1/2 and 2 hr.) ______________________
6. Clock time specimen placed in controlled water bath ______________________
7. Clock time specimen removed from controlled water bath ______________________
8. Interval in controlled water bath (specified to be between 1 1/2 and 2 hr.) ______________________hr.
9. Weight of load on needle ______________________gm
10. Time of applicaton of needle to specimen ______________________sec.
11. Temperature of controlled water bath ______________________⁰F

Penetrometer Readings

Take readings until 3 penetration values are secured whose average meets the tolerance requirements. Circle the 3 penetration values used in computing the penetration value recorded on line 12. Report penetration value as the <u>nearest whole number.</u>

Trial	1	2	3	4	5	6	7	8
Final								
Initial								
Penetration Value								

12. Penetration value for material ______________________

13. Grade of material based on penetration value secured ______________________

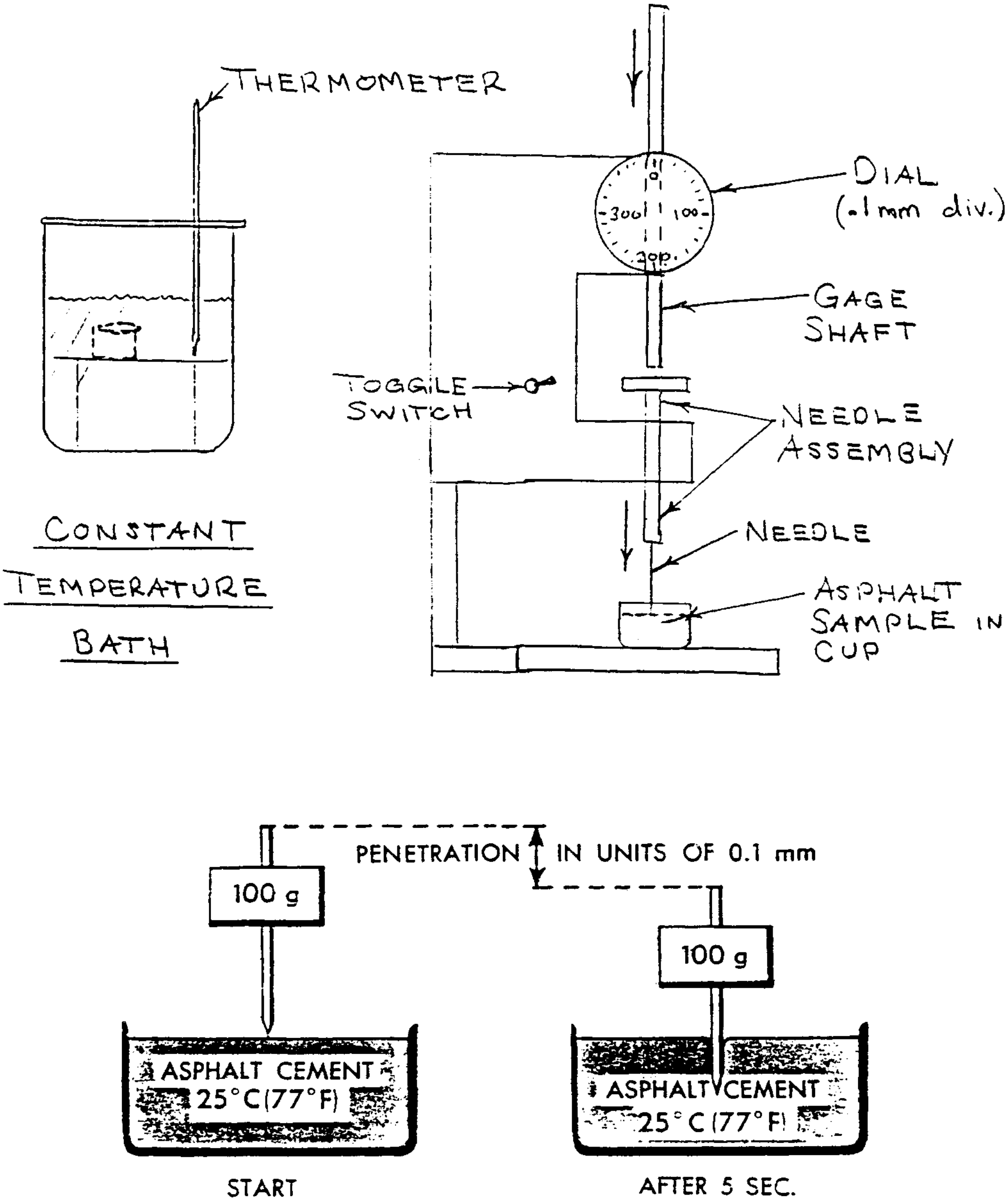

Figure 9 - Penetration Test Apparatus.

SOFTENING POINT

Reference - ASTM Designation D 36

A. Purpose: Softening point can be used as a measure of consistency of an asphalt cement. In general softening does not take place at a definite temperature. For this reason, the determination of the softening point must be made by a fixed, arbitrary, and closely defined method if the results are to be comparable.

B. Equipment and Materials: Brass-shouldered ring with a 5/8 in. diam., 3/8 in. (9.53 mm) steel ball, ball centering guide, a glass bath, ring holder, thermometer (-2^0 to 80^0C, i.e., 30^0 to 180^0F, or 30^0 to 200^0C, i.e., 85^0 to 392^0F), and asphalt cement.

C. Test Procedure: Heat the sample with care to prevent local overheating, with constant stirring until it has become sufficiently fluid to pour. In no case should the temperature be raised 111^0C (220^0F) more than the expected softening point for asphalt. Avoid incorporating air bubbles in the sample. Bring the asphalt sample to the pouring temperature in not more than 2 hrs. Pour the sample into rings, preheated to approximately the pouring temperature. While being filled, the rings should rest on a brass plate (greased). Cool for a period of 30 to 240 min. Cut the excess material off cleanly with a slightly heated knife or spatula. Two procedures are devised for finding the softening points according to above or below 80^0C (176^0F).

1. Procedure for materials having softening points 80^0C (176^0F) or below: Assemble the apparatus with the rings, the thermometer, and ball centering guides in position and fill the bath with freshly boiled distilled water at $5^0 \pm 1^0$C ($41^0 \pm 2^0$F) to a depth between 4.0 to 4.25 inches. Maintain the bath temperature at 5^0C (41^0F) for 15 min. placing the test container in ice water necessary. Using forceps, place a ball, previously adjusted to the bath temperature, in each ball centering guide. Apply heat in such a manner that the temperature of the liquid is raised 5^0C or 9^0F per min. The rate of rise of temperature shall be uniform. The maximum permissible variation for any minute period after the first three minutes shall be $\pm$ 0.5^0C ($\pm$ 0.9^0F). Record for each ring and ball the temperature shown by the thermometer at the instant the sample surrounding the ball touches the bottom plate. If the difference between values obtained in the duplicate determinations exceeds 1^0C (2^0F) repeat the test. For bitumen having a softening point above 80^0C (176^0F), follow the same procedures except use USP glycerin instead of water and the high range thermometer 30^0 to 200^0C (85^0 to 392^0F).

D. Explanation of Computations and Data Sheet:

1. Computations: record to the nearest 0.2^0 or 0.5^{0}C (0.5^0 or 1^{0}F), depending upon thermometer used, the mean of the temperatures recorded in duplicate determinations as the softening point.

2. Data Sheet: follow the steps shown on the table on the next page. On line 9 indicate the temperature that each of the balls touches the bottom plate. Line 10 is the average of the two readings to the required accuracy. The additional temperature lines are included on the Data Sheet, if the test needs to be repeated.

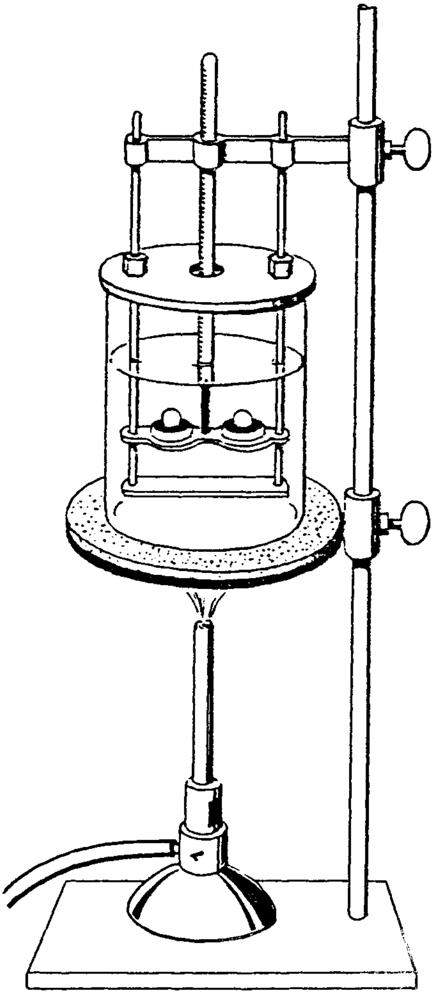

Figure 10 - Softening Point Test.
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SOFTENING POINT TEST -- Ring and Ball Method (ASTM D 36)

1. Material identification ______________________
2. Date ______________ Air Temperature ______________________ ^{0}C
3. Clock time sample poured into ring ______________________
4. Clock time ring transferred to 5^{0}C water bath ______________________
5. Interval test specimen cooled in air ________________ minutes
6. Clock time test specimen removed from 50C water bath for trimming ______________________
7. Interval test specimen in 5^{0}C water bath ______________________
8. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval.

Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C	Timer Reading Minutes	Temperature, ^{0}C	Temperature, ^{0}C
0			8		
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		

9. Temperature indicated by thermometer when material touches bottom ______________________ ^{0}C
10. Softening point ______________________ ^{0}C
11. Grade of material tested based upon the softening point test result according to the current specification requirements of the Illinois Division of Highways ______________________

SPECIFIC GRAVITY

Reference - ASTM Designation D 70

A. Purpose: To determine the specific gravity of Asphalt Cement. The specific gravity shall be expressed as the ratio of a given volume of Asphalt cement at 25^0C (77^0F) to that of an equal volume water at the same temperature.

B. Equipment and Materials: Glass pycnometer, consisting of a cylindrical or conical vessel ground to receive an accurately fitting glass stopper, approximately 22 to 26 mm in diameter. The stopper shall contain a 1.0 to 2.0 mm capillary hole, centrally located and coinciding with its vertical axis. The top surface of the stopper shall be smooth and the lower surface shall be concave, approximately 5mm deep at the center, to allow air to escape through the bore. The stopped pycnometer shall have a capacity of about 24 to 30 ml. and weigh not more than 40 grams.

C. Test Procedure:

1. Thoroughly clean, dry, and weigh the pycnometer and stopper. Designate this weight as "a".

2. Fill the pycnometer with freshly boiled distilled water, firmly insert the stopper, and completely immerse the pycnometer for 30 minutes in a bath of distilled water, maintained at 25^0C (77^0F).

3. Carefully remove the pycnometer from the constant temperature bath. Wipe the top of the stopper so that it is dry and the meniscus of water in the bore is flush with the top of the stopper. Wipe all moisture from the outer surface of the pycnometer with a clean cloth.

4. Immediately weigh the pycnometer and water. Designate this weight as "b". Dry and slightly warm the pycnometer.

5. Pour the pycnometer about half full with previously heated asphalt. Take care that no asphalt touches the sides of the pycnometer above the final level of the asphalt and that there are no air bubbles.

6. Cool the pycnometer and asphalt to room temperature and weigh with the stopper. Designate this weight as "c".

7. Fill the pycnometer with distilled water and firmly insert the stopper. Completely immerse the pycnometer again in the 25^0C (77^0F) constant temperature bath for 30 minutes.

8. Repeat No. 3 after removal of the pycnometer from the constant temperature bath.

9. Weigh the pycnometer and contents immediately. Designate this weight as "d".

10. All weights should be to the nearest thousandths of a gram.

11. Carefully clean the pycnometer after the test by placing it upside down in the oven at less than 100^0C (212^0F) until most of the asphalt has flowed out into some crucible or other dish. Swab the inside with a piece of soft cloth, cool, rinse clean in a suitable solvent, and wipe clean.

D. Explanation of Computations and Data Sheet:

1. Computations: conduct the Specific Gravity determination on 3 samples. Use the average of the three results unless one of them significantly differs from the other two. In that case average only the latter. If all three results are in substantial disagreement, rerun the entire test procedure. Report the results to the nearest third decimal place. The variation between acceptable test results should be within 0.003.

$$\text{Specific Gravity} = \frac{c-a}{(b-a) - (d-c)}$$

a - weight of pycnometer (always include the stopper).
b - weight of pycnometer filled with water.
c - weight of pycnometer plus asphalt.
d - weight of pycnometer plus asphalt filled with water.

2. Data Sheet: self-explanatory form is shown on the next page.

DATA SHEET FOR SPECIFIC GRAVITY OF ASPHALT (ASTM D 70)

ASPHALT____________________DATE_______TEMP.______________

ASPHALT CEMENT

Pycnometer No.	________	________	________
(1) Weight of Pycnometer Filled With Water	______gm	______gm	______gm
(2) Weight of Empty Pycnometer	______gm	______gm	______gm
(3) Weight of Water (Line 1 - Line 2)	______gm	______gm	______gm
(4) Weight of Pycnometer + Asphalt Cement	______gm	______gm	______gm
(5) Weight of Empty Pycnometer (Line 2)	______gm	______gm	______gm
(6) Weight of Asphalt Cement (Line 4 - Line 5)	______gm	______gm	______gm
(7) Weight of Pycnometer + Asphalt Cement + Water	______gm	______gm	______gm
(8) Weight of Pycnometer + Asphalt Cement (Line 4)	______gm	______gm	______gm
(9) Weight of Water (Line 7 - Line 8)	______gm	______gm	______gm
(10) Weight of Water Displaced by AC (Line 3 - Line 9)	______gm	______gm	______gm

$$\text{Specific Gravity} = \frac{\text{Weight of A.C.}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 10}}$$ ________ ________ ________

Average __________

LIQUID ASPHALT - ASPHALT CUTBACK AND EMULSIFIED ASPHALT

Pycnometer No.	________	________	________
(1) Weight of Pycnometer Filled With Water	______gm	______gm	______gm
(2) Weight of Empty Pycnometer	______gm	______gm	______gm
(3) Weight of Water (Line 1 - Line 2)	______gm	______gm	______gm
(4) Weight of Pycnometer Filled With Asphalt	______gm	______gm	______gm
(5) Weight of Pycnometer (Line 2)	______gm	______gm	______gm
(6) Weight of Asphalt (Line 4 - Line 5)	______gm	______gm	______gm

$$\text{Specific Gravity} = \frac{\text{Weight of Asphalt}}{\text{Weight of Water}} = \frac{\text{Line 6}}{\text{Line 3}}$$ ______ ______ ______

Average __________

SAYBOLT FUROL VISCOSITY TEST
Reference - ASTM Designation D 88

A. PURPOSE: To find the efflux time in seconds of 60ml of sample flowing through a calibrated orifice under specified conditions. The result of this empirical measurement is used as an index of the consistency or viscosity of the material.

B. EQUIPMENT and Materials: Saybolt viscometer, bath, withdrawal tube, thermometer support, filter funnel, receiving flask, timer, viscosity thermometer, No. 100 sieve and asphalt cement.

C. TEST PROCEDURE: Set up the viscometer and the bath and avoid draft and dust. Clean the viscometer with an effective non-toxic solvent and remove all solvent from the gallery and viscometer. Use a test temperature of 122^0F.

The test may be expedited by preheating the sample to not more than 3^0F above the test temperature. Never preheat any sample to within 50^0F of its flash point. Use MC 70 for test material (not typical in specifications).

Insert a cork stopper, having a cord attached for its easy removal, into the air chamber at the bottom of the viscometer. The cork shall fit tightly enough to prevent the escape of air, as evidence by the absence of oil on the cork when it is withdrawn.

Filter the prepared sample through a 100-mesh screen direcly into the viscometer until the level is above the overflow rim. Stir the sample until its temperature remains constant within 0.05^0F of the test temperature during 1 min. of continous stirring. Stir with a viscosity thermometer equipped with a thermometer support. Use a circular motion at 30 to 50 RPM in a horizontal plane.

Remove the thermometer from the sample. Quickly remove the oil from the gallery until its level is below the overflow rim. Do this by using withdrawal tube. Do not touch the overflow rim or the effective head of the sample will be reduced.

Place the receiving flask where the stream of oil from the bottom of the viscometer will just strike the neck of the flask. The graduation mark on the flask shall be between 100 and 130 mm from the bottom of the viscometer tube. Snap the cork from the viscometer using the attached chord. At the same instant start the timer. Stop the timer the instant the bottom of the meniscus reaches the graduation mark. Record the efflux time in seconds, assuming the correction factor being 1. Report this value to the nearest 0.1 sec. for the efflux time less than 200 sec. Report it to the nearest whole second for the efflux time equal or greater than 200 sec.

D. Explanation of Computations and Data Sheet:

1. Computations: multiply the efflux time by the viscometer calibration factor. Report the corrected time in seconds of the oil tested, at the temperature at which the test was conducted. Report values below 200 seconds to the nearest 0.1 seconds and above 200 seconds to the nearest whole second. Periodically the viscometers should be calibrated at 100^0 F, following the instructions in Appendix A of ASTM, Part 15. For oils having a minimum efflux time of 90 seconds, the viscometer should be calibrated at 122^0 F. The factor, F = V/t, where V = certified viscosity of the standard oil used and t = time in seconds.

2. Data Sheet: shown on the next page and is self-explanatory. The term (SFS) stands for Saybolt Furol Seconds. The term Furol is a contraction of fuel and road oils.

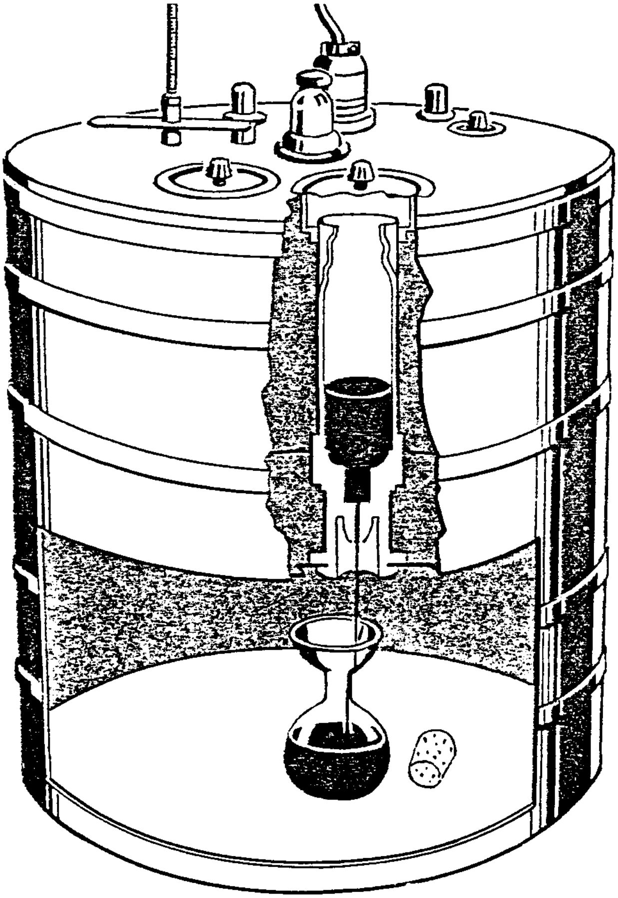

Figure 11 - Saybolt Furol Viscosity Test Apparatus. Reprinted with permission of The Asphalt Institute.

SAYBOLT VISCOSITY TEST DATA SHEET (ASTM D 88)

1. Material identification ______________________________

2. Date _______________ Air Temperature __________________________

3. Outlet tube used ______________________________

4. Designated test temperature ____________________________ ^{0}F

5. Exact temperature of material when cork was snapped ____________________________ ^{0}F

6. Time for material to flow from oil tube through outlet tube ____________________ min.

7. Saybolt-Furol viscosity value (SFS) ____________________ sec.

8. Temperature record. Record below the temperature of the bath when the cork is snapped (0 time) and at the end of each minute thereafter.

Time - Minutes	Temperature ^{0}F	Time - Minutes	Temperature ^{0}F
0		6	
1		7	
2		8	
3		9	
4		10	
5		11	

FLASH and FIRE POINTS by CLEVELAND OPEN CUP

Reference - ASTM Designation: D 92

A. Purpose: Obtain the lowest temperature at which the application of the test flame causes the vapor above the sample to ignite. This temperature will be the indicator for safe operation by users since it is below that which the asphalt will support combustion. The latter temperature is called the "Fire Point", but it is seldom used in specifications.

B. Equipment and Materials: Cleveland Open Cup Apparatus consisting of the Test cup, heating plate, test flame applicator, bunsen burner and supports, thermometer having a range of -6^0 to 400^0C (ASTM No.11C) or 20^0 to 760^0F (ASTM No.11F), and asphalt cement.

C. Test Procedure:

1. Support the apparatus on a level, steady table. Before filling the test cup with the sample of AC, be certain that it is free of all materials from previous tests. Support the thermometer in a vertical position with the bottom of the bulb 6.4 mm (1/4 inch) above the bottom of the cup and midway between the center and side of the cup on a diameter perpendicular to the arc of the sweep of the test flame and on the side opposite to the test flame burner arm.

2. Fill the test cups so that the top of the asphalt meniscus is exactly at the filling line. Do not use any sample which has any asphalt on outside of the cup. Remove any air bubbles on the surface of the sample with a flame.

3. Light the test flame and adjust to a diameter of about 4mm (1/8 inch).

4. Apply heat to the asphalt sample in the test cup so that the rate of temperature rise is 14^0 to 17^0C/min. (25^0 to 30^0F/min.). When the sample reaches about 56^0C (100^0F) below the anticipated flash point, 175^0C (350^0F) in the case of AC, decrease the rate of temperature rise to 5^0 to 6^0C/min. (9^0 to 11^0F/min.).

5. Starting at about 50^0C (90^0F) below the anticipated flash point, apply the test flame when the temperature read on the thermometer reaches each successive 3^0C (5^0F) mark. Pass the test flame across the center of the cup, at right angles to the diameter which passes through the thermometer. With a smooth, continuous motion apply the flame either in a straight line or along the circumference of a circle having a radius of at least 150mm (6 inches). The center of the test flame must move in a horizontal plane not more than 2mm (1/16 inch) above the plane of the upper edge of the cup. On each pass of the flame, move it in the opposite direction.

6. Record as the observed flash point the temperature read on the thermometer when a flash appears at any point on the surface of the surface of the sample.

7. Conduct the test on two samples. If the results do not vary by more that 8^0C (15^0F), accept the average of the two. Otherwise, determine the flash point on additional specimens until a pair of values are obtained that do not vary by more than the specified difference.

8. For the fire point determination, continue heating at 5 to 6^0C (9 to 11^0F) per minute. Apply the test flame at 2^0C (4^0F) intervals until the oil ignites and continues to burn for at least five seconds. At the bottom of the data sheet record the temperature that the oil began to burn.

D. Explanation of Computations and Data Sheet: There are no computations as such. Follow the instructions included in the Test Procedure, Part C, and in the Data Sheet on the next page.

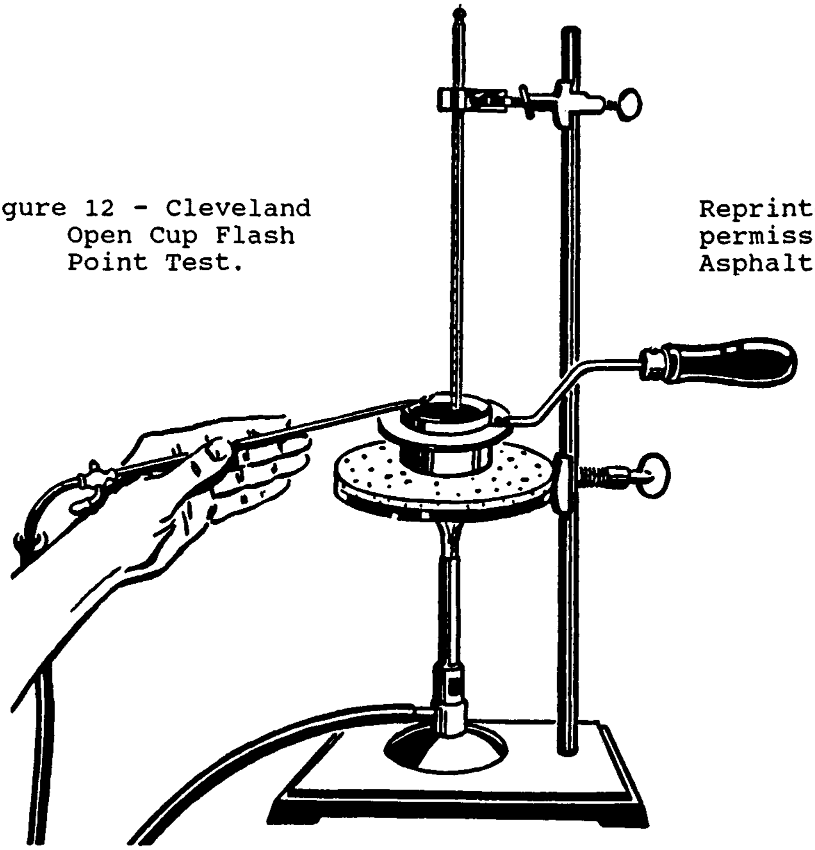

Figure 12 - Cleveland Open Cup Flash Point Test.

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FLASH AND FIRE POINTS TEST DATA (D 92)

1. Material identification ____________________________

2. Date ___________________ Air Temperature _________________

3. Apparatus used ____

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minutes.	Temperature, ^{0}F.	Temperature, ^{0}F.	Timer Reading Minutes.	Temperature, ^{0}F.	Temperature, ^{0}F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point, ^{0}F.______________. Fire point, ^{0}F. ________________.

6. Were the heating requirements met, as outlined in paragraph C of the instruction sheet? (a)__________________________________,
(b)____________________________, (c)________________________________.

FLASH POINT by the PENSKY-MARTENS CLOSED TESTER

Reference - ASTM Designation D 93

A. Purpose: Obtain the lowest temperature at which application of the test flame causes the vapor above the sample to ignite. This temperature will be the indicator for safe operation by users.

B. Equipment and Matertials: Pensky-Martens Tester, for tests in which the indicated reading falls within the limits 20^0 to 200^{0}F, use Low Range Thermometer having a range of -5^0 to + 100^{0}C (20^0 to 212^{0}F), for tests in which the indicated reading falls within the limits 220^0 to 700^{0}F, use High Range Thermometer having a range 90^0 to 370^{0}C (200^0 to 700^{0}F), and asphalt cement.

C. Test Procedure: Support the tester on a level, steady table. Heat the material to a temperature of at least 16^{0}C (3^{0}F) below its expected flash point. Fill the thoroughly cleaned cup (remove any gasoline or naphtha if used for cleaning) with the material to be tested to the level indicated by the filling mark. Place the lid on the cup and set the latter in the stove. Take care to have the locking device properly engaged. Insert thermometer. Light the test flame and adjust it to 5/32 in (4 mm) in diameter. Supply heat at such a rate that the temperature as read on the thermometer increase -5^0 to -6^{0}C (9^0 to 11^{0}F) per min. Turn the stirrer 90 to 120 rpm, stirring in a downward direction.

1. If the sample is known to have a flash point of (104^{0}C) (220^{0}F) or below, apply the test flame when the temperature of the sample reaches 10^{0}C (18^{0}F) below the expected flash point, and thereafter at each temperature reading that is a multiple of 2^{0}F (1^{0}C). The test flame is applied by operating the mechanism on the cover which controls the shutter and test flame burner so that the flame is lowered into the vapor space of the cup in 0.5 sec. left in its lowered position for 1 sec. and quickly raised to its high position. Discontinue stirring while applying the test flame.

2. If the sample is known to have a flash point above 104^{0}C (220^{0}F), apply the test flame in the manner just described at each temperature that is a multiple of 2^{0}C (5^{0}F), beginning at a temperature of 16^{0}C (30^{0}F) below the expected flash point. In order to maintain the test flame, it may be necessary to lower it into the vapor space of the cup in 1 sec.

3. Record the temperature at the time the test flame application causes a distinct flash in the interior of the cup as the flash point. Sometimes the test flame during application is surrounded with a bluish halo as the flash point temperature is approached. Do not confuse the true flash with this halo.

D. Explanation of Computations and Data Sheet: there are no computations for this test procedure as such. Follow the instructions included in Test Procedure, Part C, and the self-explanatory Data Sheet on the next page.

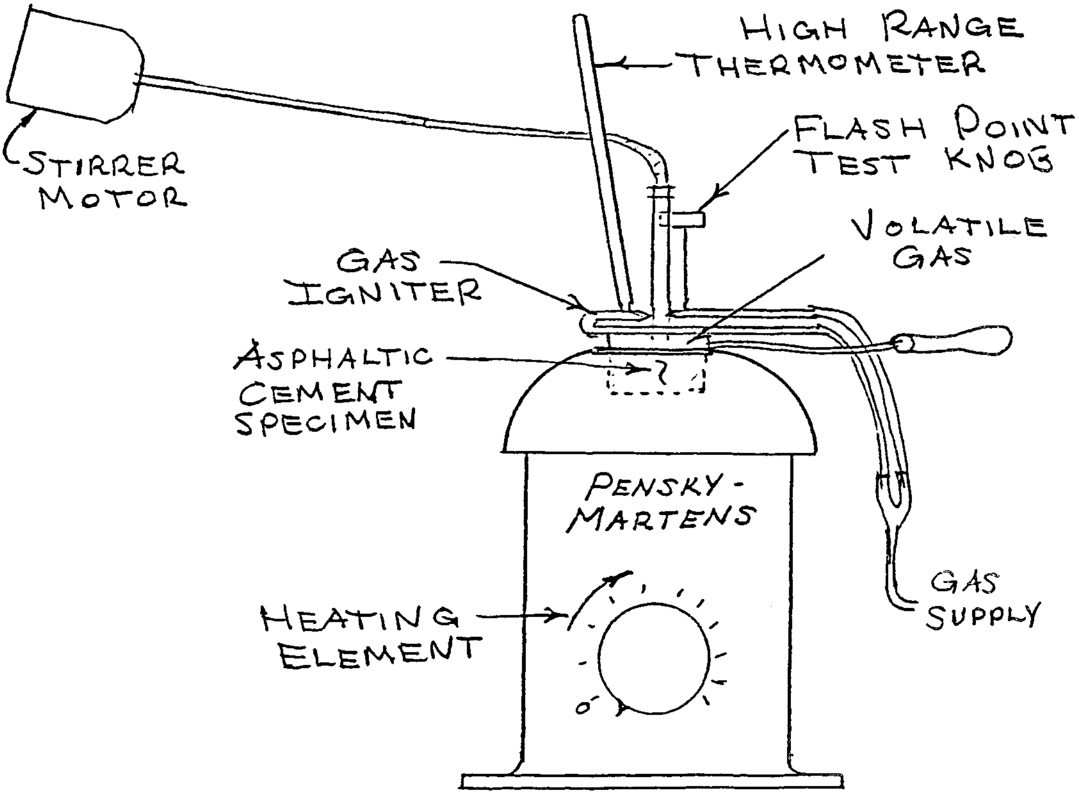


Figure 13 - Pensky-Martens Flash Point Tester.

FLASH POINT TEST by PENSKY-MARTENS APPARATUS (ASTM D 93)

1. Material identification ______________________________

2. Date __________ Air Temperature ______________________________

3. Apparatus used ______________________________

4. Record below the temperature indicated by the thermometer at the beginning of heating and at the end of each 1-min. interval. Compute the temperature rise for each 1-min. interval.

Timer Reading, Minute.	Temperature, ^{0}F.	Temperature, ^{0}F.	Timer Reading, Minute.	Temperature, ^{0}F.	Temperature, ^{0}F.
0			15		
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		

5. Flash point,^{0}F.______________.

6. Were the heating requirements met, as outlined in Section C of the Test Procedure?

(a)______________________________

(b)______________________(c)______________________________.

WATER in PETROLEUM PRODUCTS by DISTILLATION

Reference - ASTM Designation: D 95

A. Purpose: Determination of water in asphalt materials other than emulsions.

B. Apparatus and Materials: Brass still, condenser, trap, and ring gas burner as shown in the diagram on Figure 14; a solvent such as xylene; and asphalt cement.

C. Procedure:

1. Weigh 100 grams of sample into the still in the case of a solid test specimen such as asphalt concrete and 100 cc of xylene.

2. Circulate cold water through the jacket of the condenser.

3. Adjust the heat to the still so that the condensed distillate discharges from the condenser at the rate of about 200 drops per minute.

4. Read volume of water in the trap to the nearest scale division.

D. Explanation of Computations and Data Sheet:

1. Computations: Calculate the water content as follows:

$$\text{Water \%} = \frac{\text{Volume of water in trap}}{\text{Weight of Sample}} \times 100$$

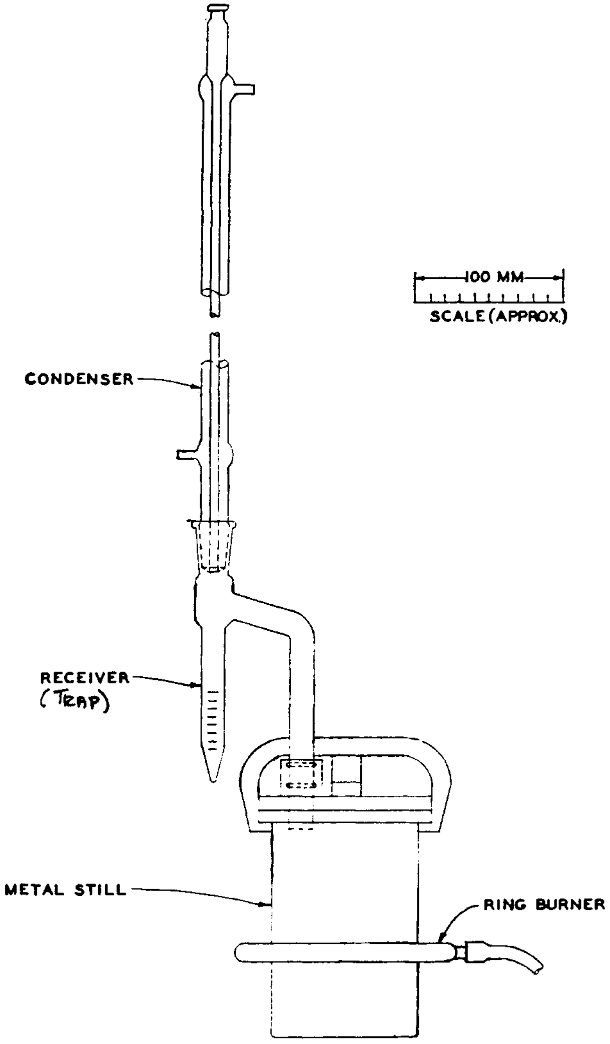
2. Data Sheet: there is no form for this test. Merely record the volume of water to the nearest scale division.

3. Duplicate determination of water by the same operator should be considered suspect if they differ by more than the following amounts:

Water Collected, ml	for 10 or 25 ml traps
0 to 0.1	0.1 ml
1.1 to 25	0.1 ml or 2% of the mean, whichever is greater.

4. The results submitted by each of two laboratories should be considered suspect if they differ by more than the following amounts:

0 to 1.0	0.2 ml
1.1 to 25	0.2 ml or 10% of the mean, whichever is greater.



NOTE—Trap shall be 15 to 16 mm in inside diameter.

Figure 14 - Typical Distillation Assembly with a Brass Still. Copyright ASTM. Reprinted with permission.

DUCTILITY TEST

Reference - ASTM Designation D 113

A. Purpose: The ductility of a bituminous material is measured by the distance to which it will elongate before breaking when a briquet specimen is pulled under specified conditions.

B. Equipment and Materials: Separable brass molds of standard dimensions when put together:

Total length	7.45 to 6.77 cm
Distance between	2.97 to 3.03 cm
Width at mouth of clip	1.98 to 2.02 cm
Width at minimum cross-section (halfway between clips)	0.99 to 1.01 cm
Thickness throughout:	0.99 to 1.01 cm

Water bath, testing machine, brass plate, thermometer, No.50 sieve, and asphalt cement.

C. Test Procedure: Heat the sample with care to prevent local over-heating until it has become sufficiently fluid to pour. Strain the melted sample through a No. 50 sieve and after a thorough stirring, pour it into the mold which should be assembled on a brass plate, and the inner surface of the mold and plate greased. In filling, pour the material in a thin stream back and forth from end to end of the mold until the mold is more than level full. Be sure that mold is placed flat and level and not disarranged to distort the briquet. Let the mold with specimen cool to the room temperature for a period of from 30 to 40 minutes and then place it in the water bath for 30 minutes, afterwards cut off the excess bitumen with a hot straight edge or knife to make the mold just level full. The water bath should be maintained $25^0 \pm 0.1^0$C ($77^0 \pm 0.18^0$F). The volume of water should be not less than 10 liters, and the specimen shall be immersed to a depth of not less than 10 cm and shall be supported on a perforated shelf not less than 5 cm from the bottom of the bath.

Place the brass plate and mold, with briquet specimen in the water bath for a period of from 85 to 95 min. Then remove the briquet from the plate, detach the side pieces, and immediately test the briquet. Attach the rings at each end of the clips to the pins or hooks in the testing machine and pull the two clips apart at a uniform speed of 5 cm/min ± 5%. Measure the distance in centimeters through which the clips have been pulled to rupture. While the test is being made, the water in the tank of the testing machine shall cover the specimen both at the specified temperature $\pm 0.5^0$C ($\pm 0.9^0$F).

Rupture of the specimen occurs at the point where the thread has practically no cross-sectional area. At no time is the material allowed contact with the surface of the water or the bottom of the bath. Adjust the specific gravity of the bath by the addition of either methyl alcohol or sodium chloride to avoid the above difficulty. If this normal test result is not obtainable, it should be stated so. If the value exceeds 100 cm, and rupture has still not occurred call the result 100+ and stop the test.

D. Explanation of Computations and Data Sheet:

1. Computations: Take readings in centimeters of three normal tests and report the average.

2. Data Sheet: see the next page and follow the format.

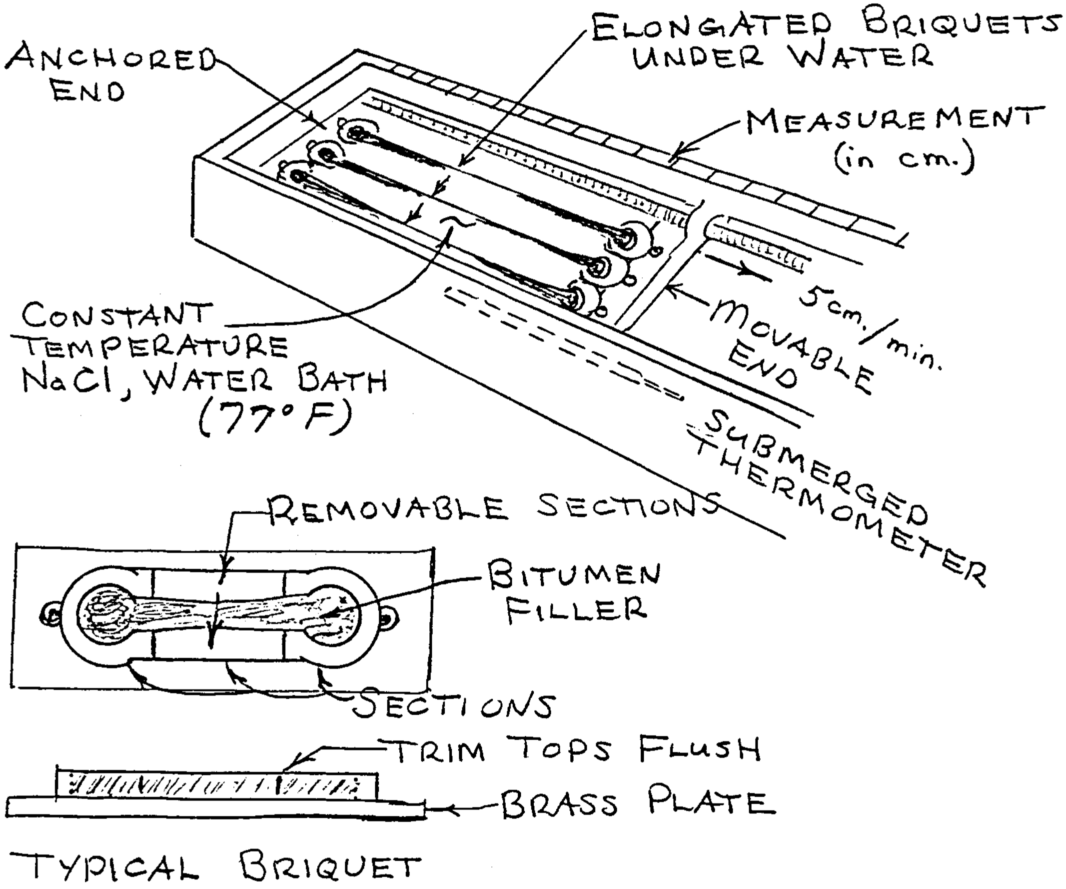


Figure 15 - Asphalt Cement Ductility Test Apparatus.

DUCTILITY TEST (ASTM D 113)

1. Material Identification ____________________

2. Date __________ Room Temperature ____________________ ^{0}F

3. Temperature of Sample during heating ____________________ ^{0}F

4. Time sample poured ____________________

5. Time placed in bath ____________________

6. Elapsed time cooling ____________________ min.

7. Temperature of Water bath ____________________ ^{0}F

8. Time: Start Test (Mold removed) ____________________

9. Curing Period in bath ____________________ min.

10. Setting of Controller for speed ____________________ rate

11. Distant of Specimen to:

    Top of Water ____________________ cm

    Bottom of Water ____________________ cm

12. Test results

Specimen	Ductility, cm
A	
B	
C	
D	
Sum	
Average	

Remarks ____

____

____

____

STANDARD METHODS of TESTING EMULSIFIED ASPHALTS

Reference - ATSM Designation: D 244

A. Purpose: to determine the water content and extract the asphalt cement residue for further testing.

1. Water Content

a. Equipment and Materials: 1. Brass Still, Condenser, Trap, and Ring Gas Burner set up as shown below.
b. Solvent - Xylol or other suitable petroleum distillate, and an asphalt emulsion.

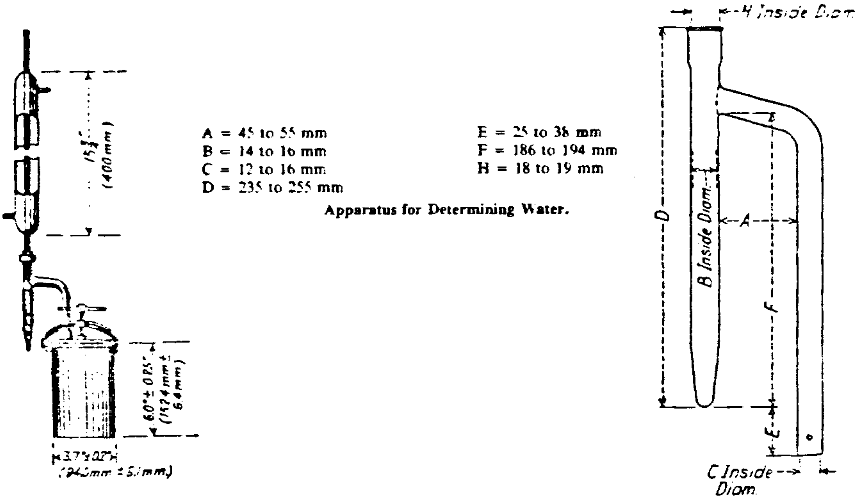


Figure 16 - Typical Apparatus for Water Determination in Emulsified Asphalts. Copyright ASTM. Reprinted with permission.

B. Procedure:

1.Thoroughly mix 50 ± 0.1 gram of the sample with 200 cc of the solvent.

2. When connecting the apparatus insert a heavy paper gasket, moistened with the solvent, between the lid and the flange before attaching the clamp.

3. Place the ring burner about 3 inches above bottom of the still at the beginning of the distillation and lower it gradually as the distillation proceeds. Regulate the heat so that the condensate falls from the end of the condenser at a rate of 2 to 5 drops per second. Continue the distillation until the volume of water in the trap remains constant. The temperature in the still should never exceed 110^0C (230^0F).

C. Computations: Calculate the water content as follows:

Water content, % A / B x (100) where
A = Volume of water in the trap, cc
B = Original weight of sample, grams

II. Residue by Distillation

A. Equipment and Materials: Aluminum Still, Ring Burner, Connecting Glass Tube, Metal Shield, Bunsen Burner, Condenser, 100 cc Graduated Cylinder, two Low-Distillation Thermometers having a range from -2^0 to 300^0C (30^0 - 580^0F) and a balance capable of weighing 3.5 KG to an accuracy of ±0.1 gram and an asphalt emulsion. The set-up is shown below.

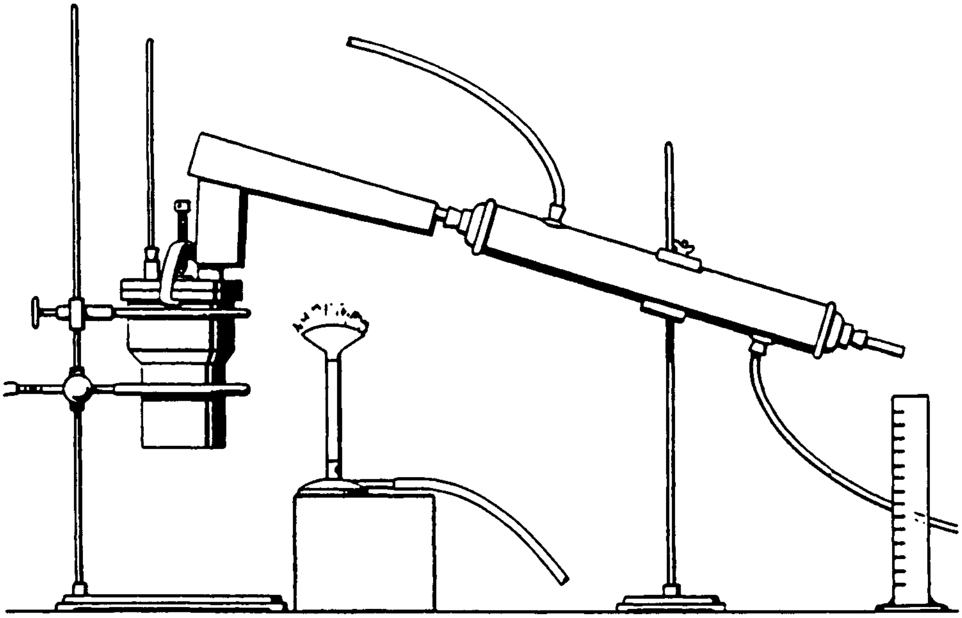


Figure 17 - Setup of Apparatus for Distillation Test of Emulsified Asphalts.
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B. Procedure: Distillation test (for emulsified Asphalts)

1. Weigh 200 ± 0.1 gram of a representative sample of the emulsion into the previously weighed still.

2. Assemble the still including the gasket between the still and the cover.

3. Set up the apparatus as shown above. Insert and adjust the thermometers so that the bulb of one is 1/4 inch (6.4mm)from the bottom of the still and the bulb of the other thermometer is approximately 6 inches (152.4mm) higher.

4. Place the ring burner 6 inches (152.4mm) from the bottom of the still. Light the ring burner, using a low flame. Also apply just enough heat with the bunsen burner to prevent condensation in the connecting tube.

5. Move the ring burner to the bottom of the still when the lower thermometer reaches 215^0C (420^0F). Increase the temperature to $260^0 \pm 5^0$C ($500^0 \pm 10^0$F) and maintain this temperature for 15 minutes from the first application of heat.

6. During the distillation procedure, keep monitoring the upper thermometer. A sudden change in temperature is indicative of foam having risen to the bulb. Remove the heat until the foaming ceases.

C. Special Instructions: Immediately at the cessation of heating, weigh the entire still assembly (including gasket and cover). The aluminum still at room temperature weighs 1.5 grams more than at 260^0C (500^0F). Correct for this discrepancy by adding 1.5 grams to the weight of the hot still.

Percent of residue by distillation = A/B x (100)

A = Weight of Residue
B = Weight of original emulsion sample

D. Preparation of Samples for Testing: Prepare appropriate specimens to test the AC residue for Ductility (ASTM D 113), Penetration (ASTM D 5), and Solubility (ASTM D 2042).

E: Explanation of Computations and Data Collection:

1. Computations: refer to paragraphs A.1.c. and A.2.c.

2. Data Collection: there are no special data sheets. Follow the instructions included in the Procedures.

DISTILLATION OF CUT-BACK ASPHALTIC PRODUCTS

Reference - ASTM Designation: D 402

A. Purpose: This method covers a distillation test for cutback asphaltic products. It is an important step in determining the type and grade of an asphalt cutback.

B. Equipment and Materials:

1. 500 cc side-arm distillation flask.
2. Condenser.
3. Adapter.
4. Steel shield to protect the flask from air currents and to reduce radiation.
5. Bunsen burner and chimney.
6. 100 cc graduated receiver.
7. Residue contained - 8 ounce seamless metal with slip on cover.
8. Thermometer.
9. Shield and flask support - two 15 cm sheets of 16-mesh chromel wire gauze on a ring and upright.
10. Cut-Back Asphalt.

C. Test Procedure:

1. Set up equipment as shown in Figure 18 - Distillation Apparatus for Cut-Back Asphalts.

2. Thoroughly stir the sample and place 200 ± 0.5 grams into the 500 cc flask.

3. Rate of heat application to the sample shall be governed as follows:
   a. First drop of distillate falls into the receiver in 5 to 15 minutes from the start of heat application.

   b. Maintain 260^0C (500^0F) for 50 to 70 drops per minute.

   c. Maintain 260^0 to 316^0C (500^0 - 600^0F) for 20 to 70 drops per minute.

   d. Not over 10 minutes to complete distillation from 316^0 to 360^0C (600^0 - 680^0F).

4. When the temperature reaches 360^0C (680^0F), extinquish the flame and remove the flask and thermometer. Remove the thermometer and immediately pour the contents into the residue container and close. When pouring, the side arm should be tilted slightly above horizontal to prevent condensate in the side arm from flowing back into the residue.

5. Drain any remaining condensate in the flask side-arm and in the condenser into the receiver.

6. Record the total volume of distillate collected as total distillate to 360^0C (680^0F).

7. When the residue has cooled and the fuming just ceases, stir thoroughly and pour into appropriate receptacles for testing of such properties as penetration, viscosity, or softening point.

D. Explanation of Computations and Data Collection:

1. Computations: results should be computed to the nearest 0.1 percent.

$$R = (200 - TD) / 200 \times 100.$$
$$TD = (TD/200) \times 100.$$

where R = asphalt residue content, in volume percent.
and TD = total distillate recovered to 360^0C (680^0F), cc.

2. Data Collection: there is no prescribed format for data collection in test. Follow the instructions for recording the data included under C. Test Procedure.

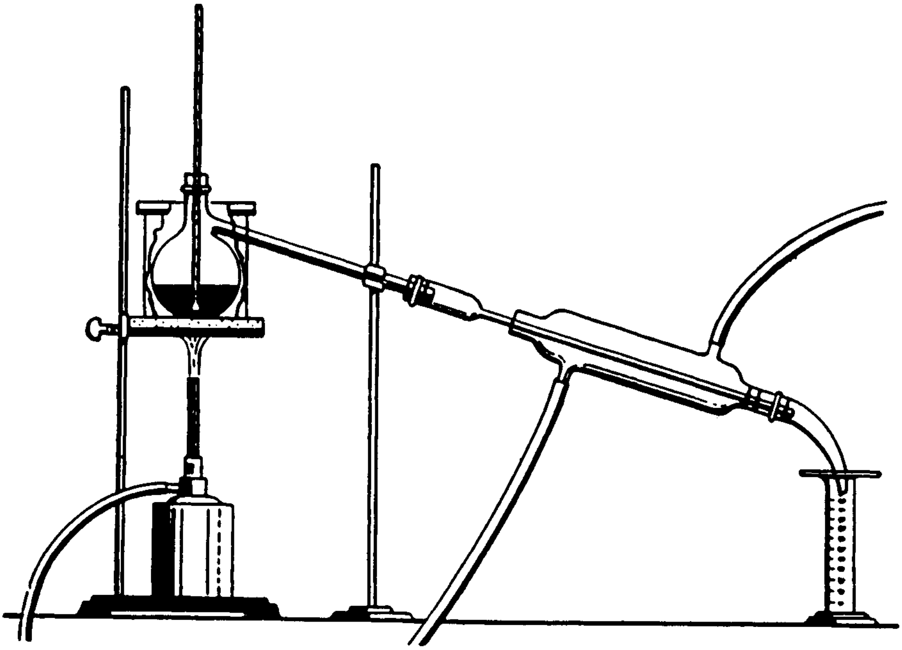

Figure 18 - Distillation Apparatus for Cut-Back Asphalts. Reprinted with permission of The Asphalt Institute.

BULK SPECIFIC GRAVITY of COMPACTED BITUMINOUS MIXTURES USING PARAFFIN-COATED SPECIMENS

Reference - ASTM Designation: D 1188

A. Purpose: The method described herein covers the bulk specific gravity determination of laboratory compacted mixtures with permeable surfaces. However, this method may also be used to determine the bulk specific gravity of cores taken from existing pavements. The procedure is similar to ASTM Designation: D 2726 on page 75 except for the need to apply a thin paraffin coating to prevent the infiltration of water. ASTM Designation: D 2726 is the more commonly used procedure.

B. Equipment and Materials: the same as for ASTM Designation: D 2726 on page 75 except for the addition of paraffin. Designate the known or laboratory obtained specific gravity of the paraffin at 25^0C (77^0F) as F.

C. Test Procedure: all weights must be made using the same scale.

1. Weight of Dry, Uncoated Specimens in Air - after the specimens have been standing at room temperature for at least one hour. Designate this weight as A.

2. Apply a thin coating of melted paraffin to all the surfaces of the specimens and allow to cool at room temperature for at least a half hour. Weigh the paraffin coated specimen in air and designate this weight as D.

3. Weigh the paraffin coated specimen in water at 25^0C (77^0F) and designate this buoyant weight as E.

4. In the case of core samples taken from existing pavements, it will be necessary to correct weights A, D, and E by deducting the weight of moisture in the specemens being tested using ASTM Designation: D 95 on page 44.

D. Explanation of Computations and Data Sheets:

1. Computations: the bulk specific gravity of the compacted mixtures are computed from the following equation with all weights in grams:

$$\text{Bulk Specific Gravity - } G_{mb} = A/[D - E - (D - A)/F]$$

Where duplicate specimens differ by more than 0.02, the results should be discarded and the test rerun.

2. Data Sheets: there is no special format for the data and computations.

MOISTURE or VOLATILE DISTILLATES in BITUMINOUS PAVING MIXTURES

Reference - ATSM Designation: D 1461

A. Purpose: It is sometimes desirable to know the amount of moisture and/or volatile distillates in an asphalt paving mixture, especially where emulsified and cutback asphalts are used. Such determinations are usually made by some type of distillation procedure as outlined herein. This ASTM method ascertains, by direct measurement, of moisture or volatile fractions of the bitumen in bituminous paving mixtures. In this manual only the determination of moisture will be addressed.

B. Equipment and Materials:

1. Apparatus is shown in Figure 16 - Typical Apparatus for Water Determination in Emulsified Asphalts for ASTM Designation: D 244, which includes a metal still, condenser and trap.
2. Solvent shall consist of xylene, or a blend of 20% toluene and 80% xylene or lubricating oil.
3. Asphaltic Concrete Test Sample.

C. Test Procedure:

1. Weigh 500 + grams of the asphalt concrete specimen, break it up into small particles and place in the still.

2. Add 200 cc of the solvent to the specimen in the still and quickly mix both components together.

3. Apply heat at such a rate that the reflux action will start in 5 to 10 minutes.

4. Continue the distillation until 3 successive readings of the trap at 15 minute intervals indicate no increase in the amount of water being condensed. In no case shall distillation be continued for more than 1-1/2 hours.

5. Allow the contents of the trap to reach room temperature and read the volume of water in the trap to the nearest scale division.

D. Explanation of Computations and Data Collection:

1. Computations: calculate the water contents as follows:

$$\text{Moisture Content in \%} = \frac{\text{Volume of water in trap}}{\text{Weight of Sample}} \times 100$$

2. Data Collection: Follow the instructions included in C. Test Procedure.

3. The precision of results shall be the same for judging acceptability as for ASTM Method D 95.

THEORETICAL MAXIMUM SPECIFIC GRAVITY - BITUMINOUS PAVING MIXTURES
Reference - ASTM Designation: D 2041

A. Purpose: Covers the determination of the theoretical maximum specific gravity of uncompacted bituminous paving mixtures. Specific gravity is defined as the mass of a given volume of asphalt concrete, with the air voids removed, to the mass of an equal volume of water at the same temperature.

B. Equipment: Only one of several variations of apparatus and procedures will be described in this reference.

1. A metal bowl having a capacity of at least one liter.

2. Balance, with capacity of at least 1-1/2 kilograms and sensitivity to 0.1 grams. The balance shall be equipped with a suitable suspension apparatus and holder to permit weighing the sample, both in air and in water, while suspended from the center of the scale pan of the balance.

3. A constant temperature bath suitable to accept the suspended metal bowl.

C: Size of samples shall conform to the following:

Size of Largest Aggregate Particle in Mixture, Inches.	Minimum Sample Size, grams.
1	2,500
3/4	2,000
1/2	1,500
3/8	1,000
No.4	

D. Procedure and Computations:

1. Soften the asphalt mixture by heating so that the particles can be manually separated into individual pieces, while taking care not to fracture the individual aggregates. This operation should all be carried out in a metal bowl.

2. Cool to room temperature and obtain the net weight in air. Make certain that the individual particles do not stick together and thereby trap air pockets. Weigh and designate the net weight of the sample in air as A.

3. Suspend the bowl and its contents in water and obtain the net buoyant weight of the asphalt mixture in water. Shake the bowl in the water to make sure that there are no trapped air pockets between particles. Designate the weight of sample in water as B.

4. The specific gravity of the mixture = A/(A -B). This value should be close to the average weighted value of the Bulk and Apparent Specific Gravities of the aggregates, from coarse to mineral filler fractions. See page 112 for Rice Method Data Sheet.

SOLUBILITY TEST
Reference - ASTM Designation: D 2042

A. Purpose: For the determination of the degree of solubility of asphalt cements in trichloroethylene. Refined asphalt is almost pure bitumen and is usually more than 99.5 percent soluble in trichloroethylene. The impurities are inert. Determining the degree of solubility is a process of dissolving about 2 grams of asphalt in 100 ml of solvent and filtering the resultant solution through a glass microfiber filter pad, placed in a porcelain (Gooch) crucible. The amount of material retained on the filter pad is determined and expressed as a percentage of the orignal sample.

B. Equipment and Materials:

1. Gooch Crucible-approximately 4.4 cm. in width at the top, tapering to 3.6 cm. at the bottom, with a depth of 2.8 cm.
2. Glass Microfiber Filter Pad, 3.2 cm.
3. Erlenmeyer Flask, 125 ml. or a 150 ml. Beaker.
4. Trichloroethylene, technical grade.
5. Distilled Water.
6. Filter Tube, 40 to 42 mm inside diameter.
7. Filtering Flask, heavy-wall with side tube, 250 or 500-ml capacity.
8. Drying oven.
9. Suction Pump.
10. Analytical balance, accurate to 0.1 gm.
11. Desiccator.
12. Approximately 10 grams of asphalt cement.

C. Test Procedures:

1. Place gooch crucible plus one thickness of the glass fiber pad in an oven at 110 ± 5^0C (230 ± 10^0F) for 15 minute and allow to cool in a desiccator. Weigh to the nearest 0.1 gm and store in the desiccator until ready for use.

2. Place approximately 2 grams of asphalt cement into a tared Erlenmeyer flask or a 150 ml. breaker and weigh to the nearest mg. Slowly add 100 cc of trichloroethylene to the beaker while continuously agitating until all of the asphalt cement is uniformly dispersed in the solution. Cover the container and set aside for at least 15 minutes.

3. Place the previously prepared and weighed Gooch crucible into the filtering flask as shown in the assembly in Figure 19. Wet the glass filter pad with a small amount of trichloroethylene and decant the solution of dissolved asphalt and trichloroethylene carefully through the filter pad in the Gooch crucible, using a light suction, if necessary. Wash the beaker with small amounts of additional trichloroethylene and continue decanting through

glass filter pad until the filtrate is colorless. Apply a strong suction to remove the remaining trichlorothylene.

4. Remove the Gooch crucible from the filtering tube, carefully clean off any bitumen from the bottom of the crucible with trichloroethylene, and place on top of the oven until there is practically no longer any odor of trichloroethylene. Put the Gooch crucible and the glass filter pad in the oven at $110^0 \pm 5^0$C ($230^0 \pm 10^0$F) for at least 20 minutes. Cool in a desiccator for about 30 minutes and weigh. Repeat the latter procedure of drying and weighing until a constant weight within ±0.3 mg is obtained.

5. A word of caution about trichloroethylene is important. This is a very toxic, highly flammable substance that requires good ventilation and rubber gloves in handling.

D. Explanation of Computations and Data Sheets:

1. Computations:

Insoluble, % = (A/B) X 100
Soluble, % = 100 - (A/B) x 100
A = Total Weight Insoluble - wt. of Gooch crucible + glass filter pad + insoluble minerals - (original wt. of Gooch crucible + glass filter pad).
B = Weight of asphalt cement sample.

For percentage of insoluble in the AC sample less than 1.0, report to the nearest 0.01%. For percentages of insoluble greater than 1.0%, report to the nearest 0.1%.

2. Data Sheets: there is no set data format for this test.

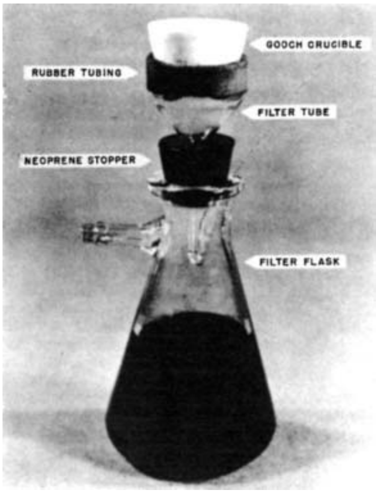

Figure 19 - Filter Apparatus Assembly.
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KINEMATIC VISCOSITY of ASPHALTS (BITUMENS)

Reference - ASTM Designation: D 2170

A. Purpose: This method covers procedures for the determination of liquid asphalts at 60^{0}C (140^{0}F) and of asphalt cements at 135^{0}C (275^{0}F). The method may be used at other temperatures. However, precision of results is only based on these two temperatures from 30 to 6,000 cSt. The absolute viscosity of paving grade asphalts, in poises, may also be determined from this method if the specific gravity at 25^{0}C (77^{0}F) is known and is multiplied by a factor of 0.934 gm/cm^3 in order to convert the density to 135^{0}C (275^{0}F).

B. Equipment and Materials: Constant temperature bath, Cannon-Fenske Opaque Viscometers (size no. governed by the kinematic viscosity), suitable thermo-regulator depending upon the test temperature plus asphalt cement and/or liquid asphalts .

C. Test Procedure:

1.Maintain the bath at the test temperature within ± 0.01^{0}C (±0.02^{0}F).

2. Select a suitable, clean, dry viscometer.

3. Pass an airjet through the viscometer to remove all traces of dust and solvent. Charge the viscometer by inverting it and applying suction to the tube L, immersing tube N in the liquid sample. Draw the liquid through tube N, filling tube D to fill mark G. Wipe excess sample off tube N and invert the viscometer to its normal position. Mount the viscometer in the constant-temperature bath, keeping tube L vertical. Place stopper in tube N.

4. Allow the viscometer to remain in the constant-temperature bath for at least 20 minutes when the test temperature is 60^{0}C (140^{0}F); 25 minutes for test temperatures up to 105^{0}C (220^{0}F); 30 minutes for test temperatures above 105^{0}C (220^{0}F).

5. At the end of the minimum specified time in the constant, remove the stopper in tube N to start the flow of asphalt.

6. Measure to within 0.1 seconds the time required for the leading edge of the meniscus to pass from the first timing mark to the second and third timing marks (F and I).

7. Upon completion of the test, place the viscometer in a heated oven at about 120^{0}C (250^{0}F) in an inverted position. Permit the used asphalt to drain into a suitable container.

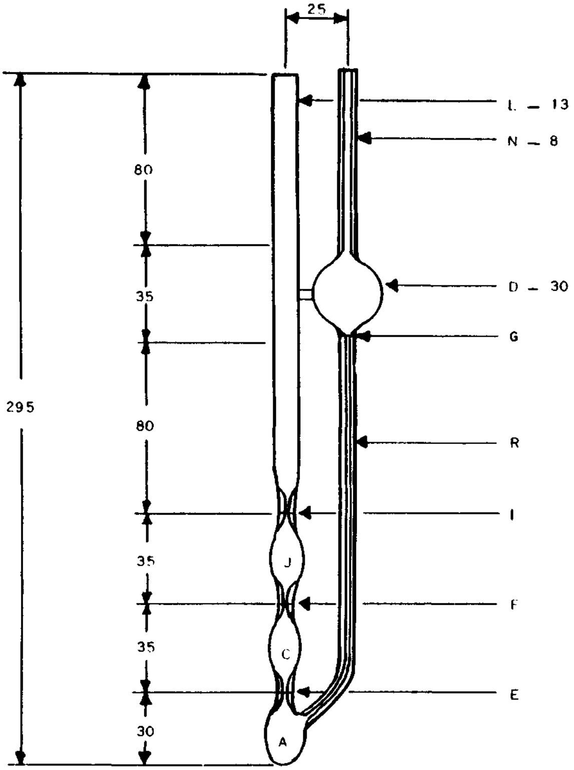
8. Remove the viscometer from the oven. Place the viscometer in the upright position in a holder and fill with trichloroethylene.

D: Explanation of Computations and Data Sheets:

1. Computations: the relationship between kinematic viscosity (ASTM D 2170) and absolute viscosity (ASTM D 2171) is as follows:

Kinematic viscosity in centistokes (cSt) = Ct.
C = calibration constant of the viscometer.
t = Efflux time in 0.1 seconds.
Absolute viscosity (poises) =
Kinematic viscosity (cSt) x density of test specimen (g/cm).

2. Data Sheets: the procedures and data collection format for determining the kinematic and absolute viscosities are practically identical. Therefore, follow the instructions included on page 86 for ASTM D 2171. Only the viscometers used are different. They are reverse-flow viscometers with either one (designated as C) or two bulbs (designated as C and J). See Figure 20 below for one of the types which is called a Cannon-Fenske opaque viscometer.Other reverse-flow viscometers have only one bulb, designated as C.



Note—All dimensions are in millimetres.

Figure 20 - Type of Reverse-Flow Vacuum Capillary Viscometer. Copyright ASTM. Reprinted with permission.

KINEMATIC VISCOSITY DATA SHEET USING REVERSE-FLOW VACUUM CAPILLARY VISCOMETERS (D 2170)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, cSt	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
140^0	300	A703	C	0.18023	0 397	78	
			J	0.25243	634 237	60	69
140^0	350	A213	C	0.32113	0 301	97	
			J	0.44266	619 318	141	119
140^0	350	A215	C	0.32189	0 319	103	
			J	0.44317	643 424	144	124

Viscometer Type: Cannon-Fenske Opaque

Type of Asphalt: Slow Curing Cut Back

Average Viscosity: 104 cSt

Asphalt Grade: SC-70, from Table 9, Page 164

Sample Computations.

KINEMATIC VISCOSITY DATA SHEET USING REVERSE-FLOW VACUUM CAPILLARY VISCOMETERS (D 2170)

Temp. ^0F	Viscometer				Time Seconds	Viscosity, cSt	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			C				
			J				
			C				
			J				
			C				
			J				

Viscometer Type:

Type of Asphalt:

Average Viscosity:

Asphalt Grade:

ABSOLUTE VISCOSITY of ASPHALTS by VACUUM CAPILLARY VISCOMETERS

Reference - ASTM Designation D 2171

A. Purpose: This method covers procedures for the determination of absolute viscosity of asphalt cement at 60^{0}C (140^{0}F) and higher. However, the 60^{0}C (140^{0}F) temperature is used for determining the asphalt grade. This procedure is applicable for asphalts with viscosities in the range from 0.036 to 200,000 poises.

B. Equipment and Materials : Constant temperature bath, vacuum manifold, pressure regulator, 3 modified Koppers type viscometer Nos. 25, 50, 100, 200, or 400 (based upon the estimated absolute viscosity of the asphalt being tested with the proper size resulting in a fill time of between 1 and 7 minutes), holders for the vacuum viscometers, suitable thermometer for use at 60^{0}C (140^{0}F), and asphalt cement.

C. Test Procedure:

1. Maintain the bath at the test temperature within ±0.01^{0}C (±0.02^{0}F).

2. Clean the Viscometer with a suitable solvent and pass an airjet through it to remove all traces of the solvent.

3. Charge the Viscometer by pouring the asphalt cement to the reservoir line on the tube, or sufficient asphalt based upon experience.

4. Place the charged Viscometer in the oven at 135^{0}C ± 5.5^{0}C (275^{0}F ± 10^{0}F) for 10 minutes to allow the specimen to melt and the air bubbles to escape.

5. Remove the Viscometer from the oven and after 5 minutes insert the Viscometer in a holder, and position the Viscometer vertically in the bath so that the uppermost timing mark is at least 2cm below the surface of the liquid bath.

6. Establish at 30±0.05 cm of mercury vacuum in the vacuum system and connect the vacuum system to the Viscometer.

7. After the Viscometer has been in the bath for 30±5 minutes, start the flow of asphalt in the Viscometer by opening the valve leading to the vacuum system.

8. Measure to within 0.1 seconds the time required for the leading edge of the meniscus to pass between successive pairs of timing marks.

9. Upon completion of the test, remove the Viscometer from the bath and place it in an inverted position in an oven maintained at $135^0 \pm 5.5^0$C ($275^0 \pm 10^0$F) until the asphalt is drained thoroughly from the Viscometer. Clean the Viscometer thoroughly by several rinsings with an appropriate solvent, followed by a completely volatile solvent. Dry the tube by passing a jet of air through the capillary for 2 minutes.

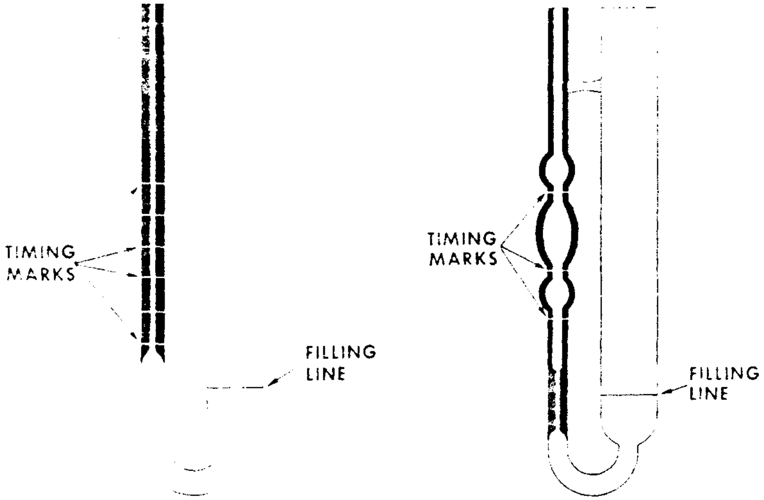
D. Explanation of Computations and Data Sheets:

1. Computations: Elect the calibration that corresponds to the pair of timing marks. Calculate and report the absolute viscosity to three significant figures using the following equation:

Absolute Viscosity, Poises = Kt

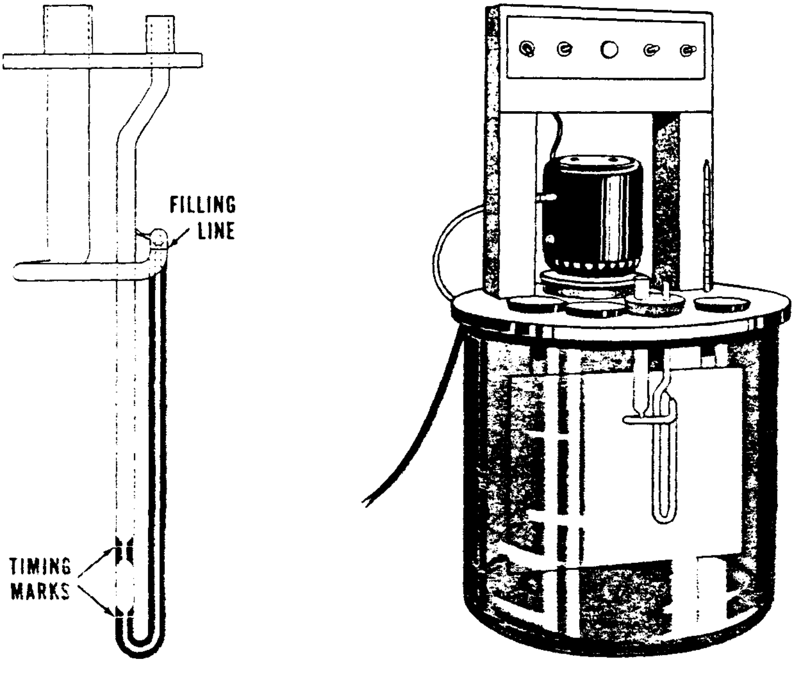
K = Selected calibration factor, in poises per second.
t = Time flow in seconds for each individual bulb. Time is cumulative.

2. Data Sheets: two identical data sheets are shown on the following two pages. Page 90 indicates the way data is recorded and the results computed. The first column shows the temperature of the constant viscometer bath; column 2, type viscometer, column 3, the bulb size and number; column 4, the bulbs as shown on the diagrams that constitutes a viscometer; column 5, the bulb factor which is determined either in the laboratory or by the manufacturer; column 6, the time in seconds with upper left number the successive times recorded as the meniscus of the asphalt column passes the bulb designation while the figure on the lower right is the difference the number in the upper left part of the box and the number in the upper left box on the previous line. For the first bulb, where there is no previous line, both numbers in the box must be the same. Column 7 is obtained by multiplying the bulb factor in column 5 and the time in seconds in the lower right hand corner of column 6. Column 8 is an average of all the values of a single viscometer in column 7. As can be seen the data from up to three viscometers can be recorded on one data sheet. Under the remarks column, the average values in column 8 are again averaged and are compared to the applicable specifications in Appendix C to determine the specification of the particular sample tested. The particular data shown is from a test conducted under ASTM D 2171. However, the format and procedures are the same for both tests. See the drawings of the equipment and setup, included on the following pages, for further clarification. To obtain the test viscosity average up to 15 results from three viscometers. However, discard those values that are obviously in error. Only accept and average those values that are close.



The Asphalt Institute vacuum viscometer

Cannon-Manning vacuum viscometer



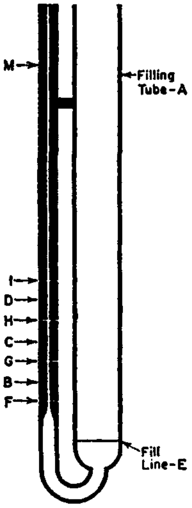
Zeitfuchs cross-arm viscometer

Viscometer in bath

Figure 21 - Commonly Used Viscometer Types and Constant Temperature Bath used in Absolute Viscosity Determination of AC. Reprinted with Permission of the Asphalt Institute

Instructions for the use of Asphalt Institute Vacuum Viscometer Modified Koppers Vacuum Viscometer

See ASTM D-2171



Asphalt Institute Vacuum Viscometer

1. Clean the viscometer using suitable solvents, and by passing clean, dry, filtered air through the instrument to remove the final traces of solvents. Periodically, traces of organic deposits should be removed with chromic acid.

2. Charge the viscometer by pouring the sample into filling tube A to ±2 mm of fill line E.

3. Insert the viscometer in a holder, and insert viscometer into a constant temperature bath. Position the viscometer vertically in the bath so that the uppermost timing mark is at least 2 cm below the surface of the bath liquid.

4. Establish a 30.00 ± 0.05 cm of mercury vacuum in the vacuum system and connect the system to tube M of the viscometer with a 3-way toggle valve closed in the line leading to the viscometer. Excellent pressure regulators are available from the Cannon Instrument Company.

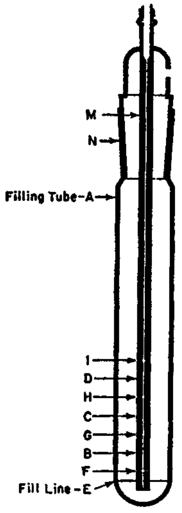
5. After the viscometer has been in the bath for 30 minutes, start the flow of sample upward through the capillary by opening the toggle valve to the vacuum system.

6. Measure to within 0.1 second the time required for the leading edge of the meniscus to pass between timing marks F and G, and with a second stop watch marks G and H, etc. Close the toggle valve.

7. Calculate the viscosity of the sample in poise by multiplying the fill time for each bulb by the viscometer constant for each bulb.

8. A check run may be made by repeating steps 1 thru 7, or in a duplicate viscometer.

9. For convenience, it is recommended to keep the fill times between 60 and 400 seconds.



Modified Koppers Vacuum Viscometer

RECOMMENDED VISCOSITY RANGES FOR THE ASPHALT INSTITUTE VACUUM VISCOMETER and MODIFIED KOPPERS VACUUM VISCOMETER

Viscometer Size Number	*Capillary Radius cm*	*Approximate Calibration Factor 30 cm Hg Vacuum, poises per sec*			*Viscosity Range, poises*
		Bulb B	Bulb C	Bulb D	
25	0.0125	2	1	0.7	42 to 800
50	0.025	8	4	3	180 to 3,200
100	0.050	32	16	10	600 to 12,800
200	0.100	128	64	40	2,400 to 52,000
400	0.200	500	250	160	9,600 to 200,000

Courtesy of the Cannon Instrument Co. - State College, PA.

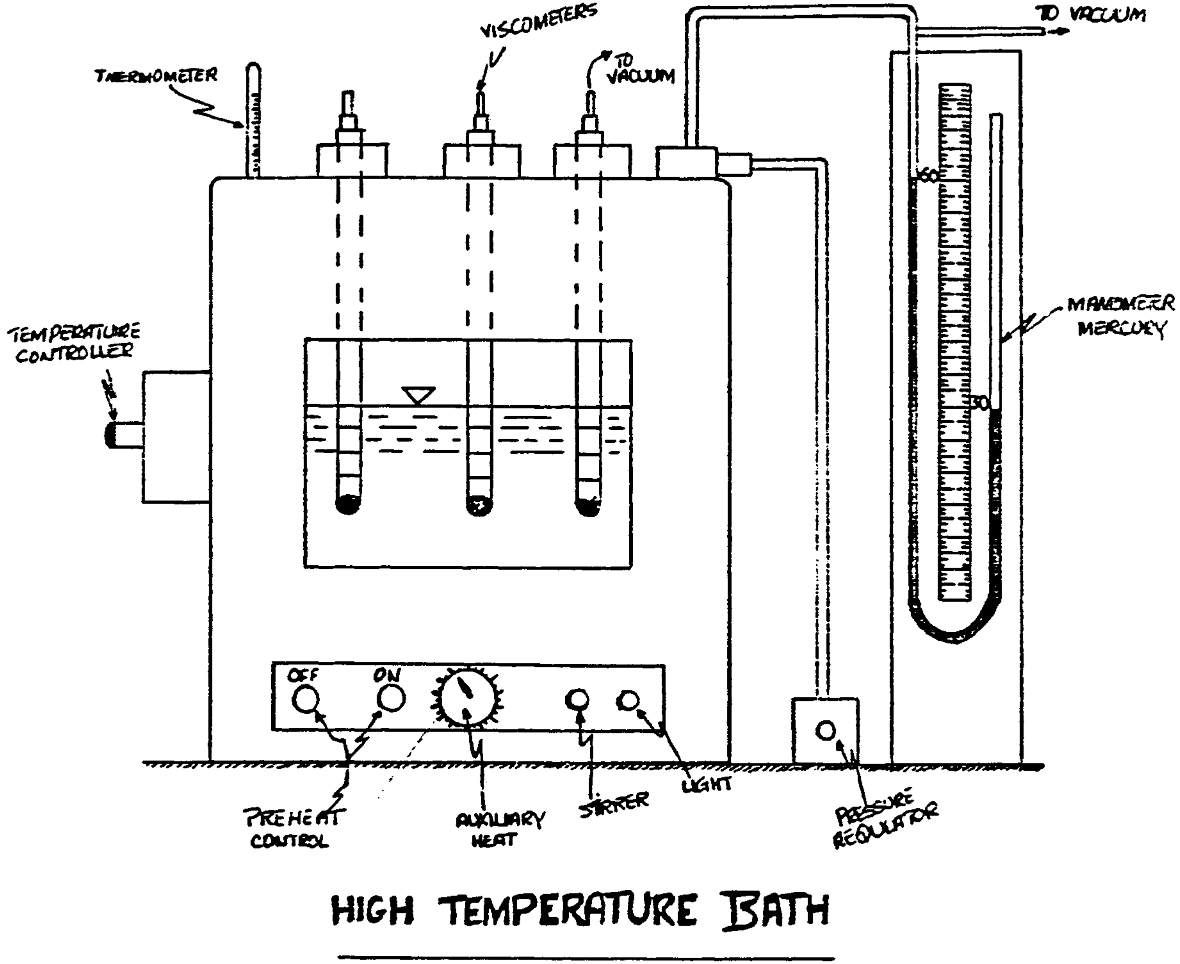


Figure 22 - Apparatus Used in the Determination of Absolute Viscosity.

ABSOLUTE VISCOSITY DATA SHEET BY VACUUM CAPILLARY VISCOMETER (D 2171)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, Poises	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
140^0	200	V141	B	123.0	0 15.6	1,919	
			C	62.1	48.1 32.5	2,018	
			D	41.4	97.3 49.2	2,037	
			E	31.21	163.8 66.5	2,075	
			F	24.00	251.9 88.1	2,114	2,032
140^0	200	V142	B	125.9	0 17.5	2,203	
			C	62.5	55.1 36.6	2,288	
			D	41.7	110.4 55.3	2,306	
			E	30.98	187.9 77.5	2,401	
			F	24.24	274.8 86.9	2,106	2,261
140^0	200	V2	B	132.2	* 16.1	*Missed Rdg.	
			C	65.1	44.0 27.9	1,816	
			D	42.6	83.7 39.7	1,691	
			E	31.48	147.2 63.5	1,999	
			F	24.89	235.9 88.7	2,208	1,928
Viscometer Type: Modified Koppers							
Type of Asphalt: Original Asphalt (not aged residue asphalt)							
Average Viscosity: 2,070 Poises							
Asphalt Grade: AC-20, from the Upper Section of Table 13, Page 168							

Sample Computations.

ABSOLUTE VISCOSITY DATA SHEET BY VACUUM CAPILLARY VISCOMETER (D2171)

Temp. ^{0}F	Viscometer				Time Seconds	Viscosity, Poises	
	Size	No.	Bulb	Factor		Bulb	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				
			B				
			C				
			D				
			E				
			F				

Viscometer Type:

Type of Asphalt:

Average Viscosity:

Asphalt Grade:

QUANTITATIVE EXTRACTION of BITUMEN from BITUMINOUS PAVING MIXTURES

Reference - ASTM Designation: D 2172

A. PURPOSE: Extraction is the procedure used for separating the asphalt from the mineral aggregates in an asphalt paving mixture. The purpose of extraction is to provide a basis for determining the asphalt content of a mixture and to provide asphalt-free aggregates which may be used for gradation analysis and such other tests on the aggregates as may be desired. Where further tests on the extracted asphalt are required, a recovery procedure as described in ASTM Designation: D 1461 is conducted. A number of different methods and types of apparatus may be used. The centrifuge method with trichloroethylene solvent will be describe herein.

B. EQUIPMENT and MATERIALS: Oven, capable of maintaining a temperature of 110±5^{0}C (230±9^{0}F).

Flat Pan 12" long, 8" wide, and 1" deep.

Scale with an accuracy to 0.1 gram.

Small-Mouth Graduate, 1000 or 2000-ml capacity.

Ignition Dish, 125-ml capacity. Desiccator.

Trichloroethylene, technical grade, Type 1, Federal Specification, O-T-634. latest revision. This solvent should be used only under a hood because of toxicity.

Saturated Ammonium Carbonate Solution.

Extraction Apparatus, consisting of a bowl approximating the accompanying diagram and an apparatus in which the bowl may be revolved at controlled speeds up to 3600 rpm. The apparatus should be provided with a container for catching the solvent thrown from the bowl and a drain for removing the solvent. The apparatus should be installed in a hood for ventilation.

Low-ash paper filter rings which consist of low ash paper stock 0.05±0.005 in. thick. The ash content should not exceed 0.2%.

Test specimens of bituminous paving mixture.

C. PROCEDURE:

1. If it is necessary to recover the bitumen from the extraction solution, a moisture determination will be conducted in accordance with ASTM Method D 1461. Otherwise the entire asphalt concrete specimen will be oven-dried to a constant mass at a temperature of 110±5^{0}C prior to extraction.

2. Place approximately 1000 grams of the test specimen into the bowl of the extraction apparatus. Cover the specimen with trichloroethylene and allow sufficient time for the solvent to disintegrate it (maximum time is one hour). Place the bowl in the extraction apparatus. Determine the mass of the paper filter ring

and fit it around the edge of the bowl. Clamp the cover on the bowl tightly and place a beaker under the drain to collect the extract.

3. Start the centrifuge revolving slowly and gradually increase the speed to a maximum of 3600 rpm or until the solvent ceases to flow from the drain. Allow the apparatus to stop and add 200 ml of solvent at least three times until such time that the extract is not darker than a light straw color. Collect the extract and washings in a suitable graduate.

4. Place the aggregate and low-ash filter rings in a clean metal pan. Dry to a constant mass in an oven at 110 ± 5^0C. Carefully fold the filter ring and stand it on the aggregate. Burn the filter ring by igniting with a match or bunsen burner. Determine the mass of the aggregate in the pan (W_3).

5. Determine the amount of mineral matter in the extract by the Ashing Method.

a. Record the volume of the total extraction in the graduate from 3. Determine the mass of an ignition dish. Agitate the extract thoroughly and immediately measure approximately 100 ml into the ignition dish. Evaporate to dryness on a hot plate. Ash residue at a dull heat 500^0 to 600^0F (932^0 to 1112^0C), cool, and add 5 ml of saturated ammonium carbonate solution per gram of ash. Digest at room temperature for 1 hour. Dry in an oven at 100^0C (212^0F) to constant mass, cool in a desicator, and determine the mass.

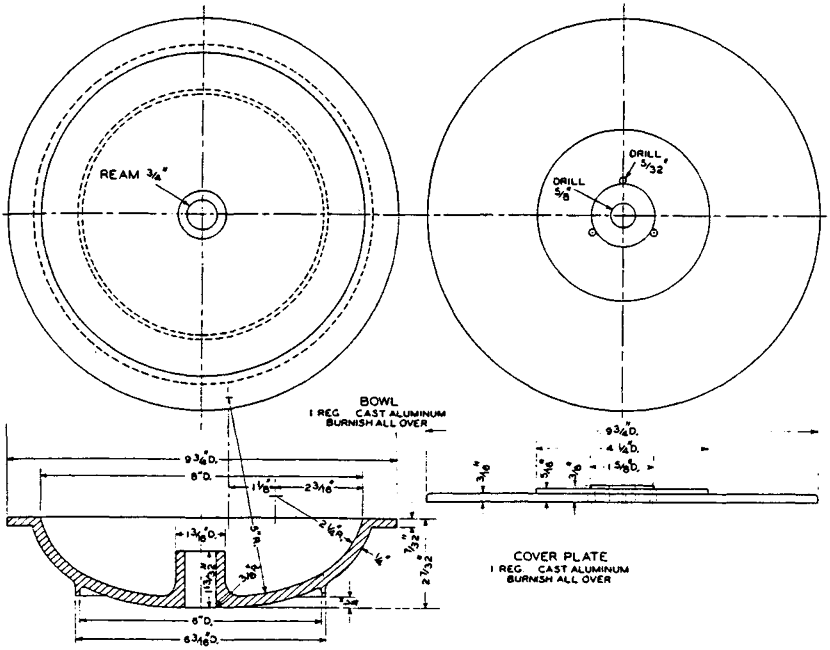
b. Calculate the mass of mineral matter in the total volume of extract ($W_4 = G[V_1/(V_1-V_2)]$ where:
G = ash in aliquot,g.
V_1 = total volume, ml, and
V_2 = volume after removing aliquot, ml.

D. Explanation of Computations and Data Sheets:

1. Computations: calculate the percent bitumen in the test portion as follows:
Bitumen content, % = $[(W_1-W_2)-(W_3+W_4)]/(W_1-W_2) \times 100$ where:
W_1 = mass of test portion.
W_2 = mass of water in test portion.
W_3 = mass of extracted mineral aggregate.
W_4 = mass of mineral matter in extract.

The precision of results between two properly conducted tests by the same operator on the same batch should not differ by more than 0.52%

2. Data Sheets: there is no specially constructed format for the collection of data and computations for this test procedure.



U.S. Customary Units, in.	Metric Equivalent, cm	U.S. Customary Units, in.	Metric Equivalent, cm	U.S. Customary Units, in.	Metric Equivalent, cm
1/8	0.32	1 11/16	4.3	5 7/8	14.9
3/16	0.48	1 3/4	4.4	6	15.2
7/32	0.56	2 3/16	5.5	6 1/8	15.5
1/4	0.63	2 7/32	5.6	6 3/16	15.7
5/16	0.79	2 5/16	5.9	6 1/4	15.9
3/8	0.95	2 1/2	6.4	6 1/2	16.5
1/2	1.27	2 5/8	6.9	7 3/8	18.7
5/8	1.59	2 13/16	7.2	8	20.7
3/4	1.9	3	7.6	9 3/4	24.7
1	2.5	3 3/4	9.6	10	25.4
1 1/8	2.86	4	10.2	10 1/8	25.7
1 3/16	3.02	4 1/4	10.8	12	30.5
1 13/32	3.57	5	12.7	14	35.5
1 1/2	3.8	5 7/16	13.8	14 1/2	37
1 5/8	4.1				

Figure 23 - Extraction Bowl and Metric Equivalents.
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VISCOSITY - TEMPERATURE CHART for ASPHALTS

ASTM Designation: D 2493

A. Purpose: The viscosity - temperature chart covered by this standard is a convenient means of plotting data for estimating the kinematic viscosity of asphalt cements within the normal temperature range for compaction. The procedure is adequate for original asphalts, aged residue asphalt, and for asphalt extracted from pavement mixtures.

B. Description: the graph used in this modified procedure is based upon a chart used by the Asphalt Institute. It uses a semi-log graph paper with kinematic viscosity as the logrithmic scale, between 50 and 1,000,000 centistokes. The temperature is plotted as the abscissa to an arithmetic scale between 48.9^0 and 162.8^0C (120^0 and 325^0F).

C. Procedure: The viscosities are determined at three temperatures. These will generally be at 60^0C (140^0F), 104.4^0C (220^0F), and 148.9^0C (300^0F). Viscosities obtained by vacuum capilarity viscometers (ASTM Designation: D 2171) will be in poises (P) with units in G/cm.s or dyne.s/cm^2. In the SI system 10P = 1 Pa.s(1N.s/m^2). The kinematic viscosity of asphalts is obtained directly from ASTM Designation: D2170. In the SI system of measurements, the unit of kinematic viscosity is m^2/s. For convenience the latter value is divided by 10^6, mm^2/s is used and it is called centistokes.

D. Relationship between Absolute and Kinematic Viscosities:

Absolute Viscosity in Poises = Kinematic Viscosity in Stokes x Specific Gravity of the Asphalt Cement

A poise is a unit of absolute viscosity in which a stress of one dyne acting tangentially between two planes one centimeter apart produces a difference in velocity of one centimeter per second. Another unit of absolute viscosity is the Pascal second (Pa.s) (1 Pa.s = 10 Poises).

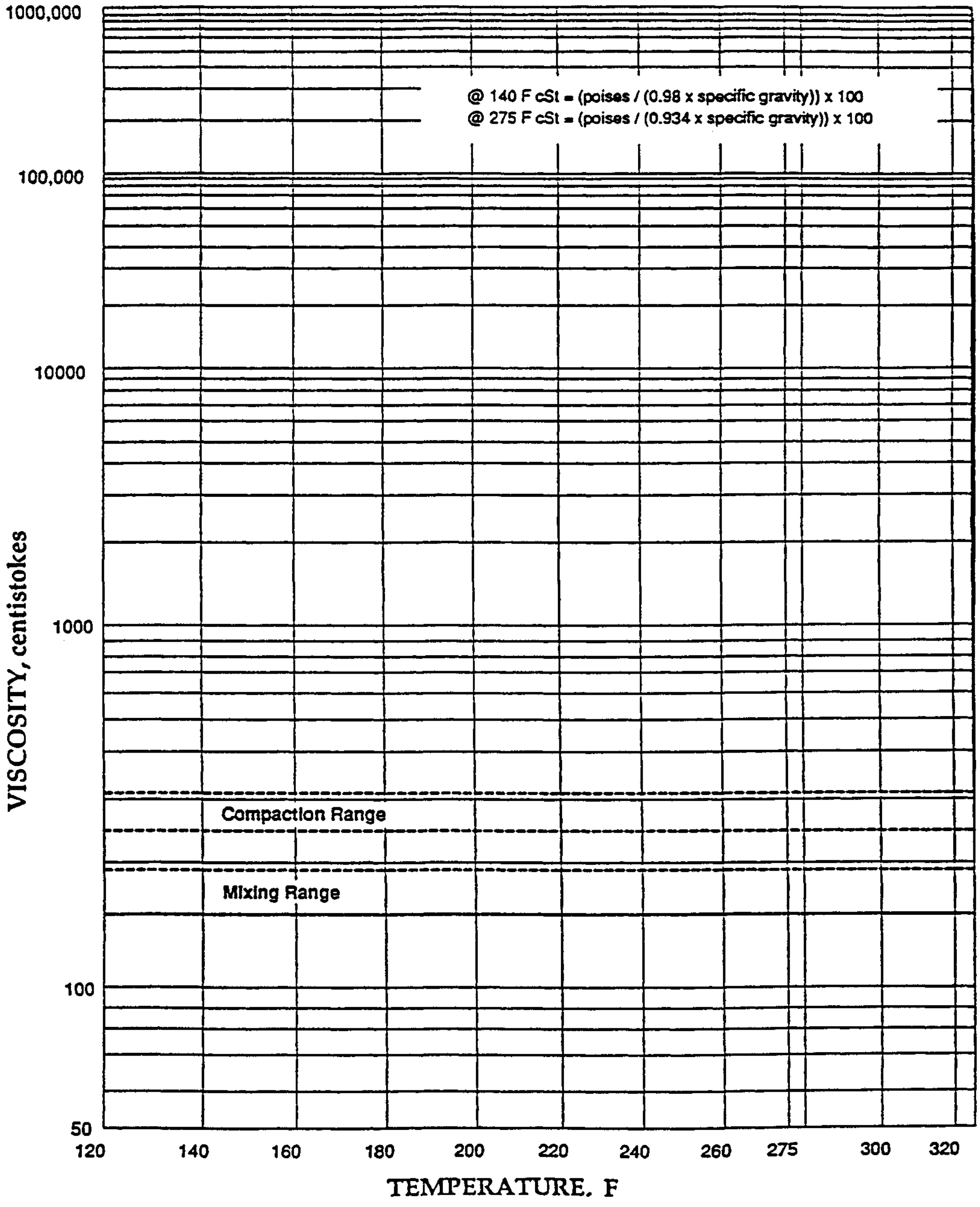
1 stoke = 100 centistokes (cST)

at 25^0C (77^0F) cSt = poises x 100/specific gravity of AC

at 60^0C (140^0F) cSt = poises x 100/specific gravity of AC x 0.98

at 135^0C (275^0F)cSt = poises x 100/specific gravity of AC x 0.934

VISCOSITY VS TEMPERATURE



BULK SPECIFIC GRAVITY of COMPACTED BITUMINOUS MIXTURES USING SATURATED SURFACE-DRY SPECIMENS

Reference - ASTM Designation: D 2726

A: Purpose: The bulk specific gavity is determined by computing the ratio of its weight in air to its bulk volume. The method described herein is for mixes having a dense impermeable surface, that does not require coating the compacted specimens with paraffin, but uses the saturated surface dry weight of the specimen. The bulk specific gravity of the compacted bituminous mixtures may be used to calculate its unit weight. For compacted mixtures with permeable surfaces use ASTM Designation: D 1188.

B: Equipment and Materials:

> Balance with a capacity of at least 1-1/2 kilograms and sensitivity to 0.1 grams. The balance shall be equipped with a suitable suspension apparatus and holder to permit weighing the sample, both in air and in water, while suspended from the center of the scale pan of the balance. Water Bath for immersing the specimens in water under the balance, equipped with an overflow outlet for maintaining a constant water level. Compacted bituminous specimens.

C: Test Procedure: all weights must be made with the same scale.

1. Weigh of Dry Specimens in Air - after the specimens have been standing in air at room temperature for at least one hour. Designate this weight as A.

2. Weight of Specimens in Water - prior to weighing, immerse the specimens in a water bath at room temperature for 3 to 5 minutes. Designate this weight as C.

3. Weight of Saturated Surface-Dry Specimens in Air - surface dry the specimens quickly by blotting with a damp towel and then weigh in air. Designate this weight as B.

D: Explanation of Computations and Data Sheets:

1. Computations: the bulk specific gravity of the compacted mixtures are computed from the following equation with all weights in grams:

$$\text{Bulk Specific Gravity} - G_{mb} = A/(B - C).$$

A = weight of the air dry specimen.
B = weight of the saturated surface-dry specimen in air.
C = weight of the specimen in water.

Where duplicate specimens differ by more than 0.02, the results should be discarded, and the test rerun.

2. Data Sheets: no special format for data and computations.

ROLLING THIN FILM OVEN TEST

Reference - ASTM Designation: D 2872

A. Purpose: To measure the effect of heat and air on a moving film of semi-solid asphaltic materials. The test provides a means for laboratory aging of the bitumen prior to testing. The effects are determined by measuring the properties of the asphalt before and after the test. This is really a procedure rather than a test.

B. Equipment and Materials: Oven as shown on the next page.
Flow Meter, suitable to measure air flow at the rate of 4,000ml/min.
Thermometer conforming to ASTM Specification E1.
Glass containers of specified dimensions.
Approximately 300 grams of Asphalt Cement.

C. Procedure:

1. Preparation of the Rolling Thin Film Oven:
   a. Position air outlet orifice to 1/4" from the opening of the glass container.
   b. Position the thermometer so that the end of the bulb is 1" above center of the shaft holding the revolving carriage. The thermometer stem should be 1/4" from the opening of the glass containers.
   c. Level the oven so that the horizontal axes of the glass containers in the carriage are level.
   d. Preheat the over for at least 16 hours prior to use. When fully loaded and the air is on, the oven should return to 163±0.5^{0}C (325±1.0^{0}F) within 10 minutes of the warmup period.

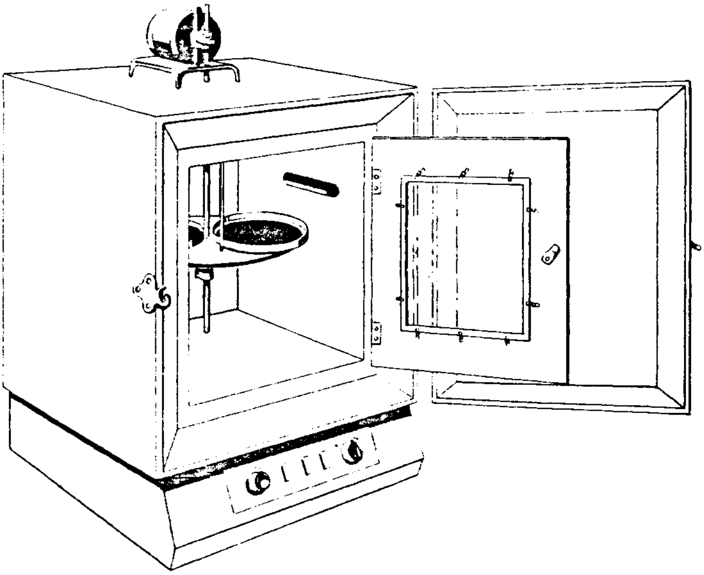
2. Heat the sample in a loosely covered container to a temperature below 163^{0}C (325^{0}F) until fluid. Stir occasionally. Pour 35±0.5 grams of the sample into each of the glass containers.

3. Arrange the containers in the carriage, filling any unused spaces with empty containers. Close oven door and rotate the carriage assembly at the rate of 15±0.2 RPM for 85 minutes (allowing 10 minutes to reach 163^{0}C (325^{0}F)).

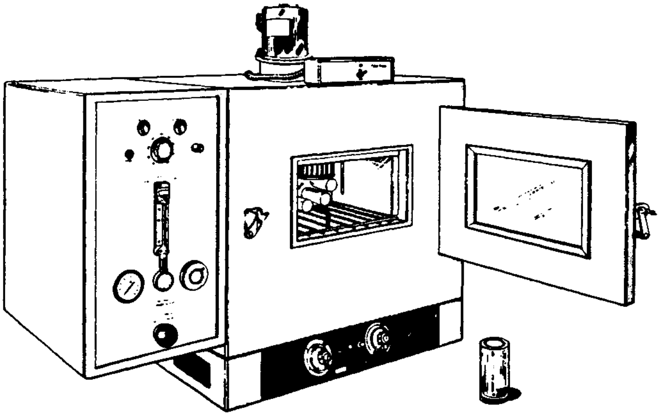
4. Immediately pour all of the residue from each container into a spout container which must not be more than 75% full. Clean out glass containers without reheating. Test residue within 24 hours of the RTFO test.

D. Summary of the Test Method: A moving film of asphaltic material is heated in an oven for 75 minutes at 163^{0}C (325^{0}F). The amount of aging is determined from physical tests for penetration, kinematic viscosity, and ductility.

Two types of ovens are shown below, the thin film oven (TFO) and the rolling thin film oven (RTFO). The time to achieve a comparable degree of hardening in the RTFO is less than for the TFO under standard testing procedures and it accommodates a larger number of samples. The properties of the aged residue from the RTFO determines the grading of the original asphalt in the AR-viscosity graded series.



Thin Film Oven test



Rolling thin film oven test

Figure 24 - Types of Thin Film Ovens.
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FLASH POINT of CUTBACK ASPHALT with the TAG OPEN-CUP APPARATUS

Reference - ASTM Designation: D 3143

A. Purpose: To determine the flash points of cutback asphalts, having flash points below 93^{0}C (200^{0}F).

B. Equipment and Materials: Tag open-cup tester as shown on the next page, shield, and a Pensky-Martens low range thermometer, -7^0 to +110^{0}C (20^0 to 230^{0}F), and asphalt cutback specimens.

C. Test Procedure:

1. Place the apparatus on a level, solid, vibration free table, and where no drafts are present. If there are drafts, it will be necessary to shield the apparatus.

2. Place the glass test cup in the metal bath and adjust the thermometer so that it is firmly supported in a vertical position halfway between the center and the edge of the cup and on a line passing through the center of the cup and the pivot of the taper. The thermometer bulb should be 1/4 inch (6.3mm) above the bottom of the cup.

3. Fill the metal bath with cool tap water until water begins to flow from the overflow spout.

4. Rest the metal leveling device on the rim of the cup and fill with the test sample until the level just touches the pointer (approximately) 1/8 inch (3.2mm) below the rim of the cup.

5. Light the ignition taper and adjust the flame to approximately the same size as the comparison head on the apparatus (about 1/8 inch or 3.2mm).

6. With the bunsen burner apply heat to the bath so that the temperature of the specimen rises at a rate of 1±0.25^{0}C (2± 0.5^{0}F) per minute.

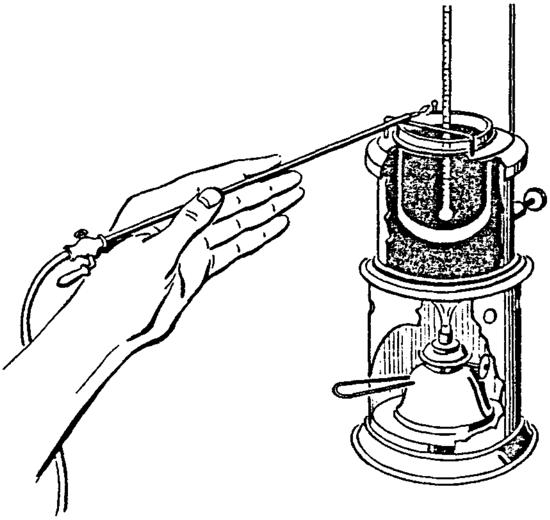
7. As the temperature rises it may be necessary to remove some of the specimen with an eye dropper to avoid overflow.

8. At 1^{0}C (2^{0}F) temperature intervals pass the ignition taper across the sample in a smooth motion such that the flame is over the specimen for 1 second.

9. Record, as the flash point, the temperature at the time the test flame causes a distinct flash over the test cup.

10. In case the flash point is not reached by the time the thermometer reads 93^{0}C(200^{0}F) shut off the heat and remove the sample from the bath. Proceed with the flash point determination by refference to the Cleveland Open Cup (ASTM Designation: D92) method.

D. Explanation of Computations and Data Sheets: merely report the lowest temperature at which the initial flash (distinct yellow flame) is noted as the tag open-cup point.



Tag Open Cup flash point test

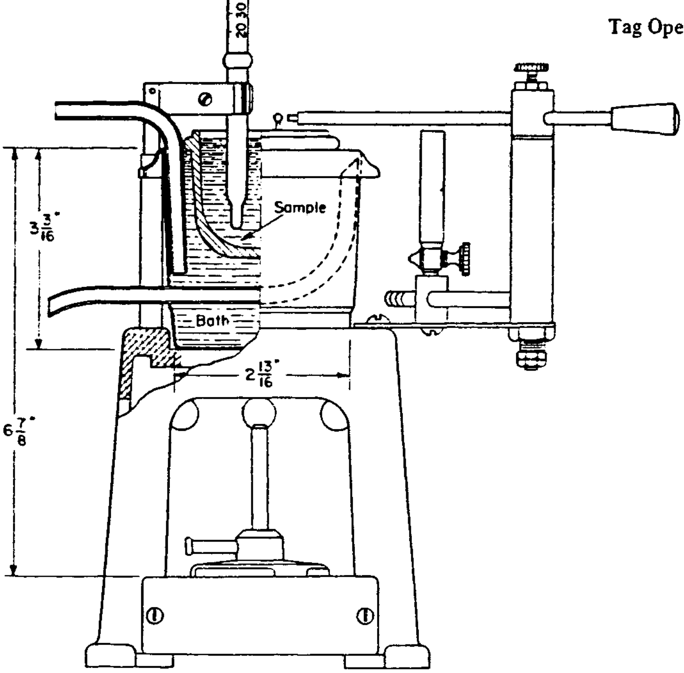


Figure 25 - Tag Open-Cup Apparatus.
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INTRODUCTION

INTRODUCTION

The purpose of the **Manual for Asphalt Materials and Mix Design** (hereafter referred to as **The MANUAL**) is to familiarize students with the technology of asphalt in its several forms namely asphalt cement, cutback asphalt, and asphalt emulsions. The laboratory work is designed to develop an understanding of asphalt properties, characteristics, testing procedures, and specifications.

For engineering purposes three properties of asphalt are paramount: consistency (usually referred to as viscosity), purity, and safety. Before asphalt cement can be used for construction purposes it must be liquefied. This implies heating. Asphalt cement must be liquefied before it can be pumped through pipes, mixed with aggregates to make asphalt concrete, or sprayed through nozzles. Once the heat is dissipated, the asphalt cement reverts to its amorphous, semi-solid state. There are other ways to liquefy asphalt. Selected petroleum based solvents can dissolve the asphalt cement to create a family of materials known as cutback asphalts. Another method is to combine asphalt cement with water in the presence of a catalyst to form various kinds of asphalt emulsions.

The procedures outlined herein are all derived from ASTM designations and practice as recommended by the Asphalt Institute. Where the particular ASTM method permits alternate procedures, the one more applicable to the available equipment and the teaching situation was chosen. In the preparation of this MANUAL, the inherent time constraints of an academic laboratory was considered, whenever possible.

The MANUAL consists of the following:

1. 35 of the frequently used ASTM tests in Asphalt Binder and Mix Design.
2. Sample computations and easy to use Data Sheets, most of which have been developed specifically for **The MANUAL.**
3. An up-to-date overview of Asphalt Technology including sources, historical development, and classifications of asphalt products.
4. Easy to understand explanations for Voids Mineral Aggregate, Absorbed Asphalt, Effective Asphalt Content, Percent Air Voids, and Percent of Voids filled with Asphalt.
5. A stand-alone asphalt manual, written specifically for university laboratory instruction, yet applicable for a commercial testing laboratory. Rarely will other reference materials need to be consulted.
6. Dimensions in both the SI and the U.S. Standard systems of measurement.
7. An Appendix with conversion factors, rules of safety and procedures, overview of SHRP SUPERPAVE, explanation of asphalt emulsions, and additional data sheets on single-sided pages.

I. NATURE, SOURCES, AND USES OF ASPHALT

A. Historical Development

Asphalt is by no means a product of our modern civilization which is attested by the fact that remains of saber-tooth tigers and other prehistoric animals have been found in the La Brea Tar Pits in Los Angeles. In reality, these so-called "tar pits" are deposits of natural asphalt.

The first recorded use of asphalt dates back to 3800 B. C. in Mesopotamia where the material was used as an adhesive mortar for building stones and paving blocks. Reservoirs, canals, and bathing pools constructed with these blocks were made watertight with this material found in natural deposits in the region.

Asphalt was first used in paving in the middle of the nineteenth century. Natural deposits of rock asphalt from the Rhone Valley in France served as the source for this construction. In 1876 portions of Pennsylvania Avenue in Washington, D. C., were paved using Trinidad lake asphalt. Most of the early paving in the United States was done using asphalt either from Trinidad or the Bermudez Lake in Venezuela.

B. What is Asphalt?

To understand what asphalt is, it is necessary to consider some definitions so that an orderly description of the material can be evolved. Since asphalt is a bituminous material, consider first the word bitumen.

Bitumen. A bitumen (according to ASTM) is a mixture of hydrocarbons of natural or pyrogenous origin, or combinations of both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid, or solid and which are completely soluble in carbon disulfide. Two types are used in construction.

Asphalt. Asphalt (according to ASTM) is a black to dark brown solid or semi-solid cementitious material which gradually liquefies when heated. The predominating constituents are bitumens, all of which occur in the solid or semi-solid form in nature or are obtained by refining petroleum or which are combinations of the bitumens mentioned or with petroleum or derivatives thereof.

There are two sources of asphalt, (1) those occurring naturally, and (2) those obtained by the refining of petroleum. In both cases, asphalt is the product of _fractional distillation of petroleum_, whether over short periods of time as in the refinery or longer periods as in nature.

Tar. Tars do not occur in nature since they are the product of chemical change. For example, tars are products of the _destructive distillation_ (as distinguished from fractional distillation in the case of asphalt) _of a number of organic materials_ such as coal, wood and sugar. Tar obtained from the destructive distillation of bituminous coal is a crude tar which must undergo further refinement to obtain road tar. Tar can also be produced from petroleum by chemical rather than physical change; that is, the destructive distillation of petroleum.

C. Sources of Asphalt

As mentioned above, asphalt is the product of fractional distillation of petroleum. This fractional distillation process can occur over a long period of time in nature resulting in deposits of material known as natural asphalts or in a short period of time in the refinery resulting in manufactured asphalts. The refinery is the primary source of asphalt today. Since natural asphalts historically have been utilized in paving, it is worth while to include a brief discussion of these materials as well as the manufactured products.

Natural Asphalts. Natural asphalts can exist either in the relatively pure form in nature or in impregnated rock deposits. The table below contains a listing of a number of different natural asphalts together with certain physical properties which give an indication of the characteristics of these materials. Of these natural asphalts, two still have commercial significance, (1) Trinidad lake asphalt, and (2) Gilsonite.

TABLE of NATURAL ASPHALTS

Name	Source	Approximate Softening Point (R&B) ^{0}F	Approximate Penetration at 77^{0}F	% Mineral Matter
Bermudez	Venezuela	145-160	20-30	1-7
Trinidad*	Trinidad Island	205	2-4	39
Gilsonite*	Utah, Colorado	250-350	0-3	trace
Manjak (Glance Pitch)	Numerous Areas	275-400	0	0-30
Grahamite	West Virginia & Utah	370-600	0	trace - 50
Elaterite	Europe & Asia	Infusible	0	2-7
Wurtzilite	Utah	Infusible	0	2
Albertite	Numerous Areas in Canada	Infusible	0	trace - 15
Impsonite	Numerous Areas	Infusible	0	trace - 15

*Natural asphalts that have commercial significance.

Trinidad asphalt is a lake asphalt obtained from the island of Trinidad and has been used for many years in highway construction. In general, the material has been successfully used and is, therefore, referred to as a quality product. This material exists in a specific form in nature and is not subjected to the variety of processes to which manufactured asphalts are submitted. It is hard enough to be dug out with picks and to support a railroad trestle on the surface of the lake.

The material exists in the lake in an emulsified form; that is, it contains approximately 40 per cent asphalt, 30 per cent water and 30 per cent mineral matter, (e. g., clay which acts as an emulsifying agent). To refine the material it is heated to a liquid consistency. The heavier particles settle out while other matter floats to the top and is skimmed off. During this process the water is also driven off. After this treatment the resulting asphalt is very hard, having a penetration of approximately 2 (100 gr., 5 sec., 77 F). The material has a higher specific gravity than manufactured asphalts since it still contains approximately 40 per cent mineral matter. For the desired consistency, the refined asphalt is fluxed with petroleum oils.

Gilsonite is an example of a practically pure natural asphalt, being more than 90 per cent soluble in carbon disulphide. This material is very hard, having a penetration of zero. While the material has not been used in road building, it is used in asphalt paints,battery boxes,and asphalt floor tile.

In addition to these forms, asphalts also occur in natural rock deposits. In these cases asphalt is the minor constituent of the material whereas the rock-- usually sandstone or limestone-- is the major portion. One of the most well known deposits is an impregnated sandstone in Kentucky which has been widely used both in Kentucky and Indiana for road construction.

This material is quarried similar to other rock deposits, crushed and laid with conventional paving equipment. Kentucky rock asphalt produces an excellent antiskid surface, due in part to the fact that it gradually erodes under the action of traffic. This particular material is considered a standard for skid resistance measurements. However, because of its expense, its use is presently limited.

Petroleum Asphalt. At present the primary source of asphalt is that obtained from the refining of petroleum. The heavier or more viscous portions of certain crude oils are asphalts. The breakdown of such a crude is shown schematically on page 5. It should be realized that this is merely a schematic representation of the constituents of a crude oil and that the proportions will vary, depending upon the particular crude. Asphalt base crudes can vary in consistency and color from that of a burgundy wine to material as black and viscous as the asphalt itself. All crude oils do not contain asphalt as the heavier portions. In general, there are two other classifications for crude,depending upon their base or more viscous constituents. These are (1) paraffin and (2) mixed base crudes. As their name implies the paraffin or wax base crudes are those in which the material left after fractional distillation of the more volatile constituents is essentially a paraffin wax. The mixed base crudes are those in which the heavier portions are a mixture of wax and asphalt. Special treatment is necessary to separate the asphalt from these crudes. In general crudes in the California area are asphalt base. Those from the mid-continent are mixed base and those from Pennsylvania, for example, are paraffin base.

Gasoline
Kerosene
Diesel Oil
Lubrication Oils
Asphalt Cement

Components Obtained in the Distillation of a Typical Asphalt Producing Crude Oil.

A general breakdown of both natural and manufactured asphalts is shown in Figure 1, page 6, together with tar to complete the classification of the bituminous materials system.

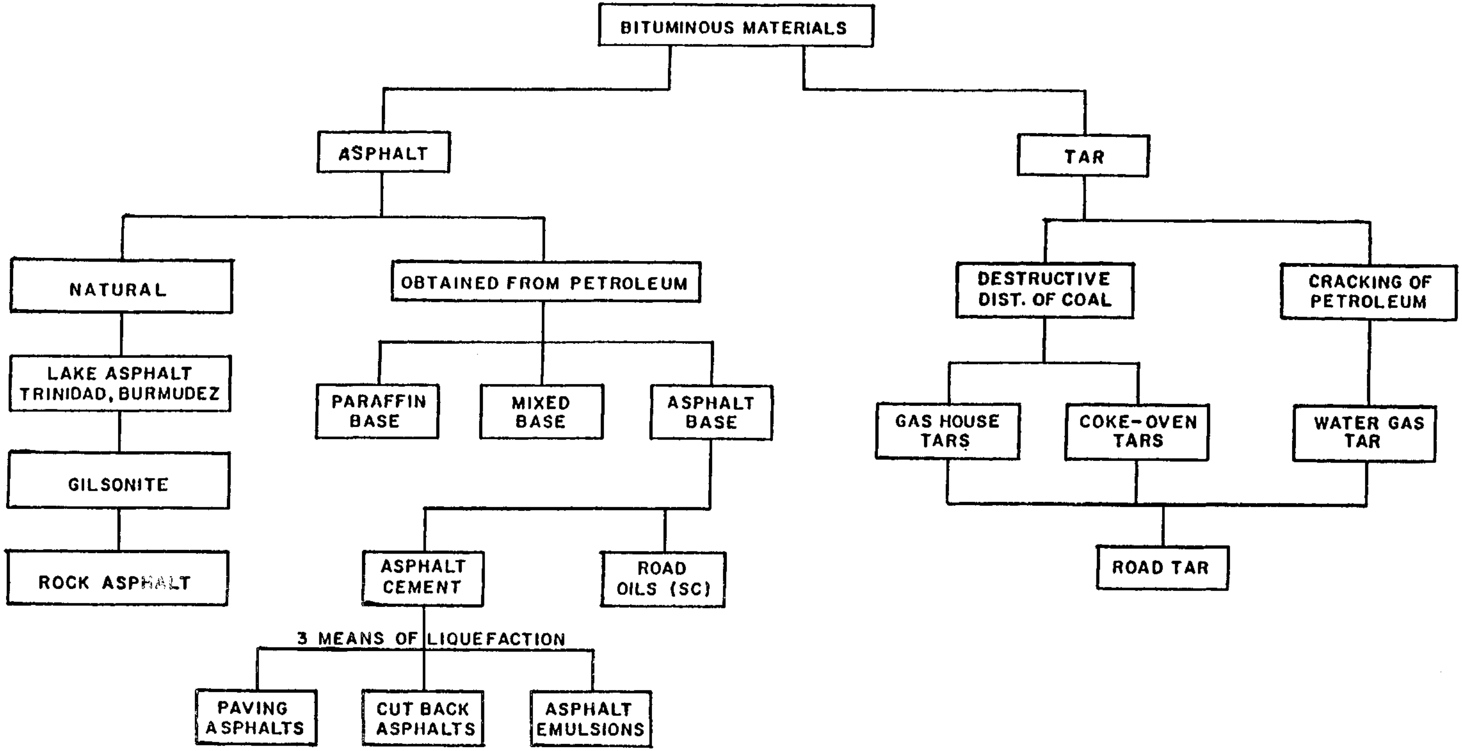

Figure 1 - Classification of Bituminous Materials.
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II. PRODUCTION AND CLASSIFICATION OF ASPHALTS

A. Manufacturing Processes

Asphalt can be refined from petroleum in a number of different ways. To a certain extent the type of crude oil controls the type of processing to be used. The majority of petroleums are refined to produce asphalt by the vacuum and steam refining process and the materials used are generally the asphalt base crudes referred to in Chapter I. To obtain asphalt from the mixed base crudes, a different type of processing, solvent deasphalting, is sometimes utilized. However, solvent deasphalting is also at times utilized for asphalt base crudes,depending upon the types of products which are desired from the crude oil. Asphalts to be used in roofing, waterproofing, and pipe coating must be further treated by an air-blowing process to produce material suitable for this type of usage. In addition, paving asphalts produced either by the vacuum and steam refining or solvent extraction processes can be diluted with solvents or emulsified in water to produce very fluid materials applicable in certain types of highway construction.

Vacuum and Steam Refining. The majority of asphalts used in paving in the United States are produced by the vacuum and steam refining process. Either a single crude or a blend of crude oils is introduced into the refinery. The crude is heated by passing through a series of heat exchangers until it reaches the crude charge heater. This heater may be a tube still which consists of a series of interconnected pipes or tubes mounted in a furnace. The crude oil is pumped through the tubes until it attains the temperature necessary to produce vaporization and is then discharged into the atmospheric tower. The oil coming into the tower at a relatively high temperature is flashed into vapor and residue as a result of the reduction in pressure. It will be noted in the figure that steam is also introduced into the tower. This further reduces the partial pressure of the oil and permits the distillation process to take place at lower temperatures, thus precluding cracking of the constituents.

The residue (reduced or "topped" crude) is continuously withdrawn from the bottom of the tower and the more volatile constituents, such as gasoline and kerosene, are removed from the top.

From the atmospheric tower the reduced crude is then pumped to another tube still where the temperature is raised still further. This heated material is then flashed into a vacuum tower where the less volatile constituents are removed in a manner similar to the gasoline and kerosene type materials in the atmospheric tower. In this tower, vacuum, as well as steam, is used to reduce the pressure so that the distillation can be accomplished without damage to the material.

The vacuum residual asphalt which leaves the bottom of the vacuum tower can be produced to any desired consistency. In general, the consistency of the material is controlled by (1) temperature, (2) quantity of steam, (3) pressure, (4) amount of

Thus, by this process it is possible to produce very hard asphalts or asphalts which are slightly more viscous than water at ordinary temperatures. The actual classification for these mateerials will be discussed in a subsequent section of this chapter.

Solvent Deasphalting (Propane Deasphalting). Some crude oils, because of a complex chemical structure, lend themselves economically to production of asphalt through a solvent deasphalting process rather than by vacuum distillation. The mixed base crudes, because of their paraffinic constituents, generally must be processed by the solvent method to produce asphalt. Hence, this method is now being used more frequently to produce paving asphalts.

In this process, distillation is quite often used to produce the "topped crude", after which solvent deasphalting further separates the asphalt from the topped crude by molecular weight and to some extent by chemical type, rather than by boiling point as in the vacuum and steam refining process.

While a number of different solvents may be used, propane appears to be the most popular; hence the name "propane deasphalting".

Essentially, the process consists of introducing propane into the bottom of a tower while the reduced crude is introduced approximately two-thirds of the way up the tower in the proportions of four to six parts of propane to one part of crude. As the crude moves down through the propane, the asphaltic fractions are precipitated from the solution. The soluble portion of the crude flows upward with the propane. The asphalt containing some propane is removed from the bottom of the tower where it is further processed to remove the remaining propane.

Asphalts produced by this process are generally harder than materials produced by the vacuum and steam refining process. However, they may be blended with the lighter fractions taken from the top of the tower, again after propane has been removed, to produce asphalts of suitable consistency or they may be blended with asphalts produced by the vacuum and steam refining process for the same purpose.

A considerable advantage of this type of processing is that it permits deeper reduction and thus permits satisfactory production of asphalts from mixed base crudes.

Air Blowing. Asphalts produced by either the vacuum and steam refining or the solvent extraction method may be subjected to further processing by blowing air through the asphalt in large stills at elevated temparatures. This process is extensively employed to make specialty asphalts for roofing, pipe coatings, waterproofed linings for hydraulic structures and the like. In addition, air blowing is used at times to produce desirable properties in paving asphalts such as reduced temperature susceptibility. The air blowing in this case, however, is not as extensive as for materials used, for example, in roofing.

Emulsifying. Paving asphalts can be made almost as fluid as water for use in specific phases of highway construction. The increase in fluidity is accomplished by dispersion of the asphalt in water. Normally, asphalt and water are considered to be immiscible liquids. Under the proper conditions, however, asphalt can be dispersed in water. This is particularly true when thermal energy and mechanical agitation are supplied and a chemical called a surface active agent or surfactant is added.

In the emulsification process, asphalt is heated to temperatures of about 121^0C (250^0F). The water containing the emulsifying agent is heated to 49^0 - 65.5^0C (120 - 150°F). Both water and asphalt are introduced into a colloid mill. This mill, illustrated schematically on Figure 42 in the Appendix, supplies the mechanical energy to break the asphalt down into particles a few microns in diameter. This production of small particles is accomplished by forcing the asphalt to pass through a small clearance between the rotating blades and the stationary drum. Since the shaft is rotated at high speed, high shearing forces are produced in the material which results in the small diameter particles. The surface-active agents permit the asphalt to remain in suspension in the water. Emulsification is a continuous process, and, with a drum 30 - 46 cm. (12 -18 in.) in diameter, a colloid mill is capable of producing 15 - 23 m^3 (4,000 - 6,000 gal.) of emulsified asphalt per hour. A number of different types of emulsified asphalt may be produced, the type being dependent on the kind and amount of emulsifying agent, the amount of asphalt, and the consistency of the base asphalt.

B. Classification According to Use

As previously mentioned, asphalt is a very diverse material and has wide spread usage. For convenience, asphalt will be categorized into three classifications which cover the majority of uses. These are (1) paving, (2) roofing, and (3) protective coatings.

Paving. The paving asphalts are the materials used in road construction and are produced primarily by the vacuum and steam refining and solvent deasphalting processes. These materials may further be processed by solvent dilution and by emulsification. They vary in consistency from solid materials at room temperature to materials whose consistency is practically the same as water. Asphalt cements, liquid asphalts, and emulsified asphalts are included in this classification.

Roofing. Included in this category are the mopping grades of asphalts used primarily in built-up roofing and are produced by the air-blowing process. These materials generally are semi-solid to solid at ordinary temperatures and are classified according to their softening point in a standardized test. The softening point is controlled by the amount of air blowing. For example, in flat deck roofs, the softening point for the mopping grade asphalts is relatively low; not differing much from the softening point for

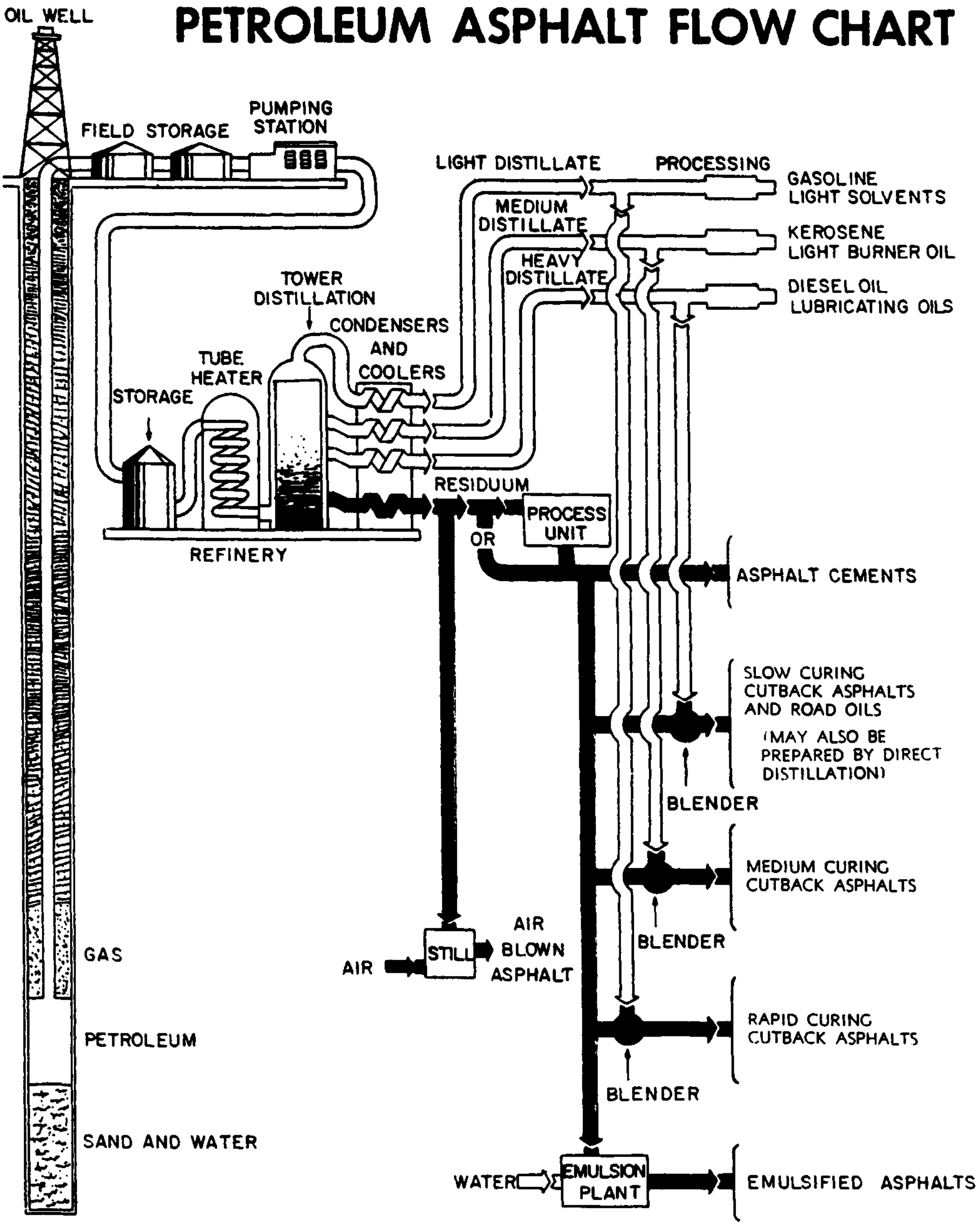

Figure 2 - Asphalt Flow Chart at a Petroleum Refinery.
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conventional paving asphalts of the same consistency. In these materials a very small amount of blowing is performed. On the other hand, mopping grade asphalts for relatively steep pitched roofs require higher softening points. Thus, considerably more blowing is performed.Included in this category are asphalts for use in prepared roofing, such as shingles and roll roofing.

Protective Coatings. Asphalts in this category consist of materials to be used in pipe coating, reservoir and canal linings, and other applications where a protective or an impervious coating is required. Generally, these materials are highly blown asphalts and quite often will contain finely divided mineral fillers, in which case the materials are referred to as filled asphalts.

C. Classification of Asphalt Grades

Asphalt Cements. From Figure 2 it can be seen that the five penetration grades of asphalt cement, vary in consistency from a solid at room temperature to a semi-liquid under the same conditions. The materials are classified as 40-50, 60-70, 85-100, 120-150, and 200-300 penetration asphalt cements, the number being indicative of the degree of hardness of the material. There are also five viscosity grades, AC-2.5, 5, 10, 20, and 40 as well as five aged residue grades, AR- 1000, 2000, 4000, 8000, and 16000. See pages 162 through 169 for asphalt grading specifications. The 40-50 penetration grade is the hardest of the paving grades while the 200-300 material is the softest. On heavy duty highways, the most commonly used material is the 85-100 penetration asphalt cement. In a particular refinery a specified degree of hardness of an asphalt can be produced by controlling the refining processes as previously discussed. Quite often a refinery will not produce all five of the grade classifications by the distillation process, but rather may produce two or three materials and, by blending, obtain the other grades.

Liquid Asphalts. There are three types of liquid asphalts: (1) rapid curing, (2) medium curing, and (3) slow curing. The rapid and medium curing materials are referred to at times as cutbacks and the slow curing materials as road oils.

Rapid-Curing (RC) liquid asphalts are produced by dissolving a relatively hard asphalt cement (85-100 penetration) in a gasoline or naphtha-type solvent. The proportions of solvent are varied to produce different grades of RC materials. See ASTM Designation D2028 for Rapid-Curing Asphalt.

Medium-Curing (MC) liquid asphalts are produced by dissolving a softer base asphalt cement (generally a 120-150 penetration) in a kerosene-type solvent. See ASTM Designation D2027 for Medium-Curing Asphalt.

Slow-Curing (SC) liquid asphalt may be produced in either of two ways. In the first case, they may be reduced directly to grade in the distillation process in the same manner as the asphalt cements. More volatile constituents, however, will remain and, as a consequence, the materials are much more fluid than the asphalt cement materials. Slow-Curing materials can also be produced by fluxing a 200-300 penetration asphalt with lighter oils to produce materials of the same consistency as obtained in the distillation process. See ASTM Designation D 2026 for Slow-Curing Asphalt.

It should be noted that for all three types of cutback asphalts, RC, MC, and SC, at a given grade, all the materials have the same viscosity at a given temperature.

Emulsions. Emulsified asphalts are emulsions of asphalt cement in water. There are three types of emulsified asphalts: (1) the rapid setting (RS), (2) medium setting (MS), and (3) slow setting (SS). This classification is based on the rate of breaking of the emulsion; that is, the rate at which the dispersed asphalt particles can be made to recombine to form a continuous film of asphalt cement. This rate of breaking or setting is controlled by the type and amount of emulsifier used.

The rapid setting materials have a relatively low concentration of emulsifier and, therefore, are very susceptible to breaking. Generally the RS materials are manufactured with a 120-150 or 150-200 penetration base asphalt. Depending on the amount of asphalt used, there are two grades available, designated as 1 and 2. The RS-2 material has a larger percentage of asphalt in the emulsion than the RS-1 and is sometimes referred to as a high viscosity emulsion.

Medium setting materials differ from the RS materials primarily in the quantity and or type of emulsifier. These materials can be mixed with coarse aggregates containing no fines and are, therefore, referred to as coarse aggregate mixing emulsions. ASTM lists specifications for three MS materials, MS 1-3, and, as with the RS materials, as the number increases the proportion of asphalt in the emulsion increases.

The slow setting emulsions are the most stable of the asphalt emulsions and can be mixed with either well-graded aggregates or with soil. For this reason, they are referred to at times as dense aggregate mixing emulsions. There are two grades of this type of emulsion: (1) the SS-1 and (2) SS-2 or SS-1h. The SS-1 contains the same base asphalt as the RS and MS emulsions. The quantity and/or type of emulsifier, however, varies. The SS-2 material differs from the SS-1 emulsion in that a harder asphalt, generally a 40-50 or 60-70 penetration material, is used.

Basically an emulsion consists of asphalt cement and water that contains a small amount of an emulsifying agent. In essence it is a heterogeneous system, containing two immiscible liquids (asphalt cement and water), in which water forms the continuous phase of the emulsion and minute globules of asphalt the discontinuous phase. Emulsified asphalts may be either anionic, negatively charged asphalt particles, or cationic, positively charged asphalt particles. The type of electrical polarity depends upon the emulsifying agent used to create the emulsion. See ASTM Designation D977 for Anionic Emulsions and ASTM Designation D2397 for Cationic Emulsions.

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U.S. Customary Unit	Physical Quantity	SI Unit Equivalent
Barrel (bbl) (petroleum) (42 U.S. gallons)	Volume	0.158987 m^3
Centimeter of Mercury (cm Hg)	Pressure	1.33322 kPa
Centipoise (cPt)	Absolute Viscosity	0.001 Pa(s)
Centistokes (cSt)	Kinematic Viscosity	10^{-6} m^2/s
Cubic foot	Volume	0.02831685 m^3 = 28.31685 L
Degree Celsius (^0C)	Temperature	$T_K=T_{0C}+273.15$
Degree Fahrenheit (^0F)	Temperature	5/9 x ($^0F-32^0F$) $T_K=T_{0F}+459.67/1.8$ $T_{0C}=(T_{0F}-32)/1.8$
Dyne per square centimeter (dyn/cm^2)	Pressure	0.1 Pa
Foot	Length	0.3048 m
Gallon (U.S. liquid) (231 in^3) (gal)	Volume	3.785412 Liters
Inch (") (1/12 foot)	Length	25.4 mm
Ounce (U.S. fl.oz.) (1/128 U.S. gallon)	Volume	29.57353 mL
Poise (dyne seconds/cm^2)	Absolute Viscosity	0.1 Pa·Seconds
Pound/Square Inch (psi)	Pressure	6.894757 kPa
Quart (U.S. liquid) (1/4 U.S. gallon)	Volume	0.9463529 L
Specific Gravity (solids & liquids) (density relative to that of water at 4^0)	Density	1,000 kg/m^3

The term Liter, as used in the above table, is presumed to have a volume of exactly 1,000 cubic centimeters.

Table 6 - Conversion Factors between the United States Standard Units of Measurements and the S.I. System.

GENERAL SAFETY RULES TO BE OBSERVED IN ALL ASPHALT MATERIALS LABORATORIES

The following safety regulations apply to all individuals engaged in asphalt testing as well as to those who even casually enter the laboratory area:

1. SMOKING - Strickly forbidden within any of the laboratory areas.

2. CLOTHING - Everyone should provide themselves with suitable work clothes, of substantial quality, in good repair, and clean, for use in the laboratory. Work shirts shall be long sleeved, rolled down, and buttoned at both the sleeves and the neck. Coveralls or a long sleeved laboratory coat are suitable alternatives to other types of work clothes. Foot gear must include hard bottoms and uppers. Sandals, open weave cloth shoes, tennis shoes, or other types with soft uppers or bottoms will not be permitted in the laboratory.

   Eye protection will be worn whenever materials are handled that could possibly shoot outward. Ordinary eyeglasses are defined as satisfactory, normal eye protection and all students are encouraged to wear them when working in the laboratory. Goggles, when required, will be available in the laboratory.

   Heavy gloves, either asbestos or a double pair of cotton gloves will be worn when handling heated materials.

3. CHEMICAL SOLVENTS - The only toxic flammable solvents used will be trichloroethylene in the Asphalt Materials and Pavement Design Laboratories. Tricholoroethylene will only be used under the hooded vents with the exhaust fans operating. Whenever this chemical is handled, substantial rubber gloves will be worn. In the event that the trichloroethylene comes in contact with the skin, the affected areas shall immediately be washed with soap and water. Never pour any trichloroethylene into the sink. The used chemical shall be disposed of in specially designated covered steel drums. The use of trichloroethylene is discouraged and will only be employed where other agents are absolutely not suitable.

4. SHIELDS - Some pieces of apparatus include special shields such as the kneading compactor in the Hveem Procedure. The design use of these shields will be scrupulously adhered to whenever these pieces of apparatus are in use.

5. JOKES AND HORSEPLAY - Tricks, practical jokes, and horseplay in any laboratory will result in severe disciplinary actions against the perpetrators. Every person has a responsibility to perform laboratory work with consideration for the safety of him or herself as well as that of the safety of every other member of the group. A compressed air or gas hose is never to be used for cleaning a work area or clothing or pointed at another person. Never leave burners or fires of any kind going when not needed. Use only safety matches or laboratory flint lighters for igniting a flame.

6. CASE OF FIRE - Leave the vicinity and immediately inform the individual in charge and/or a laboratory technician. If it can be accomplished without incurring added risk, disconnect electrical connections in the area of the fire.

7. VALVES AND CONTROLS - Do not attempt to operate any valve or control on any piece of laboratory equipment before being instructed in its use by the instructor or the laboratory technician and prior to permission from the instructor.

8. USE OF TOOLS - Use only the proper tool as directed by the instructor or laboratory technician and be certain that it is in good condition. Keep all tools and equipment clean and free from oil or grease. Never carry tools in your pockets or throw them when finished using.

9. LIFTING - Never attempt to lift a heavier weight than you can comfortably handle. Get help when needed. In lifting, keep your back straight and as nearly upright as possible. Lift with the leg muscles and not with the more vulnerable muscles of the back and abdomen. Never attempt to lift when the body is in an awkward position, as when twisting, or when your footing is insecure.

10. IN CASE OF ACCIDENT - Report every injury, no matter how slight it may appear, immediately to the responsible individual. If possible the injured person should immediately seek professional medical attention. The person in charge will make out an injury form and report the incident immediately to the proper authority in writing. In case of serious injury no attempt will be made to move the injured. Medical assistance will immediately be requested, probably from the designated medical facility.

11. CLEANUP AT THE END Of THE LABORATORY EXERCISE - Every squad and each individual is responsible for cleaning all equipment used in that period. All equipment must be cleaned before returned to its proper place. Bench tops shall be clean and all equipment or samples cleaned and neatly arranged. All sample containers shall be wiped clean before storing. No one will be dismissed or excused from the

laboratory until his or her particular squad has been checked out by the individual responsible for this important housekeeping operation.

12. GENERAL PROVISION - It is incumbent upon every individual to be thoroughly familiar with these safety rules which will be distributed at the first class meeting. Strict attention to instructions by the instructor and/or the laboratory technician is an implied responsibility of every individual. One of the most important responsibilities of the instructor and the laboratory technician is that of safety. Do not hesitate to ask questions when in doubt about any procedure or proper use of apparatus.

While these provisions were prepared specifically with college classes in mind, they apply equally to any industrial or commercial asphalt laboratory, with the normal allowances for any functional differences in the work environment.

REFERENCE SPECIFICATIONS FOR ASPHALT CEMENT, CUTBACKS AND EMULSIONS

Note: See Pages 168 and 169 for Specifications of Viscosity Graded Asphalts.

	Penetration Grade									
	40–50		60–70		85–100		120–150		200–300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 77°F (25°C) 100 g, 5 s	40	50	60	70		100		150	200	300
Flash point, °F (Cleveland open cup)	450	. . .	450	. . .		. . .		. . .	350	
Ductility at 77°F (25°C) 5 cm/min, cm	100	. . .	100	. . .	100	. . .	100	. . .	100[A]	. . .
Retained penetration after thin-film oven test, %	55+	. . .	52+	. . .	47+	. . .	42+	. . .	37+	. . .
Ductility at 77°F (25°C) 5 cm/min, cm after thin-film oven test	. . .	. . .	50	. . .	75	. . .	100	. . .	100[A]	. . .
Solubility in trichloroethylene, %	99.0	. . .	99.0	. . .	99.0	. . .	99.0	. . .	99.0	. . .

[A] If ductility at 77°F (25°C) is less than 100 cm, material will be accepted if ductility at 60°F (15.5°C) is 100 cm minimum at the pull rate of 5 cm/min.

<u>Table 7 - Specifications for Penetration Grade Asphalt Cement: ASTM Designation D 946.</u>
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Type	Rapid-Setting				Medium-Setting						Medium-Setting						Slow-Setting			
	RS-1		RS-2		MS-1		MS-2		MS-2h		HFMS-1		HFMS-2		HFMS-2h		SS-1		SS-1h	
Grade	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Tests on emulsions:																				
Viscosity, Saybolt Furol at 77°F (25°C), s	20	100			20	100	100		100		20	100	100		100		20	100	20	100
Viscosity, Saybolt Furol at 122°F (50°C), s			75	400																
Settlement,[a] 5-day, %		5		5		5		5		5		5		5		5		5		5
Storage stability test,[b] 24-h, %		1		1		1		1		1		1		1		1		1		1
Demulsibility,[c] 35 ml, 0.02 *N* $CaCl_2$, %	60		60																	
Coating ability and water resistance:																				
Coating, dry aggregate					good		good		good		good		good		good					
Coating, after spraying					fair		fair		fair		fair		fair		fair					
Coating, wet aggregate					fair		fair		fair		fair		fair		fair					
Coating, after spraying					fair		fair		fair		fair		fair		fair					
Cement mixing test, %																		2.0		2.0
Sieve test, %		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10		0.10
Residue by distillation, %	55		63		55		65		65		55		65		65		57		57	
Tests on residue from distillation test:																				
Penetration, 77°F (25°C), 100 g, 5 s	100	200	100	200	100	200	100	200	40	90	100	200	100	200	40	90	100	200	40	90
Ductility, 77°F, (25°C), 5 cm/min, cm	40		40		40		40		40		40		40		40		40		40	
Solubility in trichloroethylene, %	97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5		97.5	
Float test, 140°F (60°C), s											1200		1200		1200					
Typical applications[d]	surface treatment, penetration macadam, sand seal coat, tack coat, mulch		surface treatment, penetration macadam, coarse aggregate seal coat (single and multiple)		cold plant mix, road mix, sand seal coat, crack treatment, tack coat		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat, sand seal coat		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat		cold plant mix, road mix, sand seal coat, crack treatment, tack coat		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment road mix, tack coat, and seal		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple), crack treatment road mix, tack coat		cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, mulch			

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[a] The test requirement for settlement may be waived when the emulsified asphalt is used in less than 5 days time; or the purchaser may require that the settlement test be run from the time the sample is received until the emulsified asphalt is used, if the elapsed time is less than 5 days.

[b] The 24-h storage stability test may be used instead of the 5-day settlement test.

[c] The demulsibility test shall be made within 30 days from date of shipment.

[d] These typical applications are for use only as a guide for selecting and using the emulsion for pavement construction and maintenance.

Table 8- Requirements and Typical Applications for Emulsified Asphalt:
ASTM Designation D 977.
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NOTE 1—Kinematic Viscosity Method D 2170 covers the range from 30 to 6000 cSt while Absolute Viscosity Method D 2171 covers the range from 42 to 200 000 P.

NOTE 2—If the ductility at 77 F (25 C) is less than 100, the material will be acceptable if its ductility at 60 F (15.5 C) is more than 100.

Designation	SC-70		SC-250		SC-800		SC-3000	
	Min	Max	Min	Max	Min	Max	Min	Max
Kinematic viscosity at 140 F (60 C), cSt.	70	140	250	500	800	1600	3000	6000
Flash point (Cleveland open cup), deg F (deg C)	150 (66)	...	175 (79)	...	200 (93)	...	225 (107)	...
Distillation test:								
Total distillate to 680 F (360 C), volume percent	10	30	4	20	2	12	...	5
Kinematic viscosity on distillation residue at 140 F (60 C), St	4	70	8	100	20	160	40	350
Asphalt residue:								
Residue of 100 penetration, percent	50	...	60	...	70	...	80	...
Ductility of 100 penetration residue at 77 F (25 C), cm	100	...	100	...	100	...	100	...
Solubility in trichloroethylene, percent	99.0	...	99.0	...	99.0	...	99.0	...
Water, percent	...	0.5	...	0.5	...	0.5	...	0.5

Table 9 - Specifications for Slow Curing Cutback Asphalt:
ASTM Designation D 2026.
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Requirements for Cutback Asphalt (Medium-Curing Type)

NOTE—If the ductility at 77 F (25 C) is less than 100, the material will be acceptable if its ductility at 60 F (15.5 C) is more than 100.

Designation	MC-30		MC-70		MC-250		MC-800		MC-3000	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Kinematic viscosity at 140°F (60°C), cSt	30	60	70	140	250	500	800	1600	3000	6000
Flash point (Tag open-cup), °F (°C)	100 (38)	...	100 (38)	...	150 (66)	...	150 (66)	...	150 (66)	
Distillate test:										
Distillate, volume percent of total distillate to 680°F (360°C):										
to 437°F (225°C)	...	25	...	20	...	10	...			
to 500°F (260°C)	40	70	20	60	15	55	...	35		15
to 600°F (316°C)	75	93	65	90	60	87	45	80	15	75
Residue from distillation to 680°F (360°C), percent volume by difference	50	...	55		67	...	75		80	
Tests on residue from distillation:										
Viscosity at 140°F (60°C), P[a]†	300	1200	300	1200	300	1200	300	1200	300	1200
Ductility at 77°F (25°C), cm	100	...	100	...	100	...	100		100	
Solubility in trichloroethylene, %	99.0	...	99.0	...	99.0	...	99.0	...	99.0	
Water, %	...	0.2	...	0.2	...	0.2	...	0.2	...	0.2

[a] Instead of viscosity of the residue, the specifying agency, at its option, can specify penetration 100 g: 5 s at 77°F (25°C) of 120 to 250 for Grades MC-30, MC-70, MC-250, MC-800, and MC-3000. However, in no case will both be required.

† Editorially corrected.

Table 10 - Specifications for Medium Curing Asphalt: ASTM Designation D 2027.
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NOTE—If the ductility at 77 F (25 C) is less than 100, the material will be acceptable if its ductility at 60 F (15.5 C) is more than 100.

Designation	RC-70		RC-250		RC-800		RC-3000	
	Min	Max	Min	Max	Min	Max	Min	Max
Kinematic viscosity at 140 F (60 C), cSt	70	140	250	500	800	1600	3000	6000
Flash point (Tag open-cup), deg F (deg C)	...	...	80+ (27+)	...	80+ (27+)		80+ (27+)	
Distillation test:								
Distillate, volume percent of total distillate to 680 F (360 C):								
to 374 F (190 C)	10	...	...	...	...	...	...	...
to 437 F (225 C)	50	...	35	...	15	...	...	...
to 500 F (260 C)	70	...	60	...	45	...	25	...
to 600 F (316 C)	85	...	80	...	75	...	70	...
Residue from distillation to 680 F (360 C), percent volume by difference	55	...	65	...	75	...	80	...
Tests on residue from distillation:								
Viscosity at 140°F (60°C), P[a]	600	2400	600	2400	600	2400	600	2400
Ductility at 77 F (25 C), cm	100	...	100	...	100	...	100	...
Solubility in trichloroethylene, percent	99.0	...	99.0	...	99.0		99.0	...
Water, percent	...	0.2	...	0.2	...	0.2	...	0.2

[a] Instead of viscosity of the residue, the specifying agency, at its option, can specify penetration at 100 g: 5 s at 77°F (25°C) of 80 to 120 for Grades RC-70, RC-250, RC-800, and RC-3000. However in no case will both be required.

Table 11 - Specifications for Rapid Curing Cutback Asphalt: ASTM Designation D 2028. Copyright ASTM. Reprinted with Permission.

Type	Rapid-Setting				Medium-Setting				Slow-Setting			
Grade	CRS-1		CRS-2		CMS-2		CMS-2h		CSS-1		CSS-1h	
	min	max	min	max	min	max	min	max	min	max	min	max
Test on emulsions:												
Viscosity, Saybolt Furol at 77°F (25°C), s									20	100	20	100
Viscosity, Saybolt Furol at 122°F (50°C), s	20	100	100	400	50	450	50	450				
Settlement,[a] 5-day, %		5		5		5		5		5		5
Storage stability test,[b] 24-h, %		1		1		1		1		1		1
Classification test[c]	passes		passes									
or												
Demulsibility,[d] 35 ml 0.8 % sodium dioctylsulfosuccinate, %	40		40									
Coating, ability and water resistance:												
Coating, dry aggregate					good		good					
Coating, after spraying					fair		fair					
Coating, wet aggregate					fair		fair					
Coating, after spraying					fair		fair					
Particle charge test	positive		positive		positive		positive		positive		positive	
Sieve test, %		0.10		0.10		0.10		0.10		0.10		0.10
Cement mixing test, %										2.0		2.0
Distillation:												
Oil distillate, by volume of emulsion, %		3		3		12		12				
Residue, %	60		65		65		65		57		57	
Tests on residue from distillation test:												
Penetration, 77°F (25°C), 100 g, 5 s	100	250	100	250	100	250	40	90	100	250	40	90
Ductility, 77°F (25°C), 5 cm/min, cm	40		40		40		40		40		40	
Solubility in trichloroethylene, %	97.5		97.5		97.5		97.5		97.5		97.5	
Typical applications[e]	surface treatment, penetration macadam, sand seal coat, tack coat, mulch		surface treatment, penetration macadam, coarse aggregate seal coat (single and multiple)		cold plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat, sand seal coat		cold plant mix, hot plant mix, coarse aggregate seal coat (single and multiple), crack treatment, road mix, tack coat		cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, mulch			

[a] The test requirement for settlement may be waived when the emulsified asphalt is used in less than 5 days time; or the purchaser may require that the settlement test be run from the time the sample is received until the emulsified asphalt is used, if the elapsed time is less than 5 days.

[b] The 24-h storage stability test may be used instead of the 5-day settlement test.

[c] Material failing the classification test will be considered acceptable if it passes the demulsibility test.

[d] The demulsibility test shall be made within 30 days from date of shipment.

[e] These typical applications are for use only as a guide for selecting and using the emulsion for pavement construction and maintenance.

**Table 12 - Requirements and Typical Applications for Cationic Emulsified Asphalt:
ASTM Designation D 2397.
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Note: See Page 162 for Specifications of Penetration Graded Asphalts.

Requirements for Asphalt Cement, Viscosity Graded at 140°F (60°C)

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min, cSt	80	110	150	210	300
Penetration, 77°F (25°C), 100 g, 5 s, min	200	120	70	40	20
Flash point, Cleveland open cup, min, °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min, %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max, P	1250	2500	5000	10,000	20,000
Ductility, 77°F (25°C), 5 cm/min, min, cm	100[a]	100	50	20	10

[a] If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a rate of 5 cm/min.

Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min, cSt	125	175	250	300	400
Penetration, 77°F (25°C), 100 g, 5 s, min	220	140	80	60	40
Flash point, Cleveland open cup, min, °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min, %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max, P	1250	2500	5000	10,000	20,000
Ductility 77°F (25°C), 5 cm/min, min, cm	100[a]	100	75	50	25

[a] If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a rate of 5 cm/min.

Table 13 - Specifications for Viscosity Graded Asphalt Cement at 60^{0}C (140^{0}F): ASTM Designation D 3381.

Note: Unless the Lower Table is specified, the requirements of the Upper Table are deemed to govern.

Note: See Page 162 for Specifications of Penetration Graded Asphalts.

Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

NOTE—Grading based on residue from rolling thin-film oven test.

Tests on Residue from Rolling Thin-Film Oven Test:[a]	Viscosity Grade				
	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000
Viscosity, 140°F (60°C), P	1000 ± 250	2000 ± 500	4000 ± 1000	8000 ± 2000	16000 ± 4000
Viscosity, 275°F (135°C), min, cSt	140	200	275	400	550
Penetration, 77°F (25°C), 100 g, 5 s, min	65	40	25	20	20
% of original penetration, 77°F (25°C), min	...	40	45	50	52
Ductility, 77°F (25°C), 5 cm/min, min, cm	100[b]	100[b]	75	75	75
Tests on original asphalt:					
Flash Point, Cleveland Open Cup, min, °F(°C)	400 (205)	425 (219)	440 (227)	450 (232)	460 (238)
Solubility in trichloroethylene, min, %	99.0	99.0	99.0	99.0	99.0

[a] Thin-film oven test may be used but the rolling thin-film oven test shall be the referee method.

If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a rate of 5 cm/min.

Table 14 - Table of Specifications for Viscosity Graded Aged Residue Asphalt at 60^0C (140^0F): ASTM Designation D 3381.

OVERVIEW of the SUPERPAVE BINDER & MIX DESIGN ANALYSES & METHODS

In 1987 the Strategic Highway Research Program (SHRP) began to develop new systems to test and to specify asphalt binders and asphalt materials. The final product of SHRP asphalt research program is a new system referred to as SUPERPAVE. The latter stands for SUperior PERforming Asphalt PAVEments. SUPERPAVE includes a computer program that assists engineers in materials selection and mix design. On the basis of the evidence developed thus far, engineers involved in SHRP believe that they have developed an improved method for identifying component materials, asphalt concrete mix design and analysis, and prediction of pavement performance.

One of the decisions made by the developers of SHRP was to maintain all measurements in the SI system. The only exception to this determination is that some equipment software may also indicate equivalent English units.

Officially the Strategic Highway Research Program finished in 1993. However, the course of introduction, testing, training of personnel at all levels of industry, development of specifications, and implementation will require a number of additional years of concentrated effort.

I. SHRP Asphalt Binder Laboratory Tests and Equipment - the current methods to classify asphalt cements are by penetration at 25^0 C and viscosity at 60^0 C. Yet these parameters cannot predict how asphalts will behave at other in-service temperatures. However, asphalts graded at these temperatures may exhibit markedly different characteristics from one another at higher or lower temperatures. The SHRP tests are designed to measure physical properties that can be related directly to field performance by the application of engineering principles.

The performance grades recommended by SHRP is based upon two numbers. The first is derived from the average of the 7 hottest consecutive days ever recorded at a weather station near the proposed site of construction. The maximum pavement design temperature is used to select an asphalt that will resist rutting. The second number is derived from the lowest one-day air temperature ever recorded at the same weather station. The minimum pavement design temperature is used to select an asphalt binder that will resist low temperature cracking and fatique. A typical PG number is 64-28 for a large section of the midwest region of the United States. It represents a high pavement temperature of 64^0 C 20 mm below the surface and a minimum pavement temperature of 28^0 C at the surface. The maximum and minimum air temperatures are equated to the corresponding pavement temperatures by appropriate regression equations. The particular grade of binder is designed to sustain the conditions of an environment with the specified minimum and maximum pavement temperatures.

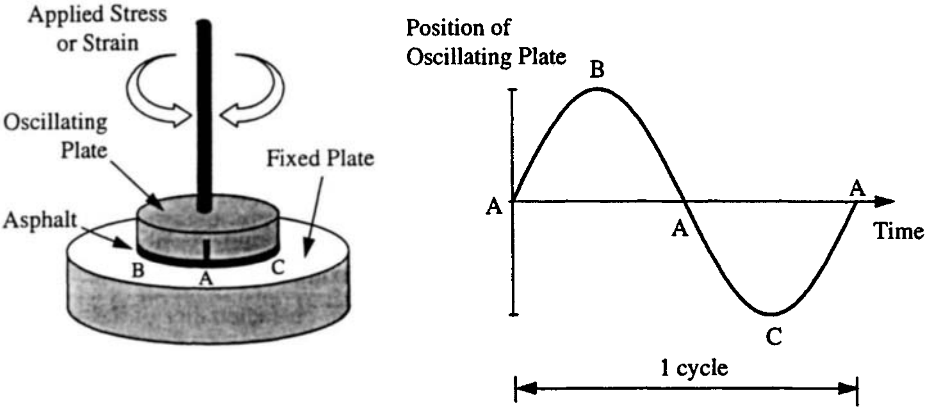
The six binder test procedures proposed by SHRP are as follows:

- High/Intermediate Temperature Properties
    - Dynamic Shear Rheometer (DSR)
    - Rotational Viscometer (RV)
- Low Temperature Properties
    - Bending Beam Rheometer (BBR)
    - Direct Tension Tester (DTT)
- Durability Properties by Simulating Hardening Characteristics
    - Rolling Thin Film Oven (RTFO)
    - Pressure Aging Vessel (PAV)

A brief description of the above pieces of apparatus is as follows:

A. Dynamic Shear Rheometer (DSR) evaluates rheological properties at higher temperatures. Rutting is probably the most serious cause of flexible pavement distress. Using conventional testing methods, the pavement designer would specify a stiffer binder to reduce the rutting problem. Unfortunately this approach might help with pavement rutting but it could accelerate low temperature fatique cracking. Unlike capillary viscometers which only measure the viscosity, the DSR measures both the viscosity and the elastic properties of the asphalt cement.

A sample of asphalt is sandwiched between two plates, as shown in the schematic shown below. The bottom plate is fixed. A torque is applied to the top plate so that it oscillates back and forth at a rate of 1.6 cycles per second. One cycle is completed when the top plate goes from A to B and back to A, from A to C and back to A.



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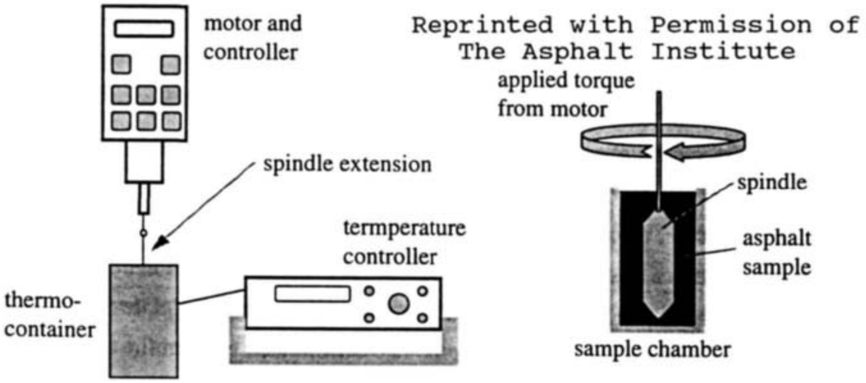
The DSR measures the complex shear modulus, G* and the phase delta angle, δ. G* is a measure of overall stiffness which includes both viscosity and elastic properties. The phase angle, δ, is used to separate the viscosity from the elastic components in G*. The higher the elastic component in G*, the greater is the asphalt binder resistance to rutting and fatique cracking. SHRP criteria specifies a minimum value of 1.0 and 2.2 kilo pascals at the designated test temperature for the $G^*/\sin\delta$ values for the original asphalt and aged residue asphalt respectively. SHRP also specifies a maximum value of 5,000 kilo pascals for the value of $G^* x \sin\delta$ of an aged residue asphalt that has been subjected either to the rolling thin film oven or the pressure aging vessel. $G^* x \sin\delta$ is analogous to the penetration test that is conducted at 25^0C. The significant difference between the two is that the penetration test is purely empirical, while the expression $G^*\sin\delta$ results in fundamental physical units.

B. Rotational Viscometer (RV) is used to evaluate the handling and pumping properties of asphalt cement (including modified binders) during construction. It is also used to establish the mixing and compaction temperatures of the hot mix asphalt concrete by conducting the test at two temperatures. The figure below illustrates a schematic of the rotational viscometer.



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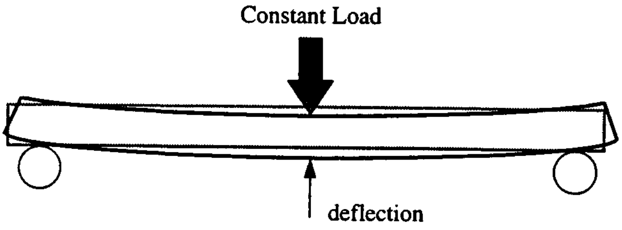
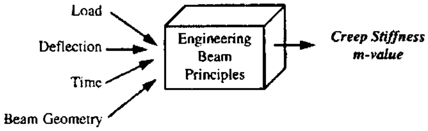
The asphalt cement is poured into the sample chamber which is placed into a thermo-container to control the test temperature. A standard spindle is inserted into the sample chamber. Torque is applied from the **motor** to the spindle to rotate it within the asphalt cement. The torque required to achieve a spindle speed of 20 rpm is measured. The viscometer indicates the asphalt viscosity as a digital read out. SHRP specifications permits a maximum viscosity of 3 pascal-seconds or 3,000 centipoises at 135^0C to that the asphalt cement can be readily pumped and mixed with the aggregates. As is the case with viscosity tests, temperature-viscosity graphs can be developed to estimate the optimum mixing and compaction temperatures. This method of measuring viscosity and description of the apparatus is detailed in ASTM Designation: D 4402.

C. Bending Beam Rheometer (BBR) evaluates rheological properties at low temperatures. Hot mixed asphalt pavements develop low-temperature thermal cracking when the asphalt cement becomes too stiff at depressed temperatures. The BBR is used to evaluate low-temperature stiffness properties {creep stiffness and m-value of asphalt cement that has been aged in the rolling thin film oven (RTFO) and the pressure aging vessel (PAV)}. By loading the asphalt beam for four minutes with a constant load and measuring the deflection at the center of the beam continuously throughout the four minutes, the creep stiffness and creep rate, m, can be measured and calculated. A diagram, showing the basics of the test and the principles involved are shown in the diagrams below.





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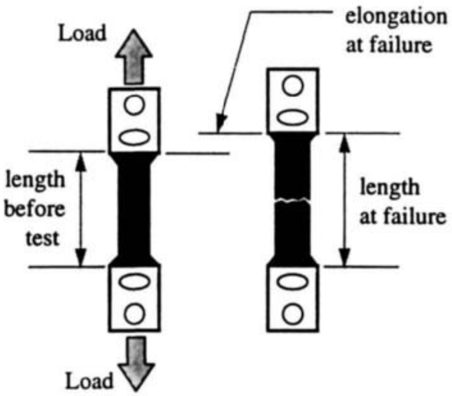
SHRP specifications recommend a maximum value of 300,000 kilo Pascals for creep stiffness and a minimum value of 0.30 for the m-value.

The equipment consists of a creep-type rheometer unit, a temperature-controlled bath, and a microcomputer based data acquisition system. A pneumatic piston controls the movement of the loading shaft. The upper end of the loading shaft is attached to a linear variable differential transducer that precisely measures the shaft movement. The loading can be operated manually or automatically. A computer monitors the deflection of the asphalt beam, load on beam, and duration of loading. The computer program displays real-time load and deflection plots, calculates stiffness values at selected loading times, and displays the results, together with input parameters, at the end of each test.

D. Direct Tension Tester (DTT) was developed in the SHRP program to accommodate those asphalts, particularly modified asphalt binders, that may be stiff at low temperatures but do not develop the expected low temperature cracking. The creep stiffness as measured by the BBR is not adequate to properly capture the ability of some asphalts to elongate before rupturing. A small dogbone shaped specimen is loaded in tension until failure. A schematic of the DTT's direct tension principle is shown below.



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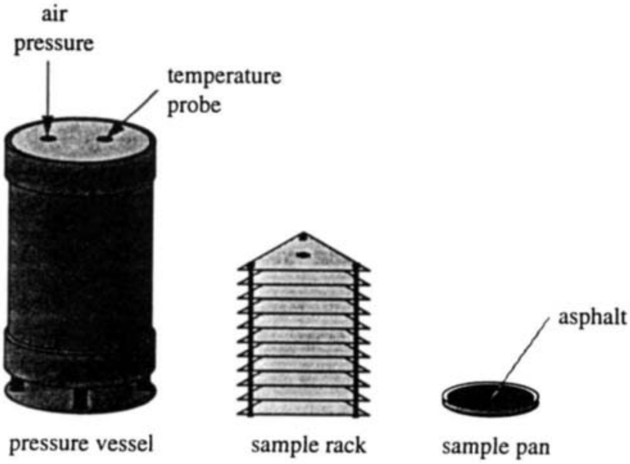
$$\text{percent strain at failure} = \frac{\text{elongation}}{\text{length before testing}}$$

Output from the direct tension test is the failure strain at the specified test temperature. Failure strain equals the change in length, or elongation, expressed as a percentage of the original length. Since the strains experienced are quite small, a laser beam is used to measure the strain at failure. Specifications require that the failure strain should be at least 1.0 percent.

E. Rolling Thin Film Oven Test (RTFO), ASTM Designation D 2872, is described on pages 98 and 99 of this manual. This procedure serves two objectives. One is to provide an aged residue asphalt that can be subject to other physical tests. The other is to determine the amount of volatile loss during the process as an indication of the amount of aging that the asphalt cement may experience during mixing in the pugmill and during construction operations.

F. Pressure Aging Vessel (PAV) determines the longterm aging that the asphalt will be subjected to during the service life of the flexible pavement. Asphalt cement undergoes two aging mechanism while in use. These are the loss of the light oils present in the asphalt cement (volatilization) and reaction with the oxygen in the air, especially in the presence of sunlight, (oxidation). The RTFO simulates the aging process during the manufacture of the asphalt cement in the paving mixture while the PAV approximates the aging process that takes place in the asphalt cement while the pavement is in use which is essentially only an oxidation process. A schematic of the PAV is shown below.



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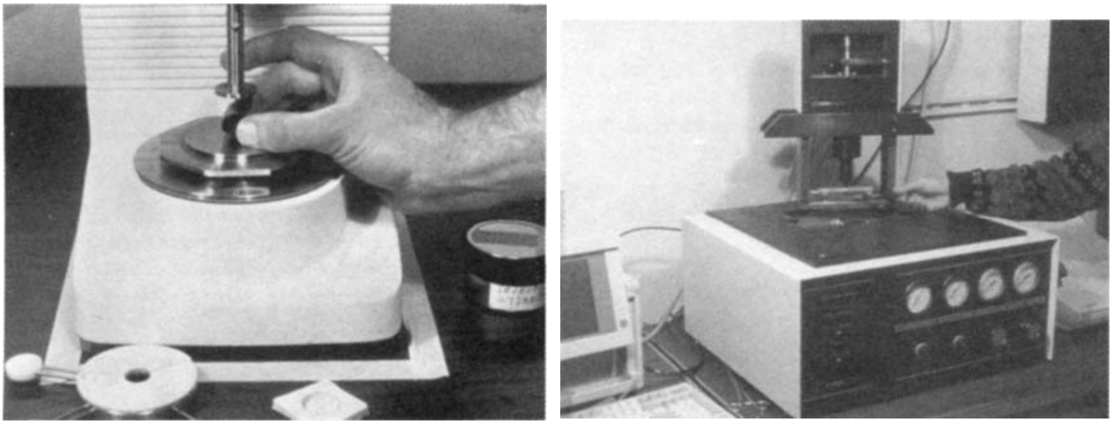
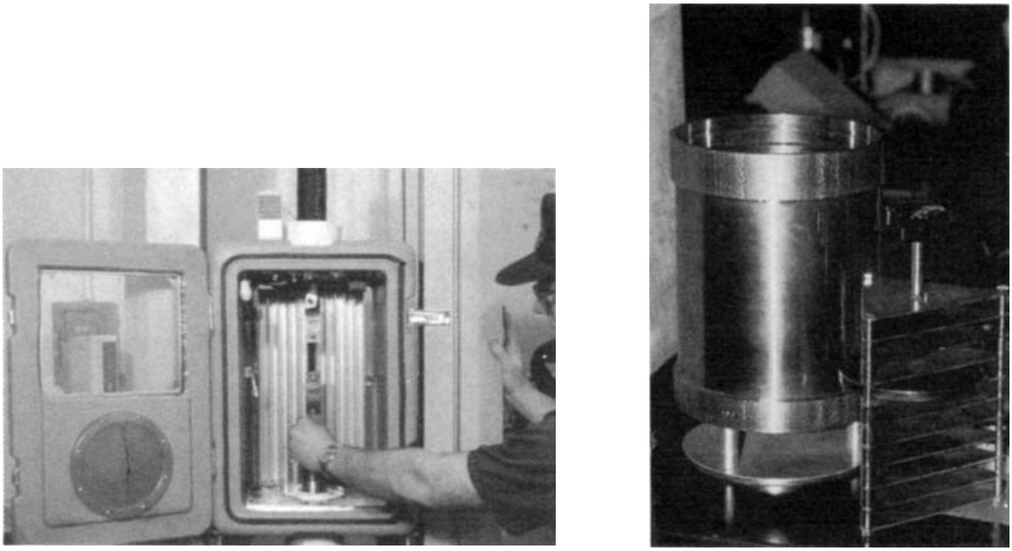
The pressure aging vessel was developed by SHRP to simulate the aging process that takes place during 5 to 10 years of service in a pavement structure. Asphalt cement that has already been subject to the RTFO is poured onto flat sample pans. These pans are placed in the sample rack, shown above, which in turn is put into the pressure vessel. The air pressure in the vessel is increased to 2.1 mega pascals and the temperature maintained at between 90^0 C to 100^0 C, depending upon the grade of the asphalt cement. The specimens in the PAV are subjected to the aging process for 20 hours and then tested for the properties specified in the performance graded binder specifications, much the same as samples taken from a rolling thin film oven.



Dynamic Shear Rheometer Bending Beam Rheometer

Photos Courtesy of the National Ashpalt Pavement Association



Direct Tension Tester Pressure Aging Vessel

Photos Courtesy of the National Asphalt Pavement Association
Figure 39 - Asphalt Binder Testing Equipment.

SHRP Asphalt Binder Data Sheet

Test of Asphalt Cement Property	Aging Condition	Test Results	SHRP Specification Requirements
Flash Point	Original Asphalt		230^0 C min
Viscosity at 135^0 C	Original Asphalt		3 Pa-s max
Dynamic Shear, $G^*/\sin\delta$ at 64^0 C	Original Asphalt		1.00 kPa min
Mass Loss	RTFO Aged Residue Asphalt		1.00% max
Dynamic Shear, $G^*/\sin\delta$ at 64^0 C	RTFO Aged Residue Asphalt		2.20 kPa min
Dynamic Shear, $G^*\sin\delta$ at 22^0 C	PAV Aged Residue Asphalt		5000 kPa max
Creep Stiffness, S at -18^0 C	PAV Aged Residue Asphalt		300 MPa max
m-value at -18^0 C	PAV Aged Residue Asphalt		0.300 min

Two forms of testing are considered in connection with the SHRP binder specifications, conformance testing and classification testing. Conformance testing is designed to determine whether the particular asphalt cement sample meets specification requirements. Classification testing determines the grade or grades, if any, that a specimen of asphalt cement meets. However, in both cases the identical series of tests are performed. Hence, the identical data sheet is utilized for both of them.

Table 15 - Conformance and Classification Data Sheet.

LOADS	HIGH PAVEMENT DESIGN TEMPERATURE ^{0}C						
Standing→ SlowTransient→ FastTransient→	28to34→ 34to40→ 40to46→	34to40→ 40to46→ 46to52→	40to46→ 46to52→ 52to58→	46to52→ 52to58→ 58to64→	52to58 58to64 64to70	58to64 64to70 70to76	64to70 70to76 76to82
LOW PAVEMENT DESIGN TEMPERATURE ^{0}C						Special Grades	
>-10	PG 46 -10	PG 52 -10	PG 58 -10	PG 64 -10	PG 70 -10	PG 76 -10	PG 82 -10
-10 to -16	PG 46 -16	PG 52 -16	PG 58 -16	PG 64 -16	PG 70 -16	PG 76 -16	PG 82 -16
-16 to -22	PG 46 -22	PG 52 -22	PG 58 -22	PG 64 -22	PG 70 -22	PG 76 -22	PG 82 -22
-22 to -28	PG 46 -28	PG 52 -28	PG 58 -28	PG 64 -28	PG 70 -28	PG 76 -28	PG 82 -28
-28 to -34	PG 46 -34	PG 52 -34	PG 58 -34	PG 64 -34	PG 70 -34	PG 76 -34	PG 82 -34
-34 to -40	PG 46 -40	PG 52 -40	PG 58 -40	PG 64 -40	PG 70 -40		
-40 to -46	PG 46 -46	PG 52 -46	PG 58 -46	PG 64 -46			
REGION	Alaska-Canada Northern U.S.		Canada North U.S.	Southern U.S.	Southwest U.S. Desert Continental U.S. - Slow Traffic		

Steps in Determining the Recommended Binder Performance Grades.

1. Select the type of loading.
2. Move horizontally to the high pavement design temperature.
3. Move down to the low pavement design temperature.
4. Identify the binder grade.

White background boxes indicate the prevalent No. American grades.
Shaded boxes indicate special binder grades.
Example: Standing Load, High Temperature = 57^0 C,
Low Temperature = -25^0 C. The asphalt cement grade, from the above chart is PG 70-28.

Table 16 - Binder Performance Grades Selection Table.

Performance Grade	PG-52							PG-58					PG-64					PG-70			
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-16	-22	-28	-34	-40	-10	-16	-22	-28
Average 7-day Max. Pavt. Design Temperature, °C[a]	<52							<58					<64					<70			
Minimum Pavement Design Temperature, °C[a]	> 10	> 16	> 22	> 28	> 34	> 40	> 46	> 16	> 22	> 28	> 34	> 40	> 16	> 22	> 28	> 34	> 40	> 10	> 16	> 22	> 28
Original Binder																					
Flash Point Temp. AASHTO T48:Min.°C	230																				
Viscosity,ASTM D4402:[b] Max.3Pa-s Test Temp. °C	135																				
Dynamic Shear, AASHTO TP5:[c] G*/sinδ,Min, 1.0kPa.Test Temp. @ 10 rad/s, °C	52							58					64					70			
Physical Hardening Index[d], h	Report																				
Rolling Thin Film Oven Test Residue (AASHTO T 240)																					
Mass Loss,Max.%	1.0																				
Dynamic Shear, AASTHO TP5: G*/sinδ, 2.2kPa Test Temp. @ 10 rad/sec. °C	52							58					64					70			
Pressure Aging Vessel Residue (AASHTO PP1)																					
PAV Aging Temp °C	90							100					100					100/(110)[e]			
Dynamic Shear, AASHTO TP5: G*sinδ,Max. 5,000 kPa: Test Temp @ 10 rad/sec. °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16	34	31	28	25
Creep Stiffness, AASHTO TP1:[f] S,Max.300,000kPa, m-value,Min.0.30 Test Temperature @60 seconds °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18
Direct Tension, AASHTO TP3:[f] Failure Strain, Minimum 1.0%, Test Temperature @1.0mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18

See notes for the above table on the next page.

Table 17 - Performance Graded Asphalt Binder (AASHTO MP1).

Notes for Table 17, Performance Graded Asphalt Binder (AASHTO MP1) - refer to the superscripts in the Table.

a. Pavement temperatures can be estimated from air temperatures using an algorithm in the SUPERPAVE software program or may be provided by the specifying agency.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of $G^*/\sin\delta$ at test temperatures where the asphalt is a Newtonian fluid (generally above 55^0 C). Any suitable standard means of viscosity measurements may be used, including capillary or rotational viscometry.

d. The physical hardening index h accounts for physical hardening and is calculated by $h=(S_{24}S_1)^{m1/m24}$ where 1 and 24 indicate 1 and 24 hours of conditioning of the tank asphalt. Conditioning and testing is conducted at the designated test temperature. Values should be calculated and reported. S is the creep stiffness after 60 seconds loading time and m is the slope of the log creep stiffness versus log time curve after 60 seconds loading time.

e. The PAV aging temperature is 100^0 C, except in desert climates, where it is 110^0 C.

f. If the creep stiffness is below 300,000 kPa, the direct tension test is not required. If the creep stiffness is between 300,000 and 600,000 kPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value must be satisfied in both cases.

II. SUPERPAVE Asphalt Concrete Mixture Design and Analysis System has three basic parts: performance based specifications for binders and mixes, tests for predicting binder and mix performance, and a simplified system for designing asphalt concrete mixes. SUPERPAVE is derived from the concept of SUperior PERformance PAVEments. It is the overall name used for the SHRP mixture design system. The system is designed to be performance based with appropriate considerations given to both environmental and traffic conditions. The various factors are combined into an overall system called, SUPERPAVE.

SUPERPAVE addresses itself to three major causes of flexible pavement distress: rutting, fatique cracking, and low temperature cracking. Moisture sensitivity, which in all cases must be evaluated by AASHTO T 283, along with aging are two additional considerations used for mixture evaluation.

The system enables the pavements design engineer to develop the following elements in order to obtain an economical asphalt concrete mixture that has sufficient binder, voids, workability, and performance:

1. Aggregate selection and blending.
2. Asphalt cement binder selection.
3. Mix design selection.
4. Performance based mixture evaluation.

For traffic considerations SUPERPAVE has established three pavement design levels, based upon traffic volume and type. These traffic guidelines are

DESIGN LEVEL	TRAFFIC DEFINITION	DESIGN TRAFFIC (ESAL)*
1	Low	≤1,000,000
2	Intermediate	≤10,000,000
3	High	>10,000,000

*ESAL=Equivalent Single Axle Load which is a measure of the traffic volume and loads expected for the design life of a pavement.

For Level 1 traffic areas the design is based upon a gyratory compactor to determine conventional aggregate and mixture properties. Selection of the asphalt cement content is determined by air voids and voids mineral aggregate (VMA) at a specified density. Moisture sensitivity testing and short term aging are also required as part of the pavement design for low density traffic areas.

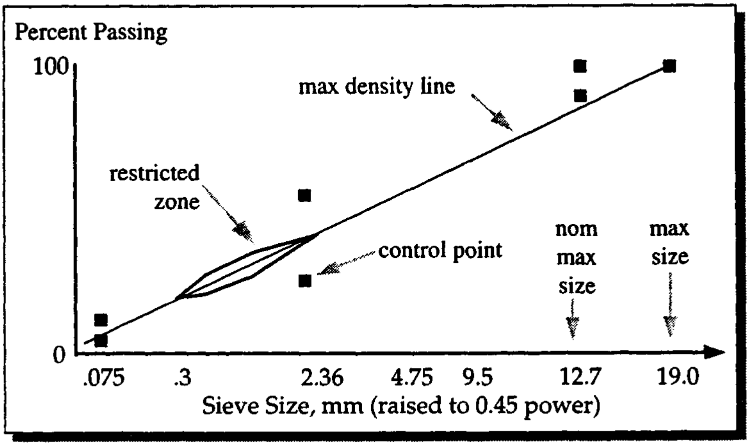
Level 2 traffic areas must meet all the requirements for Level 1. In addition, three tests utilizing the SHRP Shear Test (SST) devise is recommended. The following SST tests are used to estimate the mixture's creep and rutting potential:

1. Repeated Shear at Constant Stress.
2. Simple Shear at constant Height.
3. Frequency Sweep at Constant Height.

Level 3 traffic is essentially defined by high density freeways. It utilizes Level 1 requirements plus an additional two SST tests beyond that included in Level 2 traffic design as well as more test specimens

4. Uniaxial Strain Test.
5. Volumetric Test.

6. The SUPERPAVE gradation limits for a 12.7 mm mixture is shown on the graph below. A SUPERPAVE design aggregate structure must pass between the designated control points while avoiding the restricted zone. The maximum density gradation is drawn from the 100% passing the maximum aggregate size through the origin. The maximum aggregate size is defined as one size larger than the nominal maximum aggregate size. Nominal maximum size is defined as one size larger than the first sieve size to retain more than 10%. The purpose of the restricted zone is to avoid mixtures that have a high percentage of fine sand relative to total sand. The design aggregate structure is aimed to ensure that the aggregates will develop a strong, stone skeleton to enhance resistance to permanent deformation while achieving sufficient void space for mixture durability.



SUPERPAVE Gradation Limits for a 12.7 mm Mixture.

Dust Proportion which is the dust (defined as aggregate finer than the 0.075 mm sieve) to asphalt ratio is another aggregate requirement. It is based upon the effective asphalt cement in the mixture. An acceptable dust proportion is in the range of from 0.6 to 1.2 for all mixtures.

SHRP Asphalt Cement Binder Selection is designed to evaluate the contribution of the asphalt binder to the performance of the paving mixture. The performance characteristics considered are permanent deformation, fatique cracking, and low temperature cracking to the extent that each of these distresses relate to the binder. The binder identification system is as follows:

PG X-Y where

PG = Performance Grade
X = Average 7-day maximum pavement temperature, ^0C
Y = Lowest expected pavement temperature, ^0C

The SHRP binder specifications, methods of testing, and equipment used was discussed under I. SHRP Asphalt Binder Laboratory Tests and Equipment.

Mixture Equipment for SHRP Performance-Based Tests required the development of the following three new pieces of equipment:

SHRP Gyratory Compactor
SUPERPAVE Shear Tester
Indirect Tensile Creep and Strength Tester

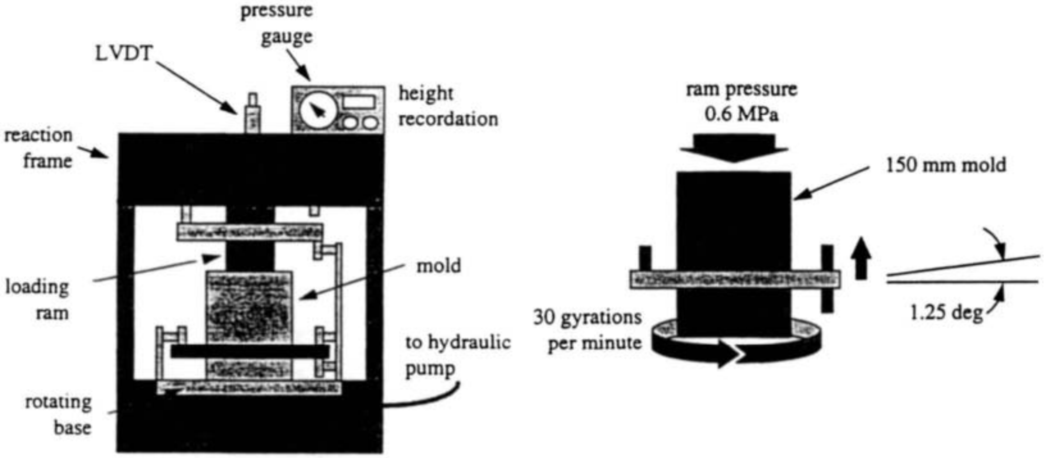
In the SUPERPAVE mixture design and analysis system, all specimens are prepared in the SHRP gyratory compactor. However, performance tests are used only for moderate (Level II) and high (Level III) traffic. Therefore, for the latter specimens, the SUPERPAVE shear tester and the indirect tensile creep and strength tester are required.

1. SHRP Gyratory Compactor (SGC) - realistically consolidates asphalt concrete specimens in a manner that simulates actual field compaction. The SGC ia an electrohydraulic device consisting of the following components:

a. Reaction frame, rotating base, and motor.

b. Hydraulic system, loading ram, and pressure gauge.
c. Height measurement and recordation system.
d. Mold and base plate.

Shown below is a schematic drawing of the gyratory compactor at the left and the mold configuration at the right



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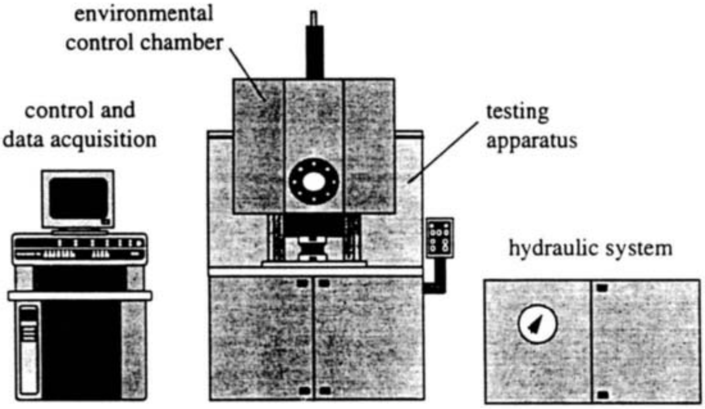
While in operation, the base of the SGC supports the mold, rotates, and is affixed to the loading frame. Reaction bearings are used to position the mold at an angle of 1.25 degrees. The 150 mm hydraulic loading ram imparts a pressure of 0.6 MPa to the specimen. During densification, the hydraulic system adjusts the position of the loading ram so that the compaction pressure remains constant. The nominal height of the mold is 250 mm.

2. <u>SUPERPAVE Shear Tester (SST)</u>- is designed to simulate the compression and shear forces that vehicle tires will impart to the pavement, when it is in operation. The SST is a very large and complex device that can perform the following six procedures: volumetric test, uniaxial strain test, repeated shear at constant stress ratio, repeated shear at constant height, simple shear at constant height, and frequency sweep at constant height. A schematic of the SST is shown below.



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By running a series of tests on mix specimens, the SST measures nonlinear viscous and elastic material behavior. This data is then entered into the SUPERPAVE software which yields information on how well the mix can be expected to resist permanent deformation, that is rutting, and fatique cracking in the field.

3. INDIRECT TENSILE CREEP and STRENGTH TESTER - predicts whether an asphalt concrete pavement will crack at low temperatures and the fatique properties of the mixture. A schematic of this piece of equipment is shown below.

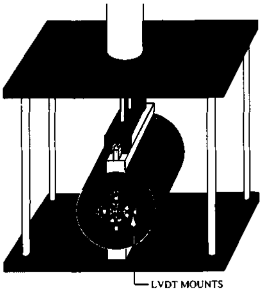
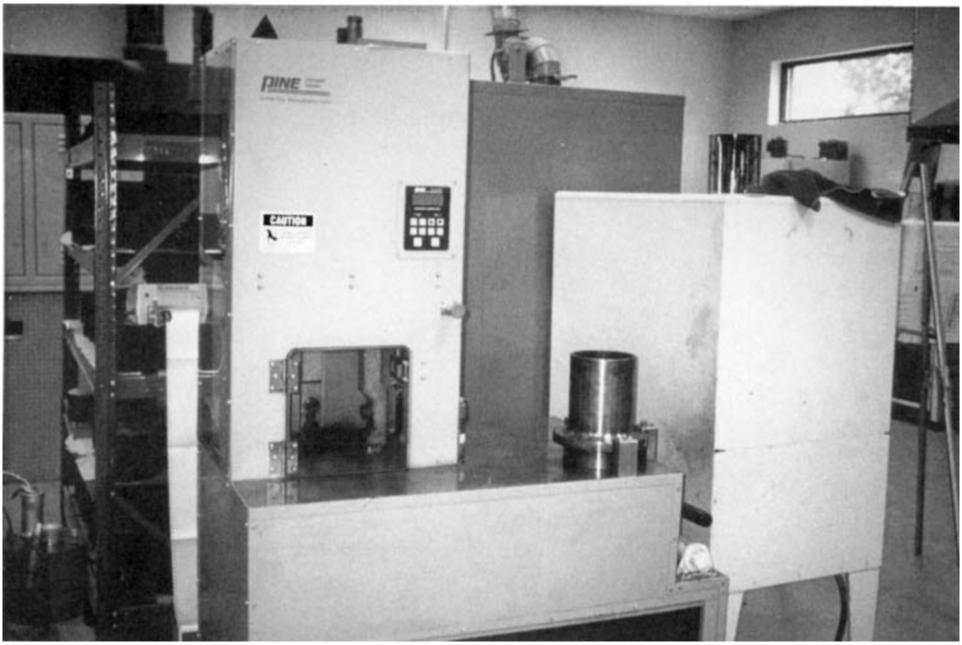


Photo Courtesy of the National Asphalt Paving Association

The hot mixed asphalt specimen is statically loaded on its edge, in much the same manner as in the Marshall test head. Deformation of the sample, at a constant load, is monitored for 1,000 seconds, then the sample is loaded to failure. The test data is then fed into the SUPERPAVE computer program.



SHRP Gyratory Compactor
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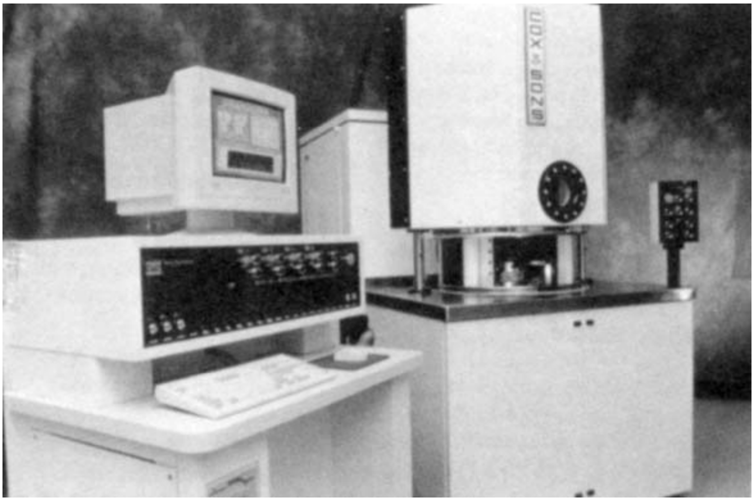

SUPERPAVE Shear tester
Figure 40 - Additional SUPERPAVE Testing Equipment.
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Understanding Asphalt Emulsions

Asphalt cement can be made fluid by one of three following methods:

1. Heating as in the case of hot mixed asphalts (HMA), which is currently the most common method for producing high quality mixtures.
2. By adding a petroleum solvent, such as naphtha or kerosene, to the asphalt cement, which then results in a cutback asphalt. Because of environmental concerns, the use of cutback asphalts has been severely curtailed.
3. When asphalt cement is broken up into minute particles and dispersed in water with an emulsifying agent it becomes an emulsion. The asphalt, in the form of tiny droplets, remain uniformly suspended until the emulsion is used, at which time the water evaporates. There is another type of emulsion called an inverted emulsion. It gets its name from the dispersion of water in asphalt cement which now becomes the continuous medium instead of water. However, inverted emulsions is not generally used and will not further be considered herein.

Types of Emulsions - there are three categories of emulsions based upon the electrical charges surrounding the asphalt cement particles: anionic, cationic, and nonionic. When an electric current is passed through an emulsion, the asphalt particles will move toward the anode (positively charged electrode), if it is negatively charged and hence it will be referred to as an anionic emulsion. Conversely an emulsion whose asphalt possesses positive charges will flow toward the cathode (negatively charged electrode) and be called a cationic emulsion. The asphalt in a nonionic emulsion is neither positively nor negatively charged. The procedure for testing the particle charge of emulsified asphalts is included in ASTM Designation D 244. A schematic of the setup to identify cationic emulsions is shown on the next page. It is performed by immersing two steel plates 2.54 cm (1 in.) 10.16 cm (4 in.), rigidly held 1.27 cm (0.5 in.) apart in a 150 or 250 ml. beaker. The emulsion is poured into the beaker until the electrodes are immersed 2.54 cm (1 in.). At least an 8 mA current is passed through the apparatus for one half hour or until the current drops to 2 mA, whichever occurs first. The apparatus is then disconnected, the electrodes are gently washed in running water, and an observation is made to determine on which electrode the asphalt deposited. A cationic emulsion will significantly coat the cathode while the anode will remain clean. Emulsions are further classified on how quickly they will break, that is the asphalt cement separates from the water. The terms RS, MS, and SS stands for rapid, medium, and slow setting emulsions. The letter "C" indicates a cationic emulsion while HF signifies High float for thicker coating.

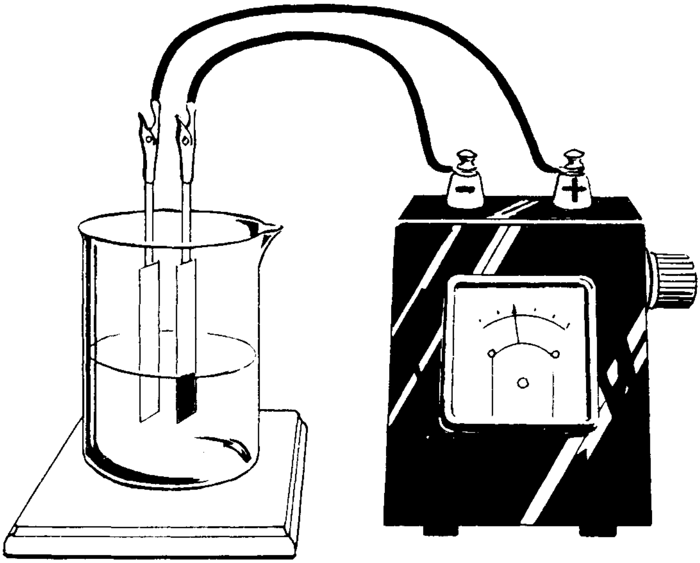

Figure 41 - Asphalt Emulsion Particle Charge Test.
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<u>Components of an Emulsion -</u> consists of asphalt cement, water, and an emulsifying agent. Many important properties of the emulsion is imparted by the emulsifying agent, such as the electical charge on the asphalt particles (whether it will be anionic or cationic), stability (how long can the emulsion be stored before breaking), and breaking time (whether the emulsion is an RS, MS, or SS). Anionic emulsifying agents are fatty acids from wood product derivatives such as lignin. Cationic emulsifyers are derived from fatty amines or fatty quarternary ammonium acids.

<u>How Emulsions are Produced -</u> a schematic diagram, showing a typical asphalt emulsion manufacturing facility is shown on the next page. Concurrent streams of heated asphalt cement and water, containing an emulsifying agent, are pumped into the colloid mill intake. The combined asphalt and water is subject to intense shear stresses as they pass through the colloid mill. The newly formed emulsion is then pumped through a heat exchanger that extracts the excess heat which is used to preheat the water before it is introduced into the colloid mell. The emulsion is then pumped into storage tanks with stirring devices to maintain the uniform product blend. The asphalt particles in an emulsion are of microscopic size and all contain a similar electrical charge which aids in dispersion. The following are the standard grades of emulsions:

EMULSIFIED ASPHALT	CATIONIC EMULSIFIED ASPHALT
RS-1	CRS-1
RS-2	CRS-2
MS-1	---
MS-2	CMS-2
MS-2h	CMS-2h
HFMS-1	---
HFMS-2	---
HFMS-2h	---
SS-1	CSS-1
SS-1h	CSS-1h

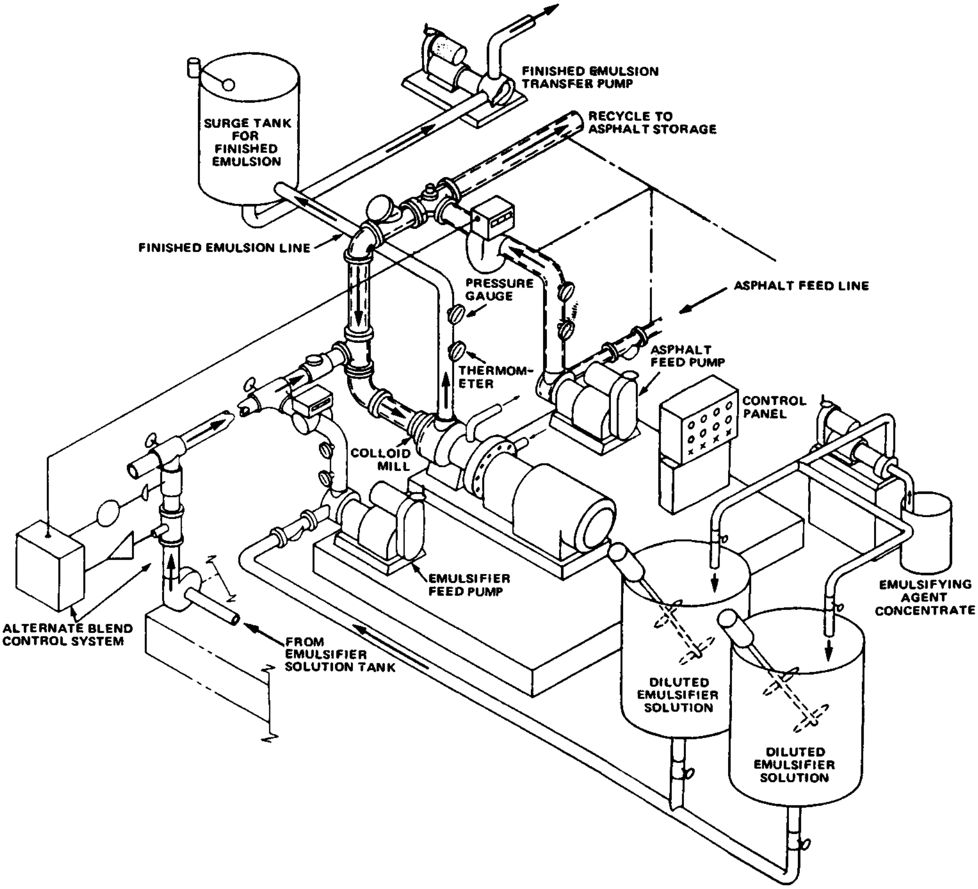

Figure 42 - Schematic of an Asphalt Emulsion Manufacturing Plant.
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Next Page

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ASPHALT MATERIALS AND MIX DESIGN MANUAL

by

Irving Kett

California State University, Los Angeles
Los Angeles, California

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Preface

The first part of my long career as a civil engineer was spent as a highway engineer in civilian life and as an officer in the U.S. Army Corps of Engineers. In all of these various activities, asphalt technology was an important part of my professional responsibilities. The subject of bituminous materials has always been of great interest to me and was the subject of my doctoral dissertation many years ago. At that time, I realized how invaluable a more thorough knowledge of organic chemistry would have been to me. I would certainly urge any aspiring young engineer entering into asphalt research to equip himself or herself in that vital discipline.

Over twenty-five years ago, I began developing an Asphalt Materials and Pavement Design Laboratory here at the California State University, where I had recently begun teaching. The Asphalt Institute and the local asphalt industry became increasingly aware of this facility. During this time, I constantly prepared laboratory materials for use in my classes. With the encouragement of Robert P. Humer, the District Engineer of the Asphalt Institute, I undertook to vastly expand my course materials into a total laboratory manual for asphalts comparable to those successfully used for many years in such fields as soil mechanics.

This Manual should effectively meet both academic and industrial requirements for learning and training in the asphalt field for the manual is broad enough to cover both needs. To the best of my knowledge, there is no similar reference in the asphalt field.

A section on the new SHRP technology has been included in the Appendix, as have sections on an understanding of asphalt emulsions, conversion factors between the U.S. Customary System of Measurements and the S.I. System, and a few other items that should prove useful both to the practitioner of asphalt technology and the student of this subject. Over the years, considerable effort was made in developing data sheets for specific tests. Additional copies of these data sheets are included in Appendix G.

While most of the text has been used by the author for many years, I will gratefully appreciate suggestions from those who use the Manual so that future editions may be improved and existing errors in the text corrected.

Los Angeles, California
January, 1998

Irving Kett

MIX DESIGN PROCEDURES

MARSHALL METHOD of MIX DESIGN

Reference - ASTM Designation: D 1559

A. Purpose: The basic concepts were formulated by Bruce Marshall of the Mississippi State Highway Department. Just prior to World War II, the U.S. Army Corps of Engineers improved and added certain features to his test procedure. These efforts resulted in the mix design criteria that were adopted by the American Society for Testing Materials in use today. The Marshall Method is applicable only to hot-mix asphalt paving mixtures using penetration grades of asphalt and containing dense or fine-graded aggregates with a maximum size of 25 mm (1-inch) or less. The Method is intended for the laboratory design of hot-mix asphalt paving mixtures. The Marshall Method of mix design consists of the following steps:

1. Preparation of test specimens.
2. Bulk specific gravity determination.
3. Stability and flow test.
4. Density and voids analysis.

B. Equipment and Materials: required for preparation of test specimens:

Pans, metal, flat bottom for heating aggregates.
Pans, metal, round, approximately 4-liters (4-qt.) capacity for mixing asphalt and aggregate.
Oven and Hot Plate, electric, for heating aggregates, asphalt, and equipment as required.
Scoops for batching aggregates.
Container, suitable for heating and pouring asphalt.
Thermometer, armored, glass, or dial-type with a metal stem, 10^0C (50^0F) to 232^0C (450^0F), for determining the temperature of aggregates, asphalt, and asphalt mixtures.
Balance, 5-kg capacity, sensitive to 1 gm for weighing aggregates and asphalt. Balance, 2-kg capacity, sensitive to 0.1 gm for weighing compacted specimens.
Mixing utensils.
Mechanical Mixer (optional), 4-liter (4-qt.) capacity or larger, equipped with two metal mixing bowls and two wire stirrers.
Constant Temperature Bath, 60^0C (140^0F) for specimens.
Compaction Pedestal for specimen preparation.
Compaction Mold, Hammer, and Mold Holder, conforming to the ASTM Designation D1559 for Marshall test apparatus. Extrusion Jack for removing the compacted specimens from the mold.
Gloves, suitable for handling hot equipment and specimens.
Gloves, rubber, for removing specimens from the Constant Temperature Bath.
Marking Crayons, for identifying the test specimens.
Kilogram of asphalt cement.

Aggregate Gradation: Use a Type 4C Mix with the following gradation (or any other dense graded aggregate mix):

Passing	Retained	Percent
25mm(1")	19mm(3/4")	10
19mm(3/4")	9.5mm(3/8")	20
9.5mm(3/8")	4.75mm(#4)	15
4.75mm(#4)	2.36mm(#8)	14
2.36mm(#8)	1.18mm(#16)	8
1.18mm(#16)	600μm(#30)	8
600 m(#30)	300μm(#50)	7
300 m(#50)	150μm(#100)	7
150 m(#100)	75μm(#200)	7
Mineral Filler - Limestone Dust or Portland Cement		4

C. Compaction Requirements: Depending upon the pavement design, the prescribed number of blows (35, 50, or 75) are administered.

D. Mixing and Compacting Temperatures: Reference should be made to the Temperature-Viscosity Chart, ASTM Designation D 2493, for the AC being used. The temperatures selected for both mixing and compaction should be those that allow the asphalt viscosities of (a) mixing, 170±20 centistokes; and (b) compacting, 280±30 centistokes. The aggregates must be dried to a constant weight and heated to between about 135^{0}C (275^{0}F) and 163^{0}C (325^{0}F). Asphalt cements should generally not be heated above 135^{0}C (275^{0}F). A good rule of thumb to follow is to heat the aggregates to approximately 28^{0}C (50^{0}F) above the required mixing temperature.

E. Specimens: Prepare five sets of compacted specimens, three per set, varying the AC content by 1/2%, between the prescribed limits. The latter depends upon the experience with the particular aggregate. Use a total weight of aggregates and AC per specimen equal to 1200 grams. Approximately 27kg (50lbs.) of aggregates and one gallon of asphalt cement is required for a test procedure.

F. Preparation of Test Specimens.
1. Equipment - molds, hammers, and other tools used in the preparation of the specimens should be clean and maintained at a temperature of 93^0 to 149^{0}C (200^{0}F to 300^{0}F).

2. Preparation - place the heated aggregates in a mixing bowl and form a crater in the middle. Add the desired amount of A.C. (asphalt cement) and mix quickly and thoroughly, preferably with a mechanical mixer.

3. Compaction of Specimens - the mold consists of a base plate, a forming section about 75mm (3")in height and 100mm (4") inside diameter, and an extension collar and a filter paper is placed on the bottom of the assembly. After the entire batch is placed in the mold, it should be spaded with a heated spatula 15 times

around the perimeter and 10 times over the interior. Place the mold assembly into the mold holder on the compaction pedestal. The hammer is removed from the hot plate, properly positioned and the prescribed number of blows delivered to the specimen. The number of blows, whether 35, 50, or 75 depends upon the pavement design (light, medium, or heavy duty). The mold is then removed from the holder, the specimen is inverted, the mold is reassembled, and the same number of compaction blows are administered to the reverse face of the specimen.

4. After compaction, the mold assembly is disassembled, and the specimen is allowed to cool until it is comfortable to the touch. It is then removed from the forming section by an extrusion jack, numbered with a yellow crayon or otherwise marked, placed on a flat surface, and allowed to cool.

G. Testing Procedure: each specimen is subject to the following tests and analysis in the following order:

1. Bulk Specific Gravity - the specimen is weighed first in air, then in water for the buoyant weight. The specimen is now towel-dried in order to obtain the saturated surface dry weight (SSD).

2. Stability and Flow Tests - the specimen is heated in a constant temperature water bath for 30 to 40 minutes at 60^0C (140^0F). It is then placed in a Marshall testing machine, where the load is applied by 2-100mm (4") diameter semicircular testing heads that move at a compressive rate of 50mm (2") per minute. The magnitude of the load (Marshall Stability) is determined by a calibrated proving ring and the flow (expressed in units of 0.0254mm or 0.001") is simultaneously measured with a dial gage held on the testing machine. Because of temperature sensitivity, the entire procedure should be completed in 30 seconds.

3. Density and voids analysis - upon completion of the stability and flow tests, a density and voids analysis is made on the previously tested, deformed specimens. The procedure is as follows:

   a. The average bulk specific gravity for each percent of asphalt used is determined. Values of individual test specimens that are obviously in error are not included in computing average values. The accepted average bulk specific gravity of specimens at each percent of asphalt is used for the several weight and volume determinations.
   b. The percent of absorbed asphalt is determined, using the measured specific gravity of the asphalt mixture, according to ASTM D 2041 (Rice's Method) and the bulk specific gravity of the aggregates. Calculate the effective specific gravity of the aggregates, absorbed asphalt as a percent by weight of the aggregates, percent air voids, and percent voids in the mineral aggregate (VMA). Estimate the optimum asphalt content and test two sets (three specimens in each set)

closest to this asphalt percent using the procedure in Rice's Method. Then compute the average value for the effective specific gravity of the aggregates in the mixture. Read and study carefully the section, EXPLANATION OF EFFECTIVE ASPHALT CONTENT DETERMINATION.

H. Preparation and Interpretation of Test Data:

1. Measured stability for specimens not 63mm (2 1/2") thick are converted to an equivalent 63mm (2 1/2") value by the conversion chart, shown on Table 2 and recorded on the appropriate form. Flow values as well as the adjusted stability values are averaged for each given asphalt content. Individual values that are obviously in error should be discarded.

2. Six graphs are prepared, plotting asphalt content against stability, flow, unit weight of total mix, air voids, percent voids in mineral aggregates (VMA), and percent voids filled with asphalt (VFA), as shown in illustrative Figure 28. The plotted values on each graph are connected with a smooth curve that results in a best fit.

3. The optimum asphalt content is determined as follows:
   a. Ascertain the asphalt content that corresponds to specification's median air voids. As shown on Table 3, this is normally 4 percent. Consider this the optimum asphalt content.
   b. Use a blank Figure 28 to plot the test data and determine the mixture properties at the optimum asphalt content for Marshall Stability, Flow, VMA, and VFA.
   c. Compare each of these values against the specification parameters shown on Table 3. If any of these values fall outside of the specification limits, the previously established optimum asphalt content is not valid, the asphalt mixture must be redesigned and the mix design process repeated.

I. Tables, Figures, and Forms on the next several pages show some of the apparatus, Stability Correlation, Marshall Mix Design criteria, and suitable data sheets for developing the test results.

J. Scheduling of Laboratory Sessions: It will normally require three laboratory periods to complete the basic Marshall Method of Mix Design. Additional sessions will be required if further testing of different aggregate gradations proves necessary. They are as follows:

1. Blending of aggregates for the five asphalt contents and 15 test specimens. A table indicating the quantities of each aggregate size, from coarse to mineral filler and asphalt cement, for each percent of asphalt should be prepared as a first step.

The aggregate compositions should be weighed out and kept in closed cans. Unless test runs are conducted to establish the correct weight to obtain 63mm (2 1/2") height of specimens, the total weights less AC should equal 1,200 grams. All weights should be to the nearest gram.

2. Compaction of the fifteen test specimens and determination of the Bulk Specific Gravity of each specimen.

3. Test all specimens for Marshall stability and flow; determine the Maximum Specific Gravity of the mixture G_{mm} by Rice's Method.

K: Explanation of Computations and Data Sheets:

1. Computations: before undertaking the mix design carefully study the section entitled, "Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures" - ASTM Designation D 2041. Then follow the sample computations on the accompanying data sheets. The final step is to complete the five graphs shown on Figure 28 and then to check the mix design results on Table 3. Table 2 is used with the data sheet on Rice Method Computation Sheet to correct the measured Marshall Stability when the specimen height is other than 2.5 inches or 63.5 mm. It is important to understand that the effective specific gravity, G_{se}, on Compacted Paving Mixtures Data Sheet does not change with the % of asphalt in the mix. What does change is the G_{mm} which is different for each % of asphalt even though it needs to be determined only for one % of asphalt in the Rice Method, ASTM D 2041. The G_{se} should be somewhere in between the bulk and apparent specific gravities of the aggregates which is why it is so important to determine all three of these specific gravities so accurately. Otherwise it will not be possible to determine the % air voids which is one of the most critical physical properties of any asphalt concrete mix design. Insufficient care in obtaining the proper amount of air voids is probably the single greatest cause of failure for asphalt concrete pavements.

2. Data Sheets: these are shown on pages 108 through 115. They should be completed in sequential order. The first sheet of each figure includes sample computations. The next is for use in the laboratory. Some of the data on the various forms, for example the specific gravities of the materials, on page 114, will be obtained early in the mix design process, while other elements part of the table will be required later. After all the data has been tabulated and computations finished, one of the last steps in determining the mixture with the optimum asphalt content, is the completion of Figure 28, the five graphs that contains the plot of percent of asphalt cement as the abscissa against the key physical properties of density, flow, voids total mix, voids mineral aggregate, and unit weight. The final design determination is made by reference to Table 3, the Marshall Design Criteria.

L. Summary of the Marshall Mix Design Method:

1. Preparation of the Marshall specimens.
2. Conduct the Marshall Stability and Flow Test on each specimen.
3. Compute the average Density and Voids for each percent of asphalt used in the testing procedure.
4. Tabulate and plot the test results.
5. Determine the optimum asphalt content in conformity with the required Marshall criteria.

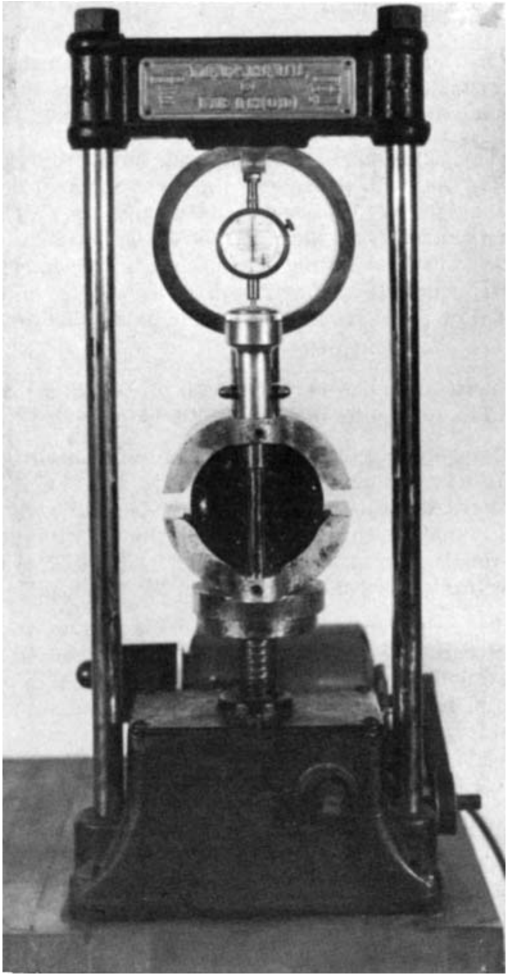

Figure 26 - Marshall Stability and Flow Test Apparatus.
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BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (D 1559)

Specimen Number	% AC by Wt. of Mix	Wt.in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4
1	4	1191	698	1199	501	2.377	
2	4	1197	701	1209	508	2.356	
3	4	1193	695	1200	505	2.362	
Average						2.365	147.58
1	4.5	1191	701	1193	492	2.421	
2	4.5	1203	708	1207	499	2.411	
3	4.5	1199	708	1203	495	2.422	
Average						2.418	150.88
1	5	1200	709	1204	495	2.424	
2	5	1193	708	1200	492	2.425	
3	5	1195	706	1199	493	2.424	
Average						2.424	151.26
1	5.5	1187	699	1189	490	2.422	
2	5.5	1199	707	1200	493	2.432	
3	5.5	1188	700	1190	490	2.424	
Average						2.426	151.37
1	6	1181	692	1182	490	2.410	
2	6	1184	696	1186	490	2.416	
3	6	1187	698	1190	492	2.413	
Average						2.413	150.56

Note: All weights measured in grams.

Bulk Specific Gravity and Density Computations.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (D 1559)

Speci-men Number	% AC by Wt. of Mix	Wt.in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

Bulk Specific Gravity and Density Computations.

MARSHALL METHOD STABILITY and FLOW
Data Sheet (ASTM D 1559)

Specimen Number	% AC by Wt. of Mix	Ht. of Specimen Inches	Marshall Stability Lbs.	Stability Corr. Ratios	Corrected Marshall Stability	Marshall Flow 0.01 Inches
1	4	2 1/2	1700	1.00	1700	12
2	4	2 7/16	2200	1.04	2288	11
3	4	2 7/16	2000	1.04	2080	10
Average					2023	11
1	4.5	2 7/16	2300	1.04	2392	11
2	4.5	2 7/16	2200	1.04	2288	13
3	4.5	2 7/16	2500	1.04	2600	13
Average					2427	12
1	5	2 7/16	2400	1.04	2496	17
2	5	2 7/16	2700	1.04	2808	14
3	5	2 3/8	2200	1.09	2398	15
Average					2567	15
1	5.5	2 7/16	2200	1.04	2288	17
2	5.5	2 3/8	1900	1.09	2071	15
3	5.5	2 3/8	2000	1.09	2180	17
Average					2180	16
1	6	2 3/8	1600	1.09	1744	19
2	6	2 3/8	1400	1.09	1526	21
3	6	2 3/8	1400	1.09	1526	17
Average					1599	19

Marshall Method Stability and Flow Record.

MARSHALL METHOD STABILITY and FLOW Data Sheet (ASTM D 1559)

Specimen Number	% AC by Wt. of Mix	Ht. of Specimen Inches	Marshall Stability Lbs.	Stability Corr. Ratios	Corrected Marshall Stability	Marshall Flow 0.01 Inches

Marshall Method Stability and Flow Record.

RICE METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt. of Bowl in Air	Wt. of Sample in Air (A)	Wt. of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C G_{mm}
5	781	108	673	92	258	404	269	2.50
5	618	108	510	92	398	306	204	2.50
5	803	108	695	92	510	418	277	2.51
						Average G_{mm} =		2.50

Note: All weights measured in grams.

Rice Method Computation Sheet.

RICE METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (ASTM D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C G_{mm}

Note: All weights measured in grams.

Rice Method Computation Sheet

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1559)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate	2.76	2.65	P_1	61.5	61.1	60.8	60.5	60.2
Fine Aggregate	2.82	2.70	P_2	30.7	30.6	30.4	30.2	30.1
Mineral Filler	3.12	N.A.	P_3	3.8	3.8	3.8	3.8	3.7
Total Aggregate	2.79	2.68	P_4	96.0	95.5	95.0	94.5	94.0
Asphalt Cement	1.01	N.A.	P_5	4.0	4.5	5.0	5.5	6.0
Bulk Sp.Gr.(G_{mb}),compacted mix,(ASTM D 2726)				2.36	2.42	2.42	2.43	2.41
Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1				2.68	2.68	2.68	2.68	2.68
Effective Sp.Gr.(G_{se}), total aggregates, Equation 2				2.71	2.71	2.71	2.71	2.71
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3				2.54	2.52	2.50	2.48	2.46
Absorbed Asphalt (P_{ba}),% by wt. of aggregates, Equation 4				0.42	0.42	0.42	0.42	0.42
Effective Asphalt Content(P_{be})% by wt.of total mix, Equation 5				3.60	4.10	4.60	5.10	5.61
Percent Voids Mineral Aggregate (VMA), Equation 6				15.46	13.76	14.22	14.32	15.47
% Air Voids (P_a), Equation 8				7.09	3.97	3.20	2.02	2.03
Percent Voids Filled with Asphalt (VFA), Equation 9				54.1	71.1	77.5	85.9	86.9

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Marshall Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1559)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate			P_1					
Fine Aggregate			P_2					
Mineral Filler			P_3					
Total Aggregate			P_4					
Asphalt Cement			P_5					
Bulk Sp.Gr.(G_{mb}),compacted mix,(ASTM D 2726)								
Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1								
Effective Sp.Gr.(G_{se}), total aggregates, Equation 2								
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3								
Absorbed Asphalt (P_{ba}),% by wt. of aggregates, Equation 4								
Effective Asphalt Content(P_{be})% by wt.of total mix, Equation 5								
Percent Voids Mineral Aggregate (VMA), Equation 6								
% Air Voids (P_a), Equation 8								
% Voids Filled with Asphalt (VFA), Equation 9								

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Marshall Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

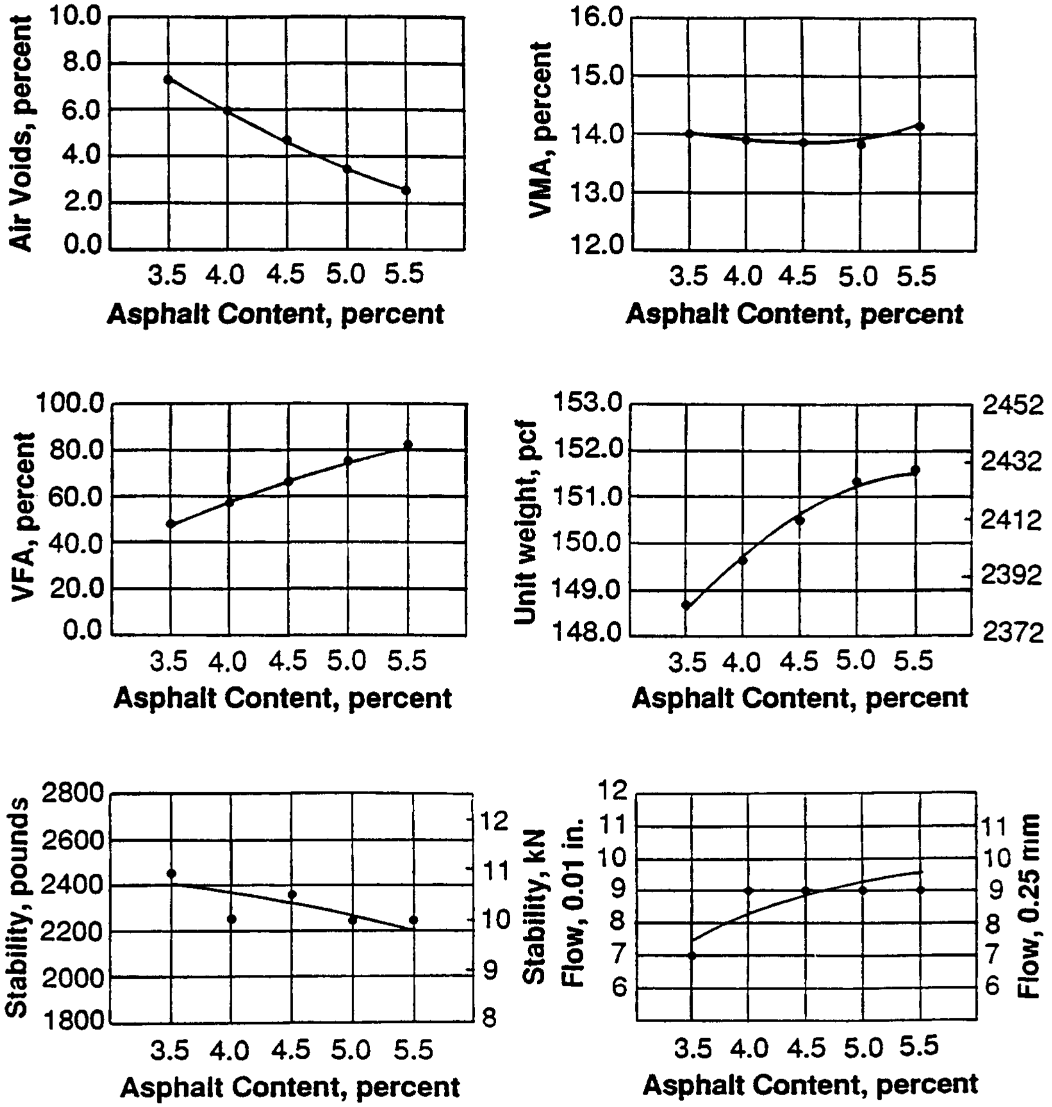

Figure 27 - Typical Test Property Curves for a Hot Mix Asphalt Paving Mixture by the Marshall Method: Six Graphs.

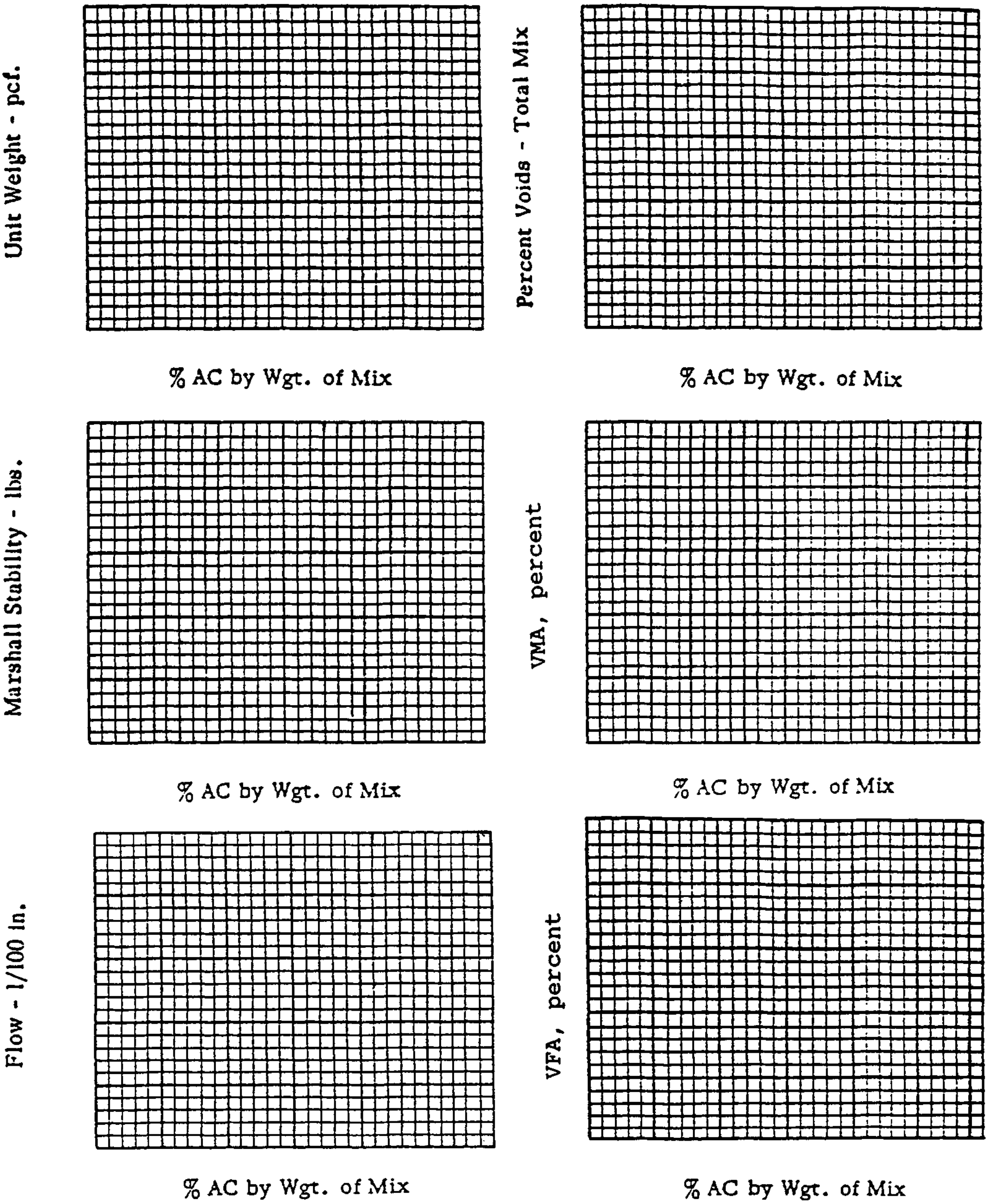

Figure 28 - Test Property Curves for a Hot Mix Asphalt Paving Mixture by the Marshall Method: Six Graphs.

Volume of Specimen, cm^3	Approximate Thickness of Specimen,		Correlation Ratio
	mm	in.	
200 to 213	25.4	1	5.56
214 to 225	27.0	1 1/16	5.00
226 to 237	28.6	1 1/8	4.55
238 to 250	30.2	1 3/16	4.17
251 to 264	31.8	1 1/4	3.85
265 to 276	33.3	1 5/16	3.57
277 to 289	34.9	1 3/8	3.33
290 to 301	36.5	1 7/16	3.03
302 to 316	38.1	1 1/2	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 3/4	1.92
368 to 379	46.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/16	1.39
432 to 443	54.0	2 1/8	1.32
444 to 456	55.6	2 3/16	1.25
457 to 470	57.2	2 1/4	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 1/2	1.00
523 to 535	64.0	2 9/16	0.96
536 to 546	65.1	2 5/8	0.93
547 to 559	66.7	2 11/16	0.89
560 to 573	68.3	2 3/4	0.86
574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78
611 to 625	76.2	3	0.76

NOTES:

1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5 mm (2 1/2-in.) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

Table 2 - Marshall Stability Correlation Ratios.

Marshall Method Mix Criteria [1]	Light Traffic Surface & Base Min	Light Traffic Surface & Base Max	Medium Traffic Surface & Base Min	Medium Traffic Surface & Base Max	Heavy Traffic Surface & Base Min	Heavy Traffic Surface & Base Max
Compaction, number of blows each end of specimen	35		50		75	
Stability, N (lb.)	3336 (750)	—	5338 (1200)	—	8006 (1800)	—
Flow, 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)			*See Table*			
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

NOTES

1. All criteria, not just stability value alone, must be considered in designing an asphalt paving mix. Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
2. Traffic classifications
    - Light Traffic conditions resulting in a Design EAL $<10^4$
    - Medium Traffic conditions resulting in a Design EAL between 10^4 and 10^6
    - Heavy Traffic conditions resulting in a Design EAL $>10^6$
3. Laboratory compaction efforts should closely approach the maximum density obtained in the pavement under traffic.
4. The flow value refers to the point where the load begins to decrease.
5. The portion of asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent air voids.
6. Percent voids in the mineral aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregate.

Minimum percent voids in mineral aggregate (VMA)

Nominal Maximum Particle Size[1, 2]		Minimum VMA, percent		
		Design Air Voids, Percent[3]		
mm	in.	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	3/8	14.0	15.0	16.0
12.5	1/2	13.0	14.0	15.0
19.0	3/4	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

1 - Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M92)

2 - The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.

3 - Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

Table 3 - Marshall Design Criteria and VMA.

HVEEM METHOD OF MIX DESIGN

Reference - ASTM Designations: D 1560 and D 1561

A. Purpose: The basic concepts were developed under the direction of Francis N. Hveem, when he was the Materials and Research Engineer of the California Highway Department, now known as CALTRANS. The Method is applicable to paving mixtures, using both asphalt cements and liquid asphalts and containing aggregates up to 25mm (1 inch) in size. It is principally used for the laboratory design of dense graded asphalt paving mixtures. Density and voids of the compacted specimens are established before determining the internal friction with a device called a stabilometer. In the stabilometer test vertical loads are applied and the resultant lateral pressures are measured. In effect the Hveem stabilometer is a modified triaxial cell, commonly used in soil mechanics.
The salient features of the Hveem Method are as follows:

1. Centrifuge Kerosene Equivalent (CKE) test.
2. Preparation of test specemens using the kneading compactor.
3. Stabilometer test.
4. Swell test.
5. Density and Voids analysis.

B. Aggregate Gradation: the aggregates must be oven dried, segragated into the proper sizes, and blended to meet project specifications. The gradation recommended for use in this laboratory procedure is the same as for the Marshall Method, shown on page 103. Coarse aggregates are defined as that retained on the 4.75mm (No.4) sieze, fine aggregates are that portion passing the 4.75mm (No.4) and retained on the 75μm (No.200) sieze, while mineral filler is that fraction passing the 75μm (No.200) and usually consists of limestone dust or Portland cement. These definitions are the same as for the Marshall Method.

C. Equipment - required at various stages in the test procedure:

1. Centriguge Kerosene Equivalent Test.
    a. Small Splitter for obtaining representative samples of fine aggregates.
    b. Pans, 113mm (4 1/2") diameter x 25mm (1") deep.
    c. 3.9 liters (1 gallon) of Kerosene.
    d. 3.9 liters (1 gallon) of SAE, No.10, lubricating oil.
    e. Two 1-1/2 liter beakers.
    f. 2-90mm (3 1/2") top diameter metal funnels by 113mm (4 1/2") high with a piece of 2mm (No.10) sieve soldered to the bottom of the opening.

g. Timer.
h. Centrifuge capable of producing 400 times gravity, either hand operated or power driven.
i. Filter papers of use at the bottom of the centrifuge cups.

2. Preparation of the test specimens.
    a. Various size pans, 200 to 300mm (8 to 12 inches) in diameter and about 50mm (2 inches) in depth.
    b. Large Splitter for quartering aggregates.
    c. Electric Hot Plate for heating molds, pans, and miscellaneous equipment, as required.
    d. 3 Large Ovens, capable of adjusting to temperatures of from 60^0 to 163^0C (140^0 to 325^0F).
    e. Scoops, spoons, pointed mixing trowel, heavy heat resistant gloves, and other small miscellaneous hand tools.
    f. 1 quart asphalt beaker.
    g. Armored Thermometers, with a 38^0 to 204^0C (100^0 to 400^0F) range.
    h. Kneading Compactor and accessories which include two mold holders, a feeding trough, a paddle shaped to fit the trough, and a 9.5mm (3/8") bullet-nosed rod 400mm (16") long.
    i. Steel Compaction Molds, 100mm (4") inside diameter, 5 inches high, and 6.3mm (1/4") wall thickness.
    j. Heavy Paper Disks, 98.7mm (3 15/16") in diameter, to place at the bottom of the mold during compaction.
    k. 25 ton Hydraulic Compaction Machine.

3. Testing of the 100mm (4") diameter specimens.

    a. Perforated Bronze Disks, 97.4mm (3 7/8") in diameter, with an adjustable stem for swell measurement.
    b. Dial Gages, mounted on a tripod, with a reading accuracy to 0.0254mm (0.001").
    c. Suitable scale to measure the height of compacted specimens and for water percolation during the swell test.
    d. Aluminum Pans, 190mm (7 1/2") in diameter by 63mm (2 1/2") inches high.
    e. Hveem Stabilometer, including an adjustable base, assembly tool, steel follower, and a rubber bulb for introducing air into the Stabilometer.

D. Centrifuge Kerosene Equivalent (CKE) Test: This is the first step in the Hveem Method of mix design. It uses the surface area theory to select an asphalt content as a starting point in the test series. The surface area of the aggregates in a mixture is determined by multiplying the percentages of material, passing a given set of sieves by a set of surface area factors, and then adding the respective products. Table 4 below shows how the surface area is determined for a specific aggregate mix design. In the diagrams that follow the surface area in m^2/kg (ft^2/lb) is used on the various charts, Chart Numbers 1 through 5.

Total Percent Passing Sieve No.	Maximum Size	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	600 µm (No. 30)	300 µm (No. 50)	150 µm (No. 100)	75 µm (No. 200)
Surface-Area Factor,* m^2/kg ($ft^2/lb.$)	.41 (2)	.41 (2)	.82 (4)	1.64 (8)	2.87 (14)	6.14 (30)	12.29 (60)	32.77 (160)

*Surface area factors shown are applicable only when all the above-listed sieves are used in the sieve analysis.

The following tabulation demonstrates the calculation of surface area by this method.

Sieve Size	Percent Passing	x	S.A. Factor	=	Surface Area
19.0 mm (3/4 in.)	100		.41 (2)		.41 (2)
9.5 mm (3/8 in.)	90				
4.75 mm (No. 4)	75		.41 (2)		.31 (1.5)
2.36 mm (No. 8)	60		.82 (4)		.49 (2.4)
1.18 mm (No. 16)	45		1.64 (8)		.74 (3.6)
600 µm (No. 30)	35		2.87 (14)		1.00 (4.9)
300 µm (No. 50)	25		6.14 (30)		1.54 (7.5)
150 µm (No. 100)	18		12.29 (60)		2.21 (10.8)
75 µm (No. 200)	10		32.77 (160)		3.28 (16.0)

Surface Area 9.98 m^2/kg
(48.7 ft^2/lb)

Table 4 - Surface Area Factors and Sample Tabulation of Computations.
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The CKE method is performed as follows:

1. 100 gram samples of fine aggregates, passing the 4.75mm (No.4) sieve, are placed in two centrifuge cups that are fitted with screens and filter paper.
2. The cups are placed in a kerosene bath until the aggregates become saturated and are then centrifuged for 2 minutes at a force of 400 G.
3. The amount of kerosene retained is determined, by the difference in the weight of the cups before and after centrifuging. This value, expressed as a percentage of the dry aggregate weight (100 grams) is called the CKE.
4. 100 gram samples of dry aggregates, passing the 9.5mm (3/8") sieve and retained on the 4.75mm (No.4) sieve are placed in two glass funnels.
5. The funnels are then placed in beakers, containing No.10 lubrication, at room temperature for 5 minutes. Afterwards they are removed from the beakers and allowed to drain in an 60^{0}C (140^{0}F) oven for 15 minutes.
6. The amount of oil retained by the aggregate is determined and again expressed as a percent of the dry aggregate weight.
7. The surface constant, K_f, is determined from Chart No. 1 by using the corrected CKE.
8. The surface constant, K_c, is determined from Chart No. 2 by using the corrected % oil retained.
9. The value K_m is determined from K_f and K_c by reference to Chart No. 3.
10. The estimated asphalt content of a mix, based upon a liquid asphalt is obtained from Chart No. 4.
11. The asphalt cement content of the mixture is determined for a penetration grade of asphalt by using Chart No.5.

E. Preparation of Test Specimens: A series of stabilometer test specimens is prepared with the amount of asphalt determined by the CKE procedure, two above and two below the CKE amount in 0.5 percent increments and one at the CKE percent, for a total of five specimens, at 1200 grams, each with a different asphalt content. Two additional specimens are prepared at the CKE asphalt percent for the swell test, each weighing 1000 grams. A mechanical kneading compactor is the principal piece of equipment. After the batches have been mixed, they are placed in flat pans and oven cured for 15 hours at 60^{0}C (140^{0}F). Just prior to compaction the batches are reheated to 110^{0}C (230^{0}F) for one hour. The specimens are compacted by a series of individual loadings by a shaped tamper foot which is capable of exerting a pressure of 500 psi and maintaining it for 0.4 seconds. The compaction procedure is as follows:

1. Preheat the compaction molds to about 110^{0}C (230^{0}F) and heat the tamper foot to a temperature that will prevent the mix from adhering to it. The latter can be controlled by a transformer

that is part of the kneading compactor.

2. Place the the compaction mold in position in the mold holder, with a 100mm (4") paper disk over the base plate.
3. Spread the prepare mixture uniformly in the feeder trough and with the specially shaped paddle, move half of the mixture into the compaction mold.
4. Rod the mix in the mold with the 9.5mm (3/8") bullet-nosed rod, 20 times in the center and 20 times around the perimeter.
5. Place the mold assembly into position on the kneading compactor and place a 6.3mm (1/4") shim under the edge of the mold so the base plate can act as a free-fitting plunger.
6. Apply approximately 20 blows at 1,723 kPa (250 psi) pressure. The number of blows may vary with the material to accomplish the semi-compaction.
7. Remove the shim and release the mold tightening screw, to allow free up and down movement of the mold.
8. Compaction of the specimen is completed after an additional 150 tamping blows at 500 psi pressure.
9. The mold and specimen are placed in an oven at 60^{0}C (140^{0}F) for 11/2 hours and then a leveling load of 6,895 kPa (1,000 psi) is applied and immediately released.
10. The compaction procedure for the two swell test specimens are the same as above with the following exceptions:
    a. The compaction molds are lined with a 16mm (3/4") wide strip of wrapping paper that has been hot dipped in paraffin. It is placed approximately 12.5mm (1/2") from the bottom of the mold while the paraffin is still hot. The purpose of paraffin impregnated strip is to prevent water from escaping between the mold and the specimen during the water immersion period of the test.
    b. The molds are not preheated prior to inserting the asphalt mixture.
    c. When the compaction is complete, the mold and specimen are removed from the compactor and immediately leveled with a 6,895 kPa (1,000 psi) static load. However, before this load is applied, the specimen is inverted and the specimen is pushed to the opposite end of the mold, again at a speed of 6.3mm (0.25") inches per minute. The original top surface of the specimen is now at the bottom.

F. Test Procedures: The compacted specimens are tested in the following order:

1. Swell Test - the specimens are allowed to stand at room temperature for one hour, after compaction is complete. The molds and specimens are placed in pans, with a perforated bronze disk on each specimen. The stem is adjusted to read 0.0254mm (0.001") on the dial gauge. 500cc of water is poured inside the mold on top of the specimen and measure the distance from the top of the mold to the top of the water. The dial gauge is read after 24 hours to the nearest 0.001 inch and the distance to the water surface is again measured. The difference in water levels is

recorded as permeability.

2. Stabilometer Test - place the specimens in a 60^{0}C (140^{0}F) oven for at least one hour prior to testing. Prior to testing the Hveem Stabilometer must be checked and adjusted. The speed of the compression machine head must be set at 1.3mm (0.05") per minute. Adjust the stabilometer base so that the distance from the bottom of the upper tapered ring to the top of the base is 90mm (3 1/2"). During the fabrication process every effort should have been made to assure that the overall height of the specimens are between 61 to 66mm (2.40 to 2.60") in height. However, if the height of any specimen is outside this range, the stabilometer values must be adjusted to the figure shown on the chart for correcting the stabilometer values to specimen height of 63mm (2.50"). The mold and the specimen is removed from the oven, a paper disk is placed on the specimen, and using a plunger, the specimen is forced from the mold into the stabilometer. With the entire assembly in the testing machine, the piston is placed on the specimen. The horizontal pressure in the stabilometer is set at 34 kPa (5 psi), using the displacement pump. Test loads of 2,224 N (500 lb), 4,448 N (1,000 lb), and every 4,448 N (1,000 lb) up to 26,688 N (6,000 lb) is applied with the compression machine. Readings of the lateral pressure are recorded for each of the seven vertical loads. However, do not permit the horizontal pressure to exceed about 1,103 kPa (160 psi). Once that pressure is reached, stop all further increments of vertical load because it may damage the stabilometer. When 26,688 N (6,000 lb) of load is reached, reduce the vertical load to 4,448 N (1,000 lb) and adjust the horizontal pressure in the stabilometer again to exactly 34 kPa (5 psi). Do not pay any attention to the drop off in vertical load. Adjust the dial gauge on the pump to zero by means of the small thumbscrew. Record the number of turns required to reach 690 kPa (100 psi) at a rate of 2 turns per second. This value to the nearest tenth of a turn is the value D_2 in the stabilometer value equation.

3. Bulk Density Determination - This is determined after the stabilometer tests are completed and on the same specimens. The conduct of the tests is the same as in the Marshall Method and ASTM Designation D 1188. A density and voids analysis is made using bulk density and the apparent specific gravity of the aggregate and the asphalt. The unit weight and percent air voids are also calculated.

G. Interpretation of Test Results: There are no calculations required for the swell test since the results are reported directly as differences. The stabilometer value, S, is calculated:

$$S = \frac{22.2}{\frac{P_h D_2}{P_v - P_h} + 0.222}$$ where

S = relative stability. D_2 = displacement on specimen.
P_v = vertical pressure at 2,758 kPa (400 psi), 22,240 N (5,000 lb) total load).
P_h = horizontal pressure corresponding to P_v = 22,240 N (400 psi).

H. Design Criteria: The suitability of the mix design by the Hveem Method is determined on the basis of whether the asphalt content and gradation will satisfy the requirements shown in the figure of Hveem Design Criteria. The optimum asphalt content for the design mix should be the highest asphalt content that the mix will accommodate without reducing stability or void content below acceptable minimum values. This is determined from stabilometer values, and percent air voids. After plotting three graphs of three properties against % AC by weight of aggregates (abscissa), the following steps are employed to select the optimum asphalt content:

1. From the five stabilometer specimens tested, select the three highest asphalt contents that do not exhibit any significant (slight) flushing. Another name for flushing is bleeding, either moderate or heavy flushing. Surface flushing considered slight possesses a light sheen; in the case of moderate flushing, paper will adhere to the surface; where heavy flushing is evident, surface puddling or specimen distortion after compaction exists.
2. From the above three asphalt contents, select the two highest asphalt contents that provide the specified minimum stabilometer values.
3. Of the two asphalt contents selected above, specify the highest asphalt content that includes at least 4% air voids.
4. The asphalt content found in Step 3 is the optimum asphalt content of the mix unless the highest asphalt content in the entire mix design series equals that percent AC. In that event an additional specimen must be prepared with an increased asphalt content of 0.5% used. In other words this specimen will have an AC content of 1.5% above the estimated optimum obtained from the CKE procedure. A new optimum asphalt determination will then be made from the results of the six specimens.

I. Photographs of various key pieces of apparatus, Diagrams, Tables, Figures, Data Sheets for developing the test results, Chart for Correcting Stability Values, and the Hveem Design Criteria are shown on the next pages.

J. Scheduling of Laboratory Sessions: It will normally require four laboratory periods to complete the basic Hveem Method of Mix Design. Additional sessions will be required if further testing of different aggregate gradations proves necessary. They are as follows:

1. Estimated Optimum AC by the CKE Method, computation of the resultant mix designs, and the composition for five 1,200 gram stabilometer specimens and two 1,000 gram swell test specimens.
2. Preparation of 7 hot mix asphalt mixes, left in curing pans.
3. Preparation of the five stabilometer and two swell test specimens with the kneading compactor and setting up the latter specimens in the swell test apparatus. Swell test readings should be taken the next day.
4. Determination of the stabilometer values, bulk specific gravity of the five specimens and the Maximum Specific Gravity of the mixture (G_{mm}) by ASTM D 2041 (Rice's Method). Dismantling of the swell test apparatus and discarding of the specimens.

K. Explanation of Computations and Data Sheets:

1. Computations: the first operation in the Hveem Method is the determination of the Optimum Asphalt Content which is covered in Chart Nos. 1 through 5. At this point seven Hveem specimens are prepared in the kneading compactor and tested for swell and stability. Place the two swell test specimens in the apparatus shown in Figure 32. Wait 24 hours and again read the dial gauges. Record the changes as swell to the nearest 0.025 mm (0.001") on the table, Compacted Paving Mixture Analysis Worksheet, page 146. Also measure the distance from the top of the mold to the water surface and record the change as permeability which is the amount of water in milimeters that percolated into and through the test specimen. No computations are required for this data. After testing the five specimens in the stabilometer, the bulk specific gravity and density is determined. Note that the Compacted Paving Mixture Analysis Worksheet on pages 146 and 147 are the same as for the Marshall Method on pages 114 and 115. At this point make use of the three specimens with the middle percentages of asphalt cement to determine the G_{mm} by the Rice Method, ASTM D 2041. As discussed in paragraph K. in the explanation for the Marshall Method, the objective is to accurately determine the G_{se}. The form for the Rice Method on pages 142 and 143 are the same as on pages 112 and 113 for the Marshall Method. The G_{se} is the same for all percentages of asphalt as long as the quantity is sufficient to fill all of the asphalt permeable voids. If the G_{se} is not almost identical for the three specimens tested by the Rice Method, use the remaining two specimens for this purpose. Again it cannot be too strongly emphasized how important it is to determine the effective specific gravity, G_{se}, with a very high degree of accuracy. Otherwise, it will not be possible to compute the % air voids which is one of the most critical physical properties of any asphalt concrete mix design.
2. Data Sheets: these are shown on pages 130 and 141 through 149. They should be completed in sequential order. The first sheet of each data sheet or graph includes sample computations or typical property curves. Some of the data will be obtained early in the mix design process while other elements of the table will be

needed later. After all the data has been tabulated and computations finished, one of the final steps in determining the optimum asphalt mixture is the completion of the three graphs on Figure 35. The final design determination is made by reference to Table No. 5, and Figure Nos. 37, and 38.

L. Summary of the Hveem Mix Design Method:

1. Centrifuge Kerosene Equivalent (CKE) for aggregates passing the 4.75mm (No. 4) sieve.
2. Surface capacity of coarse aggregate, all materials retained on the 4.75mm (No. 4) sieve.
3. Estimated optimum asphalt content.
4. Preparation of stabilometer and swell test specimens.
5. Swell and permeability tests.
6. Hveem stabilometer test.
7. Density and voids analysis.
8. Tabulate and plot the test results.
9. Analysis of test results.
10. Determine the optimum asphalt content in conformity with the required Hveem design criteria.

Figure 29 - Apparatus for the Hveem CKE Test
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DETERMINATION of OPTIMUM ASPHALT CONTENT by C.K.E. PROCEDURE
(ASTM D 1560 and D 1561)

1. Surface Area of Aggregates:

Sieve No.	% Passing	S.A. Constant	Surface Area
3/8 inch & above	100	2	2.00
4	50	2	1.00
8	36	4	1.44
16	28	8	2.24
30	20	14	2.80
50	12	30	3.60
100	8	60	4.80
200	4	160	6.40

Total S.A.: 24.3 ft.^{2}/lb.

2. Specific Gravity of Aggregates:

Fine (passing No. 4 Sieve), not including M.F.	2.70
Coarse (retained on No. 4)	2.65
Weighted Average of Fine and Coarse Aggregates	2.67

3. % Fine Aggregate 47.9 ; % Coarse Aggregate 52.1 .

4. C.K.E. of 2 Fine Aggregates Specimens: 5.6 5.7
Average C.K.E., corrected for Specific Gravity: 5.6

5. % Oil Retained of 2 Coarse Aggregate Specimens: 1.9 1.9
Average % Oil Retained, corrected for Specific Gravity: 1.9

6. Determination of Optimum Asphalt Content:

Type of Asphalt and Absolute Viscosity: AC 10, 4,000

K_f: 1.70 K_c: 0.85 K_m: 1.35 Oil Ratio: 4.9

Optimum % AC by Weight of Aggregates: 6.0

Optimum % AC by Weight of Total Mix: 5.7

Computation of Optimum Asphalt Content.

DETERMINATION of OPTIMUM ASPHALT CONTENT by C.K.E. PROCEDURE

(ASTM D 1560 and 1561)

1. Surface Area of Aggregates:

Sieve No.	% Passing	S.A. Constant	Surface Area
3/8 inch & above	100	(0.41) 2	(0.41) 2
4		(0.41) 2	
8		(0.82) 4	
16		(1.64) 8	
30		(2.87) 14	
50		(6.14) 30	
100		(12.29) 60	
200		(32.77) 160	

Total S.A.: _____ ft.^{2}/lb.
Surface Area: S.I. System in Brackets _____ (m^2/kg.)

2. Bulk Specific Gravity of Aggregates:

Fine (passing No. 4 Sieve), not including M.F. ______
Coarse (retained on No. 4) ______
Weighted Average of Fine and Coarse Aggregates ______

3. % Fine Aggregate _____ ; % Coarse Aggregate _____ .

4. C.K.E. of 2 Fine Aggregates Specimens: _____ ______
Average C.K.E., corrected for Specific Gravity: ______

5. % Oil Retained of 2 Coarse Aggregate Specimens: ______ _____
Average % Oil Retained, corrected for Specific Gravity: _____

6. Determination of Optimum Asphalt Content:

Type of Asphalt and Aged Residue Viscosity: ______________

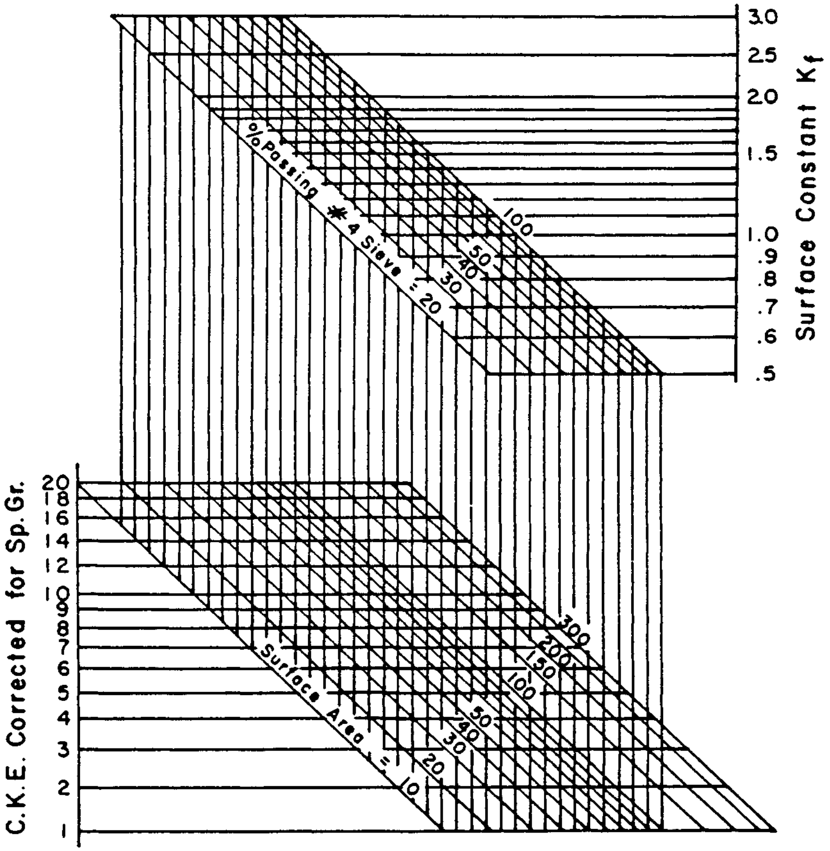
K_f: _____ K_c: _____ K_m: _____ Oil Ratio: _____

Optimum % AC by weight of Aggregates: _____

Optimum % AC by Weight of Total Mix: _____

Computation of Optimum Asphalt Content.

CHART FOR DETERMINING K_f FROM C.K.E.



$$\text{C.K.E. Corrected} = \text{C.K.E.} \times \frac{\text{sp. gr. fine}}{2.65}$$

NOTE: Do not confuse this correction to C.K.E. with that used in Fig. 4

Chart No.1 - Estimating the Optimum Asphalt Content.
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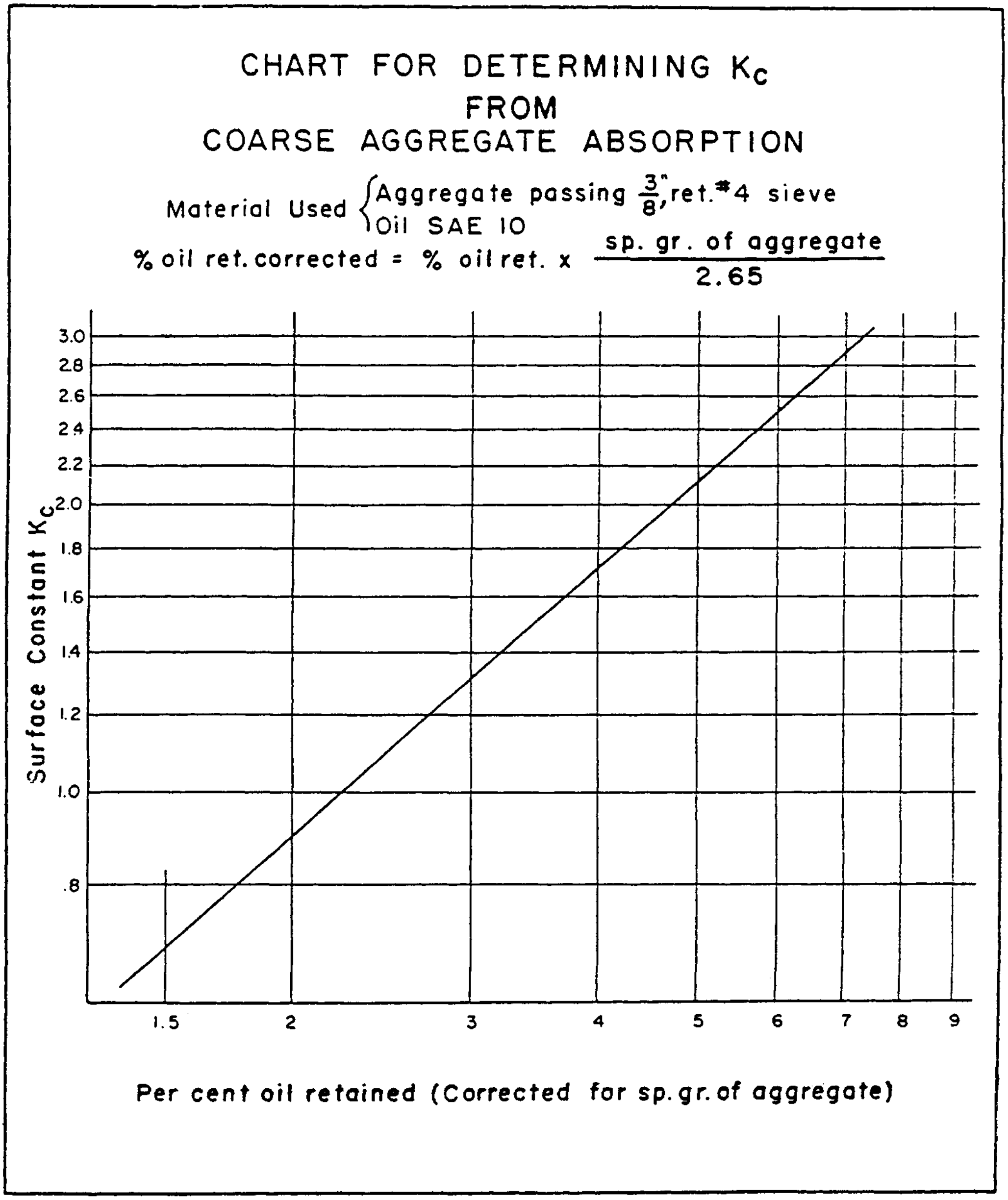

Chart No.2 - Determining the Estimated Optimum Asphalt Content.
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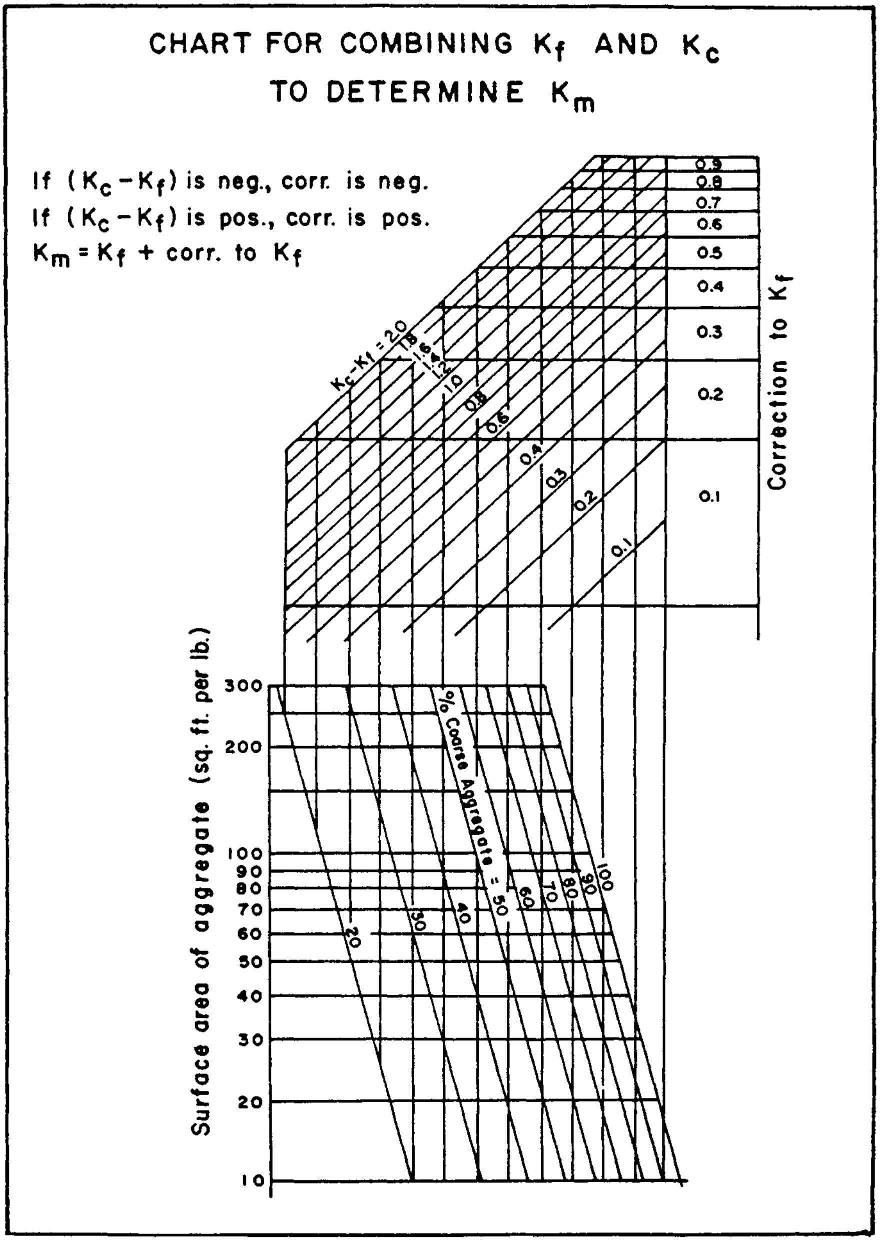

Chart No.3 - Determining the Estimated Optimum Asphalt Content.
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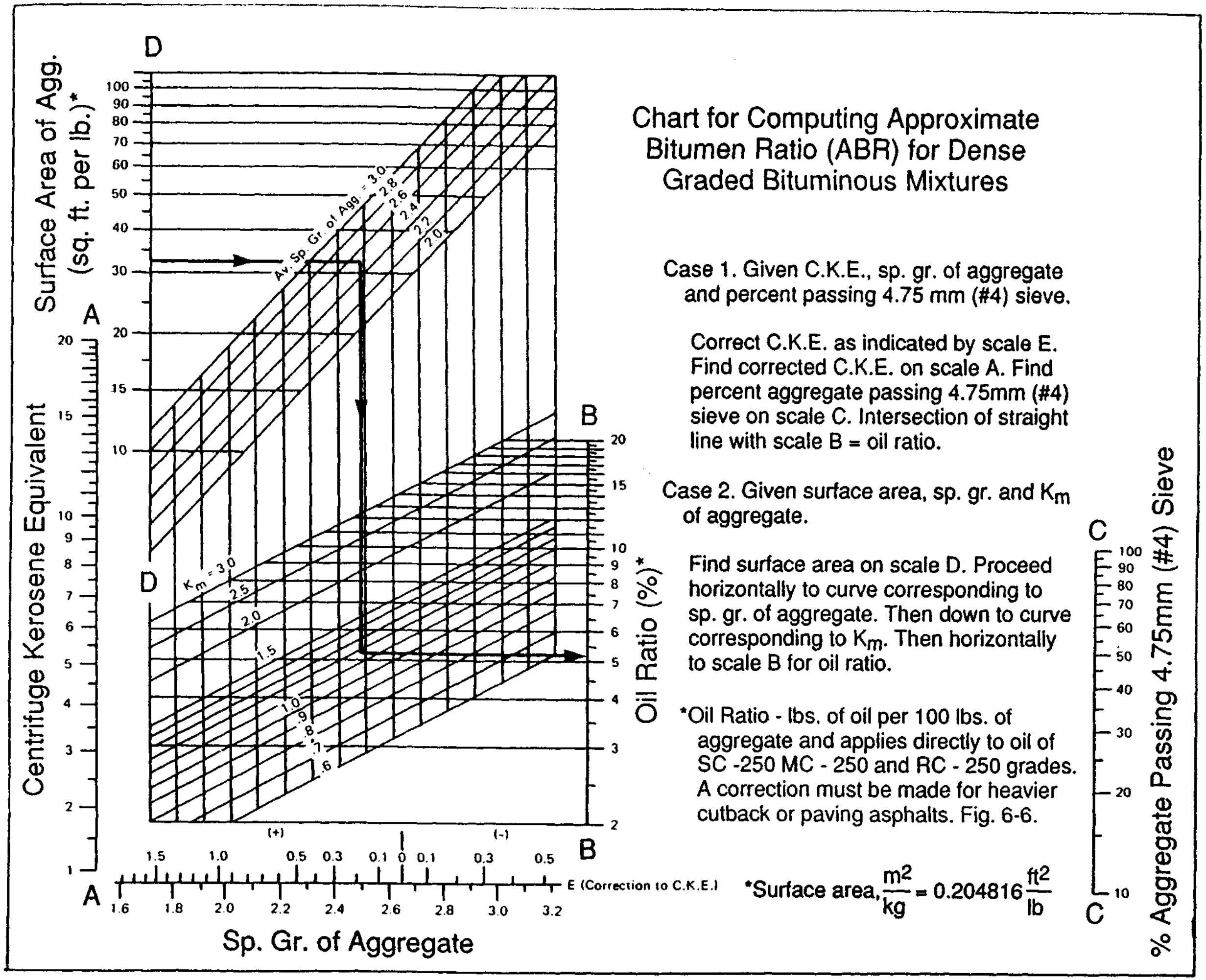

Chart for Computing Approximate Bitumen Ratio (ABR) for Dense Graded Bituminous Mixtures

Case 1. Given C.K.E., sp. gr. of aggregate and percent passing 4.75 mm (#4) sieve.

Correct C.K.E. as indicated by scale E. Find corrected C.K.E. on scale A. Find percent aggregate passing 4.75mm (#4) sieve on scale C. Intersection of straight line with scale B = oil ratio.

Case 2. Given surface area, sp. gr. and K_m of aggregate.

Find surface area on scale D. Proceed horizontally to curve corresponding to sp. gr. of aggregate. Then down to curve corresponding to K_m. Then horizontally to scale B for oil ratio.

*Oil Ratio - lbs. of oil per 100 lbs. of aggregate and applies directly to oil of SC -250 MC - 250 and RC - 250 grades. A correction must be made for heavier cutback or paving asphalts. Fig. 6-6.

*Surface area, $\frac{m^2}{kg} = 0.204816 \frac{ft^2}{lb}$

Chart No.4 - Determining the Estimated Optimum Asphalt Content.
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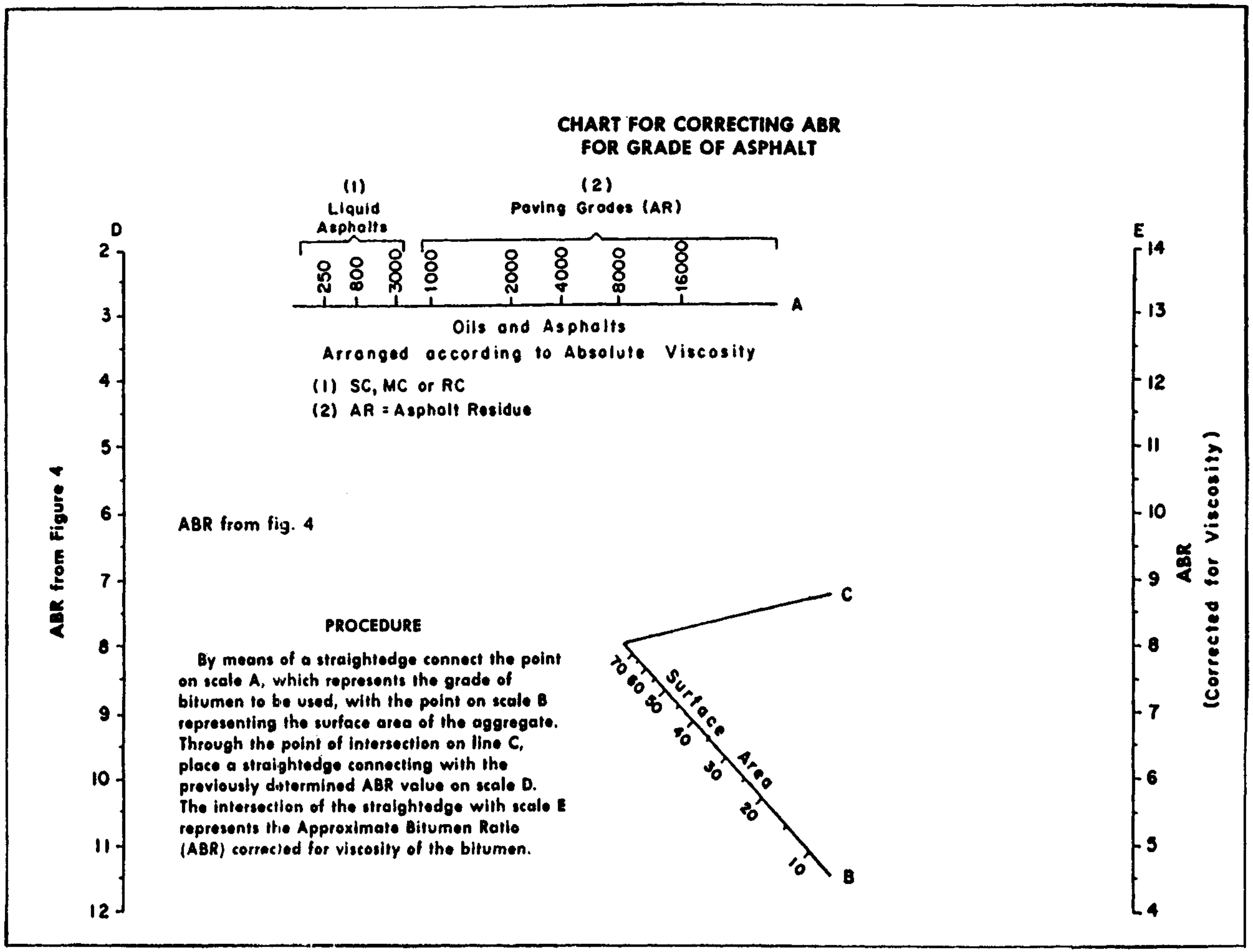

CHART FOR CORRECTING ABR
FOR GRADE OF ASPHALT

PROCEDURE

By means of a straightedge connect the point on scale A, which represents the grade of bitumen to be used, with the point on scale B representing the surface area of the aggregate. Through the point of intersection on line C, place a straightedge connecting with the previously determined ABR value on scale D. The intersection of the straightedge with scale E represents the Approximate Bitumen Ratio (ABR) corrected for viscosity of the bitumen.

Chart No.5 - Determining the Estimated Optimum Asphalt Content.
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Figure 30 - Transferring the Mix to and rodding Mix in the Mold.
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Figure 31 - Kneading Compactor and Diagram of Tamping Foot for Kneading Compactor.
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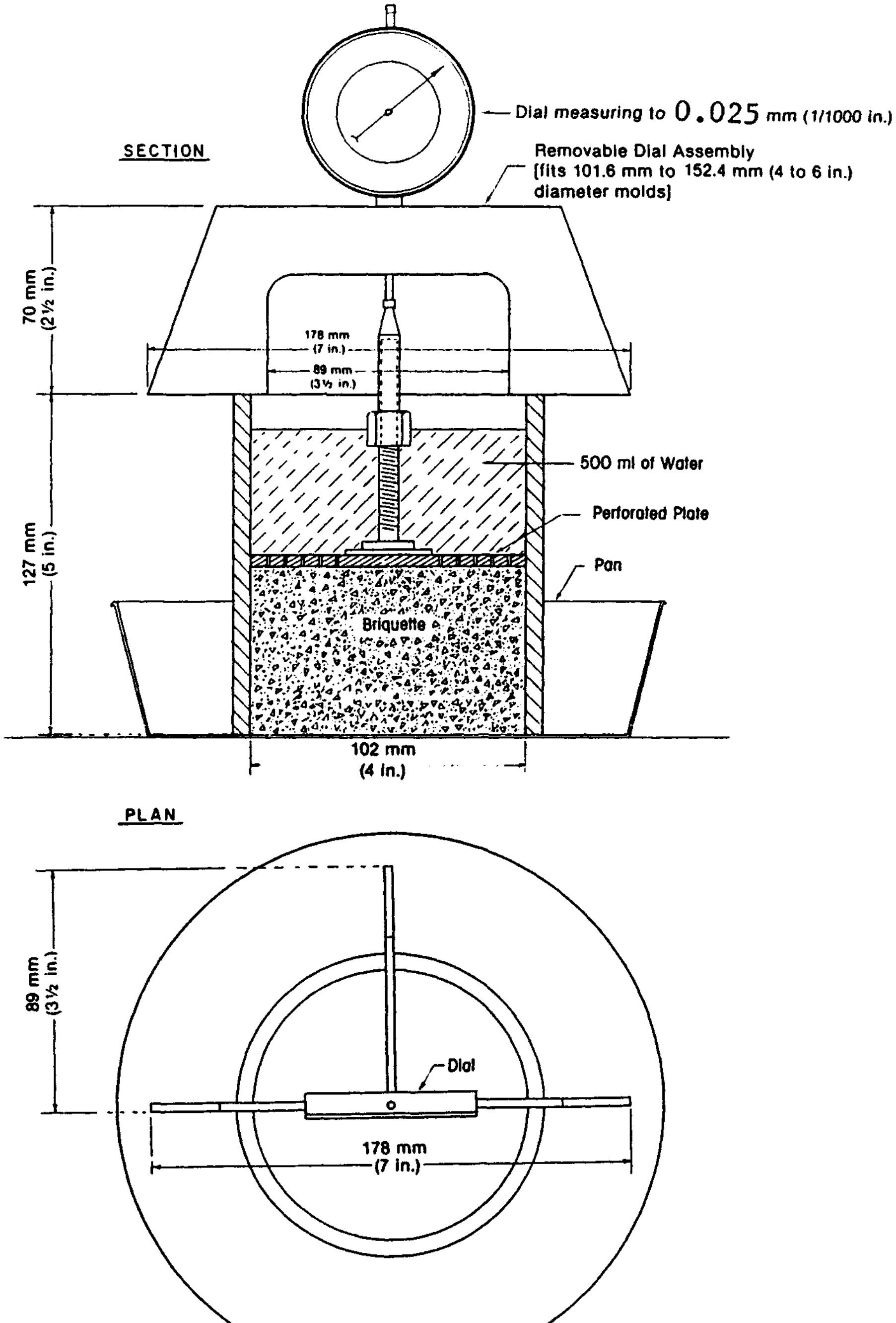

Figure 32 - Setup of the Swell Test Apparatus.
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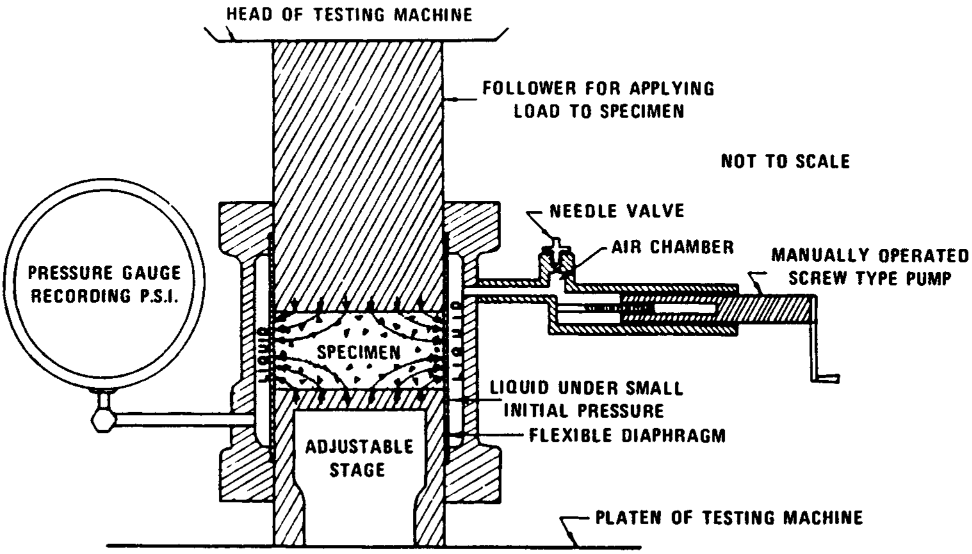

NOTE–The specimen is given lateral support by the flexible sidewall, which transmits horizontal pressure to the liquid. The magnitude of the pressure can be read on the gauge.

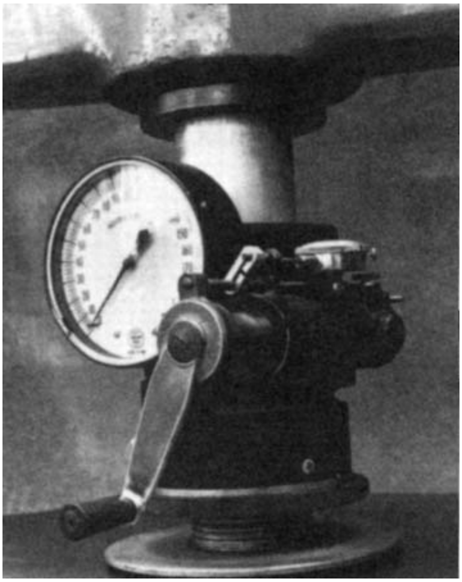

Figure 33 - Hveem Stabilometer and Schematic of its principal features.
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HOT MIX DESIGN by the HVEEM METHOD Data Sheet
(ASTM D 1560 & 1561)

Specimen Nos.		1	2	3	4	5	
% AC by Wt. Mix		4.7	5.2	5.7	6.2	6.7	
Total Load pounds	Unit Load - P_v(psi)	Stabilometer Pressure Gauge Readings - P_h Horizontal Pressure					
500	40	7	9	6	5	6	
1,000	80	11	15	12	10	14	
2,000	160	18	25	23	30	39	
3,000	240	27	34	39	51	65	
4,000	320	38	44	61	77	130	
5,000	400	49	55	94	106	200*	
6,000	480	66	70	118	160	290*	
Displacement Turns - D_2		2.7	3.1	3.2	3.6	3.3	
Uncorrected Hveem Stabilometer Value - S		37	31	18	15	6	
Ht. of Specimen mm. or Inches		2.60"	2.39"	2.45"	2.39"	2.37"	
Corrected Hveem Stabilometer Value* - S		40	27	18	13	5	
Swell - nearest 0.001 inches (0.025mm)		2 specimens tested at middle AC %		0.002" 0.001"			

$$\text{Stabilometer Value, } S = \cfrac{22.2}{\cfrac{P_h D_2}{P_v - P_h} + 0.222}$$

S = stabilometer value
D_2 = displacement on specimen
P_v = vertical pressure
P_h = horizontal pressure (Hveem Stabilometer Gauge Reading)
* See Figure 36 for correcting stabilometer values for specimen height.

HOT MIX DESIGN by the HVEEM METHOD Data Sheet
(ASTM D 1560 & 1561)

Specimen Nos.							
% AC by Wt. Mix							
Total Load pounds	Unit Load - P_v(psi)	Stabilometer Pressure Gauge Readings - P_h Horizontal Pressure					
500	40						
1,000	80						
2,000	160						
3,000	240						
4,000	320						
5,000	400						
6,000	480						
Displacement Turns - D_2							
Uncorrected Hveem Stabilometer Value - S							
Ht. of Specimen mm. or Inches							
Corrected Hveem Stabilometer Value* - S							
Swell - nearest 0.001 inches (0.025mm)		2 specimens tested at middle AC %					

$$\text{Stabilometer Value, } S = \cfrac{22.2}{\cfrac{P_h D_2}{P_v - P_h} + 0.222}$$

S = stabilometer value
D_2 = displacement on specimen
P_v = vertical pressure
P_h = horizontal pressure (Hveem Stabilometer Gauge Reading)
*See Figure 36 for correcting stabilometer values for specimen height.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1560 and D 1561)

Specimen Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt.in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4
1	4.7	1203	708	1207	499	2.411	150.45
2	5.2	1200	709	1204	495	2.424	151.26
3	5.7	1199	707	1200	493	2.432	151.76
4	6.2	1187	698	1190	492	2.413	150.57
5	6.7	1181	693	1184	491	2.405	150.09

Note: All weights measured in grams.

Bulk Specific Gravity and Density Computations.

BULK SPECIFIC GRAVITY and DENSITY DATA SHEET for ASPHALT MIX DESIGNS (ASTM D 1560 and D 1561)

Speci-men Number	% AC by Wt. of Mix	Wt. in Air (A)	Wt. in Water (C)	Wt. SSD (B)	Vol. cc (B-C)	Bulk - G_{mb} Sp.Gr. A/(B-C)=D	Unit Wt.pcf Dx62.4

Note: All weights measured in grams.

Bulk Specific Gravity and Density Computations.

RICE METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (ASTM D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C (C)	Specific Gravity = A/C
5.2	813	108	705	92	513	422	283	2.49
5.7	803	108	695	92	504	414	281	2.47
6.2	809	108	701	92	507	415	286	2.45

Note: All weights measured in grams.

Rice Method Computation Sheet.

METHOD for DETERMINATION of MAXIMUM SPECIFIC GRAVITY of PAVING MIXTURES (ASTM D 2041)

% AC by Wt. of Mix	Wt. Sample & Bowl in Air	Wt.of Bowl in Air	Wt. of Sample in Air (A)	Wt.of Bowl in Water	Wt. of Sample & Bowl in H_2O	Wt. of Sample in H_2O (B)	Volume A-B=C	Specific Gravity = A/C

Note: All weights should be measured in grams.

Rice Method Computation Sheet.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1560 and 1561)

Materials	Specific Gravity			Specimen Number				
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate	2.76	2.65	P_1	61.0	60.7	60.3	60.0	59.7
Fine Aggregate	2.82	2.70	P_2	30.5	30.3	30.2	30.0	29.9
Mineral Filler	3.12	N.A.	P_3	3.8	3.8	3.8	3.8	3.7
Total Aggregate	2.79	2.68	P_4	95.3	94.8	94.3	93.8	93.3
Asphalt Cement	1.01	N.A.	P_5	4.7	5.2	5.7	6.2	6.7
Bulk Sp.Gr.(G_{mb}), compacted mix, (ASTM D 2726)				2.411	2.424	2.432	2.413	2.405
Bulk Sp.Gr.(G_{sb}), total aggregates, Equation 1				2.68	2.68	2.68	2.68	2.68
Effective Sp.Gr.(G_{se}), total aggregates, Equation 2				2.71	2.71	2.71	2.71	2.71
Max. Sp.Gr.(G_{mm}), paving mixture**, Equation 3				2.51	2.49	2.47	2.45	2.44
Absorbed Asphalt (P_{ba}),% by wt. of total aggr., Equation 4				0.42	0.42	0.42	0.42	0.42
Effective Asphalt Content (P_{be}), Equation 5				4.30	4.80	5.30	5.81	6.31
Voids Mineral Aggregate (VMA), Equation 6				14.27	14.26	14.43	15.54	16.27
Air Voids (P_a), Equation 8				4.0	2.8	1.6	1.6	1.6

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Hveem Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

COMPACTED PAVING MIXTURES DATA SHEET (ASTM D 1560 and D 1561)

Materials	Specific Gravity		Specimen Number					
	Apparent	Bulk		1	2	3	4	5
Coarse Aggregate			P_1					
Fine Aggregate			P_2					
Mineral Filler			P_3					
Total Aggregate			P_4					
Asphalt Cement			P_5					
Bulk Sp.Gr.(Gmb),compacted mix,(ASTM D 2726)								
Bulk Sp.Gr.(Gsb), total aggregates, Equation 1								
Effective Sp.Gr.(Gse), total aggregates, Equation 2								
Max. Sp.Gr.(Gmm), paving mixture**, Equation 3								
Absorbed Asphalt (Pba),% by wt. of total aggr., Equation 4								
Effective Asphalt Content (Pbe), Equation 5								
Voids Mineral Aggregate (VMA), Equation 6								
Air Voids (Pa), Equation 8								

Notes:

* Reference for Equations See Explanation of Effective Asphalt Content Determination.

**Average value normally of three samples for the Hveem Method. Test three loose mixture specimens in the middle of the asphalt range to measure the Rice specific gravity. If the resultant G_{se}, is not identical for all the samples, extend the testing to the other specimens. G_{se} should be identical for all asphalt percentages.

Typical Test Property Curves for a Hot Mix Asphalt Concrete by the Hveem Design Method

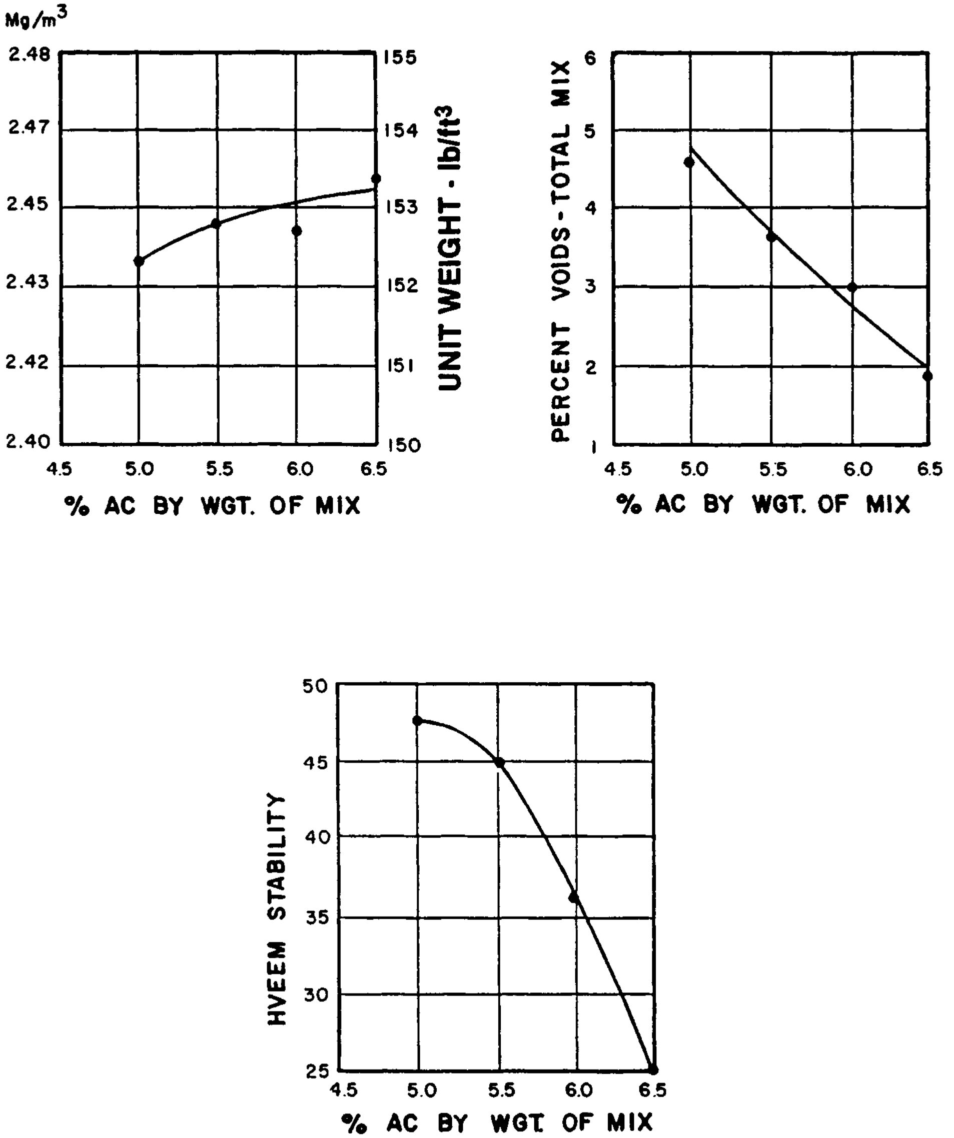

Figure 34 - Graphs of Physical Properties for Hveem Mix Design.

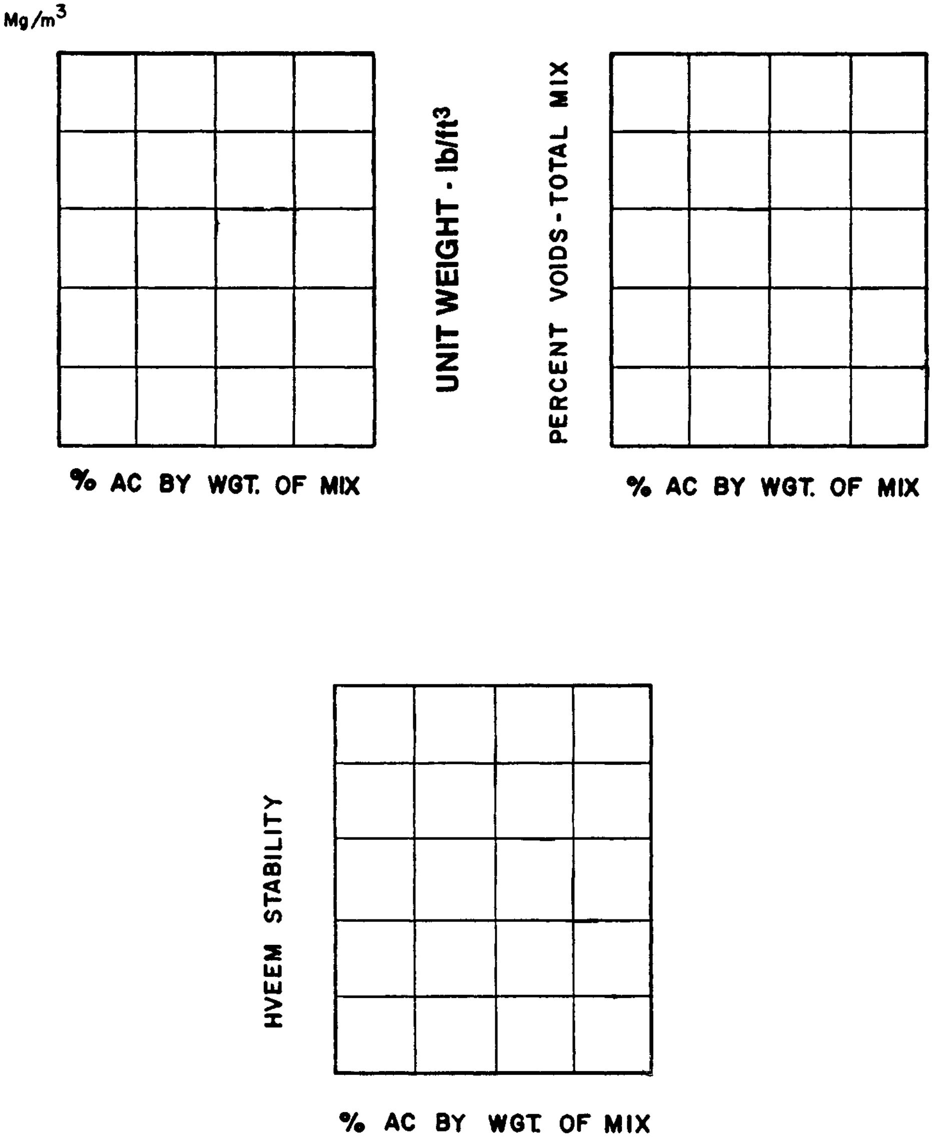

Figure 35 - Graphs of Physical Properties for Hveem Mix Design. Reprinted with Permission of The Asphalt Institute

CHART FOR CORRECTING STABILOMETER VALUES TO SPECIMEN HEIGHT OF 64 mm (2.50 in.)

Height correction should be made using the table and chart below.

Example: Overall height of 69 mm (2.74 in.) select correction curve "B". Stabilometer value uncorrected = 35 Stabilometer value corrected = 38.

Overall Specimen Ht.	Correction Curve
71mm to 76mm (2.80 in. to 3.00 in.)	A
66mm to 70mm (2.60 in. to 2.79 in.)	B
61mm to 65mm (2.40 in. to 2.59 in.)	C
56mm to 60mm (2.20 in. to 2.39 in.)	D
51mm to 55mm (2.00 in. to 2.19 in.)	E

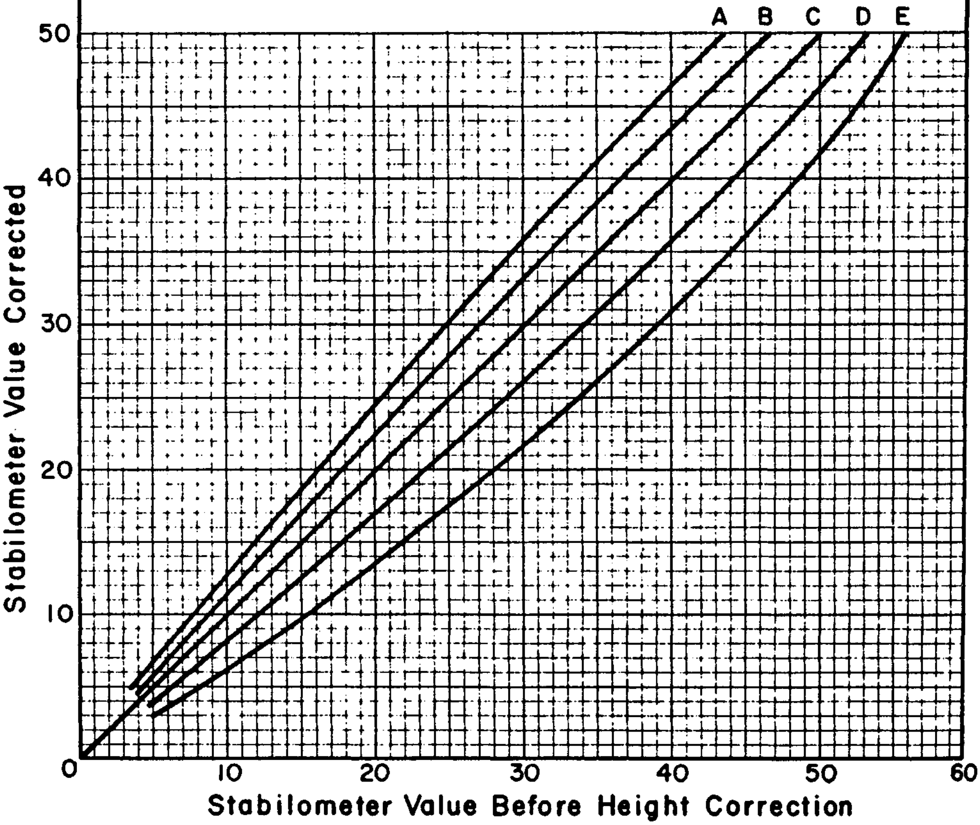

Figure 36 - Chart for Correcting Stabilometer Values to Effective Specimen Height of 63mm (2.5"). Reprinted with Permission of The Asphalt Institute

Traffic Category	Heavy		Medium		Light	
Test Property	**min.**	**max.**	**min.**	**max.**	**min.**	**max.**
Stabilometer Value	37	–	35	–	30	–
Swell	**less than 0.762 mm (0.030 in.)**					

NOTES:

1. Although not a routine part of this design method, an effort is made to provide a minimum percent air voids of approximately 4 percent.
2. All criteria, and not stability value alone, must be considered in designing an asphalt paving mix.
3. Hot-mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed at 100 mm (4 in.) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
4. Traffic Classifications:

Light:	Traffic conditions resulting in a Design EAL $<10^4$.
Medium:	Traffic conditions resulting in a Design EAL between 10^4 and 10^6.
Heavy:	Traffic conditions resulting in a Design EAL$>10^6$.

Table 5 - Hveem Mix Design Criteria.
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STEPS in SELECTING the OPTIMUM HVEEM MIX DESIGN

1. In the figure below insert the four highest asphalt contents, used in preparing the series of mix design speceimens. Insert the asphalt contents in ascending order from left to right.
2. Select from Step 1 the three highest asphalt contents that do not exhibit moderate or heavy flushing in Step 2, below. (Surface flushing and /or bleeding is considered "Slight" if the surface has a slight sheen. It is considered "Moderate" if sufficient free asphalt is apparent to cause paper to stick but no distortion is noted. Surface flushing is considered "Heavy" if there is sufficient free asphalt to cause surface puddling or specimen distortion after compaction).
3. Select from Step 2 the two highest asphalt contents that provide the specified minimum stabilometer value and enter them in Step 3.
4. Select from Step 3 the highest asphalt content that has at least 4.0% air voids and enter in Step 4.
5. The asphalt content in Step 4 is the optimum asphalt content. However, if the maximum asphalt content used in the design set (Step 1) is the asphalt content entered on Step 4, an additional specimen must be prepared with increased asphalt content in 0.5 percent increments and a new optimum asphalt content determination made.
6. On the other hand, if the air voids in Step 4 is less than 4.0%, ascertain whether the specimen with the lowest asphalt content in the design series meets the Hveem Design Criteria for minimum stabilometer value and air voids.

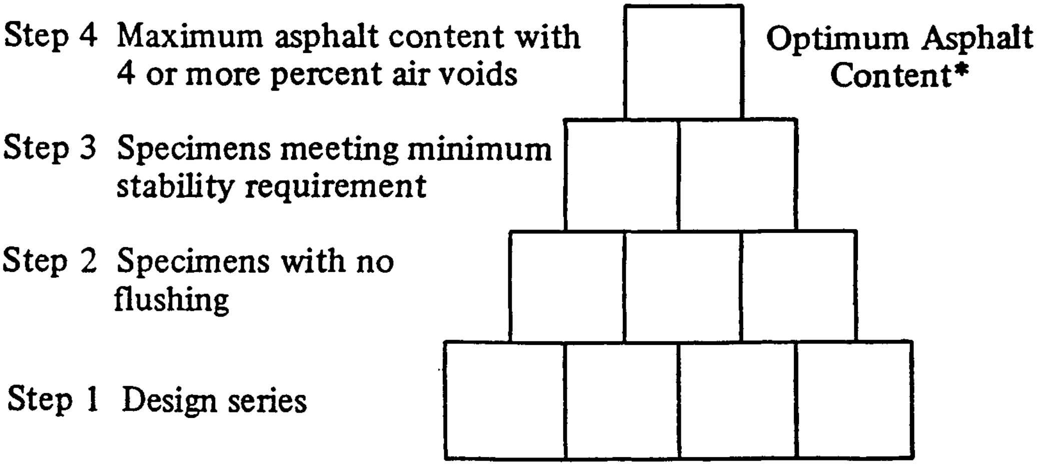

Figure 37 - Determining the Optimum Asphalt Content.

<u>Illustrative Example for Use of Figure 37</u>

1. Assume a mix design test series, consisting of five specimens, with the asphalt content between 4.5% and 6.5%. The design is for a Heavy Traffic Category as defined in Table 5.
2. The procedure described in Figure 37, in Steps 1 through 4, is shown below as Figure 51. The four highest percentages of asphalt are indicated in the boxes of Step 1.
3. The specimen with 6.5% of asphalt is presumed to exhibit moderate flushing. Therefore, in Step 2 that specemen was deleted.
4. Of the three specimens shown in Step 2, assume that only the 5.0% and 5.5% asphalt provides a Hveem stability value of at least 37. The latter are then moved up to the boxes in Step 2.
5. In the top box below is the asphalt content from Step 2 that possesses at least 4.0% air voids. In this example that is assumed to be the specimen with 5.0% asphalt. This is then the optimum asphalt content for the mix design.
6. If the specimen determined to be the optimum asphalt content turned out to be 6.5%, another specimen at 7.0% would be prepared and tested and evaluated for Hveem criteria. However, if the specimen with 5.0% asphalt still fell short of the 4.0% air voids, the specimen with 4.5% air voids would be evaluated for meeting the Hveem design criteria from Table 5.

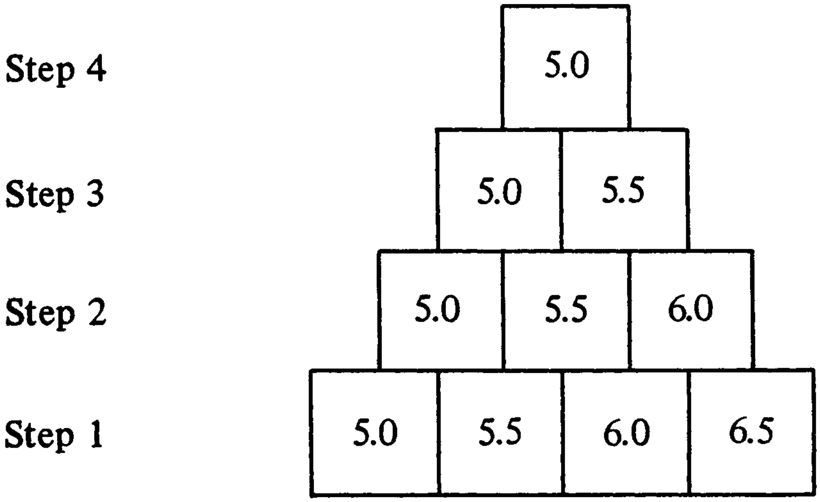

Figure 38 - Example Explaining Procedures of Figure 37.

EXPLANATION of EFFECTIVE ASPHALT CONTENT DETERMINATION and PERCENT AIR VOIDS of the COMPACTED ASPHALTIC MIXTURE

I. This concept consists of the following three factors:

A. Effective Asphalt Content (P_{be}) - assures adequate asphalt cement (AC) in the mix.

B. Voids Mineral Aggregate (VMA) - confirms that there is sufficient voids between the aggregates to accommodate both the asphalt cement volume and the air voids. Bulk Specific Gravity of aggregates are used in order to determine the actual voids between particles. Capillary voids are of no interest in the mix design.

C. Air Voids - prevents "Bleeding" of the asphaltic concrete mixture, particularly when the volume of the AC increases in a warm environment.

II. Types of Aggregate Specific Gravities-

A. Bulk Specific Gravity (G_{sb})- Ratio of the weight in air of a unit volume of permeable materials (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume of water at the same temperature. This is the Lowest Specific Gravity.

B. Apparent Specific Gravity (G_{sa}) - ratio of the weight in air of a unit volume of material, its impermeable portion, at a stated temperature to the weight in air of an equal volume of water. This is the Highest Specific Gravity .

C. Effective Specific Gravity (G_{se}) - ratio of the weight in air of a unit volume of material at a stated temperature to the weight in air of an equal volume (less volume of aggregate voids filled with AC) of water. Effective or Virtual Specific Gravity is generally considered to be equal to the average of the Bulk and Apparent Specific Gravities.

III. Key Equations

A. Bulk Specific Gravities of Aggregates:

$$G_{sb} = \frac{P_{ca} + P_{fa} + P_{mf}}{\frac{P_{ca}}{G_{ca}} + \frac{P_{fa}}{G_{fa}} + \frac{P_{mf}}{G_{mf}}} \qquad \text{Equation 1.}$$

P = % by weight of respective aggregate fractions.
G = Bulk Specific Gravity of respective aggregate fractions.

B. Effective Specific Gravity of the Aggregates:

$$G_{se} = \frac{P_{mm} - P_b}{\dfrac{P_{mm}}{G_{mm}} - \dfrac{P_b}{G_b}} \qquad \text{Equation 2.}$$

P_{mm} = % of total loose weight of mixture = 100%.
P_b = AC, % by total weight of mixture.
G_{mm} = Maximum Specific Gravity of mixture using Rice's Method with a fine mesh bowl $= \dfrac{A}{A - C}$.

A = weight of sample in air, grams. C = weight af sample in water, grams. Rice's Method is the same as ASTM Designation: D 2041.

C. Maximum Specific Gravity of Asphaltic Concrete Mixtures with different Asphalt Contents:

$$G_{mm} = \frac{P_{mm}}{\dfrac{P_s}{G_{se}} + \dfrac{P_b}{G_b}} \qquad \text{Equation 3.}$$

P_b = Asphalt, % of total weight of mixture.
P_s = Aggregate, % by total weight of mixture.
G_b = Specific Gravity (Apparent) of Asphalt.

D. Asphalt Absorption:

$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{sb} \times G_{se}} \times G_b \qquad \text{Equation 4.}$$

E. Effective Asphalt Content of an Asphaltic Mixture.

$$P_{be} = P_b - \frac{P_{ba} \times P_s}{100} \qquad \text{Equation 5.}$$

F. % VMA when mix composition is determined as percent by weight of total mixture:

$$\text{VMA} = 100 - \frac{G_{mb} \times P_s}{G_{sb}} \qquad \text{Equation 6.}$$

VMA = voids in mineral aggregate (% of bulk volume).
G_{sb} = bulk specific gravity of aggregates.

P_s = aggregates, % by total weight of mixture.

G_{mb} = Bulk Specific Gravity of Compacted Mixture = $\frac{A}{B - C}$.

A = weight of specimen in air; B = saturated surface dry weight; C = buoyant weight in water.

G. % VMA when mix composition is determined as percent by weight of aggregate:

$$VMA = 100 - \frac{G_{mb}}{G_{sb}} \times \frac{100}{100+P_b} 100 \quad \text{Equation 7.}$$

P_b = asphalt, percent by weight of aggregates.

H. % Air Voids in Compacted Asphaltic Mixture:

$$P_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}} \quad \text{Equation 8.}$$

P_a = air voids in compacted mixture, % of total volume.
G_{mm} = maximum specific gravity of AC mixture by Rice's Method.
G_{mb} = bulk specific gravity of compacted mixture.

I. % Voids Filled with Asphalt:

$$\% \, VFA = 100 \times \frac{VMA - P_a}{VMA} \quad \text{Equation 9.}$$