Bituminous Materials

Part 4, Bituminous Materials, of the Highway Materials Manual contains the test procedures, sampling requirements, and test equipment necessary to characterize and control, within specification requirements, asphalt cements, cutback asphalts, emulsified asphalts, and asphalt-aggregate mixtures.

Bituminous material, or bitumen in the form of asphalt, is one of the major highway construction materials used. Its use ranges from binders for the highest type pavements of complex engineering designs for the ultimate traffic, to direct spray applications to protect an existing pavement or to provide a low-cost, all-weather road for a minimum of traffic. Asphalt materials, as used, range in consistency from semisolid to liquid products, which are processed and blended to conform to specification requirements for various types and grades.

Asphalt is normally a residue product from the distillation of crude oil and, as refined, is a heavy, viscous material that is semisolid at normal atmospheric temperatures. By controlled processing or blending desired viscosity and hardness characteristics can be produced. This product is called asphalt cement and is also known as paving grade or penetration grade asphalt. These later names relate to use of asphalt cement as the binder in hot mix asphalt concrete and to the identification of the various grades of asphalt cement by the penetration test. Asphalt cements, as commonly used in paving, will have standard penetrations with a penetration needle of between 4 and 30 mm when tested at 25°C with a load of 100 g applied for 5 seconds. Penetration values are measured and reported in tenths of mm so that the range of penetration units for asphalt cements is 40 to 300.

The penetration test, MRDTM 404, Penetration of Asphalt Materials, yields the numerical value used to control the consistency of asphalt cements and is a means of classifying asphalt cement; e.g., 60-70, 85-100, etc. Viscosity, a fundamental materials engineering property, is another means of characterizing asphalt cements and as such, forms another means of classifying or grading these materials. Specifications for the 60-70 penetration grade asphalt include a requirement for Saybolt Furol viscosity measured at 135°C as determined by MRDTM 421, Saybolt Viscosity and for Kinematic viscosity measured at 135°C as determined by MRDTM 408, Kinematic Viscosity of Asphalts.

Asphalt cements can be blended with other materials to produce liquid asphalts. Liquid asphalts are so called because they are liquids at normal atmospheric temperatures. There are several types of paving mixtures and road applications in which the use of liquid asphalts are either essential or have advantages over the use of asphalt cements that require heating for handling, and in the case of paving mixtures, the heating of aggregates.

The major classes of liquid asphalts used are asphalt cutbacks and asphalt emulsions.

Cutback asphalt is an asphalt cement that has been liquified by blending with petroleum distillates, termed diluents. An asphalt blended with a distillate similar to gasoline results in a rapid curing (RC) material. If the distillate is similar to kerosene, the resulting material is medium curing (MC) and if a gas oil is used the cutback would be relatively slow curing (SC).

Six grades of the RC and MC types are included in the Standard Specifications, Tables 2 and 3 of Section 4.04. The basis for grading is the same for all types, so that the minimum and maximum limits are on an assumed basis that each grade covers the same increment in Saybolt Furol viscosity (MRDT M 42 1) at 60°C when plotted on a logarithmic scale. However, the Saybolt Furol viscometer is not adequate to measure the complete range in viscosities for all grades at 60°C, so the temperature of testing is varied from 25°C to 82.2°C.

Emulsified asphalts used in road construction are the oil-in-water type and basically are an asphalt cement dispersed in water treated with an emulsifying agent. Some type of high-speed colloid mill is used to break down the asphalt into minute globules and disperse them in water. There are many types of additives that can be used in the manufacture of emulsified asphalt and the kinds and amounts vary with the producer's process and formulation, the type, source, and amount of asphalt, and the type and grade of emulsion being produced.

There are two general classes of asphalt-in-water emulsions used for road construction-anionic and cationic. The basic difference is that the asphalt particles in the cationic emulsions have a positive charge; whereas the particles in the anionic emulsions have negative or neutral charges.

The emulsified asphalts included in MRDTM 4259 Design of Bituminous Surface Treatments, for use on bituminous surface treatments are of three basic types: rapid setting (RS or CRS), medium setting (NIS or CMS), and slow setting (SS or CSS). The grade within any given type is varied to provide a difference in viscosity, mixing and coating stability, and
type and consistency of the asphalt base. The rapid-setting type of emulsions (RS-1 and RS-2) (CRS-1 and CRS-2) are used primarily for construction involving direct application of the asphalt emulsion such as seal coats and surface treatments, tack coats, and mulch treatments. In all of these applications no mixing is required.

The medium-setting emulsions (MS-1 and MS-2) (CMS-1 and CMS-2) are used primarily for paving mixtures in which the aggregate is relatively free from fine material and dust. The mixtures are normally prepared with cold aggregate but can be used in hot-plant mixtures using either open or dense-graded aggregate mixtures. The primary difference in the MS-1 and MS-2 (or 2h) grades is the higher asphalt content of MS-1 grade which is preferred for hot-plant mixtures. Distillates, if present, should be recognized in the design and curing of the mixtures and possible fire hazards.

The slow-setting emulsions, SS-1 or CSS-1 are intended primarily for mixing with aggregates containing appreciable fines and in either road or plant mixing. They also are used extensively in slurry seals and for tack coats. These emulsions are readily diluted with water for the applications.

Emulsified asphalts and cutback asphalts can be applied to cold road surfaces and aggregates as in surface treatments, and mixed with cold aggregates in road or plant mixing. In the above uses, emulsified asphalts have an added advantage over cutbacks in that they can be used with damp aggregates. Their success in such cases is dependent upon good atmospheric drying conditions after application or mixing, to promote removal of the water. Under similar atmospheric conditions the emulsified asphalts used in some applications will set faster than cutbacks that depend on evaporation of solvents for setting.

Tests for the purposes of asphalt emulsion evaluation and control include: composition (water content and residue by distillation), identification of oil distillate by micro distillation (residue by evaporation and particle charge of emulsified asphalts), consistency (Saybolt Furol viscosity), stability (demulsibility, settlement, cement mixing, sieve test, miscibility with water, freezing, coating ability, water resistance, and storage stability), and examination of residue. The methods of test for these properties are included in MRDTM 424, Testing Emulsified Asphalt.

Included in this part of the Materials Manual is the design and testing of hot mixed bituminous concrete materials. These are discussed in MRDTM's 410 through 419.

The factors involved in the design of bituminous paving mixtures include:

1. Stability.
2. Durability.
3. Flexibility.
4. Fatigue resistance.
5. Skid resistance.
6. Permeability or imperviousness.
7. Fracture (tensile) strength.
8. Workability characteristics during construction.
9. Stress-strain characteristics.
10. Thermal characteristics.

Proper design of a bituminous mixture requires a balance in the above properties, which usually results in a compromise between mixture design criteria. However, there are several of the mixture variables that recur in a majority of the mix properties. These are binder content, aggregate gradation, and mixture density or amount of compaction. In order to arrive at the optimum blend of these variables a mix design procedure described in MRDTM 410, Design of Asphalt Concrete Mixtures Using Marshall Procedures, is used.

In determining the optimum bituminous binder content for a particular blend or gradation of aggregates by the Marshall method, a series of test specimens is prepared for a range of binder contents so that the test data curves show a well-defined "optimum" value. Tests should be scheduled on the basis of 1/2 percent increments in binder content, with at least two binder contents above "optimum" and at least two binder contents below "optimum."

The initial wetting and adhesion of a bituminous binder to an aggregate and the retention of the bituminous film under moist or wet conditions and traffic action are often important factors in pavement performance. The aggregate, as well as the bituminous binder, contribute to the adhesion or stripping problem. Extensive pavement distress and, in some cases, nearly complete pavement failures may result through the action of water and traffic. Many of these failures are in dense graded paving mixtures. MRDTM 415, Effect of Water on Cohesion of Bituminous Mixtures, is the test method used to identify whether asphalt aggregate mixtures are subject to potential loss of aggregate/asphalt adhesion, or stripping.
### List of Each Materials and Research Department  
**Test Method for Bituminous Materials**

The following list provides a summary of test methods by numerical order, listing Kingdom of Saudi Arabia, Ministry of Communications, Materials and Research Department, Standard Method of Test (MRDTM) and the MRDTM name.

<table>
<thead>
<tr>
<th>MRDTM Number</th>
<th>MRDTM Test Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>401</td>
<td>Sampling Bituminous Materials</td>
</tr>
<tr>
<td>402</td>
<td>Solubility of Bituminous Materials in Organic Solvents</td>
</tr>
<tr>
<td>403</td>
<td>Flash and Fire Points by Cleveland Open Cup</td>
</tr>
<tr>
<td>404</td>
<td>Penetration of Asphalt Materials</td>
</tr>
<tr>
<td>405</td>
<td>Ductility of Asphalt Materials</td>
</tr>
<tr>
<td>406</td>
<td>Softening Point of Asphalt in Ethylene Glycol (Ring-and-Ball)</td>
</tr>
<tr>
<td>407</td>
<td>Specific Gravity of Semisolid Asphalt Materials</td>
</tr>
<tr>
<td>408</td>
<td>Kinematic Viscosity of Asphalts</td>
</tr>
<tr>
<td>409</td>
<td>Effect of Heat and Air on Asphalt Materials (Thin Film Oven Test)</td>
</tr>
<tr>
<td>410</td>
<td>Design of Asphalt Concrete Mixtures Using Marshall Procedures</td>
</tr>
<tr>
<td>411</td>
<td>Bulk Specific Gravity of Compacted Bituminous Mixtures</td>
</tr>
<tr>
<td>412</td>
<td>Maximum Specific Gravity of Bituminous Paving Mixtures</td>
</tr>
<tr>
<td>413</td>
<td>Coating and Stripping of Bitumen-Aggregate Mixtures</td>
</tr>
<tr>
<td>414</td>
<td>Compressive Strength of Bituminous Mixtures</td>
</tr>
<tr>
<td>415</td>
<td>Effect of Water on Cohesion of Compacted Bituminous Mixtures</td>
</tr>
<tr>
<td>416</td>
<td>Moisture or Volatile Distillates in Bituminous Paving Mixtures</td>
</tr>
<tr>
<td>417</td>
<td>Sampling Bituminous Paving Mixtures</td>
</tr>
<tr>
<td>418</td>
<td>Quantitative Extraction of Asphalt from Asphalt Paving Mixtures</td>
</tr>
<tr>
<td>419</td>
<td>Mechanical Analysis of Extracted Aggregate</td>
</tr>
<tr>
<td>420</td>
<td>Flash Point With Tag Open Cup Apparatus</td>
</tr>
<tr>
<td>421</td>
<td>Saybolt Viscosity</td>
</tr>
<tr>
<td>422</td>
<td>Distillation of Cutback Asphalt Materials</td>
</tr>
<tr>
<td>423</td>
<td>Flakiness Index and Average Least Dimension of Aggregates</td>
</tr>
<tr>
<td>424</td>
<td>Testing Emulsified Asphalt</td>
</tr>
<tr>
<td>425</td>
<td>Design of Bituminous Surface Treatments</td>
</tr>
<tr>
<td>426</td>
<td>Design of Bituminous Plant Mix Friction Courses</td>
</tr>
<tr>
<td>427</td>
<td>Design and Testing of Slurry Seal</td>
</tr>
</tbody>
</table>
1. Scope
1.1 This method applies to the sampling of liquid, semisolid, or solid bituminous materials at the point of manufacture, supply terminal, or at the point of shipment delivery.
1.2 Samples may be taken from tanks, stockpiles, vehicles, or containers used for the storage or shipping of bituminous materials.

2. Purpose
2.1 Obtaining a sample which is representative of the material to be tested is as important as proper testing. Every precaution should be taken to obtain samples that will show the true nature and condition of the materials.
2.2 Samples may be taken by methods described hereinafter for either of the following two purposes:
2.2.1 To represent as nearly as possible an average of the bulk of the material sampled, or
2.2.2 To determine the maximum variation in characteristics which the material possesses.

3. Size of Samples
3.1 The sample size of liquid materials shall be as follows:
3.1.1 For routine laboratory examination not less than 1 liter (or 1 qt), or for emulsions, not less than 4 liters (or 1 gal.).
3.1.2 From bulk storage, 1 liter (or 1 qt) from each sampling valve.
3.1.3 From barrels or drums, 1 liter (or 1 qt).
3.2 The sample size of semisolid or solid materials shall be as follows:
3.2.1 From barrels, drums, or cakes, 1 kg (or 2.2 lbs).

4. Containers
4.1 Types of Containers
4.1.1 Containers for liquid bituminous material samples, except emulsions, shall be double friction-top cans, square cans with screw tops, or small mouth cans with screw caps.
4.1.2 Containers for emulsified asphalt samples shall be widemouth jars or bottles made of glass or plastic.
4.2 The size of containers shall correspond to the required amount of sample according to Sec 3.

5. Protection and Preservation of Samples
5.1 Sample containers shall be new. They shall not be washed or rinsed, or wiped with an oily cloth. Containers which have evidence of solder flux, or if they are not clean and dry shall not be used. Container tops and containers shall fit together tightly.
5.2 Care shall be taken to prevent the sample from becoming contaminated. Immediately after filling, the containers shall be tightly sealed.
5.3 The filled sample container shall not be submerged in solvent, nor shall it be wiped with a solvent saturated cloth. If cleaning is necessary, use a clean dry cloth.
5.4 Samples of emulsion shall be protected from freezing by correct packaging.
5.5 Transferring samples from one container to another shall be avoided if possible, as characteristics of materials can change during transfer, and there is a possibility of contaminating the sample.
5.6 Immediately after filling, sealing and cleaning (Sec 5.3), the sample containers shall be properly marked for identification with a suitable marking pencil on the container itself, not on the lid. Linen tags may also be used for identification if they can be securely fastened to the containers in such a manner as to insure that they will not be lost. The lids shall not be used to attach linen tags to containers.

6. Sampling at Place of Manufacture
6.1 Sampling liquid materials or materials made liquid by heating.
6.1.1 Samples shall be obtained by one of the following methods when sampling from bulk storage tanks not equipped with mechanical agitators (Note 1).
Note 1: During sampling by any of the methods described, all filling inlets and discharge outlets of the tank shall be closed.

6.1.1.1 Tank Tap Method—Using valves or taps at top, middle, and lower locations of the tank draw a 1 to 4 liter (or 1 qt to 1 gal.) sample from each tap after clearing the line by drawing and discarding a minimum of 4 liters (or 1 gal.) of the material.

6.1.1.2 Thief Sampler Method (not suitable for asphalt cements)—Samples shall be taken at top, middle, and lower levels of the tank by lowering a thief sampler into the material. A satisfactory type is illustrated in Fig. 1 (Notes 2 and 3).

Note 2: The thief sampler described in Fig. 1 may be used for repetitive sampling because significant sample contamination by previous contents is avoided by the self-cleaning action provided by the passage of material through the tube which is open at both ends. The practice of raising and lowering the sampler 3 or 4 times through a distance of approximately 1 m (or 3 ft) of the sampling depth is recommended.

Note 3: The thief sampler is lowered into the tank with the bottom valve open (there is no top closure). When the desired depth is reached, the lowering chain is given a snap tug which closes the bottom valve. The sampler is then withdrawn from the tank and the contents transferred to the sample container. This sampler may be used for repetitive sampling in the same tank.

6.1.1.3 Throw-away Container Method—Samples shall be taken at top, middle, and lower levels of the tank by lowering a suitable weighted holding device into the material. A satisfactory type is illustrated in Fig. 2. The essential feature of the method is to use a clean container each time a sample is taken from the tank. Pour the sample into a separate clean container and throw away the container used to take the sample (Note 4).

Note 4: The throw-away container sampler is lowered into the tank with the stopper in place. When the desired depth is reached, the stopper is removed by means of the attached wire, cord, or chain and the container allowed to fill. Complete filling is indicated by the cessation of bubbles of air from the can at the surface of the liquid. The sample is then withdrawn from the tank and the contents poured into the clean sample container. A clean container must be used for each sample taken.

6.1.1.4 The three samples from bulk storage tanks may be tested separately for consistency to detect stratification; or they may be combined, thoroughly mixed, and a 1 to 4 liter (or 1 qt to 1 gal.) sample taken for other tests as may be required for determining average characteristics of the material.

6.1.2 Samples taken from Bulk Storage Tanks Equipped with Mechanical Agitators—When the tank is equipped with operating mechanical agitators which, by observation through the sampling or observation hatch, are adequately mixing the tank contents, a single sample taken by methods described in Sec 6.1.1.1, 6.1.1.2, or 6.1.1.3 will be satisfactory to use for test purposes.

7. Sampling From Tank Cars, Tank Trucks, Distributor Trucks or Recirculating Storage Tanks

7.1 Each delivery vehicle or distributor shall be equipped with a sampling valve similar in principle to those shown in Fig. 3. It shall be installed at least 0.3 in (or 1 ft) from the shell and shall be clearly labeled as a "Sampling Valve." Before the sample is taken from the sample valve a minimum of 4 liters (or 1 gal.) shall be drawn from the sample valve and discarded.

7.2 The following methods may be used to obtain representative samples.

7.2.1 Samples of liquid materials and materials made liquid by heating may be taken by the dip method using a clean small-mouth or friction-top can in a suitable holder as shown in Fig. 4. A clean container must be used to take each sample, and the material sampled shall then be transferred to another new and clean container for retention or sample testing (Note 5).

Note 5: Dip sampler with can secured in place is rapidly lowered into tank to desired depth and allowed to fill with sample. The sampler is then withdrawn from the tank and the contents transferred to the sample container. A clean container must be used for each sample.

7.2.2 A detachable fitting, similar in design to the one shown in Fig. 5 shall be inserted in the discharge line. Before the sample is taken 4 liters (or 1 gal.) shall be drawn from this sampling valve and discarded.

7.2.3 Sampling Procedures—Drain off sufficient material through the spigot prior to taking a sample to insure removal of any contaminant lodged there. The sample should be taken after one-third and not more than two-thirds of the load has been removed. Take the sample slowly to insure it is representative of the material being evaluated.

8. Sampling From Pipe Lines During Loading or Unloading

8.1 When tankers and barges are being loaded or unloaded, samples may conveniently be taken from the pipe line through which the material is flowing by insertion of a sampling device (Fig. 5) into a rising section of the pipe line on the discharge side of the pump or in a completely filled line in which gravity creates the materials flow. The sampling device
should be turned to face the flow of liquid. This device shall be provided with a valve or plug cock and shall discharge into a sample receiver. At least three, 4 liter (or 1 gal.) samples, shall be taken at uniform intervals throughout the entire loading or unloading. At the completion of the loading or unloading operation, the individual 4 liter (or 1 gal.) samples shall be combined, thoroughly mixed without altering its characteristics, and a 4 liter (or 1 gal.) sample taken therefrom.

9. Sampling From Drums or Barrels

9.1 After thorough mixing, samples of liquid bituminous material from barrels or drums shall be obtained by tube or thief sampling by taking 1 liter (or 1 qt) of material from drums or barrels selected at random according to Sampling Semisolid or Uncrushed Solid Materials (Sec 10).

10. Sampling Semisolid or Uncrushed Solid Materials

10.1 Drums, Barrels, Cartons, and Bags where the lot of material to be sampled is from a single run or batch of the producer, one container shall be selected at random and sampled as described in Sec 10.1.1. Where the lot of material to be sampled is not obviously from a single run or batch of the producer, or where the single sample selected as described above fails on test to conform to the requirements of the specifications, a number of containers (equivalent to the cube root of the total number of packages in the lot) shall be selected at random. Table 1 shows the number of samples to be selected for shipments of various sizes.

<table>
<thead>
<tr>
<th>Size</th>
<th>Containers Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 8</td>
<td>2</td>
</tr>
<tr>
<td>9 to 27</td>
<td>3</td>
</tr>
<tr>
<td>28 to 64</td>
<td>4</td>
</tr>
<tr>
<td>65 to 125</td>
<td>5</td>
</tr>
<tr>
<td>126 to 216</td>
<td>6</td>
</tr>
<tr>
<td>217 to 343</td>
<td>7</td>
</tr>
<tr>
<td>344 to 512</td>
<td>8</td>
</tr>
<tr>
<td>513 to 729</td>
<td>9</td>
</tr>
<tr>
<td>730 to 1000</td>
<td>10</td>
</tr>
<tr>
<td>1001 to 1331</td>
<td>11</td>
</tr>
</tbody>
</table>

10.1.1 Samples shall be taken from at least 76 mm (or 3 in.) below the surface and at least 76 mm (or 3 in.) from the side of the container. A clean hatchet may be used if the material is hard enough to shatter or a broad, stiff putty knife if the material is soft. When more than one container in a lot is sampled each individual sample shall be not less than 115 g (or 1/4 lb) in mass. When the lot of material is obviously from a single run or batch of the producer, all samples from the lot shall be melted and thoroughly mixed, and an average 4 liter (or 1 gal.) sample taken from the combined material for examination. In case more than a single run or batch is present, and the batches can be clearly identified, a composite 4 liter (or 1 gal.) sample shall be prepared for examination from each batch. Where it is not possible to distinguish between the various batches, each sample shall be examined separately.

11. Sampling at Point of Shipment Delivery

11.1 Sampling of bituminous materials shall be done as soon as practicable after the bituminous material has arrived at the plant site, storage site, or job destination or at the time of unloading.

11.2 The required number of samples shall be taken from each delivery of bituminous material. In the case of small delivery units such as distributors, the samples shall be taken to represent a maximum of 38,000 liters (or 10,000 gal.).

11.3 Sampling shall be done by one of the following methods:

11.3.1 In accordance with Sec 6, Sampling at Place of Manufacture,

11.3.2 By bleeding through a sample valve or tap in the transfer line during the unloading of the appropriate middle third of the load, or

11.3.3 By means of a sampling device inserted to a level of approximately the middle third of the load or tank.

11.4 Tests for material acceptability shall be made on one of the samples taken. The other samples are to be retained for confirmation in the event the first sample tested should fail to comply with requirements.
12. Precautions

12.1 There is an opportunity for contaminating shipping containers with residues, precipitates, or cleaning solvents. It is incumbent upon the producer, transporter, user, and sampler, to exercise continuous caution in the sampling of bituminous materials.
Fig. 1. Thief Sampler.

Fig. 2. Throw-Away Container Sampler
Fig. 3. Submerged Asphalt Sampling Device.

Fig. 4. Dip Sampler.
Fig. 5. Typical Device for Sampling Liquid Asphalts from Transports
Standard Method of Test for
Solubility of Bituminous Materials in Organic Solvents

MRD Test Method 402
(Adaptation of AASHTO T 44-80)

1. Scope
1.1 The solubility test determines the bitumen content of asphalt cement. The portion of asphalt cement that is soluble in carbon disulfide represents the active cementing constituents. This method of test is applicable to the determination of the degree of solubility in organic solvents of bituminous road materials having little or no mineral matter. Most bituminous materials are equally soluble in carbon disulfide, carbon tetrachloride, and trichloroethylene. Because carbon tetrachloride and trichloroethylene are not flammable they are recommended solvents to be used in this test method.

2. Summary of Method
2.1 The sample is dissolved in a specified solvent and filtered through an asbestos filter mat. The insoluble material is washed, dried and weighed.

3. Apparatus and Materials
3.1 Filtering Assembly-Any suitable assembly permitting vacuum filtration with the Gooch crucible may be used. One such assembly is shown in Fig. 1. Details of the components are as follows:
3.1.1 Filter Flask-Heavy wall with side tube, 250 ml or larger.
3.1.2 Filter Funnel--40 to 42 mm inside diameter.
3.1.3 Rubber Tubing or Adapter-For holding the Gooch crucible on the filter funnel.
3.2 Gooch Crucible-Glazed inside and outside with the exception of the outside bottom surface. The appropriate dimensions shall be a diameter of 44 mm at the top tapering to 36 mm at bottom and a depth of 28 mm.
3.3 Asbestos-Long fiber (amphibole), acid-washed for Gooch crucibles.
3.4 Desiccator-Of suitable size, charged with an effective desiccant.
3.5 Analytical Balance-A class A balance conforming to the requirements of MRDTM 102.
3.6 Muffle Furnace-A furnace capable of obtaining temperatures of 650 C. Not required when using the glass fiber filter discs in place of asbestos.

Note 1: Fiberglass filter discs may be used instead of asbestos filter mats if experience has shown them to be satisfactory.

4. Solvents
4.1 The solvent to be used shall be specified. Solvents suitable for use in this method are as follows:
4.1.1 Carbon Tetrachloride, Reagent Grade-Since it is nonflammable this solvent is generally designated for use in determining the degree of solubility of petroleum asphalts.
4.1.2 Trichloroethylene, Technical Grade -This is a nonflammable solvent applicable to petroleum asphalts as a substitute for carbon tetrachloride for determining the degree of solubility. It is less toxic than carbon tetrachloride.

5. Safety Precautions
5.1 All organic solvents are toxic to some degree and good ventilation should be provided in all cases.

6. Preparation of Gooch Crucible
6.1 Thoroughly shake a portion of the asbestos fiber in distilled water so as to form a thin suspension in which the asbestos fibers are evenly dispersed.
6.2 Assemble the filtering apparatus as shown in Fig. 1. Fill the crucible with some of the suspension of asbestos in water and allow it to partly settle in the crucible. Apply a light suction to draw off the water, leaving a firm mat of asbestos in the crucible. Add more suspended asbestos and repeat the process until a mat is built up that after ignition, will weigh 0.5 ± 0.1 g (Note 2). Wash the asbestos mat thoroughly with water, dry in an oven, and ignite in a muffle furnace at 600 to 650 C. Cool the crucible in a desiccator and weigh to the nearest 0.1 mg. Repeat the ignition and cooling until constant mass (± 0.3 mg) is obtained. Store in a desiccator until ready for use.
Note 2: In the determination, the asbestos irreversibly absorbs a small amount of soluble bitumen (usually 1 to 5 mg per g of asbestos). The mass of asbestos used should, therefore, be kept within the specified limits to ensure reproducible results.

7. Temperature of Test

7.1 Normally the temperature at which this test is run is not critical and it may be performed at the laboratory air temperature. For referee tests, however, the flask and sample in solution should be placed in a water bath maintained at 37.8 ± 0.25 C for one h before filtering.

8. Procedure

8.1 Note safety precautions in Sec 5 and 7. Transfer approximately 2 g of the sample into a tared 125 ml Erlemmeyer flask or other suitable container. Weigh accurately to the nearest mg. Add 100 ml of the specified solvent to the container in small portions with continuous agitation until all lumps disappear and no undissolved sample adheres to the container. Stopper the flask or otherwise cover the container and set aside for at least 15 minutes (Sec 7).

8.2 Place the previously prepared and weighed Gooch crucible in the filtering funnel. Wet the asbestos mat with a small portion of clean solvent and decant the solution through the asbestos mat of the crucible with or without light suction as may be necessary. When the insoluble matter is appreciable, retain as much of it as possible in the container until the solution has drained through the mat. Wash the container with a small amount of solvent and using a stream of solvent from a wash bottle, transfer all insoluble matter to the crucible. Use a policeman, if necessary, to remove any insoluble matter adhering to the container, rinse the policeman and container thoroughly. Wash the insoluble matter in the crucible with solvent until the filtrate is substantially colorless, then apply strong suction to remove the remaining solvent. Remove the crucible from the tube, wash the bottom free of any dissolved matter, and place the crucible on top of an oven or on a steam bath until all odor of the solvent is removed. (Note the safety precautions in Sec 5). Place the crucible in an oven at 110 ± 5 C for at least 20 minutes. Cool in a desiccator and weigh. Repeat the drying and weighing until a constant mass (± 0.3 mg) is obtained (Note 3). Except for referee tests, previously used crucibles may be used.

Note 3: In order to obtain precise results when using an asbestos mat, the cooling time in the desiccator must be approximately the same (within ± 5 minutes) after all heatings. For example, if the empty crucible is weighed after a 30 minute cooling time in the desiccator, the crucible containing the insoluble matter must also be weighed after 30 ± 5 minutes cooling time in the desiccator. Empty crucibles or crucibles containing insoluble matter that have remained in a desiccator overnight should be reheated in an oven for at least 30 minutes, then allowed to cool before weighing.

9. Calculations and Report

9.1 On Form No. MRDWS 402 calculate either the total percentage of insoluble matter or the percentage of the sample soluble in the solvent used as follows:

\[
\text{Insoluble Matter, } \% = \frac{A}{B} \times 100 \\
\text{Soluble Matter, } \% = 100 - \frac{A}{B} \times 100
\]

where:
A = total mass insoluble, g, and
B = total mass of sample, g.

9.1.1 For percentages of insoluble less than 1.0 percent, report on Form No. MRDTR 400A, to the nearest 0.01 percent; percentages of insoluble of 1.0 or more, report to the nearest 0.1 percent.
Fig. 1. Filtering Apparatus Assembly.
# Solubility of Bituminous Material in Organic Solvent

**Field Sample No.** 4  
**Lab Sample No.** BR 2424  
**Project:** FCP 285  
**Date Sampled:** 5/5/82  
**Date Received:** 5/7/82  
**Date Tested:** 5/8/82  
**Sampled By:** Y. Toha  
**Title:** Inspector  
**Sampled Material:** MC-3 Cutback Asphalt  
**Tested By:** F. Manrubia  
**Title:** Lab Technician  
**Road No.:** 202-203  
**Road Name:** DAMMAM - RES TAMUR

<table>
<thead>
<tr>
<th>Reagent Grade Solvent Used:</th>
<th>Carbon Tetrachloride</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trichloroethylene</td>
<td></td>
</tr>
</tbody>
</table>

### Calculation Table

<table>
<thead>
<tr>
<th>Mass of Flask and Sample</th>
<th>g</th>
<th>137.360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Flask</td>
<td>g</td>
<td>135.860</td>
</tr>
<tr>
<td>Mass of Sample</td>
<td>g</td>
<td>9.120</td>
</tr>
<tr>
<td>Mass of Crucible, Filter and Residue</td>
<td>g</td>
<td>26.163</td>
</tr>
<tr>
<td>Mass of Crucible and Filter</td>
<td>g</td>
<td>26.158</td>
</tr>
<tr>
<td>Mass of Residue</td>
<td>0.005</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insoluble Matter, Percent*</th>
<th>A/B x 100</th>
<th>0.24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble Matter, Percent**</td>
<td>100 - A/B x 100</td>
<td>99.76</td>
</tr>
</tbody>
</table>

### Notes

- **NOTE:** Report to the nearest 0.01 percent if less than 1.0 percent.  
  Report to the nearest 0.1 percent if equal to or greater than 1.0 percent.  
- **NOTE:** Record on MRDTR 400-A, Line 1 or 2.

### Remarks

- 

### Checked by:

**T. Williams**  
**Title:** Lab Supervisor  
**Date:** 5/8/82

**Materials Engineer:** J. Smith  
**Consultant:** R. White  
**Resident Engineer:** J. Dunbar  
**Contractor:**

**Distribution:**  
- Contractor  
- Resident Engineer  
- Ministry  
- Other (Specify)
<table>
<thead>
<tr>
<th>Line</th>
<th>MRDTM</th>
<th>Material Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>402</td>
<td>Bitumen Soluble in Trichloroethylene</td>
<td>percent</td>
<td>99.76</td>
<td>99.5+</td>
</tr>
<tr>
<td>2</td>
<td>402</td>
<td>Bitumen Soluble in Carbon Tetrachloride</td>
<td>percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>403</td>
<td>Cleveland Open Cup Flash Point</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>403</td>
<td>Cleveland Open Cup Fire Point</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>404</td>
<td>Penetration @ 5 C, 60 C, and 80 C</td>
<td>0.10 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>405</td>
<td>Ductility @ 25 C and 50 mm/minute</td>
<td>cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>406</td>
<td>Softening Point</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>421</td>
<td>Saybolt Universal Viscosity @ 60 C, SSU</td>
<td>s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>421</td>
<td>Saybolt Furol Viscosity @ 60 C, SSF</td>
<td>s</td>
<td>325</td>
<td>150-500</td>
</tr>
<tr>
<td>10</td>
<td>422</td>
<td>Volume Percent of Total Distillate to 360 C</td>
<td>percent</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>422</td>
<td>Residue Content, Volume Percent</td>
<td>percent</td>
<td>75</td>
<td>73.1+</td>
</tr>
<tr>
<td>12</td>
<td>422</td>
<td>Volume Percent of Distillate of Original Sample Up to 190 C</td>
<td>percent</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>422</td>
<td>Volume Percent of Distillate of Original Sample Up to 225 C</td>
<td>percent</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>422</td>
<td>Volume Percent of Distillate of Original Sample Up to 260 C</td>
<td>percent</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>422</td>
<td>Volume Percent of Distillate of Original Sample Up to 316 C</td>
<td>percent</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>422</td>
<td>Distillate, Volume Percent of Total Distillate to 360 C, Up to 190 C</td>
<td>percent</td>
<td>0</td>
<td>0.5+</td>
</tr>
<tr>
<td>17</td>
<td>422</td>
<td>Distillate, Volume Percent of Total Distillate to 360 C, Up to 225 C</td>
<td>percent</td>
<td>3</td>
<td>0.4+</td>
</tr>
<tr>
<td>18</td>
<td>422</td>
<td>Distillate, Volume Percent of Total Distillate to 360 C, Up to 260 C</td>
<td>percent</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>422</td>
<td>Distillate, Volume Percent of Total Distillate to 360 C, Up to 316 C</td>
<td>percent</td>
<td>60</td>
<td>5.5-84</td>
</tr>
<tr>
<td>20</td>
<td>422</td>
<td>Penetration of Residue (MRDTM 404)</td>
<td>0.10 mm</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>422</td>
<td>Ductility of Residue (MRDTM 405)</td>
<td>cm</td>
<td>150+</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>422</td>
<td>Softening Point of Residue (MRDTM 406)</td>
<td>C</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>422</td>
<td>Saybolt Viscosity of Residue @ 40 C (MRDTM 421)</td>
<td>s</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>422</td>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>420</td>
<td>Tag Open Cup Flash Point</td>
<td>C</td>
<td>75</td>
<td>55.6+</td>
</tr>
<tr>
<td>26</td>
<td>408</td>
<td>TFOT: Mass Percent of Original Material</td>
<td>percent</td>
<td>99.24</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>409</td>
<td>TFOT: Percent Retained Penetration</td>
<td>percent</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>409</td>
<td>TFOT: Percent Retained Ductility</td>
<td>percent</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>409</td>
<td>TFOT: Other:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>407</td>
<td>Specific Gravity @ 25 C, 25 C</td>
<td>cSt</td>
<td>1.015</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>408</td>
<td>Kinematic Viscosity @ 25 C</td>
<td>cSt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remarks:

CHECKED BY: T. Williams | TITLE: Lab Supervisor | DATE: 5/11/82
MATERIALS ENGINEER: J. Smith | CONSULTANT: R White
RESIDENT ENGINEER: J. Dunbar

DISTRIBUTION: □ CONTRACTOR | □ MINISTRY | □ RESIDENT ENGINEER | □ OTHER (Specify)
### Bituminous Mixtures

<table>
<thead>
<tr>
<th>Line</th>
<th>MRDTM</th>
<th>Material Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>418</td>
<td>Bitumen Content of Dry Sample (Asphalt Content)</td>
<td>g</td>
<td>5.9</td>
<td>4-7</td>
</tr>
<tr>
<td>2</td>
<td>418</td>
<td>Ash Correction</td>
<td>%</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>416</td>
<td>Moisture Content of Bituminous Mixture by Mass</td>
<td>%</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>416</td>
<td>Volatile Distillate Content of Bituminous Mixture by Mass</td>
<td>%</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>411</td>
<td>Bulk Specific Gravity, Method XA</td>
<td>kg/cm³</td>
<td>2.445 - 2.448</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>414</td>
<td>Compressive Strength</td>
<td>Kg/cm²</td>
<td>107.8</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>413</td>
<td>Coated Area: X Above 95% □ Below 95%</td>
<td>%</td>
<td>70.4</td>
<td>70 min</td>
</tr>
<tr>
<td>8</td>
<td>412</td>
<td>Maximum Specific Gravity</td>
<td>kg/cm³</td>
<td>2.444</td>
<td>2.45</td>
</tr>
<tr>
<td>9</td>
<td>415</td>
<td>Index of Retained Strength</td>
<td>%</td>
<td>70.4</td>
<td>70 min</td>
</tr>
<tr>
<td>10</td>
<td>410</td>
<td>Marshall Design: Stability</td>
<td>kg</td>
<td>925</td>
<td>700 min</td>
</tr>
<tr>
<td>11</td>
<td>410</td>
<td>Marshall Design: Unit Mass</td>
<td>g/cm³²</td>
<td>2.483</td>
<td>2.48</td>
</tr>
<tr>
<td>12</td>
<td>410</td>
<td>Marshall Design: Air Voids</td>
<td>%</td>
<td>5.9</td>
<td>3.0-5.0</td>
</tr>
<tr>
<td>13</td>
<td>410</td>
<td>Marshall Design: Flow</td>
<td>%</td>
<td>4.0</td>
<td>24.4</td>
</tr>
<tr>
<td>14</td>
<td>410</td>
<td>Marshall Design: VMA</td>
<td>%</td>
<td>16.8</td>
<td>16.8</td>
</tr>
<tr>
<td>15</td>
<td>410</td>
<td>Marshall Design: Asphalt Content</td>
<td>%</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>423</td>
<td>Average Least Dimension of Cover Aggregate</td>
<td>mm</td>
<td>10.80</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>419</td>
<td>Mechanical Analysis of Extracted Aggregate</td>
<td>mm</td>
<td>10.80</td>
<td></td>
</tr>
</tbody>
</table>

#### Sieve Analysis

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Percent Passing</th>
<th>Job Mix Formula</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0</td>
<td>100</td>
<td>100</td>
<td>+6</td>
</tr>
<tr>
<td>12.5</td>
<td>90</td>
<td>95</td>
<td>+6</td>
</tr>
<tr>
<td>6.0</td>
<td>55</td>
<td>59</td>
<td>+6</td>
</tr>
<tr>
<td>2.0</td>
<td>40</td>
<td>39</td>
<td>+5</td>
</tr>
<tr>
<td>0.425</td>
<td>21</td>
<td>19</td>
<td>+5</td>
</tr>
<tr>
<td>0.180</td>
<td>14</td>
<td>13</td>
<td>+5</td>
</tr>
<tr>
<td>0.075</td>
<td>61</td>
<td>61</td>
<td>+2</td>
</tr>
</tbody>
</table>

### Remarks:

__________________________

### Checked by:

T. Williams  
TITLE: Lab Supervisor  
DATE: 5/18/82

### Materials Engineer:

J. Smith  
(Consultant)

### Resident Engineer:

J. Dunbar  
(Contractor)

### Distribution:

- [x] Contractor
- [x] Resident Engineer
- [ ] Ministry
- [ ] Other (Specify)
Kingdom of Saudi Arabia  
Ministry of Communications  
Materials and Research Department

Standard Method of Test for  
Flash and Fire Points by Cleveland Open Cup 

MRD Test Method 403  
(SAS 25/1976)

1. Scope  
1.1 This standard is concerned with the method of determining the Flash and Fire Points for petroleum products by 
Cleveland Open Cup, except fuel oils and petroleum products having a flash point lower than 79 C.

2. Definitions  
2.1 Flash point  
2.1.1 The lowest temperature at which the vapours above the surface of the sample are ignited when the test flame is 
applied to them.  
2.2 Fire point  
2.2.2 The lowest temperature at which the sample itself is ignited when the test flame is applied to it.

3. Apparatus  
3.1 Cleveland Open Cup Apparatus as shown in Fig. 1 consists of:  
3.1.1 The test cup shown in Fig. 2.  
3.1.2 Heating plate.  
3.1.3 Test flame applicator to give a small flame.  
3.1.4 A shield 460 mm square area and 6 10 mm high with an open front.  
3.2 Certificated thermometers having a range from -6 C to 400 C.

4. Preparation of Apparatus  
4.1 Put the apparatus on a fixed horizontal table away from air draughts. Protect the apparatus from strong light to 
allow easy detection of the flash.  
4.1.1 In special cases, when the sample produces objectionable vapours, put the apparatus in a hood and adjust the draft 
of air so that it does not affect the surface of the liquid, especially during the final 56 C before the expected flash point.  
4.2 Wash the test cup with an appropriate solvent to remove any residual oil or traces of gum remaining from the 
previous test. Also remove any carbonic deposits. Wash the cup with cold water and dry for a few minutes over an open 
flame or hot plate. Cool the cup to at least 56 C below the expected flash point before using.  
4.3 Support the thermometer in a vertical position with the bottom of the bulb at 6.4 mm from the bottom of the cup and 
locate it at a point midway between the centre and side of the cup on the opposite side from the test flame.

5. Procedure  
5.1 Fill the cup of the apparatus with the oil at any convenient temperature so that the top of meniscus is exactly at the 
filling line of the cup. If too much of the sample is added, it can be removed by using a fine tube. Care should be taken that 
any part of the sample shall not flow on the outside surface of the cup. If this occured, empty the sample, clean the cup and 
refill again. Any air bubbles on the surface of the sample must be removed.  
5.1.1 In case of high viscous oils the sample shall be heated to not more than a temperature of 56 C less than the 
anticipated flash point.  
5.2 Light the test flame and adjust it to a diameter of 3.2 - 4.8 mm, the size of the comparison bead mounted on the 
apparatus.  
5.3 Begin heating the sample so that the rate of the temperature-increase of the sample is 14 -16 C degrees per minute. 
When the temperature is 56 C below the anticipated flash point, decrease the heat so that the rate of temperature-increase in 
the last 28 C before the flash point is 5-6 degrees per minute.  
5.4 At the heat degree of 28 C below the flash point, and whenever the temperature rises 2 C, pass the test flame in one 
direction only, horizontally, across the centre of the cup not more than 2 mm above the upper edge of the cup, then pass the 
test flame in the opposite direction. The time taken to pass the test flame across the cup shall be about one second. When the 
flash point approaches, care shall be taken not to avoid breathing or making any movement that may cause air draughts near 
the cup.
5.5 Record the temperature read on the thermometer when a flash appears at any point on the surface of the oil as the observed flash point. Care shall be taken not to confuse the true flash with the bluish halo that sometimes surrounds the test flame.

5.6 To determine the observed Fire Point, continue heating the sample at the rate of 5-6 degrees per minute, applying the test flame at 2 C intervals until the oil ignites and continues to burn for at least 5 seconds.

5.6.1 Record this temperature as the observed Fire Point.

6. Report

6.1 The observed Flash or Fire Point (items 5.5 and 5.6) shall be corrected when the prevailing pressure differs from the normal atmospheric pressure, by using the following equation:

\[
\text{Flash or Fire Point} = \text{Observed Flash or Fire Point} + 0.025 (1013-P)
\]

where:

P = Atmospheric pressure prevailing at the time of experiment in m. bars.

7. References

7.1 American Society for Testing and Materials-ASTM D92 (1966), "Flash and Fire Points by Cleveland Open Cup".

7.2 Egyptian Organization for Standardization-E.S. 159/62 "Determination of Flash and Fire Points by Cleveland Apparatus".

---

**Fig. 1. Cleveland Open Cup Apparatus**

**Fig. 2. Cleveland Open Cup**
Standard Method of Test for
Penetration of Asphalt Materials

MRD Test Method 404
(Adaptation of AASHTO T 49-80)

1. Scope

1.1 This method describes a procedure for determining the penetration of semisolid and solid asphalt materials.

1.2 The penetration test determines the relative hardness or consistency of an asphalt material by measuring the distance that a standard needle will penetrate vertically into a sample under known conditions of temperature, loading, and time. When other conditions are not specifically mentioned, it is understood that a penetration value or measurement is made at 25 °C that the needle is loaded to 100 g and that load is applied for 5 s. This is known as standard penetration. The unit of penetration is 0.10 mm. The softer the asphalt material, the greater will be its number of penetration units. By means of penetration units, asphalt cements are classified into grades on the basis of hardness or consistency, such as 40-50, 60-70, 85-100, 120-150, and 200-300.

2. Outline of Method

2.1 The sample is melted and cooled under controlled conditions. The penetration is measured with a penetrometer by means of which a standard needle is applied to the sample.

3. Description

3.1 The penetration of an asphalt material is the distance in tenths of a millimeter that a standard needle penetrates vertically into a sample of the material under fixed conditions of temperature, load, and time.

4. Apparatus

4.1 Penetration Apparatus—Any apparatus permitting movement of the spindle without appreciable friction and which is accurately calibrated to yield results in accordance with the description of the term penetration (Sec 3.1) will be acceptable. The surface on which the sample container rests shall be flat and the axis of the plunger shall be at approximately 90 degrees to this surface. The spindle shall be detachable without the use of special tools, for checking its mass. When the needle is mounted in the ferrule, the mass of the moving spindle shall be 47.5 ± 0.05 g. Regardless of the type of mounting of the needle, the total mass of the needle and spindle assembly shall be 50.0 ± 0.1 g. Masses of 50.0 ± 0.05 g and 100.0 ± 0.05 g shall be provided for total loads of 100 g and 200 g depending upon the condition of test to be applied. A typical test setup is illustrated in Fig. 1.

4.2 Needle—The needle (Fig. 2) shall be made from fully hardened and tempered stainless steel, grade 440 C or equal, HRC 54 to 60. It shall be approximately 50 mm (or 2 in.) in length and 1.00 to 1.02 mm (0.039 to 0.040 in.) in diameter. It shall be symmetrically tapered at one end to a cone whose angle shall be within the range of 8.7 to 9.7 degrees over the entire length from full needle diameter, and whose axis shall be coincident with the needle axis within 0.0127 mm (0.0005 in.) maximum runout (total indicator reading). After tapering, the point shall be ground off to a truncated cone, the smaller base of which shall be from 0.14 to 0.16 mm (0.0055 to 0.0063 in.) in diameter. The truncation shall be square with the needle axis within 2 degrees and the edge shall be sharp and free from burrs.

4.2.1 When the surface texture of the tapered cone surface is measured in accordance with American National Standards Institute Standard B46. 1, the surface roughness height shall be 0.2 to 0.3 micro m (8 to 12 micro in.).

4.2.2 The exposed length of the needle when mounted in the chuck of the penetration apparatus or in a ferrule shall be approximately 40 to 45 mm (1.57 to 1.77 in.). When the needle is mounted in a ferrule, the ferrule shall be a cylindrical rod, 3.20 ± 0.05 mm (0.126 ± 0.002 in.) in diameter and approximately 38 mm (or 1.5 in.) long, made of stainless steel or brass, in which the needle shall be rigidly and coaxially mounted. The mass of the ferrule needle assembly shall be 2.50 ± 0.05 g. A drill hole is permissible at the end of the ferrule to control its mass.

4.3 A container, in which the sample is tested, shall be made of metal or glass, be cylindrical in shape, and have a flat bottom. The container to be used for materials having a penetration of 200 or less shall have a nominal capacity of 90 ml (or 3 oz). Its inside dimensions shall be approximately as follows: 55 mm (2.17 in.) in diameter and 35 mm (1.38 in.) in depth. The container to be used for materials having a penetration over 200 shall have a nominal capacity of 175 ml (or 6 oz). Its inside dimensions shall be approximately as follows: 70 mm (2.75 in.) in diameter and 45 mm (1.77 in.) in depth (Note 1).
Note 1: Containers known as tin boxes or as seamless ointment boxes may be obtained in dimensions conforming to the requirements of Sec 4.3.

4.4 A water bath maintained at a temperature varying not more than 0.1 C from the temperature of the test shall be used. The volume of water shall not be less than 10 liters. The height of the bath shall be such that the perforated shelf will be at least 50 mm above the bottom of the bath and that the level of water will be at least 150 mm above the top of the perforated shelf. Do not allow the water bath to become contaminated with oil or slime. Brine may be used in the water bath for determinations at low temperatures. If penetration tests are to be made without removing the sample from the bath, a shelf strong enough to support the penetration apparatus shall be provided.

4.5 Transfer Dish for Container-When used, the transfer dish for the container shall be a cylinder with a flat bottom made of glass, metal, or plastic. It shall be provided with some means which will insure a firm bearing and prevent rocking of the container. It shall have a minimum inside diameter of 90 mm (or 3.5 in.) and a minimum depth above the bottom bearing of 55 mm (or 2.2 in.).

4.6 Thermometers for Water Bath-The following thermometers conforming to the requirements of ASTM Specification E 1, ASTM Thermometers are required:
   4.6.1 For tests at 25 C use an ASTM Saybolt Viscosity Thermometer 17 C having a range of 19 to 27 C. The thermometer shall be immersed 150 ± 15 mm in the bath.
   4.6.2 For tests at 0 C and 4 C use ASTM Precision Thermometer 63 C having a range of -8 to +32 C. The thermometer shall be immersed 150 ± 15 mm in the bath.
   4.6.3 For tests at 46.1 C use ASTM Precision Thermometer 64 C having a range of 25 to 55 C. The thermometer shall be immersed 150 ± 15 mm in the bath.
   4.6.4 Since the accuracy of the test results is dependent upon closely controlled temperature conditions, the thermometer used for the water bath should be calibrated by ASTM E 77, Inspection, Test, and Standardization of Etched-Stem Liquid-in-Glass Thermometers.
   4.7 Timing Device-For hand operated penetrometers any convenient timing device such as an electric timer, a stop watch, or other spring activated device may be used provided it is graduated in 0.1 s or less and is accurate to within ± 0.1 s for a 60 s interval. An audible seconds counter adjusted to provide 1 beat each 0.5 s may also be used. The time for an 11 count interval must be 5 ± 0.1 s. Any automatic timing device attached to a penetrometer must be accurately calibrated to provide the desired test interval within ± 0.1 s.

4.8 An oven or hot plate, heated by electricity or gas, shall be provided for melting samples.

5. Preparation of Sample

5.1 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 not more than 100 C above its expected softening point determined in accordance with the Test for Softening Point of Asphalt in Ethylene Glycol (Ring-and-Ball) (MRDTM 406). Avoid the inclusion of air bubbles. Then 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. Pour separate samples for each variation in test conditions.

5.2 Loosely cover each container and its contents as a protection against dust, and allow to cool in an atmosphere at a temperature not higher than 30 C and no lower than 20 C for not less than 1½ h nor more than 2 h when the sample is in a 175 ml (or 6 oz) container and for not less than 1 h nor more than 1½ h when the sample is in a 90 ml (or 3 oz) container. Then place the sample in the water bath maintained at the prescribed temperature of test, along with the transfer dish if used, and allow it to remain for not less than 1½ h nor more than 2 h when the sample is in the 175 ml (or 6 oz) container, and for not less than 1 h nor more than 1½ h when the sample is in a 90 ml (or 3 oz) container.

6. Test Conditions

6.1 Where the conditions of test are not specifically mentioned, the temperature, load, and time are understood to be 25 C, 100 g, 5 s respectively. Other conditions of temperature, load, and time may be used for special testing. The temperatures, loads and times are summarized in Table 1. In such cases, the specific conditions of test shall be reported.

<table>
<thead>
<tr>
<th>Temperature, C</th>
<th>Load, G</th>
<th>Time, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>46.1</td>
<td>50</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1

Other Penetration Test Conditions
7. Procedure

7.1 Unless otherwise specified, place the 50 g weight above the needle, making the nominal total load of 100 g for the needle and attachment. If 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. Using the above procedures the container shall be kept completely submerged during the entire test. 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 completely cover 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 loaded with the specified mass to just make contact with the surface of the sample. Accomplish this by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light (Note 2). Bring the pointer on the dial to read zero. Then quickly release the needle for the specified period of time and adjust the instrument to measure the distance penetrated. Observe the sample container as the needle is applied, and if any movement of the container is noted, discard the test result (Note 3).

Note 2: The positioning of the needle can be materially aided by using an illuminated methyl methacrylate rod.

Note 3: For referee tests, penetrations at temperatures other than 25 C should be made without removing the sample from the bath.

7.2 Make at least three penetrations at points on the surface of the sample not less than 10 mm (or 3/8 in.) from the side of the container and not less than 10 mm (or 3/8 in.) 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 toluene or other suitable solvent to remove all adhering bitumen, and then wipe with a clean dry cloth. For penetration values greater than 200, use at least three needles, leaving them in the sample until completion of the penetrations.

8. Report

8.1 Report on Form No. MRDTR 400A to the nearest whole unit the average of at least three penetrations whose values do not differ by more than the amount shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Penetration Range</th>
<th>Maximum Difference Between Highest and Lowest Determinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 49</td>
<td>2</td>
</tr>
<tr>
<td>50 to 149</td>
<td>4</td>
</tr>
<tr>
<td>150 to 249</td>
<td>6</td>
</tr>
<tr>
<td>250 and over</td>
<td>8</td>
</tr>
</tbody>
</table>
Fig. 1. Penetrometer with Automatic Timer.

1.00 to 1.02 mm

8.7 to 9.7 Degrees

0.14 to 0.16 mm

Approx. 6.35 mm

Approximately 50 mm (2 Inches)

Fig. 2. Needle for Penetration Test.
1. Scope
   1.1 The ductility of an asphalt material is measured by the distance to which it will elongate before breaking when two ends of a briquet specimen of the material, of the form described in Sec 2, are pulled apart at a specified speed and at a specified temperature. Unless otherwise specified, the test shall be made at a temperature of 25 ± 0.5 \(^{\circ}\)C and at the rate of 50 mm per minute ± 2.5 mm per minute (± 5.0 percent). The test may be run at other temperatures as specified.

   1.2 In many applications, ductility is an important characteristic of asphalt cements. The presence or absence of ductility, however, is usually of more significance than the actual degree of ductility. Asphalt cements possessing ductility are normally more adhesive than asphalt cements lacking this characteristic. Asphalt cements having an exceedingly high degree of ductility are usually more temperature susceptible. In some applications, such as paving mixtures, ductility and adhesion are important; while in others, such as undersealing and crack filling, the more essential property is low temperature susceptibility.

2. Apparatus
   2.1 Molds-The mold shall be similar in design to that shown in Fig. 1. Dimensions shown in Fig. I shall be as given with the permissible variations indicated. The mold shall be made of brass, the ends b and b’ being known as clips, and the parts a and a’ as sides of the mold. The dimensions of the mold shall be such that, when properly assembled, it will form a briquet specimen having the following dimensions:

   - Total length (A) ..................... 74.5 to 75.5 mm
   - Distance between clips (B) .... 29.7 to 30.3 mm
   - Width at mouth of clip(C) ..... 19.8 to 20.2 mm
   - Width at minimum cross section (halfway between clips) (D) ... 9.9 to 10.1 mm
   - Thickness throughout(E) ........9.9 to 10.1 mm

   2.2 Base Plate-The base plate shall be made of non-absorbent material, of sufficient thickness to prevent deformation, and of a sufficient size to hold from one to three molds, as desired. The plate shall be flat so that the bottom surfaces of each mold will touch it throughout.

   2.3 Water Bath-The water bath shall be maintained at the specified test temperature, varying not more than 0.1 \(^{\circ}\)C from this temperature. The volume of water shall be not less than 10 liters. The height of the bath shall be such that the mold can be immersed to a depth of not less than 100 mm and be supported on a perforated shelf not less than 50 mm from the bottom. The water in the bath shall be free from oil and slime or other organic growths.

   2.4 Thermometers-For tests at 25 \(^{\circ}\)C use ASTM Saybolt Viscosity Thermometer No. 17 \(^{\circ}\)C to measure the temperature of the water of the bath and the temperature of the water in the testing machine. For tests at other temperatures, use ASTM thermometers of an appropriate range and an accuracy equal to that of the No. 17 \(^{\circ}\)C. Since the accuracy of the test results is dependent upon closely controlled conditions of temperature, the thermometers should be calibrated using the Method for Verification and Calibratation of Liquid-in-Glass Thermometers (ASTM Designation E 77).

   2.5 Testing Machine-For pulling the briquet of asphalt material apart, any apparatus may be used which is so constructed that the specimen will be continuously immersed in water as specified in See 3.4, while the two clips are pulled apart at a uniform speed, as specified, without undue vibration.

   2.6 An oven or hot plate, heated by electricity or gas, may be used to melt the asphalt material.

   2.7 Any suitable container may be used to hold the asphalt material while being melted.

   2.8 Trimmer-Any convenient implement, such as a putty knife or spatula, may be used provided that the cutting edge is straight and at least 38 mm (1½ in.) wide.

3. Procedure
   3.1 Preparation of Apparatus-Assemble the mold on the base plate, and to prevent the material under test from sticking, coat the surface of the plate and the interior surfaces of sides a and a’ with a suitable release agent (Note 1).
Note 1: Mixtures of glycerine and dextrine or talc: Dow-Corning Silicone Stop Cock Grease, and castor oil Versamid 900 (100:1 mixture by mass heated from 204 to 232°C stirred until homogeneous) are suitable. Other release agents may be used provided results obtained are comparable to those obtained when using one of the above.

3.2 Molding Test Specimens-Heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour. After thorough stirring, taking care not to entrain any air bubbles, pour the asphalt material into the mold. Pour the material in a thin stream back and forth from end to end until the mold is more than level full. In filling the mold, take care not to disarrange the parts of the mold and so distort the briquet. Let the mold and contents cool to room temperature for a period of from 30 to 40 minutes and then place the base plate and filled mold in the water bath, maintained at the specified test temperature for 30 minutes. Remove the base plate and filled mold from the water bath, and with a hot trimmer cut off the excess asphalt material so that the mold is just level full. Take care during trimming that the specimen is not pulled away from the base plate or from the side pieces of the mold.

3.3 Keeping Specimen at Standard Temperatures-Place the base plate and mold, with briquet specimen, in the water bath and keep at the specified temperature for a period of from 85 to 95 minutes. Then remove the briquet from the plate, detach the side pieces, and immediately test the briquet.

3.4 Testing-At the start of the test, the water in the tank of the testing machine shall cover the specimen both above and below by 25 mm. Attach the clips to the pins or hooks of the testing machine and pull the clips apart at the specified rate of speed until the briquet ruptures or the limit of travel of the machine is reached. If necessary, by the use of a solute which does not interfere with the test, adjust the specific gravity of the liquid in the testing machine so that the asphalt material neither comes to the surface nor touches the bottom of the bath at any time during the test. Measure and record the distance (cm) through which the clips have been pulled to produce rupture. If the specimen failed to rupture within the capacity of the machine, record the distance (cm) which the clips have been pulled followed by a plus (+) symbol in parentheses.

4. Report

4.1 A normal test is one in which the material between the two clips pulls out to a point or thread until rupture occurs at the point where the thread has practically no cross sectional area or until the capacity of the machine is reached. If the material comes in contact with the surface of the water or the bottom of the bath, the test shall not be considered normal.

4.2 Report the average of three normal tests as the ductility of the sample. If a normal test is not obtained on three successive tests, report the ductility as being unobtainable under the conditions of the test.

![Fig. 1. Mold for Ductility Test Specimen.](image-url)
Standard Method of Test for

Softening Point of Asphalt in Ethylene Glycol (Ring-and-Ball)

MRD Test Method 406
(Adaptation of AASHTO T 53-80)

1. Scope

1.1 This method covers the determination of the softening point of asphalt (bitumen) in the range of 30 to 175 °C using the ring-and-ball apparatus in an ethylene glycol bath.

1.2 Different grade asphalts soften at different temperatures. The softening point is usually determined by the ring-and-ball test method. Although this test is not included in the specification tests for the paving grade asphalts, it is often used to characterize the harder materials used in applications other than paving. It indicates the temperatures at which these harder asphalts reach an arbitrary degree of softening. In this test the heated asphalt is poured into a brass ring of specified dimensions. The sample thus prepared is suspended in a water bath and a steel ball of specified dimensions and mass is placed on the center of the sample. The bath is heated at a controlled rate and the temperature at the instant the steel ball reaches the bottom plate is the softening point of the asphalt.

2. Summary of Method

2.1 A steel ball of specified mass and diameter is placed upon a disk of sample contained within a horizontal, shouldered, metal ring of specified dimensions. The assembly is heated in an ethylene glycol bath at a uniform prescribed rate and the softening point taken as the temperature at which the sample becomes soft enough to allow the ball enveloped in the sample material, to fall a distance of 25.4 mm (1 in.).

3. Significance

3.1 Asphalts do not change from the solid state to the liquid state at any definite temperature, but gradually become softer and less viscous as the temperature rises. For this reason, the determination of softening point must be made by a fixed, arbitrary, and closely defined method if the results obtained are to be comparable.

3.2 Softening point is useful in the classification of certain asphalts (bitumens) and is indicative of the tendency of the material to flow at elevated temperatures encountered in service.

4. Apparatus

4.1 Rings-Brass, square-shouldered rings conforming to the dimensions shown in Fig. 1 (a).

4.2 Balls-Steel balls 9.5 mm (or 3/8 in.) in diameter, each having a mass of 3.50 ± 0.05 g.

4.3 Ball Centering Guides-Guides constructed of brass and having the general shape and dimensions shown in Fig. 1 (c).

4.4 Bath-An 800 ml low form Griffin beaker of heat resistant glass.

4.5 Ring Holder-The rings shall be supported on a brass ring holder, Fig. 1 (b) in an assembly as shown in Fig. 1 (d).

4.5.1 Rings shall be supported in a horizontal position with the bottoms of the rings 25.4 mm ± 0.8 mm (1.00 ± 0.03 in.) above the upper surface of the bottom plate. There shall be a minimum distance of 12.7 mm (0.5 in.) and a maximum distance of 19.1 mm (0.75 in.) between the lower surface of the bottom plate and the bottom of the bath.

4.5.2 The thermometer shall be suspended so that the bottom of the bulb is level with the bottom of the rings and within 12.7 mm (0.5 in.) of the rings but not touching them.

4.6. Thermometers-A bituminous material softening point thermometer having a range from -1 to 175 °C and conforming to the requirements for Thermometer 113 °C as prescribed in ASTM E 1 or Thermometer 89 °C conforming to the IP Specification for Standard Thermometers.

5. Reagents and Materials

5.1 Bath Liquid-Ethylene glycol with a boiling point between 193 and 204 °C.

6. Preparation of Sample

6.1 Heat the sample with care, stirring as necessary, to prevent local overheating until it has become sufficiently fluid to pour. In no case should the temperature be raised above the expected softening point by more than 100 °C for asphalt. Do not heat for more than 30 minutes over a flame or hot plate or for more than 2 h in an oven, and avoid incorporating air bubbles in the sample.

6.2 Place two rings on a metal plate coated with a suitable release agent (Note 1).
**Note 1:** Mixtures of glycerine and dextrine or talc: Dow-Corning Silicone Stop Cock Grease, or castor oil Versamid 900 (100:1 mixture by mass heated to 204 to 232°C and stirred until homogeneous) have proven suitable. Other release agents may be used provided results obtained are comparable to those obtained when using one of the above.

6.3 Fill the rings with sufficient molten sample to give an excess of sample above the top of each ring when cooled. Cool 30 minutes in air, then level the specimens in the rings by cutting away the excess with a warmed knife (Note 2).

**Note 2:** For materials soft at room temperatures, cool for 30 minutes at a temperature of at least 8°C below the expected softening point.

6.4 Not more than 240 minutes should elapse between the time of pouring specimens and the completion of the test.

**7. Procedure**

7.1 Assemble the apparatus with the rings, thermometer, and ball guides in position, and fill the bath to a depth of 100 to 108 mm (or 4.0 to 4.25 in.) with ethylene glycol (Note 3).

**Note 3:** Caution-Ethylene glycol is toxic when taken internally or when inhaled as a vapor. Its flash point is 115°C when tested in accordance with MRDTM 403, Flash and Fire Points by Cleveland Open Cup. Conduct the test in a hood or other well ventilated location. Avoid prolonged or repeated contacts with skin and inhalation of vapors.

7.2 Maintain the bath temperature at 4 ± 1°C for 15 minutes (Note 4) and using forceps, place a ball previously cooled to the bath temperature in each ball guide.

**Note 4:** Any convenient means for maintaining the bath temperature at 4 ± 1°C may be used. Take care to avoid any contamination of the ethylene glycol with water or another liquid.

7.3 Heat the bath from below so that the temperature rises at a uniform rate of 5 ± 0.5°C per minute. Avoid drafts, use a shield if necessary (Note 5).

**Note 5:** Either a gas burner or electric heater may be used; however, the latter must be of the low lag, variable output type to maintain the specified rate of heating.

7.4 Do not average the rate of temperature rise over the test period. Reject any determination in which the rate of temperature rise does not fall within the specified limits after the first 3 minutes.

7.5 Record for each ring and ball, the temperature shown by the thermometer at the instant the material surrounding the ball touches the bottom plate. Make no correction for the emergent stem of the thermometer. If the difference between values obtained in the duplicate determinations exceed 1°C, repeat the test.

**8. Report**

8.1 Report on Form No. MRDTR 400A to the nearest 0.5°C the mean of the temperatures recorded in duplicate determinations as the softening point.
Fig. 1(a). Shouldered Ring.

A  (23.0 mm ± 0.3 mm)  0.91" ± 0.01"
B  (19.8 mm ± 0.3 mm)  0.78" ± 0.01"
C  (19.1 mm ± 0.3 mm)  0.75" ± 0.01"
D  (15.9 mm ± 0.3 mm)  0.63" ± 0.01"
E  ( 4.4 mm ± 0.3 mm)  0.17" ± 0.01"
F  ( 2.0 mm ± 0.3 mm)  0.08" ± 0.01"
G  ( 6.4 mm ± 0.4 mm)  0.25" ± 0.02"
H  ( 3.6 mm ± 0.3 mm)  0.14" ± 0.01"
I  ( 2.8 mm ± 0.3 mm)  0.11" ± 0.01"

Note A: This Diameter to be Slightly Larger (Approximately 0.002" (0.05 mm) than Dimension "A" of Fig. 1(a) Shouldered Ring-to-Slide Over Ring.

Fig. 1(b). Ring Holder.

A (19.1 mm See Note A)  0.75" (See Note A)
B (23.9 mm ± 0.5 mm)  0.94" ± 0.02"
C (76.2 mm ± 0.5 mm)  3.00" ± 0.02"
D ( 5.6 mm ± 0.5 mm)  0.22" ± 0.02"
E ( 5.6 mm ± 0.5 mm)  0.22" ± 0.02"
F (66.5 mm ± 0.5 mm)  2.62" ± 0.02"

Note A: This Diameter to be Slightly Larger (Approximately 0.002" (0.05 mm) than Dimension "C" of Fig. 1(a) Shouldered Ring-to-Permit Insertion of Ring. In Final Assembly the Thermometer Bulb Shall be Within 0.50" (12.7 mm) of, but not Touching the Ball Centering Guide.

Fig. 1(c). Ball Centering Guide

A (23.1 mm See Note B)  0.91" (See Note B)
B (9.6 mm See Note C)  0.38" (See Note C)
C ( 1.5 mm ± 0.5 mm)  0.06" ± 0.02"
D (24.6 mm ± 0.3 mm)  0.97" ± 0.01"
E ( 0.8 mm ± 0.5 mm)  0.03" ± 0.02"
F ( 3.0 mm ± 0.5 mm)  0.12" ± 0.02"
G ( 1.5 mm ± 0.3 mm)  0.06" ± 0.01"
H ( 4.8 mm ± 0.3 mm)  0.19" ± 0.01"
I ( 4.3 mm ± 0.3 mm)  0.17" ± 0.01"

Note B: This Diameter to be Slightly Larger (Approximately 0.002" (0.05 mm) than Dimension "A" of Fig. 1(a) Shouldered Ring-to-Slide Over Ring.

Note C: This Diameter to be Slightly Larger (Approximately 0.002" (0.05 mm) than 0.38" (9.6 mm) to Allow Placing and Centering of the Steel Ball.

Fig. 1(d). Two-Ring Assembly.

Fig. 1. Shouldered Ring, Ring Holder, Ball-Centering Guide, and Assembly of Apparatus Showing Two Rings
Standard Method of Test for
Specific Gravity of Semisolid Asphalt Materials

MRD Test Method 407
(Adaptation of AASHTO T 228-79)

1. Scope
1.1 This method covers the determination of the specific gravity of semisolid asphalt materials by use of a pycnometer.

2. Specific Gravity
2.1 The specific gravity of semisolid asphalt materials is expressed as the ratio of the mass of a given volume of the material at either 25 C, or 15.6 C, to that of an equivalent volume of water at the same temperature, and is expressed thus:

Specific gravity, 25/25 C or 15.6/15.6 C

3. Apparatus
3.1 Pycnometer, glass, consisting of a cylindrical or conical vessel carefully ground to receive a fitted glass stopper 22 to 26 mm in diameter. The stopper shall be provided with a hole 1.0 to 2.0 mm in diameter, centrally located in reference to the vertical axis. The top surface of the stopper shall be smooth and substantially plane, and the lower surface shall be concave in order to allow all air to escape through the bore. The height of the concave section shall be 4.0 to 6.0 mm at the center. The stoppered pycnometer shall have a capacity of 24 to 30 ml, and shall not weigh more than 40 g. Suitable pycnometers are illustrated in Fig. 1.

3.2 Water bath, constant temperature, capable of maintaining the temperature within 0.1 C of the test temperature.

3.3 Thermometer, having a range from -8 to 32 C, and conforming to the requirements for Thermometer 63 C as prescribed in ASTM Specification E 1, for ASTM Thermometers.

4. Materials
4.1 Distilled Water—Freshly boiled and cooled distilled water shall be used to fill the pycnometer and the beaker.

5. Preparation of Equipment
5.1 Partially fill a 600 ml or larger Griffin low form beaker with freshly boiled and cooled distilled water to a level that will allow the top of the pycnometer to be immersed to a depth of not less than 40 mm.

5.2 Partially immerse the beaker in the water bath to a depth sufficient to allow the bottom of the beaker to be immersed to a depth of not less than 100 mm, while the top of the beaker is above the water level of the bath. Clamp the beaker in place.

5.3 Maintain the temperature of the water bath within 0.1 C of the test temperature.

6. Calibration of Pycnometer
6.1 Thoroughly clean, dry, and weigh the pycnometer to the nearest 1 mg. Designate this mass as A.

6.2 Remove the beaker from the water bath. Fill the pycnometer with freshly boiled distilled water placing the stopper loosely in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Return the beaker to the water bath.

6.3 Allow the pycnometer to remain in the water for at least 30 minutes. Remove the pycnometer and immediately dry the top of the stopper with one stroke of a dry towel (Note 1), then quickly dry the remaining outside area of the pycnometer and weigh to the nearest 1 mg. Designate the mass of the pycnometer plus water as B.

Note 1: Do not redry the top of the stopper even if a small droplet of water forms due to expansion. If the top is dried at the instant of removing the pycnometer from the water, the proper mass of the contents at the test temperature will be recorded. If moisture condenses on the pycnometer during weighing, quickly dry the outside of the pycnometer (excluding the top) before recording the mass.

Note 2: Calibration should be done at the specified temperature. A pycnometer calibrated at one temperature cannot be used at a different temperature without calibration at that temperature.
7. Procedure

7.1 Preparation of Sample—Carefully heat the sample by stirring to prevent local overheating until the sample has become sufficiently fluid to pour. In no case should the temperature be raised to more than 100 °C above the expected softening point for the asphalt samples. Do not heat for more than 30 minutes over a flame or hot plate or for more than 2 h in an oven, and avoid incorporating air bubbles in the sample.

7.2 Pour enough sample into the clean, dry, warmed pycnometer to fill it about three fourths of its capacity. Take precautions to keep the material from touching the sides of the pycnometer above the final level, and to prevent the inclusion of air bubbles (Note 3). Allow the pycnometer and its contents to cool to ambient temperature for a period of not less than 40 minutes, and weigh with the stopper to the nearest 1 mg. Designate the mass of the pycnometer plus sample as C.

Note 3: If any air bubbles are inadvertently included, remove by brushing the surface of the asphalt in the pycnometer with a high “soft” flame of a bunsen burner. In order to avoid overheating, do not allow the flame to remain in contact with the asphalt for more than a few seconds at any one time.

7.3 Remove the beaker from the water bath. Fill the pycnometer containing the asphalt with freshly boiled distilled water, placing the stopper loosely in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Return the beaker to the water bath.

7.4 Allow the pycnometer to remain in the water bath for at least 30 minutes. Remove the pycnometer from the bath. Dry and weigh using the same procedure and timing as that prescribed in Sec 6.3. Designate this mass of pycnometer plus sample plus water as D.

8. Calculations

8.1 Calculate the specific gravity to four significant figures (the nearest third decimal), as follows:

\[
\text{Specific Gravity: } \frac{C - A}{(B - A) - (D - C)}
\]

where:
A = mass of pycnometer (plus stopper), g,
B = mass of pycnometer filled with water, g,
C = mass of pycnometer partially filled with asphalt, g, and
D = mass of pycnometer plus asphalt plus water, g.

9. Report

9.1 Report the specific gravity to the nearest third decimal at 25/25 °C or 15.6/15.6 °C.

![Fig. 1. Suitable Pycnometers.](image)
Specific Gravity of Semi-Solid Asphalt Materials

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38.774</td>
<td>38.774</td>
<td>38.774</td>
</tr>
<tr>
<td>B</td>
<td>63.892</td>
<td>63.892</td>
<td>63.892</td>
</tr>
<tr>
<td>C</td>
<td>56.64</td>
<td>56.64</td>
<td>56.64</td>
</tr>
<tr>
<td>D</td>
<td>62.763</td>
<td>62.763</td>
<td>62.763</td>
</tr>
</tbody>
</table>

**Sample Number**

- A. Mass of Pyrometer, *
- B. Mass of Pyrometer Plus Water, *
- C. Mass of Pyrometer Plus Sample, *
- D. Mass of Pyrometer Plus Sample Plus Water, *

**Specific Gravity**

\[
\begin{align*}
\text{Sample} & \quad 25^\circ & 25^\circ & \text{(B-A)} \\
A & 1.015 & 1.017 & 1.013 \\
B & 1.015 & 1.017 & 1.013 \\
C & 1.015 & 1.017 & 1.013 \\
D & 1.015 & 1.017 & 1.013 \\
\end{align*}
\]

**NOTES:**

- *Measure Mass to Nearest mg.

- **Calculate to 4 Significant Figures and Report on MRDTR 400-A, Line 30.

- ***Temperature of Sample (15.6 or 25 Ci).

- ****Temperature of Water (15.6 or 25 Ci).
1. Scope
   1.1 This standard is concerned with the method of determining the kinematic viscosity of liquid petroleum products both transparent and opaque (and calculating the dynamic viscosity from it) by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.

2. Definitions
   2.1 Viscosity (dynamic viscosity)-Measuring of the resistance to flow of a liquid. It is equal to the ratio between applied shear stress and the rate of shear.
   2.2 Kinematic Viscosity-The quotient obtained from dividing the viscosity by the density of the liquid.
   2.2.1 The unit of kinematic viscosity is centistoke or mm²/s.
   2.3 Viscometer Constant-A number when multiplied by the flow time of a liquid by a certain viscometer gives the value of kinematic viscosity of that liquid.

3. Apparatus
   3.1 Viscometer of the glass capillary type capable of measuring kinematic viscosity within the limits of precision given in 6.2. Table 1 in the Appendix gives names of some viscometers and their viscosity ranges.
   3.2 Viscometer holder to hold the viscometer in a vertical position while immersed in constant temperature bath.
   3.3 Bath of viscometer and thermostat.
   3.3.1 A bath filled with any transparent liquid (or a vapour bath) provided that it is of sufficient depth that (at any time during the measurement) any portion of the sample inside the viscometer shall be at least 20 mm below the surface of the bath liquid and that the lowest point of the viscometer be at least 20 mm above the bottom of the bath.
   3.3.2 A thermostat for controlling the bath temperature so that within the range of 15-100 C, the bath temperature variation shall not exceed ± 0.01 C. As for temperatures outside this range, the variation shall not exceed 0.03 C.
   3.4 Calibrated thermometer of a narrow range and a minimum accuracy of 0.02 C.
   3.5 A timing device (such as a stop watch) with a accuracy within ± 0.07% when tested over intervals of 15 minutes each and with the provision that the reading can be taken with a discrimination of 0.2 seconds or less.

4. Calibration
   4.1 Viscometers shall be calibrated by standard oil of known viscosity (Table 2 in Appendix).
   4.2 Thermometers shall be calibrated to 0.01 C by direct comparison with a calibrated reference thermometer.

5. Procedure
   5.1 Maintain the bath at the required test temperature according to the corrected reading of the thermometer. The thermometer shall be immersed in the bath so that the top of the mercury column remains below the surface of the bath liquid.
   5.2 Select a calibrated viscometer having a suitable range of viscosity, (the flow time shall not be less than 200 s) clean, and dry carefully.
   5.3 Charge the viscometer with the sample at the ambient temperature in the manner recommended by the manufacturer of the apparatus. If the sample contains solid particles, filter through a 75 μm screen. With certain products which exhibit gel-like behaviour, care must be taken that measurements be made at sufficiently high temperatures for such materials to flow freely so as to obtain similar results in viscometers of different capillary diameters.
   5.4 Heavy products such as dark lubricating oils, residual fuel oils and similar waxy products whose viscosity may be affected by the previous thermal history, shall be thermally treated as follows:
      5.4.1 Heat the sample in the original container up to about 50 C. Probing the bottom of the container with a rod till the sample is completely mixed.
      5.4.2 Pour 100 ml of the sample into a 125 ml Erlenmeyer flask, stopper with a cork stopper, immerse the flask into a bath of boiling water for 30 minutes and mix the sample well.
5.4.3 Remove the flask from the bath and strain the sample through 75 μm screen directly into the viscometer already in the bath. Complete the viscosity test within 1 hour after this heat treatment.

5.5 Allow the charged viscometer to remain in the bath a long enough period to reach the required test temperature, (about 30 minutes) then adjust the volume of the test sample.

5.6 Use suction (if the sample contains no volatile constituent) or pressure to adjust the head level of the test sample to a position in the capillary of the apparatus about 5 mm before the first timing mark. The time (in seconds) required for the meniscus to pass from the first timing mark to the second, shall be recorded. If this flow time is less than the specified minimum (or much more higher) use another viscometer with a capillary of smaller (or larger) diameter and repeat the operation.

5.7 In case of modified Ostwald and suspended level types, repeat the steps specified in 5.6 to make a second measurement of the flow time by the same apparatus. If the two measurements agree within 0.2% use the average for calculating and recording the kinematic viscosity.

5.7.1 As for reverse flow types, duplicate determinations shall be made. If the two measurements agree within 0.35% use the average for calculating and recording the kinematic viscosity.

5.8 Cleaning of the viscometer:

5.8.1 Between each two successive determinations clean the viscometer thoroughly by rinsing several times with an appropriate solvent completely miscible with the sample, followed by a detergent, water then by a volatile solvent such as acetone. Dry the tube by passing a slow stream of filtered dry air through the viscometer for 2 minutes.

5.8.2 Periodically clean the viscometer to remove any inorganic deposits by rinsing with hydrochloric acid and by chromic acid solution to remove organic deposits. Rinse the viscometer thoroughly with distilled water then with acetone and dry by clean dry air.

6. Result

6.1 Calculation

6.1.1 Kinematic viscosity is calculated from the equation,

\[ V = C \cdot t \]

where:

- \( V \) = the kinematic viscosity in centistokes (mm²/s).
- \( C \) = viscometer constant of the used viscometer.
- \( t \) = time of flow in seconds from the first timing mark to the second timing mark.

6.1.2 The dynamic viscosity \( \eta \) is calculated from the equation,

\[ \eta = \rho \cdot V \]

where:

- \( \eta \) = dynamic viscosity in centipoise.
- \( V \) = kinematic viscosity in centistoke.
- \( \rho \) = the density of the liquid as determined to the nearest 0.001 g/cm³.

6.2 Precision

6.2.1 Repeatability: The difference between successive test results obtained by the same operator with the same apparatus on identical test material shall not exceed 0.35% of the mean values.

6.2.2 Reproducibility: The difference between two single and independent results obtained by two different operators working in different laboratories on identical test material shall not exceed 0.7% of the mean values.

7. Report

7.1 The result of either the kinematic or dynamic viscosity shall be rounded to the nearest 0.01% of the value measured or calculated with reference to the temperature at which measuring has been carried out.

8. References

8.1 Main Reference


8.2 Other References

8.2.1 International Standard ISO3105/1976, "Glass Capillary Kinematic Viscometers Specifications and Operating Instructions."

8.2.3 Institute of Petroleum IP 71/1975, "Measurement of Kinematic Viscosity Transparent and Opaque Liquids and Calculation of Dynamic Viscosity."

Appendix

Table 1

A List of Some Viscometers and the Range of Their Viscosity

Note 1: Tables from (3) to (9) denote sizes, dimensions and ranges of viscosity for each of the viscometers mentioned in Table 1.

Note 2: The following letters mentioned in these figures indicate the parts of the viscometer as follows:

A Lower reservoir.
B Suspended level bulb.
C and J Timing bulbs.
D Upper reservoir.
E, F and I Timing marks.
G and H Filling marks.
K Over flow tube.
L Mounting tube.
M Lower vent tube.
N Upper vent tube
P Connecting tube.
R Capillary tube

Table 2

Standard Viscosity Oils and Their Kinematic Viscosity

<table>
<thead>
<tr>
<th>Viscosity Standard Designation</th>
<th>Kinematic Viscosity (Centistoke) at:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(-53.89) C</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>200</td>
<td>-</td>
</tr>
<tr>
<td>600</td>
<td>-</td>
</tr>
<tr>
<td>2000</td>
<td>-</td>
</tr>
<tr>
<td>8000</td>
<td>-</td>
</tr>
<tr>
<td>30000</td>
<td>-</td>
</tr>
</tbody>
</table>
### Table 3

Dimensions and Kinematic Viscosity Ranges for the Various Sizes of Cannon Fenske Routine Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range</th>
<th>Inside Diameter of Tube R (mm²/s)</th>
<th>Inside Diameter of Tubes N, E and P (mm)</th>
<th>Bulb Volume ml (±5)%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inside Diameter</td>
<td></td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>25</td>
<td>0.002</td>
<td>0.5 to 2</td>
<td>0.30</td>
<td>2.6 to 3.0</td>
<td>3.1</td>
</tr>
<tr>
<td>50</td>
<td>0.004</td>
<td>0.8 to 4</td>
<td>0.44</td>
<td>2.6 to 3.0</td>
<td>3.1</td>
</tr>
<tr>
<td>75</td>
<td>0.008</td>
<td>1.6 to 8</td>
<td>0.54</td>
<td>2.6 to 3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>100</td>
<td>0.015</td>
<td>3 to 15</td>
<td>0.63</td>
<td>2.8 to 3.6</td>
<td>3.1</td>
</tr>
<tr>
<td>150</td>
<td>0.035</td>
<td>7 to 35</td>
<td>0.78</td>
<td>2.8 to 3.6</td>
<td>3.1</td>
</tr>
<tr>
<td>200</td>
<td>0.1</td>
<td>20 to 100</td>
<td>1.01</td>
<td>2.8 to 3.6</td>
<td>3.1</td>
</tr>
<tr>
<td>300</td>
<td>0.25</td>
<td>50 to 250</td>
<td>1.27</td>
<td>2.8 to 3.6</td>
<td>3.1</td>
</tr>
<tr>
<td>350</td>
<td>0.5</td>
<td>100 to 500</td>
<td>1.52</td>
<td>3.0 to 3.8</td>
<td>3.1</td>
</tr>
<tr>
<td>400</td>
<td>1.2</td>
<td>240 to 1 200</td>
<td>1.92</td>
<td>3.0 to 3.8</td>
<td>3.1</td>
</tr>
<tr>
<td>450</td>
<td>2.5</td>
<td>500 to 2500</td>
<td>2.35</td>
<td>3.5 to 4.2</td>
<td>3.1</td>
</tr>
<tr>
<td>500</td>
<td>8</td>
<td>1 600 to 8000</td>
<td>3.20</td>
<td>3.7 to 4.2</td>
<td>3.1</td>
</tr>
<tr>
<td>600</td>
<td>20</td>
<td>4000 to 20000</td>
<td>4.20</td>
<td>4.4 to 5.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

*250 s Minimum flow time.
200 s Minimum flow time for all other sizes.

Fig. 1. Cannon—Fenske Routine Viscometer

Dimensions in mm.
### Table 4
Dimensions and Kinematic Viscosity Ranges for the Various Sizes of BS/U/M U-Tube Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range mm²/s</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Outside Diameter of Tubes L, N and P mm</th>
<th>Volume Bulb C ml (±5)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.001</td>
<td>0.2 to 1</td>
<td>0.20</td>
<td>6 to 7</td>
<td>0.50</td>
</tr>
<tr>
<td>M2</td>
<td>0.005</td>
<td>1 to 5</td>
<td>0.30</td>
<td>6 to 7</td>
<td>0.50</td>
</tr>
<tr>
<td>M3</td>
<td>0.015</td>
<td>3 to 15</td>
<td>0.40</td>
<td>6 to 7</td>
<td>0.50</td>
</tr>
<tr>
<td>M4</td>
<td>0.04</td>
<td>8 to 40</td>
<td>0.50</td>
<td>6 to 7</td>
<td>0.50</td>
</tr>
<tr>
<td>M5</td>
<td>0.1</td>
<td>20 to 100</td>
<td>0.65</td>
<td>6 to 7</td>
<td>0.50</td>
</tr>
</tbody>
</table>

200 s Minimum flow time for all sizes.

---

![Diagram](image.png)

Dimensions in mm.

**Fig. 2. BS/U/M U-Tube Viscometer**
Table 5
Dimensions and Kinematic Viscosity Ranges for the Various Sizes of BS/IP/SL Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range Mm²/s</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Volume Bulb C ml (±5)%</th>
<th>Inside Diameter of Tube N mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.01</td>
<td>3.5 to 10</td>
<td>0.64</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>1 A</td>
<td>0.03</td>
<td>6 to 30</td>
<td>0.84</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>20 to 100</td>
<td>1.15</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>2A</td>
<td>0.3</td>
<td>60 to 300</td>
<td>1.51</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>200 to 1000</td>
<td>2.06</td>
<td>5.6</td>
<td>3.7 to 4.3</td>
</tr>
<tr>
<td>3A</td>
<td>3.0</td>
<td>600 to 3000</td>
<td>2.74</td>
<td>5.6</td>
<td>4.6 to 5.4</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>2000 to 10000</td>
<td>3.70</td>
<td>5.6</td>
<td>4.6 to 5.4</td>
</tr>
<tr>
<td>4A</td>
<td>30</td>
<td>6000 to 30000</td>
<td>4.97</td>
<td>5.6</td>
<td>4.6 to 5.4</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>20000 to 100000</td>
<td>6.76</td>
<td>5.6</td>
<td>6.8 to 7.5</td>
</tr>
</tbody>
</table>

*350 s minimum flow time.
200 s minimum flow time for all other sizes.

Fig. 3. BS/IP/SL Viscometer
Table 6
Dimensions and Kinematic Viscosity Ranges
for the Various Sizes of BS/IP/SL(S) Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range mm²/s</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Volume Bulb C ml (±5)%</th>
<th>Inside Diameter of Tube N mm</th>
<th>Inside Diameter of Tube at E mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0008</td>
<td>1.05*</td>
<td>0.36</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0.003</td>
<td>2.1 ** to 3</td>
<td>0.49</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0.01</td>
<td>3.8*** to 10</td>
<td>0.66</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>0.03</td>
<td>6 to 30</td>
<td>0.87</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
<td>20 to 100</td>
<td>1.18</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>60 to 300</td>
<td>1.55</td>
<td>5.6</td>
<td>2.8 to 3.2</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>200 to 1000</td>
<td>2.10</td>
<td>5.6</td>
<td>3.7 to 4.3</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>3.0</td>
<td>600 to 3000</td>
<td>2.76</td>
<td>5.6</td>
<td>4.6 to 5.4</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>10.0</td>
<td>2000 to 10000</td>
<td>3.80</td>
<td>5.6</td>
<td>4.6 to 5.4</td>
<td>5</td>
</tr>
</tbody>
</table>

* 1320 s minimum flow time.
** 600 s minimum flow time.
*** 380 s minimum flow time.
200 s minimum flow time for all other sizes.

Fig. 4. BS/IP/SL (S) Viscometer

Dimensions in mm.
Table 7
Dimensions and Kinematic Viscosity Ranges for the Various Sizes of BS/IP/MSL Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range mm²/s</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Volume Bulb C ml (±5)%</th>
<th>Inside Diameter of Tubes N and P mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.003</td>
<td>0.6 to 3</td>
<td>0.35</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>2 to 10</td>
<td>0.45</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>3</td>
<td>0.03</td>
<td>6 to 30</td>
<td>0.62</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>20 to 100</td>
<td>0.81</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>60 to 300</td>
<td>1.10</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>200 to 1000</td>
<td>1.45</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
<tr>
<td>7</td>
<td>3.0</td>
<td>600 to 3000</td>
<td>1.98</td>
<td>1.2</td>
<td>4 to 6</td>
</tr>
</tbody>
</table>

200 s minimum flow time for all sizes.

Fig. 5. BS/IP/MSL Viscometer
Table 8

Dimensions and Kinematic Viscosity Ranges for the Various Sizes of Cannon-Fenske Opaque Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm²/s)/s</th>
<th>Kinematic Viscosity Range mm²/s</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Inside Diameter of Tubes E, F and I mm (±5)%</th>
<th>Volume Bulbs A, C and J ml (±5)%</th>
<th>Volume Bulb D ml (±5)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.002</td>
<td>0.4 to 2</td>
<td>0.31</td>
<td>3.0</td>
<td>1.6</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>0.004</td>
<td>0.8 to 4</td>
<td>0.42</td>
<td>3.0</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>75</td>
<td>0.008</td>
<td>1.6 to 8</td>
<td>0.54</td>
<td>3.0</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>100</td>
<td>0.015</td>
<td>3 to 15</td>
<td>0.63</td>
<td>3.2</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>150</td>
<td>0.035</td>
<td>7 to 35</td>
<td>0.78</td>
<td>3.2</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>200</td>
<td>0.1</td>
<td>20 to 100</td>
<td>1.02</td>
<td>3.2</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>300</td>
<td>0.25</td>
<td>50 to 200</td>
<td>1.26</td>
<td>3.4</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>350</td>
<td>0.5</td>
<td>100 to 500</td>
<td>1.48</td>
<td>3.4</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>400</td>
<td>1.2</td>
<td>240 to 1200</td>
<td>1.88</td>
<td>3.4</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>450</td>
<td>2.5</td>
<td>500 to 2500</td>
<td>2.20</td>
<td>3.7</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>500</td>
<td>8</td>
<td>1600 to 8000</td>
<td>3.10</td>
<td>4.0</td>
<td>2.1</td>
<td>11</td>
</tr>
<tr>
<td>600</td>
<td>20</td>
<td>4000 to 20000</td>
<td>4.00</td>
<td>4.7</td>
<td>2.1</td>
<td>13</td>
</tr>
</tbody>
</table>

200 s minimum flow time for all sizes.

Fig. 6. Cannon-Fenske Opaque Viscometer
Table 9

Dimensions and Kinematic Viscosity Ranges for the Various Sizes BS/IP/RF U-Tube Reverse Flow Viscometer

<table>
<thead>
<tr>
<th>Size No.</th>
<th>Nominal Viscometer Constant (mm$^2$/s)/s</th>
<th>Kinematic Viscosity Range (mm$^2$/s)</th>
<th>Inside Diameter of Tube R mm (±2)%</th>
<th>Length of Tube R mm</th>
<th>Inside Diameter at E, F and H mm</th>
<th>Volume Bulb C ml (±5)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.003</td>
<td>0.6 to 3</td>
<td>0.51</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>2 to 10</td>
<td>0.71</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>0.03</td>
<td>6 to 30</td>
<td>0.93</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>20 to 100</td>
<td>1.26</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>60 to 300</td>
<td>1.64</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>200 to 1000</td>
<td>2.24</td>
<td>185</td>
<td>3.0 to 3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>3.0</td>
<td>600 to 3000</td>
<td>2.93</td>
<td>185</td>
<td>3.3 to 3.6</td>
<td>4.0</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>2000 to 10000</td>
<td>4.00</td>
<td>185</td>
<td>4.4 to 4.8</td>
<td>4.0</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>6000 to 30000</td>
<td>5.5</td>
<td>185</td>
<td>6.0 to 6.7</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>20000 to 100000</td>
<td>7.70</td>
<td>210</td>
<td>7.7</td>
<td>4.0</td>
</tr>
<tr>
<td>11</td>
<td>300</td>
<td>60000 to 300000</td>
<td>10.00</td>
<td>210</td>
<td>10.00</td>
<td>4.0</td>
</tr>
</tbody>
</table>

200 s minimum flow time for all sizes.

Fig. 7. BS/IP/RF U-Tube Reverse Flow Viscometer.
Standard Method of Test for
Effect of Heat and Air on Asphalt Materials
(Thin Film Oven Test)

MRD Test Method 409
(Adaptation of AASHTO T 179-80)

1. Scope

1.1 This method covers the determination of the effect of heat and air on a film of semisolid asphalt materials. The effects of this treatment are determined from measurements of selected asphalt properties before and after the test.

1.2 The thin film oven test is used to obtain a general indication of the amount of hardening which may be expected to occur in an asphalt cement during the plant mixing operation. This hardening tendency is measured by penetration tests, made before and after the thin film oven test. The penetration of the asphalt cement after the thin film oven test is expressed as a percentage of the penetration prior to the test. Specifications prescribe minimum values for the percent retained penetration, which vary for the different grades of asphalt cement.

2. Summary of Method

2.1 A 3.2 mm (1/8 in.) film of asphalt material is heated in an oven for 5 h at 163 C. The effects of heat and air are determined from changes occurring in physical properties measured before and after the oven treatment. An optional procedure is provided for determining the change in sample mass.

3. Significance

3.1 This method indicates an approximate change in properties of asphalt during conventional hot-mixing at about 150 C as indicated by viscosity, penetration, or ductility measurements. It yields a residue which approximates the asphalt condition as incorporated in the pavement. If the mixing temperature differs appreciably from the 150 C a different effect on materials properties will occur.

4. Apparatus

4.1 An oven which is electrically heated and conforming to the performance requirements of ASTM E 145, for Gravity-Convection and Forced-Ventilation Ovens Type 113, for operating temperatures up to 180 C.

4.1.1 Construction-The oven shall be rectangular with minimum interior dimensions (exclusive of space occupied by the heating element), of 330 mm (or 13 in.) in each direction (Note 1). The oven shall have, in front, a tightly fitted hinged door, which shall provide a clear opening substantially the same as the interior height and width of the oven. The door may contain a 100 by 100 mm (or 4 by 4 in.) window through which a vertical thermometer, located as specified in Sec 6.1 may be read without opening the door; or the oven may be provided with an inner glass door, through which the thermometer may be observed on opening the outer door. The oven shall be ventilated by convection currents of air.

Note 1: Minimum size ovens accommodate two containers. For routine operations, larger ovens, having proportionately larger shelves to accommodate a greater number of containers may be advantageous and are suitable, provided the requirements of ASTM E 145, Type IB are met. Under no circumstances should more than one shelf, properly centered, be used in an oven.

4.1.2 Rotating Shelf-The oven shall be provided with a metal circular shelf having a minimum diameter of 250 mm (or 10 in.) (Note 1). The shelf construction shall be such that it provides a flat surface for support of the containers without blocking all air circulation through the shelf when the containers are in place. The shelf shall be suspended by a vertical shaft and centered with respect to the horizontal interior dimensions of the oven and shall be provided with a mechanical means of rotating it at the rate of 5.5 ± 1 rpm. The shelf shall be vertically located as close to the center of the oven as permitted by compliance with the requirements of Sec 6.1 regarding thermometer placement.

4.2 Thermometer-An ASTM Loss on Heat Thermometer having a range of 155 to 170 C and conforming to the requirements for Thermometer 13 C, as prescribed in ASTM E 1.

4.3 Container-A cylindrical pan 140 mm (or 5 1/2 in.) in inside diameter and 9.5 mm (or 3/8 in.) deep with a flat bottom. Fifty ml of the sample in this size container gives a film thickness of 3.2 mm (1/8 in.). Pans shall be made of aluminum or stainless steel. Aluminum pans should have a metal thickness of approximately 0.76 mm (or 0.030 in.). Stainless steel pans should have a metal thickness of approximately 0.65 mm (or 0.025 in.) (Note 2).
Note 2: Pans have a tendency to become warped or bent with use. Although a small amount of warp does not significantly affect results, frequent inspection to eliminate badly warped or damaged pans shall be made. The indicated metal thicknesses are those found to provide adequate rigidity without excessive mass. Stainless steel pans manufactured from No. 24 stainless sheet gauge steel comply with this thickness. Pans made from No. 26 stainless sheet gauge metal are also acceptable but have a greater tendency to warp during use. In no case shall the thickness of the metal be less than 0.381 mm (0.015 in.).

4.4 A class D balance is required for weighing hot samples into the pans and if the loss-on-heating is desired, a class B balance is also necessary. The balance(s) shall conform to the requirements of MRDTM 102.

5. Preparation of Samples

5.1 Place sufficient material for the test in a suitable container and heat to a fluid condition. Extreme care should be taken so that there is no local overheating of the sample and that the highest temperature reached does not exceed 100 C above the expected softening point of the sample. Stir the sample with a general purpose thermometer during the heating period, but avoid incorporating air bubbles in the samples. Weigh 50 ± 0.5 g into each of two or more tared sample pans meeting the requirements of Sec 4.3 (Note 3).

Note 3: When tests on the residue other than penetration and ductility are desired, more than two containers may be needed to provide sufficient material for test.

5.2 At the same time, pour a portion of the sample into the containers specified for measurement of original asphalt properties.

5.3 If the quantitative value of the loss or gain in sample mass is desired, cool the samples for the oven test to room temperature and weigh each sample separately to the nearest 0.001 g. If the change in mass is not required, allow the samples to cool to room temperature before placing in the oven as directed in Sec 6.2.

6. Procedure

6.1 Level the oven so that the shelf rotates in a horizontal plane. Determine the temperature of the oven by means of the specified thermometer (Sec 4.2) supported from the shaft of the circular shelf in a vertical position at a point equidistant from the center and the outer edge of the shelf. The bottom of the thermometer bulb shall be 6.4 mm (1/4 in.) above the top of the shelf.

6.2 With the oven at 163 C, quickly place the containers with the sample on the circular shelf, close the oven, and start rotating the shelf. Under no circumstances shall asphalt materials of different grades be tested in the oven at the same time. Maintain the temperature at 163 ± 1 C for 5 h after the sample has been placed in the oven and the oven has reached the test temperature. The 5 h period shall start when the temperature reaches 162 C and in no case shall the total time that a sample is in the oven be more than 51/4 h. At the conclusion of the heating period, remove the samples from the oven. If the change in mass is not being determined, proceed in accordance with Sec 6.4. If the change in mass is being determined, cool to room temperature, weigh to the nearest 0.001 g, and calculate the change in mass on the basis of the asphalt in each container. When complete tests cannot be made in the same day, and if the loss or gain in the sample mass is being determined, weigh the residues and store them overnight before reheating. If the change in mass is not being determined, transfer the residue to the 240 ml (8 oz) container as described in Sec 6.4 before storing overnight.

6.3 After weighing the containers with the residues, place them on abestos-cement board(s). Put the board(s) and the containers on the circular shelf of the oven maintained at 163 C. Close the oven and rotate the shelf for 15 minutes, remove the samples and board(s), and immediately proceed as described in Sec 6.4.

6.4 Pour both samples into a 240 ml (8 oz) ointment tin. Remove the material from the 140 mm (5½ in.) pans by scraping with a suitable spatula or putty knife. Stir the combined residues thoroughly, placing the 240 ml (8 oz) container on a hot plate to maintain the material in a fluid condition if necessary. Pour the material into the proper containers or molds for the penetration, ductility or other tests if required. Complete the tests on residue in accordance with the appropriate MRDTM.

7. Report

7.1 Report the values of the original asphalt properties measured in Sec 5.2 and the residue property values as measured in Sec 6.4. Viscosity change may also be expressed as the ratio of the residual asphalt viscosity to the original asphalt viscosity. Penetration change is evaluated as the penetration of the residue expressed as the percentage of the original penetration.

7.2 Report ductility or other test results in accordance with the appropriate MRDTM.

7.3 When determined, report the average change in mass of the material in all the containers used in the test as mass percent of the original material.
### Effect of Heat and Air on Asphalt Materials

**Heat Loss**

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Mass Percent of Original Material, ( \frac{D}{B} \times 100 )</th>
<th>Average Mass Percent of Original Material, **</th>
<th>Percent Retained Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>16</td>
<td>99.26</td>
<td>99.26</td>
<td>%</td>
<td>%</td>
<td>1a</td>
</tr>
</tbody>
</table>

#### Percent Retained Penetration

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>E</th>
<th>F</th>
<th>Percent Retained Penetration, ( \frac{E}{F} \times 100 )</th>
<th>Average Percent Retained Penetration, **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>16</td>
<td>71</td>
<td>73</td>
</tr>
</tbody>
</table>

#### Percent Retained Ductility

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>G</th>
<th>H</th>
<th>Percent Retained Ductility, ( \frac{G}{H} \times 100 )</th>
<th>Average Percent Retained Ductility, **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>16</td>
<td>72</td>
<td>73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>I</th>
<th>J</th>
<th>Percent Retained, ( \frac{I}{J} \times 100 )</th>
<th>Average Percent Retained, ** (Name of Test Property)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>16</td>
<td>%</td>
<td>%</td>
</tr>
</tbody>
</table>

**NOTE:**

**Report on MRDT 400 A as Other, Line 29.
****Report on MRDT 400 A as Other, Line 29.

**Remarks:**

---

**Checked By:** T. Williams  
**Materials Engineer:** J. Smith  
**Resident Engineer:** J. Dunbar  
**DISTRIBUTION:** ☒ Contractor  ☒ Ministry  ☒ Resident Engineer  ☐ Other (Specify):
1. Introduction

1.1 The principal feature of this MRDTM is the detailed outline of test methods and procedures for asphalt paving mix design using the Marshall Method.

1.2 The design of asphalt paving mixes is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction. The overall objective of the design of asphalt paving mixes is to determine an economical blend and gradation of aggregates and asphalt that will provide a mix having:

1.2.1 Sufficient asphalt to ensure a durable pavement,
1.2.2 Sufficient mix stability to satisfy the demands of traffic without distortion,
1.2.3 Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding, and loss of stability, yet low enough to keep out harmful air and moisture, and
1.2.4 Sufficient workability to permit efficient placement of the mix without segregation.

1.3 Often, in the process of developing a specific mix design, it is necessary to make several trial mixes to find one that meets all the design criteria. Each trial mix design, therefore, serves as a guide for evaluating and adjusting the trials that follow. For preliminary or exploratory mix designs, it is best to start with an aggregate of a gradation that approaches the median of the specification limits. Initial trial mixes for establishing the job-mix formula, however, should have an aggregate gradation within the specification limits capable of being produced by the hot mix plant.

1.4 Where the initial trial mixes fail to meet the design criteria, it will be necessary to modify or, in some cases, redesign the mix. Adjustments in the grading of the original aggregate blend may be required to correct the deficiency. A general guide for adjusting the trial mix is summarized in Appendix B.

1.5 For many engineering materials, the strength of the material frequently is thought of as denoting quality; however, this is not the only material property that denotes quality in the case of hot mixed asphalt paving. Extremely high stability often is obtained at the expense of lowered durability, and vice versa. Therefore, in evaluating and adjusting mix designs, note that the aggregate gradations and asphalt content in the final mix design must strike a favorable balance between the stability and durability requirements for the use intended.

1.6 The mix design method and design requirements form an essential part of the specifications for asphalt paving. Mix design testing for asphalt paving construction should be thoroughly coordinated with the other features of materials and construction control. Normally, mix design testing will have four important applications to the overall project construction. These are: preliminary design, source identification, job-mix control, and construction control. Sec 1.6.1 through 1.6.4 summarizes the relation of mix design testing to the overall program of inspection.

1.6.1 Preliminary Design Testing-The principal purpose of preliminary design testing is to determine that the prospective sources of aggregate are of satisfactory quality and will produce a paving mix satisfying both the gradation and mix design requirements of the specifications. Scheduling preliminary mix designs should include assurance that both the asphalt and aggregate materials meet their respective specification requirements. Initial trial mixes should be made with an aggregate gradation approaching the median of the specification limits. Where there are several possible sources of aggregate to be considered, it will often be necessary to make a number of trial mix designs to determine the most economical combination of aggregates that will fulfill all of the specification requirements. The results of the preliminary mix designs can serve as a basis for making an estimate of costs; they further assure that the design requirements can be obtained within the the framework of the specification.

1.6.2 Source Identification Testing-Source testing often is performed after the award of contract and after the contractor has indicated the proposed sources of all aggregate materials and asphalt. While this testing is primarily a matter of materials control and inspection, it also involves mix design. The main objective is to determine the most economical blend of aggregates that will satisfy both the gradation and mix design requirements of the specifications. Source tests serve to assure the Ministry and contractor that the proposed sources of aggregate and asphalt will provide a paving mixture that satisfies all specification requirements.

1.6.3 Job-Mix Control Testing-Job-mix control testing is performed at the start of plant production and in conjunction with the calibration of the mixing plant for the job-mix formula. This is one of the key points of design control for the paving construction since the job-mix formula establishes, using the project aggregates and asphalt, the final mix design and
or other wood having an average dry mass of 0.67 to 0.77 g/cm³ (42 to 48 lbs/ft³). The wooden post shall be secured by four wooden post capped with a 304.8 by 304.8 by 25.4 mm (12 by 12 by 1 in.) steel plate. The wooden post shall be oak, pine, note 2:

lb) sliding weight with a free fall of 457.2 mm (18 in.). Two compaction hammers are recommended (note 2). Required to transfer the load from the ring dynamometer adapter to the extension collar while extracting the specimen. A suitable bar is thick for extracting the compacted specimen from the specimen mold with the use of the mold collar. A suitable bar is

3. Apparatus

2. General

2.1 Application-The Marshall method presented here is applicable only to hot mix asphalt paving mixtures using penetration or viscosity graded asphalt cements and containing aggregates with maximum sizes of 25 mm (1 in.) or less. The method may be used for both laboratory design and field control of asphalt hot-mix paving.

2.2 Outline of Method-The procedure for the Marshall method starts with the preparation of test specimens. Preliminary to this operation it is required:

2.2.1 That the materials proposed for use meet the requirements of the project specifications,

2.2.2 That aggregate blend combinations meet the gradation requirements of the project specifications (note 1), and

2.2.3 That, for use in density and voids analyses, the bulk specific gravity of all aggregates used in the blend, and the specific gravity of the asphalt cement, are determined.

Note 1: Appendix A, Gradation Analysis of Aggregates, contains a schedule of preparation and analysis of aggregates.

2.3 The Marshall method uses standard test specimens of 63.5 mm (2 1/2 in.) height by 101.6 mm (4 in.) diameter. These are prepared using a specified procedure for heating, mixing, and compacting the asphalt-aggregate mixtures. The two principal features of the Marshall method of mix design are a density/voids analysis and stability and flow tests of the compacted test specimens.

2.3.1 The stability of the test specimen is the maximum load resistance in kg (or lbs) that the standard test specimen will develop at 60 C when tested as outlined in Sec 5.3.

2.3.2 The flow value is the total movement or displacement, in units of 1.0 mm (.04 in.) occurring in the specimen between no load and maximum load during the stability test.

3. Apparatus

3.1 Specimen Mold Assembly-Mold cylinders 101.6 mm (4 in.) in diameter by 76.2 mm (3 in.) in height, base plates, and extension collars shall conform to the details shown in Fig. 1. Five mold cylinders are recommended.

3.2 Specimen extractor, steel, in the form of a disk with a diameter not less than 100 mm (3.95 in.), and 13 mm (½ in.) thick for extracting the compacted specimen from the specimen mold with the use of the mold collar. A suitable bar is required to transfer the load from the ring dynamometer adapter to the extension collar while extracting the specimen.

3.3 Compaction Hammer-The compaction hammer (Fig. 2) shall have a flat, circular tamping face and a 4.536 kg (10 lb) sliding weight with a free fall of 457.2 mm (18 in.). Two compaction hammers are recommended (Note 2). Note 2: The compaction hammer may be equipped with a finger safety guard as shown in Fig. 2.

3.4 Compaction Pedestal-The compaction pedestal shall consist of a 203.2 by 203.2 by 457.2 mm (8 by 8 by 18 in.) wooden post capped with a 304.8 by 304.8 by 25.4 mm (12 by 12 by 1 in.) steel plate. The wooden post shall be oak, pine, or other wood having an average dry mass of 0.67 to 0.77 g/cm³ (42 to 48 lbs/ft³). The wooden post shall be secured by four angle brackets to a solid concrete slab. The steel cap shall be firmly fastened to the post. The pedestal assembly shall be installed so that the post is plumb and the cap is level.

3.5 Specimen mold holder, mounted on the compaction pedestal so as to center the compaction mold over the center of the post. It shall hold the compaction mold, collar, and base plate securely in position during compaction of the specimen.

3.6 Breaking Head-The breaking head (Fig. 3) shall consist of upper and lower cylindrical segments or test heads having an inside radius of curvature of 50.8 mm (2 in.) accurately machined. The lower segment shall be mounted on a base having two perpendicular guide rods or posts extending upward. Guide sleeves in the upper segment shall be in such a position as to direct the two segments together without appreciable binding or loose motion on the guide rods.

3.7 Loading Jack-The loading jack (Fig. 4) shall consist of a screw jack mounted in a testing frame and shall produce a uniform vertical movement of 50.8 mm (2 in.) per minute (Note 3).
3.8 Ring Dynamometer Assembly—One ring dynamometer (Fig. 4) of 2267 kg (5000 lb) capacity and sensitivity to 4,536 kg (10 lb) up to 453.6 kg (1000 lb), and 11,340 kg (25 lb) between 453.6 and 2267 kg (1000 and 5000 lb) shall be equipped with a micrometer dial. The micrometer dial shall be graduated in 0.0025 mm (0.0001 in.). Upper and lower ring dynamometer attachments are required for fastening the ring dynamometer to the testing frame and transmitting the load to the breaking head (Note 4).

Note 4: Instead of the ring dynamometer assembly, any suitable load-measuring device may be used provided the capacity and sensitivity meet the requirements of Sec 3.8.

3.9 Flow Meter—The flow meter shall consist of a guide sleeve and a gauge. The activating pin of the gauge shall slide inside the guide sleeve with a minimum amount of frictional resistance. The guide sleeve shall slide freely over the guide rod of the breaking head. The flow meter gauge shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flow meter gauge shall be in 0.25 mm (0.01 in.) divisions (Note 5).

Note 5: Instead of the flow meter, a micrometer dial or stress-strain recorder graduated in 0.025 mm (0.001 in.) may be used to measure flow.

3.10 Ovens or Hot Plates—Ovens or hot plates shall be provided for heating aggregates, bituminous material, specimen molds, compaction hammers, and other equipment to the required mixing and molding temperatures. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 2.8 C. Suitable shields, baffle plates, or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

3.11 Mixing Apparatus—Mechanical mixing is recommended. Any type of mechanical mixer may be used provided it can be maintained at the required mixing temperature and will produce a well-coated, homogeneous mixture of the required amount in the allowable time, and further provided that essentially all of the batch can be recovered. Hand mixing may also be used with a metal pan or bowl of sufficient capacity.

3.12 Water Bath—The water bath shall be at least 150 mm (or 6 in.) deep and shall be thermostatically controlled so as to maintain the bath at 60 ± 1.0 C or 37.8 ± 1 C. The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 50 mm (or 2 in.) above the bottom of the bath.

3.13 Air Bath—The air bath for asphalt cutback mixtures shall be thermostatically controlled and shall maintain the air temperature at 25 ± 1.0 C.

4. Preparation of Test Specimens

4.1 General—In determining the optimum asphalt content for a particular blend or gradation of aggregates by the Marshall method, a series of test specimens is prepared for a range of different asphalt contents so that the test data curves show a well-defined optimum value. Tests should be scheduled on the basis of ½ percent increments of asphalt content, with at least two asphalt contents above the optimum and at least two below the optimum.

To provide adequate data, triplicate test specimens are the minimum prepared for each asphalt content used. Therefore, a hotmix design study using six different asphalt contents will normally require at least 18 test specimens. Each test specimen will usually require approximately 1.2 kg (or 2.6 lb) of aggregate. Therefore, the minimum aggregate requirements for one series of test specimens of a given blend and gradation will be approximately 23 kg (or 50 lb). Approximately 4 liters (or 1 gal.) of asphalt cement will be adequate.
4.2 Preparation of Test Specimens

4.2.1 Number of Specimens-Prepare at least three, and preferably five, specimens for each combination of aggregate and asphalt.

4.2.2 Preparation of Aggregates-Dry aggregates to constant mass at 105 to 110 C and separate the aggregates by dry-sieving into the desired size fractions.

4.2.3 Determination of Mixing and Compaction Temperature-The temperature to which the asphalt must be heated to produce kinematic viscosities of 170 ± 20 centistokes and 280 ± 30 centistokes shall be established as the mixing temperature and compaction temperature, respectively.

4.2.4 Preparation of Mold and Hammer -Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them in a boiling water bath or on the hot plate to a temperature between 93 and 149 C. Place a piece of filter paper toweling cut to size in the bottom of the mold before the mixture is placed in the mold.

4.2.5 Preparation of Mixtures-Weigh into separate pans for each test specimen the amount of each aggregate size fraction required to produce a batch that will result in a compacted specimen 63.5 ± 1.3 mm (2.5 ± 0.05 in.) in height. Combine the coarse aggregate fractions in the manner prescribed in MRDTM 414, Sec 3.4. This will normally be about 1.2 kg (2.6 lb) (see Appendix A, Gradation Analysis of Aggregates, for suggested method of calculating the mass of each batch). It is generally desirable to prepare a trial specimen prior to preparing the aggregate batches. If the trial specimen height falls outside the limits, the amount of aggregate used for the specimen may be adjusted as follows:

\[
\text{Adjusted Mass of Aggregate} = \begin{cases} 
63.5 \times \text{(mass of aggregate used, kg)}, \\
\text{Specimen Height (mm) Obtained}, \\
2.5 \times \text{(mass of aggregate used, lb)}, \\
\text{Specimen Height (in.) Obtained}
\end{cases}
\]

Place the pans in the oven or on the hot plate and heat to a temperature approximately 28 C above the mixing temperature specified in Sec 4.2.3. If a hot plate is used, provision should be made for dead space, baffle plate, or a sand bath between the pans and the hot plate to prevent local overheating. Charge the mixing bowl with heated aggregates and dry mix thoroughly. Form a crater in the dry blended aggregate and weigh the required amount of asphalt cement into the mixture in accordance with the accumulative batch mass. At this point, the temperature of the aggregate and asphalt must be within the limits of the mixing temperature established in Sec 4.2.3. Asphalt should not be held at the mixing temperature for more than 1 h before using. Mix the aggregate and asphalt cement, preferably with a mechanical mixer or by hand with a trowel, as quickly and thoroughly as possible to yield a mixture having a uniform distribution of asphalt throughout.

4.2.6 Compaction of Specimens-Place a piece of filter paper or paper toweling cut to size in the bottom of the mold before the mixture is introduced. Place the entire batch in the mold, spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and ten times over the interior. Remove the collar and smooth the surface to a slightly rounded shape. The temperature of the mixture immediately prior to compaction shall be within the limits of the compaction temperature established in Sec 4.2.3, otherwise, it shall be discarded. In no case shall the mixture be reheated.

4.2.7 Replace the collar, place the mold assembly on the compaction pedestal in the mold holder. Apply either 50 or 75 blows, as specified according to the design traffic category, with the compaction hammer using a free fall of 457.2 mm (18 in.). Hold the axis of the compaction hammer as nearly perpendicular to the base of the mold assembly as possible during compaction. Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction remove the base plate and allow the specimen to cool in air until no deformation will result when removing it from the mold. When more rapid cooling is desired, table fans may be used, but not water, unless the specimen is in a water tight bag. Remove the specimen from the mold by means of an extrusion Jack or other compression device, then place on a smooth, level surface until ready for testing. Normally, specimens are allowed to cool overnight.

5. Test Procedure

5.1 General-In the Marshall method each compacted test specimen is subjected to the following tests and analysis in the following order:

5.1.1 Bulk Specific Gravity Determination (MRDTM 411).

5.1.2 Stability and Flow Test (MRDTM 410, Sec 5.3).

5.1.3 Density and Voids Analysis.
**Bulk Specific Gravity Determination**

5.2 Bulk Specific Gravity Determination - The bulk specific gravity test may be performed as soon as the freshly compacted specimens have cooled to room temperature. This test is performed according to MRDTM 411, Method A, Bulk Specific Gravity of Compacted Bituminous Mixtures using paraffin-coated specimens or MRDTM 411, Method B, Bulk Specific Gravity of Compacted Bituminous Mixtures using saturated-surface-dry specimens.

**Stability and Flow Tests**

5.3 Stability and Flow Tests - After the bulk specific gravity of the test specimens have been determined, the stability and flow tests are performed as follows:

5.3.1 Zero the flow meter by inserting a 101.6 mm (4.00 in.) diameter metal cylinder in the testing head, placing the flow meter over the guide rod and adjusting the flow meter to read "zero" (Note 6).

**Note 6:** This adjustment should be made on the guide post marked with a "0" and with the side of the upper segment of the testing head marked with a "0" being placed on the same side as the guide post so marked. The same assembly of testing head and flow meter must then be used in testing the specimens. Specimens should be 101.6 mm ± 0.25 mm (4.00 ± 0.01 in.), otherwise, an initial and final reading of flow meter is required for the determination of the flow value.

5.3.2 Immerse test specimens in a water bath at 60 ± 1 C for 30 to 40 minutes before testing.

5.3.3 Thoroughly clean the inside surfaces of the testing head. Temperature of the head shall be maintained between 21 and 37.8 C, using a water bath when required. Lubricate guide rods with a thin film of oil so that the upper test head will slide freely without binding. If a proving ring is used to measure the applied load, check to see that the dial indicator is firmly fixed and set at zero for the no-load condition.

5.3.4 With the testing apparatus ready, remove the test specimen from the water bath and carefully dry its surface. Place the specimen in the lower testing head and center; then fit the upper testing head into position and center complete assembly in the loading device. Place flow meter over marked guide rod as noted in Sec 5.3.1.

5.3.5 Apply the test load to the specimen at a constant rate of deformation of 51 mm (2 in.) per minute, until failure occurs. The point of failure is defined by the maximum load reading obtained. The total load, kg (lb) required to produce failure of the specimen at 60 C shall be recorded as its Marshall stability value.

5.3.6 While the stability test is in progress, hold the flow meter firmly in position over the guide rod and remove as the load begins to decrease; observe reading and record. This reading is the flow value for the specimen, expressed in units of 1.0 mm (0.04 in.). For example, if the specimen deformed 3.8 mm (0.15 in.) the flow value would be 3.8.

5.3.7 The entire procedure, both stability and flow tests, starting with the removal of the specimen from the water bath, shall be completed within a period of 30 seconds.

**Density and Voids Analysis**

5.4 Density and Voids Analysis - After the completion of the stability and flow tests, a density and voids analysis is made for each series of test specimens as follows (Detailed analysis is summarized in Appendix C):

5.4.1 Average the bulk specific gravity values for all test specimens of a given asphalt content; values obviously in error shall not be included in the average.

5.4.2 Determine the average unit mass for each asphalt content by multiplying the average bulk specific gravity value by 1 g/cm³ (62.4 lb/ft³) (Fig. 7).

5.4.3 Prepare a graphical plot of unit mass vs. asphalt content and connect the plotted points with a smooth curve that represents the best-fit for all values (Fig. 8).

5.4.4 Read unit mass values directly from the plotted curve for each asphalt content tested and compute equivalent bulk specific gravity values by dividing by 1 g/cm³ (62.4 lb/ft³). The values of bulk specific gravity obtained shall be used in further computations of voids (Fig. 7).

5.4.5 Using the bulk specific gravity of the aggregates and the Maximum Specific Gravity of Bituminous Paving Mixtures (MRDTM 412), calculate the absorbed asphalt in kg (or lb) of dry aggregate, percent air voids, and percent voids in mineral aggregate (VMA) as illustrated in Fig. 7. For routine mix design, the Maximum Specific Gravity of Bituminous Paving Mixtures (MRDTM 412) is determined in duplicate for at least two asphalt contents, preferably on mixes at or near the optimum asphalt content. An average value for asphalt absorption by the aggregate is calculated. This value may then be used for calculation of percent air voids, and percent voids in mineral aggregate, as illustrated in Appendix C. Table 2 lists the minimum percent voids in mineral aggregate for different sizes of aggregate.

6. Interpretation of Test Data

6.1 Preparation of Data - The stability and flow values and void data are prepared as follows:
6.1.1 Measured stability values for specimens that depart from the standard 63.5 mm (2½ in.) thickness shall be converted to an equivalent 63.5 mm (2½ in.) value by means of a conversion factor. Applicable correlation ratios to convert the measured stability values are set forth in Table 1.

6.1.2 Average the flow values and the converted stability values for all specimens of a given asphalt content. Values that are obviously in error shall not be included in the average.

6.1.3 Prepare a separate graphical plot for the following values as illustrated in Fig. 8.
   6.1.3.1 Stability vs. Asphalt Content,
   6.1.3.2 Flow vs. Asphalt Content,
   6.1.3.3 Unit Mass of Total Mix vs. Asphalt Content,
   6.1.3.4 Percent Air Voids vs. Asphalt Content, and
   6.1.3.5 Percent Voids in Mineral Aggregate (VMA) vs. Asphalt Content.

In each graphical plot connect the plotted values with a smooth curve that represents the best-fit for all values.

6.2 Trends and Relations of Test Data-The test property curves, plotted as described in See 6.1.3, have been found to follow a reasonably consistent pattern for dense graded asphalt paving mixes. Trends generally obtained are outlined as follows:

   6.2.1 The stability value increases with increasing asphalt content up to a maximum after which the stability decreases.
   6.2.2 The flow value increases with increasing asphalt content.
### Table 1
Stability Correlation Ratios

<table>
<thead>
<tr>
<th>Volume of Specimen $\text{cm}^3$</th>
<th>Approximate Thickness of Specimen $\text{mm (in.)}$</th>
<th>Correlation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 to 213</td>
<td>25.4 (1)</td>
<td>5.56</td>
</tr>
<tr>
<td>214 to 225</td>
<td>27.0 (1 1/16)</td>
<td>5.00</td>
</tr>
<tr>
<td>226 to 237</td>
<td>28.6 (1 1/8)</td>
<td>4.55</td>
</tr>
<tr>
<td>238 to 250</td>
<td>30.2 (1 3/16)</td>
<td>4.17</td>
</tr>
<tr>
<td>251 to 264</td>
<td>31.8 (1 1/4)</td>
<td>3.85</td>
</tr>
<tr>
<td>265 to 276</td>
<td>33.3 (1 5/16)</td>
<td>3.57</td>
</tr>
<tr>
<td>277 to 289</td>
<td>34.9 (1 3/8)</td>
<td>3.33</td>
</tr>
<tr>
<td>290 to 301</td>
<td>36.5 (1 7/16)</td>
<td>3.03</td>
</tr>
<tr>
<td>302 to 316</td>
<td>38.1 (1 1/2)</td>
<td>2.78</td>
</tr>
<tr>
<td>317 to 328</td>
<td>39.7 (1 9/16)</td>
<td>2.50</td>
</tr>
<tr>
<td>329 to 340</td>
<td>41.3 (1 5/8)</td>
<td>2.27</td>
</tr>
<tr>
<td>341 to 353</td>
<td>42.9 (1 11/16)</td>
<td>2.08</td>
</tr>
<tr>
<td>354 to 367</td>
<td>44.4 (1 3/4)</td>
<td>1.92</td>
</tr>
<tr>
<td>368 to 379</td>
<td>46.0 (1 13/16)</td>
<td>1.79</td>
</tr>
<tr>
<td>380 to 392</td>
<td>47.6 (1 7/8)</td>
<td>1.67</td>
</tr>
<tr>
<td>393 to 405</td>
<td>49.2 (1 15/16)</td>
<td>1.56</td>
</tr>
<tr>
<td>406 to 420</td>
<td>50.8 (2)</td>
<td>1.47</td>
</tr>
<tr>
<td>421 to 431</td>
<td>52.4 (2 1/16)</td>
<td>1.39</td>
</tr>
<tr>
<td>432 to 443</td>
<td>54.0 (2 1/8)</td>
<td>1.32</td>
</tr>
<tr>
<td>444 to 456</td>
<td>55.6 (2 3/16)</td>
<td>1.25</td>
</tr>
<tr>
<td>457 to 470</td>
<td>57.2 (2 1/4)</td>
<td>1.19</td>
</tr>
<tr>
<td>471 to 482</td>
<td>58.7 (2 5/16)</td>
<td>1.14</td>
</tr>
<tr>
<td>483 to 495</td>
<td>60.3 (2 3/8)</td>
<td>1.09</td>
</tr>
<tr>
<td>496 to 508</td>
<td>61.9 (2 7/16)</td>
<td>1.04</td>
</tr>
<tr>
<td>509 to 522</td>
<td>63.5 (2 1/2)</td>
<td>1.00</td>
</tr>
<tr>
<td>523 to 535</td>
<td>64.0 (2 9/16)</td>
<td>0.96</td>
</tr>
<tr>
<td>536 to 546</td>
<td>65.1 (2 5/8)</td>
<td>0.93</td>
</tr>
<tr>
<td>547 to 559</td>
<td>66.7 (2 11/16)</td>
<td>0.89</td>
</tr>
<tr>
<td>560 to 573</td>
<td>68.3 (2 3/4)</td>
<td>0.86</td>
</tr>
<tr>
<td>574 to 585</td>
<td>71.4 (2 13/16)</td>
<td>0.83</td>
</tr>
<tr>
<td>586 to 598</td>
<td>73.0 (2 7/8)</td>
<td>0.81</td>
</tr>
<tr>
<td>599 to 610</td>
<td>74.6 (2 15/16)</td>
<td>0.78</td>
</tr>
<tr>
<td>611 to 625</td>
<td>76.2 (3)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

**Note 6**: 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 (2½ in.) specimen.

**Note 7**: Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

6.2.3 The curve for unit mass of total mix is similar to the stability curve except that the maximum unit mass normally, but not always, occurs at a slightly higher asphalt content than the maximum stability.

6.2.4 The percent of air voids decreases with increasing asphalt content, ultimately approaching a minimum void content.

6.2.5 The percent voids in the mineral aggregate generally decrease to a minimum value then increase with increasing asphalt content.

6.3 Determination of Optimum Asphalt Content-The optimum asphalt content of the asphalt paving mix is determined from data presented in Sec 6.1.3. Consideration is given to three of the test property curves illustrated in Fig. 8 in making this determination. From these data curves, asphalt contents are determined which yield the following:

6.3.1 Maximum stability.

6.3.2 Maximum unit mass.

6.3.3 Percent Air Voids-Median of limits specified in Sec 3.05 and 4.04 of the General Specification for Road and Bridge Construction, and supplemental specification thereto, for percent air voids. The optimum asphalt content of the mix is then the numerical average of the values for the asphalt content determined in Sec 6.3.1, 6.3.2, and 6.3.3.
6.3.4 The average values must be within acceptable limits on plots described in Sec 6.1.3.1, 6.1.3.2, 6.1.3.3, 6.1.3.4, and 6.1.3.5. If adjustments are necessary, they should be made in accordance with Appendix B.

Example

Assume that data shown in Fig. 8 represent laboratory tests on a dense graded asphalt concrete mix [19 mm (3/4 in.) nominal maximum particle size aggregate] to be used as a bituminous wearing course (75 compaction blows).

Compute optimum asphalt content as follows:

<table>
<thead>
<tr>
<th>Percent</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Asphalt content at maximum unit mass</td>
<td>5.3</td>
</tr>
<tr>
<td>b. Asphalt content providing 4 percent air voids</td>
<td>4.6</td>
</tr>
<tr>
<td>(median of 3 to 5 percent)</td>
<td></td>
</tr>
<tr>
<td>c. Asphalt content at max. stability</td>
<td>5.0</td>
</tr>
<tr>
<td>Optimum asphalt content, average</td>
<td>5.0</td>
</tr>
</tbody>
</table>

7. Criteria for Satisfactory Paving Mix

7.1 Whether the asphalt paving mix will be satisfactory at the optimum asphalt content selected is determined as shown in the Example. This determination is made by applying certain specifications limiting criteria to test data for the mix at its optimum asphalt content. An example of the application of the above criteria may also be illustrated by use of the data shown in Fig. 8, and information contained in Sec 6.3. The optimum asphalt content of the mix, as illustrated, is 5.0 percent. At this asphalt content, properties of the mix are determined from Fig. 8 to be as follows:

7.1.1 Stability, 853 kg (1880 lb),
7.1.2 Flow, 2.4 mm,
7.1.3 Percent air voids, 2.2,
7.1.4 Percent voids in mineral aggregate, 14.4, and
7.1.5 The stability value exceeds the minimum of 700 kg (1540 lb) and the percent voids in mineral aggregate exceeds the minimum of 14. The flow value, however, is not within the limiting range of 2.5 to 5.0, and the percent voids in the total mix falls below the lower limit shown in the table of criteria for the design conditions. Normally, adjustments would be made in the mix, as suggested in Appendix B, to provide a mix design having all test properties within allowable limits. In this instance, a greater percentage of coarse aggregate, consistent with specifications, would be selected and the mixture redesigned.

7.2 Selection of Mix Design-The selected mix design is usually the most economical one which will satisfactorily meet all of the established criteria. Mixes with abnormally high values of Marshall stability and abnormally low flow values are often less desirable because pavements of such mixes tend to be more rigid or brittle and may crack under heavy volumes of traffic. This is particularly true where base deflections and high subgrade deflections are such as to permit moderate to relatively high deflections of the pavement.

Table 2

Percent Voids in Mineral Aggregate

<table>
<thead>
<tr>
<th>Sieve Designation</th>
<th>Nominal Maximum Particle Size</th>
<th>Min. Voids in Mineral Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td>Mm (in.)</td>
<td>Percent</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>1.18 0.0469</td>
<td>23.5</td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>2.36 0.093</td>
<td>21</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>4.75 0.187</td>
<td>18</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>9.5 0.375</td>
<td>16</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>12.5 0.500</td>
<td>15</td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>19.0 0.750</td>
<td>14</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>25.0 1.0</td>
<td>13</td>
</tr>
<tr>
<td>37.5 (1½ in.)</td>
<td>37.5 1.5</td>
<td>12</td>
</tr>
<tr>
<td>50 (2 in.)</td>
<td>50 2.0</td>
<td>11.5</td>
</tr>
<tr>
<td>63 (2½ in.)</td>
<td>63 2.5</td>
<td>11</td>
</tr>
</tbody>
</table>

Note 9: Laboratory compactive efforts should closely approach the maximum density obtained in the pavement under traffic.
Note 10: The flow value refers to the point where the load begins to decrease.

Note 11: The portion of the asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent air voids.

Note 12: Percent voids in the mineral aggregate is to be calculated on the basis of the bulk specific gravity (MRDTM 411) for the aggregate.

Note 13: All criteria, and not stability values alone, must be considered in designing an asphalt paving mix.

Note 14: Compare the average asphalt content and aggregate gradation of two Marshall samples prepared using the design values to the asphalt content obtained from extraction, MRDTM 418, and aggregate gradation obtained from MRDTM 419. Comparison of values indicates potential corrections to asphalt contents obtained from job control extractions and potential degradation of aggregate and loss of fines.

8. Effect of Water on Compacted Mix

8.1 Using the mix design (aggregate proportions and asphalt content), prepare mix and test samples in accordance with MRDTM 415, Effect of Water on Cohesion of Compacted Bituminous Mixtures, and report results with the Marshall Mix Design data.
Table of Equivalents

<table>
<thead>
<tr>
<th>mm</th>
<th>(in)</th>
<th>mm</th>
<th>(in)</th>
<th>mm</th>
<th>(in)</th>
<th>mm</th>
<th>(in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
<td>(0.005)</td>
<td>17.5</td>
<td>(1 1/16)</td>
<td>58.7</td>
<td>(2 5/16)</td>
<td>104.8</td>
<td>(4 1/8)</td>
</tr>
<tr>
<td>0.8</td>
<td>(1/32)</td>
<td>19.0</td>
<td>(3/4)</td>
<td>63.5</td>
<td>(2 1/2)</td>
<td>108.7</td>
<td>(4 9/32)</td>
</tr>
<tr>
<td>1.6</td>
<td>(1/16)</td>
<td>22.2</td>
<td>(7/8)</td>
<td>69.8</td>
<td>(2 3/4)</td>
<td>109.1</td>
<td>(4 19/64)</td>
</tr>
<tr>
<td>3.2</td>
<td>(1/8)</td>
<td>23.8</td>
<td>(15/16)</td>
<td>73.0</td>
<td>(2 7/8)</td>
<td>114.3</td>
<td>(4 5/8)</td>
</tr>
<tr>
<td>4.8</td>
<td>(3/16)</td>
<td>25.4</td>
<td>(1)</td>
<td>76.2</td>
<td>(3)</td>
<td>117.5</td>
<td>(4 5/8)</td>
</tr>
<tr>
<td>6.4</td>
<td>(1/4)</td>
<td>28.6</td>
<td>(1 7/8)</td>
<td>82.6</td>
<td>(3 1/4)</td>
<td>120.6</td>
<td>(4 1/4)</td>
</tr>
<tr>
<td>7.1</td>
<td>(9/32)</td>
<td>31.8</td>
<td>(1 1/4)</td>
<td>87.3</td>
<td>(3 7/16)</td>
<td>128.6</td>
<td>(5 1/16)</td>
</tr>
<tr>
<td>9.5</td>
<td>(3/8)</td>
<td>34.9</td>
<td>(1 3/8)</td>
<td>98.4</td>
<td>(3 7/8)</td>
<td>130.2</td>
<td>(5 1/8)</td>
</tr>
<tr>
<td>12.6</td>
<td>(0.496)</td>
<td>38.1</td>
<td>(1 1/2)</td>
<td>101.2</td>
<td>(3 63/64)</td>
<td>146.0</td>
<td>(5 3/4)</td>
</tr>
<tr>
<td>12.67</td>
<td>(0.499)</td>
<td>41.3</td>
<td>(1 5/8)</td>
<td>101.35</td>
<td>(3.990)</td>
<td>152.4</td>
<td>(6)</td>
</tr>
<tr>
<td>12.7</td>
<td>(1/2)</td>
<td>44.4</td>
<td>(1 1/4)</td>
<td>101.47</td>
<td>(3.995)</td>
<td>158.8</td>
<td>(6 1/4)</td>
</tr>
<tr>
<td>14.3</td>
<td>(9/16)</td>
<td>50.8</td>
<td>(2)</td>
<td>101.6</td>
<td>(4)</td>
<td>193.7</td>
<td>(7 5/8)</td>
</tr>
<tr>
<td>15.9</td>
<td>(5/8)</td>
<td>57.2</td>
<td>(2 1/4)</td>
<td>101.73</td>
<td>(4.005)</td>
<td>685.8</td>
<td>(27)</td>
</tr>
</tbody>
</table>

Fig. 1. Compaction Mold
Fig. 2 Compaction Hammer

Fig. 3. Breaking Head
Fig. 4. Compression Testing Machine
Fig. 5. Pedestal, Hammer and Mold Used in Preparing Marshall Test Specimens

Fig. 6. Marshall Stability and Flow Test Apparatus
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A</td>
<td>4.0</td>
<td>1306.8</td>
<td>794.8</td>
<td>512.0</td>
<td>2.552</td>
<td>63.5</td>
<td>812</td>
<td>812</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>4.0</td>
<td>1309.5</td>
<td>796.4</td>
<td>513.1</td>
<td>2.563</td>
<td>63.5</td>
<td>821</td>
<td>821</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>4.0</td>
<td>1309.6</td>
<td>798.5</td>
<td>511.1</td>
<td>2.562</td>
<td>63.5</td>
<td>839</td>
<td>839</td>
<td>8</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.559</td>
<td>2.699</td>
<td>5.2</td>
<td>14.8</td>
<td>65.9</td>
</tr>
<tr>
<td>2 A</td>
<td>4.5</td>
<td>1315.3</td>
<td>806.3</td>
<td>509.0</td>
<td>2.584</td>
<td>63.5</td>
<td>862</td>
<td>862</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>1315.1</td>
<td>806.8</td>
<td>508.3</td>
<td>2.587</td>
<td>61.9</td>
<td>787</td>
<td>818</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>4.5</td>
<td>1311.6</td>
<td>803.5</td>
<td>508.1</td>
<td>2.581</td>
<td>61.9</td>
<td>821</td>
<td>854</td>
<td>8</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.584</td>
<td>2.678</td>
<td>3.5</td>
<td>14.5</td>
<td>76.6</td>
</tr>
<tr>
<td>3 A</td>
<td>5.0</td>
<td>1320.1</td>
<td>812.1</td>
<td>508.0</td>
<td>2.599</td>
<td>63.5</td>
<td>850</td>
<td>850</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>1318.1</td>
<td>811.0</td>
<td>507.1</td>
<td>2.599</td>
<td>61.9</td>
<td>862</td>
<td>895</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>5.0</td>
<td>1318.7</td>
<td>811.0</td>
<td>507.7</td>
<td>2.597</td>
<td>61.9</td>
<td>789</td>
<td>821</td>
<td>10</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.598</td>
<td>2.654</td>
<td>2.1</td>
<td>14.4</td>
<td>86.6</td>
</tr>
<tr>
<td>4 A</td>
<td>5.5</td>
<td>1320.5</td>
<td>811.5</td>
<td>509.0</td>
<td>2.594</td>
<td>63.5</td>
<td>810</td>
<td>810</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>5.5</td>
<td>1326.1</td>
<td>814.7</td>
<td>511.4</td>
<td>2.593</td>
<td>63.5</td>
<td>764</td>
<td>764</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>5.5</td>
<td>1324.2</td>
<td>814.6</td>
<td>509.6</td>
<td>2.599</td>
<td>63.5</td>
<td>764</td>
<td>764</td>
<td>13</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.595</td>
<td>2.632</td>
<td>1.4</td>
<td>15.0</td>
<td>91.6</td>
</tr>
<tr>
<td>5 A</td>
<td>6.0</td>
<td>1327.6</td>
<td>813.6</td>
<td>514.0</td>
<td>2.583</td>
<td>63.5</td>
<td>676</td>
<td>676</td>
<td>17</td>
</tr>
<tr>
<td>B</td>
<td>6.0</td>
<td>1330.6</td>
<td>815.4</td>
<td>515.3</td>
<td>2.582</td>
<td>63.5</td>
<td>653</td>
<td>653</td>
<td>17</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>1329.3</td>
<td>814.4</td>
<td>514.9</td>
<td>2.582</td>
<td>63.5</td>
<td>717</td>
<td>717</td>
<td>17</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.582</td>
<td>2.611</td>
<td>1.1</td>
<td>15.9</td>
<td>94.1</td>
</tr>
</tbody>
</table>

(1) From MRDTM 412 = ____

\[
G_{sb'} = \text{Avg. Bulk Sp. Gr. of Aggregates} = 2.885
\]

(2) Air Voids, \( P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 \)

\[
G_{se'} = \text{Effective Sp. Gr. of Aggregates} = 3.037 G_{mm}
\]

(3) VMA=100 - \( \frac{100 - Pb}{G_{mb}} \times \frac{G_{mb} - P_{ba}}{G_{sb}} \)

\[
P_{ba'}, \text{Asphalt Absorption} = 0.16\%
\]

(4) \% VMA Filled= \( \frac{Gb}{VMA} \times 100 \)

\[
P_{be'}, \text{Effective Asphalt Cont.} = \text{____}%
\]

(5) From Table 1, MRDTM 410

\[
G_{sb'}, \text{Specific Gravity of Asphalt} = 1.010
\]

Fig. 7. Sample Test Report Form Showing Test Data for a Typical Marshall Mix Design
Fig. 8. Test Property Curves for Hot-Mix Design by the Marshall Method
Appendix A
Gradation Analysis of Aggregates

A.1 Use of Grading Curves

A.1.1 Grading curves are helpful in making necessary adjustments in mix designs. For example, curves determined from the Fuller equation (A1) represent maximum density and minimum voids in mineral aggregate (VMA) conditions. Paving mixtures with such curves tend to be workable and readily compacted. However, their void contents may be too low. Usually, deviations from these curves will result in lower densities and higher VMA. The extent of change in density and VMA depends on the amount of adjustment in fine or coarse aggregate. Fig. A-1 illustrates a series of Fuller maximum density curves plotted on a semilog grading chart.

A.1.2 Fig. A-2 illustrates maximum density curves determined from the Fuller equation raised to the 0.45 power, equation (A2) and plotted on a grading chart (based on a scale raising sieve openings to the 0.45 power). The curves on this chart may be obtained by drawing a straight line from the origin at the lower left of the chart to the desired nominal maximum particle size (Note A.1) at the top. Gradings that closely approach this straight line usually must be adjusted away from it within acceptable limits to increase the VMA values.

\[ p = \left( \frac{d}{D} \right)^{0.5} \]  
\[ \text{(A1)} \]

where:

- \( p \) = total percentage passing a given sieve,
- \( d \) = size of sieve opening, mm (in.), and
- \( D \) = largest size (sieve opening) mm (in.) in gradation.

\[ p = \left( \frac{d}{D} \right)^{0.45} \]  
\[ \text{(A2)} \]

Note A.1: For processed aggregate, the nominal maximum particle size is the largest sieve size listed in the applicable specification upon which not more than 5 percent of the material is permitted to be retained.

Fig. A-1. Fuller Maximum Density Curves on Standard Semi-log Grading Chart
A.2 Aggregate Gradations and Fractions

A.2.1 For the purpose of specifications and test reporting, specify the gradation of aggregates on the basis of the total aggregate gradation, or total percent by mass passing designated sieve sizes. The individual fractions of the total aggregate gradation are designated as: (Note A.2),

A.2.1.1 Coarse aggregate (retained 4.75 mm (No. 4) sieve: (Rock).
A.2.1.2 Fine aggregate passing 4.75 mm (No. 4) sieve: (Sand).
A.2.1.3 Mineral dust passing 0.075 mm (No. 200) sieve: (Filler).

Note A.2: The aggregate gradations as well as the individual fractions are specified independently of the total mix, that is, the total aggregate equals 100 percent.

A.3 Example

A.3.1 On a certain paving job, it is determined that the most economical sources of aggregate are crushed limestone for the coarse sizes, and natural sand supplemented with limestone dust for the fine sizes. The gradation analysis on each of these three materials shows that they should be blended as follows:

- 46 percent rock (crushed limestone)
- 48 percent sand (sand)
- 6 percent filler (limestone dust)
- 100 percent

(Refer to Sec A.4 for typical gradation and blending calculations). The total gradation produced by the above blend proportions is illustrated in Fig. A-3.

<table>
<thead>
<tr>
<th>Total Passing, Percent by Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specifications (example)</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
</tr>
<tr>
<td>2.00 (No. 10)</td>
</tr>
<tr>
<td>0.425 (No. 40)</td>
</tr>
<tr>
<td>0.180 (No. 80)</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
</tr>
</tbody>
</table>

Fig. A-3. Gradation of Aggregate Blend (example)

A.4 Blending Aggregates by Mass

A.4.1 Determining the proportions of two or more aggregates, to blend for a gradation within the specification limits, is largely a matter of trial and error, although graphical methods may be used to advantage. It is desirable first to plot the sieve analyses for all aggregates to be used as shown in Fig. A-4 and A-5. In this way, it is often possible to make a visual estimate of the blend proportions required.
A.5 Basic Formula

A.5.1 Regardless of the number of aggregates combined or of the method by which the proportions are determined, the basic formula expressing the combination is:

\[ P = Aa + Bb + Cc + \ldots + Nn \] (A3)

where:
- \( P \) = the percentage of material passing a given sieve for the combined aggregates A, 13, C, ... N,
- A, B, C, ...N = percentage of material passing a given sieve for aggregates A, 13, C, ...N, and,
- a, b, c, ...n = proportions of aggregates, A, B, C, ...N, used in the combination and where the total = 1.00.

A.5.2 The combined percentages, \( P \), in equation (A3), should closely agree with the desired percentages for the combination for the different sieve sizes. None should fall outside the established grading specification limits. Note that there may be several acceptable combinations. An optimum combination would be one in which the percentages of the
blend are in as close agreement as possible to the desired percentages originally set up, and using the fewest number of aggregate sources.

A.6 General Solutions

A.6.1 For two and sometimes three aggregate materials, graphical solutions may be used to advantage over trial and error methods.

A.7 Combining Two Aggregates

A.7.1 The basic formula for combining two aggregates is:

\[ P = Aa + Bb \]  \hspace{1cm} (A4)

Since \( a + b = 1 \), then \( a = 1 - b \). Substituting this into equation (A4) and solving for \( b \):

\[ b = \frac{P - A}{B - A} \]  \hspace{1cm} (A5)

An expression for \( a \), can also be found:

\[ a = \frac{P - B}{A - B} \]  \hspace{1cm} (A6)

A.7.2 Assume that a single aggregate stockpile is to be blended with sand to meet grading requirements for an asphalt paving mixture. These are given in Fig. A-6 (a) as aggregates A and B. To make a determination:

A.7.2.1 Examine the two gradations to determine which aggregate will contribute most of the material for certain sizes. In this case, most of the minus 2.00 mm (No. 10) aggregate will be furnished by aggregate B.

A.7.2.2 Using the percentages for the 2.00 mm (No. 10) sieve and substituting into equation (A5) the proportions are determined to meet the midpoint of the specification (Fig. A-6 (b)).

A.7.2.3 Inspection of the blended gradation shows the percent passing the 0.075 mm (No. 200) sieve is close to the lower specification limit. Increase the proportion of aggregate B (in this case to 0.55) and compute the gradation of the revised blend (Fig. A-6 (c)).

A.7.2.4 Inspection now shows the gradation is critical on the 4.75 mm (No. 4) sieve. Reduce the proportion of aggregate B to 0.52 or 0.53 and compute the gradation of the revised blend (Fig. A-6 (d)).
(a) Grading Specification and Sieve Analysis of Aggregates, Percent Passing

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt.)</td>
<td>¾ in.</td>
<td>½ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>Spec.</td>
<td>100</td>
<td>80-95</td>
<td>48-62</td>
<td>32-45</td>
<td>16-26</td>
<td>8-18</td>
<td>4-8</td>
</tr>
<tr>
<td>Aggr. A</td>
<td>100</td>
<td>80</td>
<td>16</td>
<td>3.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aggr. B</td>
<td>100</td>
<td>100</td>
<td>96</td>
<td>74</td>
<td>36</td>
<td>21</td>
<td>9.2</td>
</tr>
</tbody>
</table>

For 2.00 mm (No. 10), \( b = \frac{P-A}{B-A} = \frac{38.5-3.2}{74-3.2} = 0.50 \), \( a = 1-0.50 = 0.50 \)

(b) First Trial Combination, Percent Passing

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt.)</td>
<td>¾ in.</td>
<td>½ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>.50 X A</td>
<td>50</td>
<td>40.0</td>
<td>8.0</td>
<td>1.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.50 X B</td>
<td>50</td>
<td>50.0</td>
<td>48.0</td>
<td>37.0</td>
<td>18.0</td>
<td>10.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>90.0</td>
<td>56.0</td>
<td>38.6</td>
<td>18.0</td>
<td>10.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Spec. (Example)</td>
<td>100</td>
<td>80-95</td>
<td>48-62</td>
<td>32-45</td>
<td>16-26</td>
<td>8-18</td>
<td>4-8</td>
</tr>
</tbody>
</table>

Minus 0.075 mm (No. 200) low, increase \( b \) to 0.55, \( a = 0.45 \)

(c) Second Trial Combination, Percent Passing

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt.)</td>
<td>¾ in.</td>
<td>½ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>.45 X A</td>
<td>45</td>
<td>36.0</td>
<td>7.2</td>
<td>1.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.55 X B</td>
<td>55</td>
<td>55.0</td>
<td>52.8</td>
<td>40.7</td>
<td>19.8</td>
<td>11.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>91.0</td>
<td>60.0</td>
<td>42.1</td>
<td>19.8</td>
<td>11.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Spec. (Example)</td>
<td>100</td>
<td>80-95</td>
<td>48-62</td>
<td>32-45</td>
<td>16-26</td>
<td>8-18</td>
<td>4-8</td>
</tr>
</tbody>
</table>

Minus 4.75 mm (No. 4) high, let \( b = 0.52 \), \( a = 0.48 \)

(d) Third Trial Combination, Percent Passing

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt.)</td>
<td>¾ in.</td>
<td>½ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>.48 X A</td>
<td>48</td>
<td>38.4</td>
<td>7.7</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.52 X B</td>
<td>52</td>
<td>52</td>
<td>49.9</td>
<td>38.5</td>
<td>18.7</td>
<td>10.9</td>
<td>4.8</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>90.4</td>
<td>57.6</td>
<td>40.0</td>
<td>18.7</td>
<td>10.9</td>
<td>4.8</td>
</tr>
<tr>
<td>Spec. (Example)</td>
<td>100</td>
<td>80-95</td>
<td>48-62</td>
<td>32-45</td>
<td>16-26</td>
<td>8-18</td>
<td>4-8</td>
</tr>
</tbody>
</table>

Fig. A-6. Trial and Error Calculations for Combining Two Aggregates
Two Aggregate Combination—Graphically

A.7.3 The two aggregates may be combined graphically (Fig. A-7) as follows:

A.7.3.1 The percents passing the various sizes for aggregate A are plotted on the right hand vertical scale (representing 100 percent aggregate A).

A.7.3.2 The percents passing the various sizes for aggregate B are plotted on the left hand vertical scale (representing 100 percent aggregate B).

A.7.3.3 Connect the points common to the same size with straight lines, and label.

A.7.3.4 For a particular size, indicate on the straight line where the line crosses the specification limits measured on the vertical scale. For the 4.75 mm (No. 4) size, two points are plotted on the line at 48 and 62 percent on the vertical scale.

A.7.3.5 That portion of the line between the two points represents the proportions of aggregates A and B, measured on the horizontal scale, that will not exceed limits for that particular size.

A.7.3.6 The portion of the horizontal scale designated by two vertical lines, when projected vertically, is within specification limits for all sizes and represents the limits of proportions possible for satisfactory blends. In this case, 43 to 55 percent of aggregate A and 45 to 57 percent of aggregate B will meet specifications when blended. From this graph note that the percent of blended material passing the 4.75 mm (No. 4) and 0.425 mm (No. 40) sieves will be critical for controlling values for keeping the blend within specification limits.

A.7.3.7 For blending, usually the midpoint of that horizontal scale is selected for the blend. In this case, 49 percent aggregate A and 51 percent aggregate B.

![Diagram of two aggregate combination graphically](image-url)

Fig. A-7. Solution for Proportioning Two Aggregates
A.8 Combining Three Aggregates

A.8.1 Mineral filler, C, is to be blended with aggregates A and B to obtain a gradation meeting specification requirements. The specification and gradations are given in Fig. A-8.

A.8.2 An inspection of the gradations indicates that there is a reasonably clean separation between the plus 2.00 mm (No. 10) sizes and minus 2.00 mm (No. 10) sizes. Aggregate A will furnish most of the plus 2.00 mm (No. 10) sizes.

A.8.3 Determine the approximate proportion of aggregate A required to obtain 38.5 percent passing the 2.00 mm (No. 10) sieve (midpoint of specification range), using equation (A6) (Fig. A-8).

A.8.4 The percentages passing the 0.075 mm (No. 200) sieve are examined next. Values are substituted into equation (A3).

A.8.5. If the blended gradation exceeds specification limits, that proportion in the blend responsible should be altered, with the other proportions altered to make up a total of 100 percent.

A.8.6 Graphical methods usually help in trial and error solutions; when they do not, it is necessary to determine the proportions in cases of aggregate gradations having overlapping grading curves. Each of the aggregates is divided into the following gradings:

A.8.6.1 Percent material retained on the 2.00 mm (No. 10) sieve,
A.8.6.2 Percent material passing the 2.00 mm (No. 10) sieve but retained on the 0.075 mm (No. 200) sieve, and
A.8.6.3 Percent material passing the 0.075 mm (No. 200) sieve.

---

(a) Example Grading Specification and Gradations

<table>
<thead>
<tr>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve, mm</td>
</tr>
<tr>
<td>19.0</td>
</tr>
<tr>
<td>12.5</td>
</tr>
<tr>
<td>4.75</td>
</tr>
<tr>
<td>2.00</td>
</tr>
<tr>
<td>0.425</td>
</tr>
<tr>
<td>0.180</td>
</tr>
<tr>
<td>0.075</td>
</tr>
<tr>
<td>Sieve (alt.)</td>
</tr>
<tr>
<td>3/4 in.</td>
</tr>
<tr>
<td>½ in.</td>
</tr>
<tr>
<td>No. 4</td>
</tr>
<tr>
<td>No. 10</td>
</tr>
<tr>
<td>No. 40</td>
</tr>
<tr>
<td>No. 80</td>
</tr>
<tr>
<td>No. 200</td>
</tr>
<tr>
<td>Spec. (Example)</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>80-95</td>
</tr>
<tr>
<td>48-62</td>
</tr>
<tr>
<td>32-45</td>
</tr>
<tr>
<td>16-26</td>
</tr>
<tr>
<td>8-18</td>
</tr>
<tr>
<td>4-8</td>
</tr>
<tr>
<td>Aggr. A</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>3.2</td>
</tr>
<tr>
<td>Aggr. B</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>96</td>
</tr>
<tr>
<td>74</td>
</tr>
<tr>
<td>36</td>
</tr>
<tr>
<td>21</td>
</tr>
<tr>
<td>9.2</td>
</tr>
<tr>
<td>Aggr. C</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>98</td>
</tr>
<tr>
<td>93</td>
</tr>
<tr>
<td>56</td>
</tr>
</tbody>
</table>

2.00 mm (No. 10), \( a = \frac{P-B}{A-B} = \frac{38.5-74}{3.2-74} = 0.50 \)

0.075 mm (No. 200), \( P = Aa + Bb + Cc \)
\[ 6 = 0(0.50) + 9.2b + 56c \]
\[ 6 = 9.2 \times 0.50 + 56c \]
\[ 6 = 9.2 \]
\[ 56c = 0.03, b = 0.50 - 0.03 = 0.47 \]

(b) First Trial Solution for Combining Three Aggregates.

<table>
<thead>
<tr>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve, mm</td>
</tr>
<tr>
<td>19.0</td>
</tr>
<tr>
<td>12.5</td>
</tr>
<tr>
<td>4.75</td>
</tr>
<tr>
<td>2.00</td>
</tr>
<tr>
<td>0.425</td>
</tr>
<tr>
<td>0.180</td>
</tr>
<tr>
<td>0.075</td>
</tr>
<tr>
<td>Sieve (alt.)</td>
</tr>
<tr>
<td>3/4 in.</td>
</tr>
<tr>
<td>½ in.</td>
</tr>
<tr>
<td>No. 4</td>
</tr>
<tr>
<td>No. 10</td>
</tr>
<tr>
<td>No. 40</td>
</tr>
<tr>
<td>No. 80</td>
</tr>
<tr>
<td>No. 200</td>
</tr>
<tr>
<td>.50 X A</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>40.0</td>
</tr>
<tr>
<td>8.0</td>
</tr>
<tr>
<td>1.6</td>
</tr>
<tr>
<td>.47 X B</td>
</tr>
<tr>
<td>47</td>
</tr>
<tr>
<td>47.0</td>
</tr>
<tr>
<td>45.1</td>
</tr>
<tr>
<td>34.8</td>
</tr>
<tr>
<td>16.9</td>
</tr>
<tr>
<td>9.9</td>
</tr>
<tr>
<td>4.3</td>
</tr>
<tr>
<td>.03 X C</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>2.8</td>
</tr>
<tr>
<td>1.7</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>90.0</td>
</tr>
<tr>
<td>56.1</td>
</tr>
<tr>
<td>39.4</td>
</tr>
<tr>
<td>19.9</td>
</tr>
<tr>
<td>12.7</td>
</tr>
<tr>
<td>6.0</td>
</tr>
<tr>
<td>Spec. (Example)</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>80-95</td>
</tr>
<tr>
<td>48-62</td>
</tr>
<tr>
<td>32-48</td>
</tr>
<tr>
<td>16-26</td>
</tr>
<tr>
<td>8-18</td>
</tr>
<tr>
<td>4-8</td>
</tr>
</tbody>
</table>

Fig. A-8. Trial and Error Solution for Combining Three Aggregates
A.8.7. The specification limits are divided in a similar manner: allowable percentage limits retained on the 2.00 mm (No. 10) sieve, and allowable percentage limits passing the 0.075 mm (No. 200) sieve. Points representing each of the three aggregate gradings are plotted on a chart, Fig. A-9. Although only the portion retained on the 2.00 mm (No. 10) sieve and the portion passing the 0.075 mm (No. 200) sieve are used for each of the three aggregates to locate points on the chart, the point designated A represents the coarse aggregate grading, B the fine aggregate grading, and C the mineral filler grading. Point S represents the middle of the specification grading band for material retained on the 2.00 mm (No. 10) sieve and passing the 0.075 mm (No. 200) sieve. Lines are drawn between Points A and S and between Points B and C. Line AS is extended to Line BC to establish Point B'. Each line segment is determined by using the differences in percentages between terminal points. Then the percentage of each aggregate material needed for the blend is calculated using the following formulas derived from the basic formula (equation (A3)).

\[
\begin{align*}
    a &= \frac{\text{Line Segment SB'}}{\text{Line AB'}} \\
    b + c &= 1.00 - a \\
    c &= (1.00 - a) \times \frac{\text{Line Segment B'B}}{\text{Line CB}} \\
    b &= 1.00 - (a + c)
\end{align*}
\]

Fig. A-9. Chart for Estimating Three Aggregate Blends
A.9 Adjusting for Different Specific Gravities

A.9.1 Aggregate gradations and grading curves are determined and expressed in percentages of total mass. Grading specifications, however, are established to meet volumetric requirements in the asphalt paving mix. As long as the specific gravities of the combined aggregate materials are reasonably alike, the percentages by mass may be interpreted as percentages by volume for all practical purposes. When the specific gravities of the individual aggregates differ significantly (usually by 0.20 or more), the aggregate proportions should be adjusted. The adjustment is based on equation (A7).

\[
\text{Mass} = \text{Volume} \times \text{Specific Gravity} \quad (A7)
\]

A.9.2. Assume the following combination was calculated for three aggregates having different specific gravities:

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Specific Gravity</th>
<th>Proportion,</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.000</td>
<td>52%</td>
</tr>
<tr>
<td>B</td>
<td>2.000</td>
<td>45%</td>
</tr>
<tr>
<td>C</td>
<td>3.000</td>
<td>3%</td>
</tr>
</tbody>
</table>

Calculations for adjustments are shown in Fig. A-10.

\[
\begin{array}{c|c|c|c|c|c}
\text{Aggregate} & \text{Percent by Vol.} & \text{Sp. Gr.} & \text{Mass, W (Vol. X Sp. Gr.)} & \text{Percent by Mass}^{(1)} \\
\hline
A & 52.0 & 1.000 & 52.00 & 34.4 \\
B & 45.0 & 2.000 & 90.00 & 59.6 \\
C & 3.0 & 3.000 & 9.00 & 6.0 \\
\hline
\text{Total} & 100.0 & - & 151.00 & 100.0 \\
\end{array}
\]

\[
\% \text{ by Mass} = \frac{\text{Individual Mass, W}}{\text{Total Mass}} \times 100 = \frac{W}{151} \times 100
\]

Fig. A-10. Adjusting Percentages by Volume to Percentages by Mass

A.10 Adjusting by Wasting

A.10.1 It may be the case that crusher-run aggregates are either coarser or finer than desired. If the gradation is coarser than desired, finer material can usually be blended with the crusher-run aggregate. But for gradations that have an excess of fines, the most economical adjustment is usually made by wasting a portion of the fine fraction. Most crushing plants make the separation on the 4.75 mm (No. 4) or the 2.00 mm (No. 10) screens. Where an excess on a small size occurs, the correction is made by wasting a portion of the minus 4.75 mm (No. 4) or 2.00 mm (No. 10) fraction. The amount of waste is expressed as a percent, where the total crusher-run material is 100 percent.

A. 10.2. The formula for analysis of gradations before and after wasting are as follows:

A.10.2.1 Sizes above waste screen;

\[
R_b = \frac{R_2}{R_a} \quad (A8)
\]

A. 10.2.2 Sizes below waste screen;

\[
P_b = \frac{P_2}{P_1} \quad (A9)
\]

where:

\(P_a, R_a\) = percent passing, or retained, of given size before wasting,

\(P_b, R_b\) = adjusted percent passing, or retained, of given size after wasting,

\(P_1, R_1\) = percent passing, or retained, of waste size before wasting, and

\(P_2, R_2\) = percent passing, or retained, or waste size after wasting.
A.10.3 The percent of waste, $W$, is found as follows:

$$W = \frac{P_1 - P_2}{100 - P_2} \times 100 \quad (A\ 10)$$

A.10.4 Assume that a single aggregate stockpile is being produced from a local roadside pit. The specification limits and crusher-run gradation are shown in Fig. A-11. Note that the 4.75 mm (No. 4) size is above specification limits and that the other percentages approach the upper limits of the specification. A portion of the minus 4.75 mm (No. 4) fraction will be wasted to reduce the percent passing 4.75 mm (No. 4) from 65 to 60 percent. The adjusted percentages of the passing 4.75 mm (No. 4) sizes are found using equation (A9) as shown. The percentages of the passing 4.75 mm (No. 4) sizes are first converted to percent retained and the adjusted percent retained on 4.75 mm (No. 4) is determined. The percentages of coarse sizes are found using equation (A8) and reconverted to percent passing. The percent of waste of the passing 4.75 mm (No. 4) fraction is then found using equation (A10). Assume, in this case, that the 0.425 mm (No. 40) size exceeds specification limits. Therefore, a sufficient amount of the minus 4.75 mm (No. 4) fraction will be wasted to reduce the 0.425 mm (No. 40) from 31 percent to 25 percent (Fig. A-11 (b)). In this case, $P_1$ and $P_2$ for the fine fraction are values for the 0.425 mm (No. 40) sieve. When the adjusted percentages are obtained, $R_1$ and $R_2$ for the 4.75 mm (No. 4) sieve are used for the coarse fraction.

(a) Calculations Based on Adjusting Percent Passing 4.75 mm (No. 4) Sieve.

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt)</td>
<td>⅜ in.</td>
<td>⅓ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>Spec. (Example)</td>
<td>100</td>
<td>80 - 95</td>
<td>48 - 62</td>
<td>32 - 45</td>
<td>16 - 26</td>
<td>8 - 18</td>
<td>4 - 8</td>
</tr>
<tr>
<td>% Pass, $P_a$</td>
<td>100</td>
<td>93</td>
<td>65</td>
<td>41</td>
<td>23</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>Adj % Ret, $R_a$</td>
<td>0</td>
<td>7</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj % Ret, $R_b$</td>
<td>0</td>
<td>8</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj % Pass, $P_b$</td>
<td>100</td>
<td>92</td>
<td>60</td>
<td>38</td>
<td>21</td>
<td>16</td>
<td>6.4</td>
</tr>
</tbody>
</table>

$$P_b = \frac{P_2}{P_1} \times P_a = \frac{60}{65} \times P_a = 0.92 P_a \quad R_b = \frac{R_2}{R_1} \times R_a = \frac{40}{35} \times R_a = 1.14 R_a$$

Waste, $W = \frac{100 (P_1 - P_2)}{100 - P_2} = \frac{100 (65 - 60)}{100 - 60} = 12.5\%$

(b) Calculations Based on Adjusting Percent Passing 0.425 mm (No. 40)

<table>
<thead>
<tr>
<th>Sieve, mm</th>
<th>19.0</th>
<th>12.5</th>
<th>4.75</th>
<th>2.00</th>
<th>0.425</th>
<th>0.180</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve (alt)</td>
<td>¼ in.</td>
<td>½ in.</td>
<td>No. 4</td>
<td>No. 10</td>
<td>No. 40</td>
<td>No. 80</td>
<td>No. 200</td>
</tr>
<tr>
<td>Spec. (Example)</td>
<td>100</td>
<td>80 - 95</td>
<td>48 - 62</td>
<td>32 - 45</td>
<td>16 - 26</td>
<td>8 - 18</td>
<td>4 - 8</td>
</tr>
<tr>
<td>% Pass, $P_a$</td>
<td>100</td>
<td>92</td>
<td>60</td>
<td>42</td>
<td>31</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>% Ret, $R_a$</td>
<td>0</td>
<td>8</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj % Ret, $R_b$</td>
<td>0</td>
<td>10</td>
<td>51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj % Pass, $P_b$</td>
<td>100</td>
<td>90</td>
<td>49</td>
<td>34</td>
<td>25</td>
<td>13</td>
<td>4.9</td>
</tr>
</tbody>
</table>

$$P_b = \frac{P_2}{P_1} \times P_a = \frac{25}{31} \times P_a = 0.81 P_a \quad R_b = \frac{R_2}{R_1} \times R_a = \frac{51}{40} \times R_a = 1.28 R_a$$

Waste, $W = \frac{100 (P_1 - P_2)}{100 - P_2} = \frac{100 (60 - 49)}{100 - 49} = 21.6\%$

Fig. A-11. Adjusting Gradation by Wasting

Computing Laboratory Batch Weights

A.11 Computing Laboratory Batch Weights

A.11.1 In the analysis of aggregates for a given mix design, the final operation is the computation of the laboratory batch weights. It is convenient to use the same mass of aggregate in each batch to produce a trial mix series of constant mass.
A.11.2 Determine the blend proportions of the sized fractions and mineral filler required to approximate the original trial blend. Fig. A-12 shows the washed sieve analysis of the aggregate fractions and the blend proportions required for this example.

A.11.3 After the desired blend proportions have been determined, the computation of batch weights requires calculating the amount of each aggregate fraction and asphalt cement required to yield a total amount of mix suitable for the preparation of individual test specimens. Fig. A-13 shows the laboratory batch weights for this example. Note that the accumulative mixture mass is constant for all trial mixes and the required mass of asphalt and aggregate vary for each sample to allow for expressing the asphalt content as a percentage of the total mixture mass.

**Gradation of Aggregate Fractions**

<table>
<thead>
<tr>
<th>Aggregate Fractions (alternate)</th>
<th>Percent Used</th>
<th>Sieve Size—Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td></td>
<td>19.0</td>
</tr>
<tr>
<td>19.0 — 12.5</td>
<td>¾ in. — ½ in.</td>
<td>100</td>
</tr>
<tr>
<td>12.5 — 4.75</td>
<td>½ in. — No. 4</td>
<td>100</td>
</tr>
<tr>
<td>4.75 — 2.00</td>
<td>No. 4 — No. 10</td>
<td>100</td>
</tr>
<tr>
<td>−2.00</td>
<td>No. 10</td>
<td>100</td>
</tr>
<tr>
<td>−0.075</td>
<td>MF</td>
<td>100</td>
</tr>
</tbody>
</table>

**Combined Gradation for Blend—Trial Mix**

<table>
<thead>
<tr>
<th>Aggregate Fractions (alternate)</th>
<th>Percent Used</th>
<th>Sieve Size—Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td></td>
<td>19.0</td>
</tr>
<tr>
<td>19.0 — 12.5</td>
<td>¾ in. — ½ in.</td>
<td>20</td>
</tr>
<tr>
<td>12.5 — 4.75</td>
<td>½ in. — No. 4</td>
<td>20</td>
</tr>
<tr>
<td>4.75 — 2.00</td>
<td>No. 4 — No. 10</td>
<td>18</td>
</tr>
<tr>
<td>−2.00</td>
<td>No. 10</td>
<td>38</td>
</tr>
<tr>
<td>−0.075</td>
<td>MF</td>
<td>4</td>
</tr>
</tbody>
</table>

| Blend Grading                | 100 | 93.1 | 60.4 | 42.3 | 22.6 | 12.3 | 6.8   |
| Desired Grading              | 100 | 87.5 | 55.0 | 38.5 | 21.0 | 13.0 | 6.0   |

Fig. A-12. Work Sheet for Analysis of Aggregate Blends
## Trial Mix Series: Cold Aggregates Blend; CA-57%, FA-39%, MF-4%

<table>
<thead>
<tr>
<th>Computed Gradation of Hot Aggregate Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve, mm</td>
</tr>
<tr>
<td>Sieve (alternate)</td>
</tr>
<tr>
<td>% Passing</td>
</tr>
</tbody>
</table>

### Aggregates

<table>
<thead>
<tr>
<th>Fraction Used</th>
<th>Percent Used</th>
<th>Individual Mass, g</th>
<th>Accumulative Mass, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.0 – 12.5</td>
<td>3/4 in. – 1/2 in.</td>
<td>20</td>
<td>240</td>
</tr>
<tr>
<td>12.5 – 4.75</td>
<td>1/2 in. – No. 4</td>
<td>20</td>
<td>240</td>
</tr>
<tr>
<td>4.75 – 2.00</td>
<td>No. 4 – No. 10</td>
<td>18</td>
<td>216</td>
</tr>
<tr>
<td>–2.00</td>
<td>No. 10</td>
<td>38</td>
<td>456</td>
</tr>
<tr>
<td>–0.075</td>
<td>MF</td>
<td>4</td>
<td>48</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100</td>
<td>1200</td>
</tr>
</tbody>
</table>

### Asphalt Cement

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Percent Asphalt Used (By Mass of Total Mix)</th>
<th>Individual Asphalt Mass, g</th>
<th>Accumulative Mixture Mass, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.0</td>
<td>48</td>
<td>1248</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>54</td>
<td>1254</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>60</td>
<td>1260</td>
</tr>
<tr>
<td>4</td>
<td>5.5</td>
<td>66</td>
<td>1266</td>
</tr>
<tr>
<td>5</td>
<td>6.0</td>
<td>72</td>
<td>1272</td>
</tr>
</tbody>
</table>

---

Fig. A-13 Computation of Laboratory Batch Weights
Appendix B
Guides for Adjusting Trial Mix

B.1 General Guide for Adjusting the Trial Mix
   B.1.1 Voids Low, Stability Low:
   B.1.1.1 Voids may be increased in a number of ways. As a general approach to obtaining higher voids in the mineral aggregate (and therefore providing sufficient void space for an adequate amount of asphalt and air voids) the aggregate grading should be adjusted by adding more coarse or more fine aggregate.
   B.1.1.2 If the asphalt content is higher than normal and the excess is not required to replace that absorbed by the aggregate, the asphalt content may be lowered to increase the voids. Lowering the asphalt content increases the void content and reduces the film thickness, which, however, decreases the durability of the pavement. Too great a reduction in film thickness also may lead to pavement brittleness, accelerated asphalt oxidation, and increased permeability.
   B.1.1.3 If the above adjustments do not produce a stable mix, the aggregate may have to be changed. It usually is possible to improve the stability and increase the aggregate void content of the mix by increasing the amount of crushed materials. With some aggregates, however, the freshly fractured faces are as smooth as the weather worn faces and an appreciable increase in stability is not possible. This is generally true of quartz or similar rock types.

   B.1.2 Voids Low, Stability Satisfactory:
   B.1.2.1 Low void content may result in instability or flushing after the pavement has been exposed to traffic for a period of time because of reorientation of particles and additional compaction. It also may result in insufficient void space for the amount of asphalt required for high durability, even though stability is satisfactory. Degradation of the aggregate under the action of traffic may also lead to instability and flushing if the void content of the mix is not sufficient. For these reasons, mixes low in voids should be adjusted by methods summarized in See B.1.1.1 and B.1.1.2 or B.1.1.3, even though the stability appears satisfactory.

   B.1.3 Voids Satisfactory, Stability Low:
   B.1.3.1 Low stability when voids and aggregate grading are satisfactory may indicate some deficiencies in the aggregate. Consideration should be given to improving the quality as discussed in See B.1.1.3.

   B.1.4 Voids High, Stability Satisfactory:
   B.1.4.1 High voids frequently are, though not always, associated with high permeability. High permeability, by permitting circulation of air and water through the pavement, may lead to premature hardening of the asphalt. Even though stabilities are satisfactory, adjustments should be made to reduce the voids. This usually may be accomplished by increasing the mineral dust content of the mix.
   B.1.4.2 In some cases, it may be necessary to select or combine aggregates to more closely approximate the gradation of a maximum density grading curve.

   B.1.5 Voids High, Stability Low:
   B.1.5.1 Two steps maybe necessary when the voids are high and the stability is low. First the voids are adjusted by the methods discussed in See B.1.4.1 If this adjustment does not also improve the stability, the second step should be a consideration of aggregate quality as discussed in Sec B.1.1.3.
Appendix C
Analysis of Compacted Paving Mixtures

C.1 General

C.1.1 The analytical procedures described in Appendix C apply either to paving mixtures that have been compacted in the laboratory, or to undisturbed samples that have been cut from a pavement in the field. When a paving mixture is compacted in the laboratory, the compactive effort should provide a density equal to the density the mixture will ultimately attain under traffic following compaction by rolling during construction.

C.1.2 By analyzing a compacted paving mixture for air voids, $V_a$, voids in the mineral aggregate, $V_{MA}$, and effective asphalt content, $P_{be}$, some indication of the probable service performance of the pavement is provided. The degree of compaction, either during construction or after years of service can be determined by comparing the specific gravity of an undisturbed sample, cut from a pavement, with the laboratory compacted specific gravity of the same paving mixture.

C.1.3 Three different aggregate specific gravity values are used for analyzing paving mixtures, bulk specific gravity, $G_{sb}$, apparent specific gravity, $G_{sa}$, and effective specific gravity, $G_{se}$.

C.1.4 The VNIA values for compacted paving mixtures should be calculated in terms of the aggregate's bulk specific gravity, $G_{sb}$. The bulk specific gravity, with an allowance for the portion of the asphalt binder lost by absorption into the aggregate particles, or the equivalent of this procedure, should be the basis for calculating the air voids in a compacted asphalt paving mixture. The effective asphalt content, $P_{be}$, of a paving mixture is the total asphalt content minus the portion of the total asphalt content that is lost by absorption into the aggregate particles.

C.1.5 Values for voids in the mineral aggregate, $V_{MA}$, and air voids, $V_a$, are expressed as a percent by volume of the sample of paving mixture being analyzed. The effective asphalt content is expressed as a percent by mass of the total mass of the sample of paving mixture being examined.

C.1.6 Because air voids and voids in mineral aggregate are volume quantities and therefore cannot be weighed, a paving mixture must first be designed or analyzed on a volume basis. For design purposes, this volume approach can easily be changed over to a mass basis to provide a job-mix formula.

C.2 Definitions

C.2.1 Mineral aggregate is porous and can absorb various amounts of water and asphalt. The ratio of water to asphalt absorption varies with each aggregate. Three methods of measuring aggregate specific gravity that are in current use take these variations into consideration. They are bulk, apparent, and effective specific gravities, and these are defined as follows:

C.2.1.1 Bulk Specific Gravity, $G_{sb}$-The ratio of mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature, Fig. C-1.

C.2.1.2 Apparent Specific Gravity, $G_{sa}$-The ratio of the mass in air of a unit volume of an impermeable material at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature, Fig. C-1.

C.2.1.3 Effective Specific Gravity, $G_{se}$-The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature, Fig. C-1.

C.2.2 As the terms effective asphalt content, $P_{be}$, air voids, $V_a$, and voids in the mineral aggregate, $V_{MA}$, are used throughout this Appendix, they are defined as follows:

C.2.2.1 Voids in the Mineral Aggregate, $V_{MA}$-The volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample, as illustrated in Fig. C-2.

C.2.2.2 Effective Asphalt Content, $P_{be}$-The total asphalt content of a paving mixture minus the portion of asphalt that is lost by absorption into the aggregate particles, illustrated in Fig. C-2.

C.2.2.3 Air Voids, $V_a$-The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture, illustrated in Fig. C-2.

C.2.3 Fig. C-2 depicts the volume relationships between aggregate, air voids, voids in mineral aggregate, total asphalt content, asphalt lost by absorption into the aggregate particles, and effective asphalt content.

C.3 Specific Gravities

C.3.1 The accuracy of determinations of specific gravity for mix design is important. Unless specific gravities are determined to four significant figures (three decimal places) an error in the value of air voids of as much as 0.8 percent can occur. Therefore,
the use of scales whose sensitivity will allow the weighing of a batch mix between 1 and 5 kg to an accuracy of 0.1 g should be used. Calculators rather than slide rules should be used for all calculations in order to achieve required accuracy.

Fig. C–1. Illustrating VMA, Air Voids and Effective Asphalt Content in Compacted Asphalt Paving Mixture

Fig. C–2. Representation of Volumes in a Compacted Asphalt Specimen

\[ V_{ma} = \text{Volume of Voids in Mineral Aggregate} \]
\[ V_{mb} = \text{Bulk Volume of Compacted Mix} \]
\[ V_{mm} = \text{Voidless Volume of Paving Mix} \]
\[ V_a = \text{Volume of Air Voids} \]
\[ V_b = \text{Volume of Asphalt} \]
\[ V_{ba} = \text{Volume of Absorbed Asphalt} \]
\[ V_{sb} = \text{Volume of Mineral Aggregate (By Bulk Specific Gravity)} \]
\[ V_{se} = \text{Volume of Mineral Aggregate (By Effective Specific Gravity)} \]
C.4 Outline of Procedure for Analyzing a Compacted Paving Mixture

C.4.1 Measure the bulk specific gravities of the coarse aggregate (MRDTM 304) and of the fine aggregate (MRDTM 305).
C.4.2 Measure the specific gravity of the asphalt cement (MRDTM 407) and of the mineral filler (MRDTM 207).
C.4.3 Calculate the bulk specific gravities of the aggregate combination in the paving mixture.
C.4.4 Measure the maximum specific gravity of the loose paving mixture (MRDTM 412).
C.4.5 Measure the bulk specific gravity of the compacted paving mixture (MRDTM 411).
C.4.6 Calculate the effective specific gravity of the aggregate.
C.4.7 Calculate asphalt absorption of the aggregate.
C.4.8 Calculate the effective asphalt content of the paving mixture.
C.4.9 Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
C.4.10 Calculate the percent air voids in the compacted paving mixture.
C.4.11 Equations for the calculations in Sec CA are found in Sec C.6 through C.12.

C.5 Paving Mixture Data For Sample Calculations

C.5.1 The following tabulation (Table C-1) illustrates the basic data for a sample paving mixture. These design data are used in the sample calculation employed throughout the remainder of Appendix C.

C.6 Bulk Specific Gravities of Aggregate

C.6.1 When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities, the bulk and apparent specific gravities for the total aggregate are calculated as follows:

C.6.1.1 Bulk Specific Gravity, \( G_{sb} \):

\[
G_{sb} = \frac{P_1 \cdot G_1 + P_2 \cdot G_2 + \ldots + P_n \cdot G_n}{P_1 + P_2 + \ldots + P_n}
\]  
(C 1)

where:
- \( G_{sb} \) = bulk specific gravity for the total aggregate mixture,
- \( P_1, P_2, \ldots, P_n \) = percentages by mass of aggregates 1, 2, ..., \( n \), and
- \( G_1, G_2, \ldots, G_n \) = bulk specific gravity of aggregates 1, 2, ..., \( n \).

C.6.2 The bulk specific gravity of mineral filler is determined on the basis of the apparent specific gravity. Calculations use the data in Table C-1.

\[
G_{sb} = \frac{51.450 \cdot 2.606 + 34.240 \cdot 2.711 + 7.350 \cdot 2.697}{51.450 + 34.240 + 7.350} = \frac{93.040}{19.743 + 12.630 + 2.725} = 2.651
\]

C.7 Effective Specific Gravity of Aggregate

C.7.1 When based on the maximum specific gravity of a paving mixture, \( G_{mm} \), the effective specific gravity, \( G_{se} \), of the aggregate includes all void spaces in the aggregate particles except those that absorb asphalt. It is determined as follows:

\[
G_{se} = \frac{P_{mm} \cdot G_{mm} - P_b \cdot G_b}{P_{mm} - P_b}
\]  
(C2)

where:
- \( G_{se} \) = effective specific gravity of aggregate,
- \( P_{mm} \) = total loose mixture, where percent by total mass of mixture is 100 percent,
- \( P_b \) = asphalt, percent by total mass of mixture,
- \( G_{mm} \) = maximum specific gravity of paving mixture (no air voids), MRDTM 412 and, Sec C.8 of MRDTM 410, and
- \( G_b \) = specific gravity of asphalt.
C.7.2 Calculation using the data in Table C-1 (Note C.1):

\[
G_{se} = \frac{100 - 6.960}{2.438} = \frac{93.040}{100 - 6.960} = 2.726
\]

Note C.1: The volume of asphalt binder absorbed by an aggregate is almost invariably less than the volume of water absorbed. Consequently, the value for the effective specific gravity of an aggregate should be between its bulk and apparent specific gravities. When the effective specific gravity falls outside these limits, its value must be assumed to be incorrect. The calculations of the maximum specific gravity of the total mix by MRDTM 412, and the composition of the mix in terms of aggregate and total asphalt content should then be rechecked for the source of the error.

### Table C-1
Basic Design Data for Sample Calculations

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Specific Gravity</th>
<th>Mix Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulk (G)</td>
<td>MRDTM</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>1.010 (Gb)</td>
<td>407</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>2.606 (G1)</td>
<td>304</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>2.711 (G2)</td>
<td>305</td>
</tr>
<tr>
<td>Mineral Filler</td>
<td>2.697 (G3)</td>
<td>207</td>
</tr>
</tbody>
</table>

C.8 Maximum Specific Gravities of Mixtures With Different Asphalt Contents

C.8.1 In designing a paving mixture with a given aggregate, the maximum specific gravities, \( G_{mm} \), at different asphalt contents are needed to calculate the percentage of air voids for each asphalt content. While the same maximum specific gravity can be determined for each asphalt content by MRDTM 412, the precision of the test is best when the mixture has close to the optimum asphalt content. Also, it is preferable to measure the maximum specific gravity in duplicate or triplicate. After averaging the results from these tests and calculating the effective specific gravity of the aggregate, the maximum specific gravity for any other asphalt content can be obtained as shown below. For all practical purposes, the effective specific gravity of the aggregate is constant because the asphalt absorption does not vary appreciably with variations in asphalt content.

\[
G_{mm} = \frac{P_{mm}}{P_b + P_b} \quad \text{(C3)}
\]

where:

\( G_{mm} \), maximum specific gravity

\( G_{se} \), effective specific gravity

\( P_{mm} \), asphalt content

\( P_b \), asphalt content

\( P_b \), asphalt content

\( G_b \), asphalt specific gravity
where:

- $G_{mm}$ = maximum specific gravity of paving mixture (no air voids),
- $P_{mm}$ = total loose mixture, where percent by total mass of mixture is 100 percent,
- $P_s$ = aggregate, percent by total mass of mixture,
- $P_b$ = asphalt, percent by total mass of mixture,
- $G_{se}$ = effective specific gravity of aggregate, and
- $G_b$ = specific gravity of asphalt.

C.8.2 The calculation using specific gravity data from Table C-1, effective specific gravity, $G_{se}$ determined in Sec C.7 and an asphalt content, $P_b$, of 7.46 percent is as follows:

$$G_{mm} = \frac{100}{92.540 + 7.460} = \frac{100}{41.333} = 2.419$$

C.9 Asphalt Absorption

C.9.1 Absorption is expressed as a percentage by mass of aggregate rather than as a percentage by total mass of mixture. Asphalt absorption, $P_{ba}$, is determined as follows:

$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{sb}G_{se}} \times G_b \quad (C4)$$

where:

- $P_{ba}$ = absorbed asphalt, percent by mass of aggregate,
- $G_{se}$ = effective specific gravity of aggregate,
- $G_{sb}$ = bulk specific gravity of aggregate, and
- $G_b$ = specific gravity of asphalt.

C.9.2 The calculation using bulk and effective specific gravities determined in Sec C.6 and C.7 and asphalt specific gravity from Table C-1 is as follows:

$$P_{ba} = 100 \times \frac{2.726 - 2.651}{2.726 \times 2.651} = 1.05$$

C.10 Effective Asphalt Content of a Paving Mixture

C.10.1 The effective asphalt content, $P_{be}$, of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles, and is the asphalt content on which service performance of an asphalt paving mixture depends. The formula is:

$$P_{be} = P_b - P_{ba} \times P_s \quad (C5)$$

where:

- $P_{be}$ = effective asphalt content, percent by total mass of mixture,
- $P_b$ = asphalt, percent by total mass of mixture,
- $P_{ba}$ = absorbed asphalt, percent by mass of aggregate, and
- $P_s$ = aggregate, percent by total mass of mixture.

C. 10.2 The calculation using data from Table C-1 and Sec C. 9 is as follows:

$$P_{be} = 6.96 - \frac{1.05}{100} \times 93.04 = 5.98$$

C.11 Percent VMA in Compacted Paving Mixture

C.11.1 The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, the VMA can be calculated by subtracting the
volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted paving mixture. The method of calculation specifying the mix composition as percent by mass of the total mixture, is as follows:

\[ VMA = 100 - \frac{G_{mb} - P_s}{G_{sb}} \]  \hspace{1cm} (C6)

where:

- \(VMA\) = voids in mineral aggregate (percent of bulk volume),
- \(G_{sb}\) = bulk specific gravity of aggregate,
- \(G_{mb}\) = bulk specific gravity of compacted mixture, MRDTM 411, and
- \(P_s\) = aggregate, percent by total mass of mixture.

C.11.2 The calculation using data from Table C-1 and Sec C.6 is as follows:

\[ VMA = 100 - \frac{2.344 \times 93.04}{2.651} = 100 - 82.27 = 17.73 \]

C.12 Calculation of Percent Air Voids in Compacted Mixture

C.12.1 The air voids, \(P_a\), in a compacted paving mixture consist of the small air spaces between the coated aggregate particles. The percentage of air voids in a compacted mixture can be determined by equation (C7):

\[ P_a = \frac{100 \times G_{mm} - G_{mb}}{G_{mm}} \]  \hspace{1cm} (C7)

where:

- \(P_a\) = air voids in compacted mixture, percent of total volume,
- \(G_{mm}\) = maximum specific gravity of paving mixture, as determined in Sec C.8 or as determined directly for a paving mixture by MRDTM 412, and
- \(G_{mb}\) = bulk specific gravity of compacted mixture.

C.12.2 The calculation using data from Table C-1 is as follows:

\[ P_a = \frac{100 \times 2.438 - 2.344}{2.438} = \frac{9.400}{2.438} = 3.85 \]
Determination of Laboratory Batch Masses for Asphalt Mix Design

FIELD SAMPLE NO: 10-13  
LAB SAMPLE NO: 82-2430 to 32  
PROJECT: FCP 2B5

DATE SAMPLED: 5/13/82  
DATE RECEIVED: 5/17/82  
ROAD NO: 202-203

SAMPLED BY: Y. Taha  
TESTED BY: F. Manrupah  
ROAD NAME: Damman - Ros Tanura

TITLE: Proj. Inspector  
TITLE: Lab Technician

Material: 80/100 Crude Class A

Gradation as Received

<table>
<thead>
<tr>
<th>Sieve mm (alt.)</th>
<th>Aggregate #1</th>
<th>Aggregate #2</th>
<th>Aggregate #3</th>
<th>Mineral Filler</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0 (3/4 in.)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.5 (1 1/2 in.)</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>2B</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00 (No. 10)</td>
<td>2</td>
<td>E7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.425 (No. 40)</td>
<td>38</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.180 (No. 80)</td>
<td>24</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>8</td>
<td></td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>

Trial Blending: 57 % Agg. #1, 39 % Agg. #2, 3 % Agg. #3, 4 % MF

Blend Satisfactory: Yes

Laboratory Agg. Batch Weights

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>% Agg's</th>
<th>% MF</th>
<th>Agg. Mass</th>
<th>Accum. Agg.</th>
<th>MF Mass</th>
<th>Accum. MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0-12.5</td>
<td>4.4</td>
<td></td>
<td>152</td>
<td>137</td>
<td>137</td>
<td>1152</td>
</tr>
<tr>
<td>12.5-4.75</td>
<td>29.4</td>
<td></td>
<td>355</td>
<td>422</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.75-2.00</td>
<td>24.0</td>
<td></td>
<td>240</td>
<td>732</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00-0.075</td>
<td>31.0</td>
<td>0.9</td>
<td>383</td>
<td>115</td>
<td>11</td>
<td>1163</td>
</tr>
<tr>
<td>0.075-</td>
<td>3.1</td>
<td>3.1</td>
<td>37</td>
<td>1152</td>
<td>37</td>
<td>1200</td>
</tr>
</tbody>
</table>

Lab. Mix Batch Weights

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>% of Mix</th>
<th>Asph. Mass, g</th>
<th>Mix Mass, g</th>
<th>Aggregate No. 1</th>
<th>Aggregate No. 2</th>
<th>Aggregate No. 3</th>
<th>Mineral Filler</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.0</td>
<td>48</td>
<td>1248</td>
<td>Aggregate No. 2</td>
<td>Aggregate No. 3</td>
<td>Mineral Filler</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>54</td>
<td>1254</td>
<td>Aggregate No. 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>60</td>
<td>1260</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.0</td>
<td>60</td>
<td>1260</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>6.0</td>
<td>72</td>
<td>1272</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remarks:

CHECKED BY: T. Williams  
TITLE: Lab Supervisor  
DATE: 5/11/82

MATERIALS ENGINEER: J. Smith  
(CONSULTANT)

RESIDENT ENGINEER: J. Dunbar  
(CONTRACTOR)

DISTRIBUTION: ❌ CONTRACTOR  ❌ MINISTRY  ❌ OTHER (Specify)
**KINGDOM OF SAUDI ARABIA**  
**MINISTRY OF COMMUNICATIONS**  
**MATERIALS AND RESEARCH DEPARTMENT**  

**Marshall Asphalt Mix Design Data**

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Project</th>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Sampled By</th>
<th>Tested By</th>
<th>Title</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-19</td>
<td>82-2430 to 32</td>
<td>FCP 285</td>
<td>5/5/82</td>
<td>5/7/82</td>
<td>5/9/82</td>
<td>J. Taha</td>
<td>F. Mansufah</td>
<td>Proj Inspt</td>
<td>Bl War Crs Class A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A</td>
<td>4.0</td>
<td>1306.0</td>
<td>794.4</td>
<td>510.0</td>
<td>2.622</td>
<td>67.5</td>
<td>81.2</td>
<td>61.2</td>
<td>284</td>
</tr>
<tr>
<td>B</td>
<td>4.0</td>
<td>1309.5</td>
<td>796.4</td>
<td>518.1</td>
<td>2.632</td>
<td>67.5</td>
<td>821</td>
<td>621</td>
<td>284</td>
</tr>
<tr>
<td>C</td>
<td>4.0</td>
<td>1309.6</td>
<td>798.2</td>
<td>511.1</td>
<td>2.642</td>
<td>67.5</td>
<td>839</td>
<td>639</td>
<td>284</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>67.5</td>
<td>824</td>
<td>624</td>
<td>284</td>
</tr>
<tr>
<td>2 A</td>
<td>4.5</td>
<td>1316.3</td>
<td>806.3</td>
<td>509.0</td>
<td>2.584</td>
<td>67.5</td>
<td>842</td>
<td>642</td>
<td>284</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>1315.1</td>
<td>808.8</td>
<td>508.3</td>
<td>2.587</td>
<td>61.9</td>
<td>787</td>
<td>618</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>4.5</td>
<td>1314.6</td>
<td>805.5</td>
<td>508.1</td>
<td>2.581</td>
<td>61.9</td>
<td>821</td>
<td>634</td>
<td>8</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>61.9</td>
<td>745</td>
<td>645</td>
<td>12</td>
</tr>
<tr>
<td>3 A</td>
<td>5.0</td>
<td>1301.0</td>
<td>812.1</td>
<td>508.0</td>
<td>2.595</td>
<td>63.5</td>
<td>850</td>
<td>850</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>1301.1</td>
<td>811.0</td>
<td>507.1</td>
<td>2.599</td>
<td>61.9</td>
<td>842</td>
<td>842</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>5.0</td>
<td>1300.7</td>
<td>810.5</td>
<td>507.7</td>
<td>2.597</td>
<td>61.9</td>
<td>838</td>
<td>838</td>
<td>10</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>61.9</td>
<td>840</td>
<td>840</td>
<td>10</td>
</tr>
<tr>
<td>4 A</td>
<td>5.5</td>
<td>1307.4</td>
<td>815.3</td>
<td>509.0</td>
<td>2.594</td>
<td>67.5</td>
<td>810</td>
<td>810</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>5.5</td>
<td>1306.1</td>
<td>814.7</td>
<td>514.1</td>
<td>2.593</td>
<td>67.5</td>
<td>784</td>
<td>784</td>
<td>13</td>
</tr>
<tr>
<td>C</td>
<td>5.5</td>
<td>1304.2</td>
<td>814.6</td>
<td>509.6</td>
<td>2.595</td>
<td>67.5</td>
<td>784</td>
<td>784</td>
<td>13</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>67.5</td>
<td>784</td>
<td>784</td>
<td>13</td>
</tr>
<tr>
<td>5 A</td>
<td>6.0</td>
<td>1307.6</td>
<td>813.4</td>
<td>514.0</td>
<td>2.583</td>
<td>63.5</td>
<td>676</td>
<td>676</td>
<td>17</td>
</tr>
<tr>
<td>B</td>
<td>6.0</td>
<td>1308.6</td>
<td>813.4</td>
<td>515.3</td>
<td>2.582</td>
<td>63.5</td>
<td>653</td>
<td>653</td>
<td>17</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>1329.3</td>
<td>814.4</td>
<td>514.9</td>
<td>2.582</td>
<td>63.5</td>
<td>717</td>
<td>717</td>
<td>17</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63.5</td>
<td>678</td>
<td>678</td>
<td>17</td>
</tr>
</tbody>
</table>

(1) From MRDTM 412 = Gpav, Avg. Bulk Sp. Gr. of Aggregates = 2.885
(2) Air Voids, Pa = Gm = Gm = Gm = 3.037
(3) VMA = 100 = Psa, Asphalt Absorption = 0.16 %
(4) % VMA Filled = VMA x 100 = Psa, Effective Asphalt. Cont. =
(5) From Table 1, MRDTM 410

Gpav, Specific Gravity of Asphalt = 1.610

Remarks:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

From MRWS 498C - Recommended Asphalt, % of Mix 5.0 %

CHECKED BY: T. Williams Date: 5/11/82  
MATERIALS ENGINEER: J. Smith  
CONTRACTOR: R. White  
RESIDENT ENGINEER: J. Dunbar  
DISTRIBUTION: X CONTRACTOR  
X MINISTRY  
X OTHER (Specify)
Marshall Mix Design Graphs

FIELD SAMPLE NO: 10-13
LAB SAMPLE NO: 82-2435 10-32
PROJECT: FCP 285

DATE SAMPLED: 6/5/92
DATE RECEIVED: 6/7/92
ROAD NO: 202-203

SAMPLED BY: Y. Taha
DATE TESTED: 6/3/92
ROAD NAME: Damman - Ras Tanura

LAB INSPECTOR: F. Manupah
TITLE: Lab Technician

A. Bulk Density Graph:
- AC, % by Mass of Mix
  Optimum AC,A = 6.4 %

B. Void Total Mix, VMA:
- AC, % by Mass of Mix
  Optimum AC,B = 5.8 %

C. % Air Voids, %:
- AC, % by Mass of Mix
  Optimum AC,C = 4.6 %

D. Voids Filled by Asphalt:
- AC, % by Mass of Mix
  Optimum AC,D = 4.7 %

E. Marshall Stability:
- AC, % by Mass of Mix
  Optimum AC,E = 5.0 %

F. Flow 0.75":
- AC, % by Mass of Mix
  Optimum AC,F = 5.2 %

Recommended Asphalt, % of Mix, from Inspection of Curves = 5.0 %

Remarks:

CHECKED BY: J. Williams
TITLE: Lab Supervisor
DATE: 6/11/92

MATERIALS ENGINEER: J. Smith
(Consultant)
R. White
(Contractor)

RESIDENT ENGINEER: J. Durber

DISTRIBUTION: X CONTRACTOR
X RESIDENT ENGINEER
X MINISTRY

Form No. MRDWS-410C
1. Scope
   1.1 The bulk specific gravity of a compacted bituminous paving mixture is determined for the following purposes:
   1.1.1 On laboratory compacted specimens:
   1.1.1.1 Provide a basis for computing the percent of air voids and voids in mineral aggregate (VMA) in the compacted
   1.1.1.2 Establish a basis for controlling compaction during construction of the asphalt pavement.
   1.1.2 On specimens obtained from pavements, to check density of the pavement and effectiveness of rolling operations.
   1.2 This method of test covers the determination of bulk specific gravity of specimens of compacted bituminous
   mixtures as defined in MRDTM 103, Terms Relating to Density and Specific Gravity of Solids, Liquids and Gases.

2. Apparatus
   2.1 Balance, conforming to the requirements of MRDTM 102, Class C or D, equipped with suitable suspension
   apparatus and holder to permit weighing the specimen while suspended from the center of a scale pan of a balance as shown
   in Fig. 1 (Note 1).

   Note 1: The holder should be immersed to a depth sufficient to cover it and the test sample during weighing. Wire
   suspending the holder should be the smallest practical size to minimize any possible effects of a variable immersed length.

   2.2 Water bath, for immersing the specimen in water while suspended under the balance, equipped with an overflow
   outlet for maintaining a constant water level.

3. Test Specimens
   3.1 Test specimens may be either laboratory molded bituminous mixtures or from bituminous pavements. The mixtures
   may be surface wearing course, binder or leveling course, or hot mix base.

   3.2 Size of Specimens-It is recommended that: (1) the diameter of cylindrically molded or cored specimens, or the
   length of the sides of sawed specimens, be at least equal to four times the maximum size of the aggregate; and that (2) the
   thickness of specimens be at least one and one half times the maximum size of the aggregate.

   3.3 Pavement specimens shall be obtained with a core drill, diamond saw, or carborundum saw.

   3.4 Care shall be taken to avoid distortion, bending, or cracking of specimens during and after removal from pavement
   or mold. Specimens shall be stored in a safe, cool place.

   3.5 Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

   3.6 Specimens may be separated from other pavement layers by sawing.
Method A

Paraffin Coated Specimens

4. Procedure

4.1 Determine the Mass of Uncoated Specimens—Weigh the specimen after it has been dried to a constant mass. Designate this mass as A (Note 2).

**Note 2:** Constant mass shall be defined as the mass at which further drying at 60 ± 5 °C does not alter the mass 0.1 percent, the precision of weighing. The sample shall initially be dried overnight at 60 ± 5 °C and then weighed at 2 h drying intervals.

4.2 Determine the Mass of Coated Specimens in Air—Coat the test specimen on all surfaces with melted paraffin sufficiently thick to seal all surface voids. Allow the coating to cool in air at room temperature for 30 minutes and then weigh the specimen. Designate this mass as D.

**Note 3:** If it is desired to use the specimen for further tests which require the removal of the paraffin coating, the specimen may be dusted with powdered talc prior to coating.

**Note 4:** Application of the paraffin may be accomplished by chilling the specimen in a refrigerating unit to a temperature of approximately 4.5 °C for 30 minutes and then dipping the specimen in warm paraffin (5.5 °C above the melting point of the paraffin). It may be necessary to brush the paraffin coated specimen with additional paraffin in order to seal any pinpoint holes.

4.3 Determine the Mass of the Coated Specimen in Water—Weigh the coated specimen in a water bath at 25 ± 1 °C. Designate this mass as E.

4.4 Determine the Specific Gravity of the Paraffin—Determine the specific gravity of the paraffin at 25 ± 1 °C, if unknown, and designate this as F.

5. Calculation

5.1 Calculate the bulk specific gravity of the specimen as follows:

\[
\text{Bulk Sp. Gr.} = \frac{A}{(D - E) - \frac{(D - A)}{F}}. \tag{1}
\]

where:
A = mass of the dry specimen in air, g,
D = mass of the dry specimen plus paraffin coating in air, g,
E = mass of the dry specimen plus paraffin coating in water, g, and
F = specific gravity of the paraffin at 25 ± 1 °C.

Method B

Uncoated Specimens, Dense Graded Mixtures Only

6. Procedure

6.1 Dry the specimen to a constant mass at 60 °C. Cool the specimen to room temperature (25 ± 1 °C) and record the dry mass, A. Immerse each specimen in water at 25 ± 1 °C for one minute and record the immersed mass, C. Remove the specimen from the water, surface dry by blotting with a damp towel, and weigh to determine the surface-dry mass, B.

7. Calculation

7.1 Calculate the bulk specific gravity as follows:

\[
\text{Bulk Specific Gravity} = \frac{A}{B - C}. \tag{2}
\]

where:
A = mass of sample in air, g,
B = mass of surface-dry specimen in air, g, and
C = mass of sample in water, g.
Method C

Cored, Dense Graded Mixture Specimens

8. Procedure

8.1 Bring the specimen to room temperature (approximately 25 C). Immerse the specimen in water at room temperature for one minute, and record the immersed mass, C. Remove the specimen from the water, dry the surface by blotting with a damp towel, and weigh the surface-dry mass and record as B.

8.2 Place the specimen in a large flat bottom drying pan of known mass. Place the pan and specimen in an oven at 110 ± 5 C. Leave the specimen in the oven until it can be easily separated to the point where the particles of the fine aggregate-asphalt portion are not larger than 6.4 mm (1/4 in.). Place the separated specimen in an oven at a 60 ± 5 C and dry to a constant mass (Note 2).

8.3 Cool the pan and specimen to room temperature (25 ± 1 C). Weigh the pan and specimen, subtract the mass of the pan and record the dry mass, A.

9. Calculation and Report

9.1 Calculate the bulk specific gravity according to equation 2, Sec 7.1, and record on Form No. MRDWS 411.
### Bulk Specific Gravity of Compacted Bituminous Mixtures

<table>
<thead>
<tr>
<th>FIELD SAMPLE NO.</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB SAMPLE NO.</td>
<td>82-2422</td>
</tr>
<tr>
<td>PROJECT</td>
<td>FCP 285</td>
</tr>
<tr>
<td>DATE SAMPLED</td>
<td>5/5/82</td>
</tr>
<tr>
<td>DATE RECEIVED</td>
<td>5/7/82</td>
</tr>
<tr>
<td>SAMPLED BY</td>
<td>Y. Taha</td>
</tr>
<tr>
<td>DATE TESTED</td>
<td>5/8/82</td>
</tr>
<tr>
<td>TESTED BY</td>
<td>F. Manrubes</td>
</tr>
<tr>
<td>MATERIAL</td>
<td>Bitumen Crs Class A</td>
</tr>
<tr>
<td>TITLE</td>
<td>Proj. Inspector</td>
</tr>
<tr>
<td>TITLE Lab Technician</td>
<td>500T</td>
</tr>
</tbody>
</table>

#### Method A: Paraffin Coated Specimen

<table>
<thead>
<tr>
<th>Sample No(s)</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Dry Mass of Uncoated Specimen in Air, g</td>
<td>1246</td>
<td>1251</td>
<td>1249</td>
</tr>
<tr>
<td>D Dry Mass of Coated Specimen in Air, g</td>
<td>1271</td>
<td>1278</td>
<td>1274</td>
</tr>
<tr>
<td>E Mass of Coated Specimen in Water, g</td>
<td>737</td>
<td>741</td>
<td>739</td>
</tr>
<tr>
<td>F Specific Gravity of Paraffin at 25 C.</td>
<td>1.030</td>
<td>1.030</td>
<td>1.030</td>
</tr>
</tbody>
</table>

**Bulk Sp. Gr. of Bituminous Mixture,**\[ \frac{A}{D - E} = \frac{(D - A)}{F} \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.443</td>
<td>2.448</td>
<td>2.444</td>
</tr>
</tbody>
</table>

#### Method B: Uncoated Specimen, Dense Graded Mixtures Only

<table>
<thead>
<tr>
<th>Sample No(s)</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Dry Mass of Specimen in Air, g</td>
<td>1232</td>
<td>1236</td>
<td>1245</td>
</tr>
<tr>
<td>B Surface Dry Mass of Specimen in Air, g</td>
<td>1255</td>
<td>1258</td>
<td>1249</td>
</tr>
<tr>
<td>C Mass of Specimen in Water, g</td>
<td>741</td>
<td>744</td>
<td>739</td>
</tr>
</tbody>
</table>

**Bulk Sp. Gr. of Bituminous Mixture,**\[ \frac{A}{B - C} \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.441</td>
<td>2.444</td>
<td>2.441</td>
</tr>
</tbody>
</table>

#### Method C: Rapid Test, Dense Graded Mixtures

<table>
<thead>
<tr>
<th>Sample No(s)</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Surface Dry Mass of Specimen, g</td>
<td>1256</td>
<td>1252</td>
<td>1261</td>
</tr>
<tr>
<td>C Mass of Specimen in Water, g</td>
<td>740</td>
<td>738</td>
<td>747</td>
</tr>
<tr>
<td>H Mass of Dry Sample and Pan, g</td>
<td>1524</td>
<td>1531</td>
<td>1528</td>
</tr>
<tr>
<td>G Tare Mass of Drying Pan, g</td>
<td>273</td>
<td>286</td>
<td>269</td>
</tr>
<tr>
<td>A Dry Mass of Specimen in Air, H – G, g</td>
<td>1261</td>
<td>1245</td>
<td>1254</td>
</tr>
</tbody>
</table>

**Bulk Sp. Gr. of Bituminous Mixture,**\[ \frac{A}{B - C} \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.440</td>
<td>2.442</td>
<td>2.440</td>
</tr>
</tbody>
</table>

NOTE: *Record on MRDTR 400-B, Line 5.*

**Remarks:**

---

**CHECKED BY:** T. Williams  DATE: 5/6/82
**MATERIALS ENGINEER:** J. Smith
**CONSULTANT:** R. White
**CONTRACTOR:**

**RESIDENT ENGINEER:** J. Dunbar
**DISTRIBUTION:** CONTRACTOR, MINISTRY, OTHER (Specify)
1. Scope
1.1 This method covers the determination of the maximum specific gravity of uncompacted bituminous paving mixtures.

1.2 The maximum specific gravity of a bituminous paving mixture represents the maximum theoretical mass of a unit volume of mixture composed entirely of impermeable aggregate coated with asphalt, that is, no air voids present in the mixture. This value is required to determine a mixture's asphalt absorption, percent air voids and percent voids in mineral aggregate as described in MRDTM 410, The Marshall Method of Asphalt Concrete Mix Design.

2. Apparatus
2.1 Balance, with ample capacity, and with sufficient sensitivity to enable maximum specific gravities of samples of uncompacted paving mixtures to be calculated to at least four significant figures; that is to at least three decimal places. It shall be equipped with a suitable suspension apparatus and holder, as illustrated in Fig. 1, to permit weighing the sample while suspended from the center of the scale pan of the balance (Note 1).

Note 1: Since no more significant figures can be used in the maximum specific gravity than appear in either of the figures used to calculate it, the mass of the sample in air or the volume of the sample (the values used to calculate it), must also be determined to four significant figures. This means that the balance must have a sensitivity capable of measuring mass to at least four significant figures.

2.2 Container-The container may be either a glass or metal bowl or a volumetric flask having a capacity of at least 1000 ml. Containers shall be sufficiently strong to withstand a partial vacuum and shall have covers as follows: for use with the bowl, a cover fitted with a rubber gasket and a hose connection; for use with the flask, a rubber stopper with a hose connection. A small piece of fine wire mesh covering the hose opening will minimize the possibility of loss of fine material. The top surfaces of all containers shall be smooth and substantially plane.

Note 2: The bottom portion of a 1.4 liter (1.5 qt) capacity, borosilicate glass, double boiler unit is a satisfactory bowl.

2.3 Vacuum pump or water aspirator, for evacuating air from the container.

2.4 Water Bath- For use with the bowl, a water bath suitable for immersing the bowl and apparatus for suspending the bowl from the center of the scale pan of balance; and for use with the flask, a constant temperature water bath.

3. Calibration of Flask
3.1 Calibrate the volumetric flask by determining the mass of water required to fill it at 25 ± 0.5 C. Accurate filling of the flask may be ensured by the use of a glass cover plate.

4. Test Samples
4.1 The sample shall be obtained in accordance with MRDTM 417, Sampling Bituminous Paving Mixtures.

4.2 The size of the sample shall conform to the requirements of Table 1. Samples larger than the capacity of the container may be separated and tested a portion at a time.

5. Procedure
5.1 Separate the particles of the sample, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.4 mm (1/4 in.). If the mixture is not sufficiently soft to be separated manually, place it in a large flat pan and warm it in an oven only until it can be manually separated.
Table 1

Requirements for Sample Size

<table>
<thead>
<tr>
<th>Nominal Maximum Size of Aggregate</th>
<th>Minimum Mass of Sample, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 (1 in.)</td>
<td>2.5</td>
</tr>
<tr>
<td>19.0 (1/4 in.)</td>
<td>2</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>1.5</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>1</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

5.2 Cool the sample to room temperature, place in the flask or bowl, and weigh. Designate the net mass of the sample as A. Add sufficient water at approximately 25°C to cover the sample.

5.3 Remove entrapped air by subjecting the contents to a partial vacuum (air pressure less than 30 mm Hg) for 15 ± 2 minutes. Continuously agitate the container and contents with a mechanical device, or manually by vigorous shaking, at approximately 2 minute intervals (Note 3).

Note 3: The release of entrapped air may be facilitated by the addition of a suitable wetting agent such as Aerosol OT in a concentration of 0.01 percent or 1 ml of 10 percent solution in 1000 ml of water.

5.4 Bowl Determination-Suspend the bowl and contents in water at 25 ± 1°C and weigh after 9 to 11 minutes immersion. Designate the net mass of sample in water as C.

5.5 Flask Determination-Fill the flask with water and bring the contents to a temperature of 25 ± 0.5°C in a constant temperature water bath. Determine the mass of flask (filled) and contents within 9 to 11 minutes after completing the process described in See 5.3.

6. Calculation

6.1 Calculate the specific gravity of the sample as follows:

6.1.1 Bowl Determination (Note 4):

\[
\text{Specific Gravity} = \frac{A}{A-C} \tag{1}
\]

where:
A = mass of dry sample in air, g, and
C = mass of sample in water, g.

6.1.2 Flask Determination (Note 4):

\[
\text{Specific Gravity} = \frac{A}{A+D-E} \tag{2}
\]

where:
A = mass of dry sample in air, g,
D = mass of flask filled with water at 25°C, g, and
E = mass of flask filled with water and sample at 25°C, g.

Note 4: To calculate the specific gravity in See 6.1.1 and 6.1.2, use a calculator in order to achieve 4 significant figures.

7. Supplemental Procedure for Mixtures Containing Porous Aggregate Not Completely Coated

7.1 If the pores of the aggregates are not thoroughly sealed by a bituminous film, they may become saturated with water during the evacuation procedure (See 5.3). To determine if this has occurred, proceed as follows after completing the procedure through See 5.4 or 5.5. Drain the water from the sample. To prevent loss of fine particles, decant the water through a towel held over the top of the container. Break several large pieces of aggregate and examine broken surfaces for wetness.
7.2 If the aggregate has absorbed water, spread the sample before an electric fan to remove surface moisture. Weigh at 15 minute intervals. When the loss in mass is less than 0.5 g for a 15 minute interval, the sample is surface dry. This procedure requires about 2 h and should be accompanied by intermittent stirring of the sample. Conglomerations (lumps) of mixture should be broken by hand. Care must be taken to prevent loss of any of the mixture.

7.3 To calculate the specific gravity of the sample, the final surface dry mass is substituted for A in the denominator of equation (1) or (2), See 6.1.1 and 6.1.2.

8. Report

8.1 Record test results on Form No. MRDWS 412.
Fig. 1.
# Maximum Specific Gravity of Bituminous Paving Mixtures

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>82-2422</td>
<td>FCP 285</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Date Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/5/82</td>
<td>5/9/82</td>
<td>5/8/82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampled By</th>
<th>Tested by</th>
<th>Road No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y. Toha</td>
<td>F. Menruthah</td>
<td>202-203</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Road Name</th>
<th>Quantity Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oammam - Ros Tanura</td>
<td>500 T</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>la</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Bottle or Flask and Dry Sample,</td>
<td>g 2820 2170</td>
</tr>
<tr>
<td>Mass of Bottle or Flask,</td>
<td>g 1234 592</td>
</tr>
<tr>
<td>A Net Mass of Dry Sample in Air (See Table 1),</td>
<td>d 1586 1586</td>
</tr>
<tr>
<td>C Net Mass of Sample in Water,</td>
<td>g 937</td>
</tr>
</tbody>
</table>

Maximum Specific Gravity (Bowl Determination): \[
\frac{A}{A - C} \]

\[2.444\]

D Mass of Flask (Filled with Water) at 25 C, | g 1588 |
E Mass of Flask (Filled with Water and Sample) at 25 C, | g 2525 |

Maximum Specific Gravity (Flask Determination): \[
\frac{A}{A + D - E} \]

\[2.444\]

<table>
<thead>
<tr>
<th>Specimen Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Bottle or Flask and Dry Sample,</td>
</tr>
<tr>
<td>Mass of Bottle or Flask,</td>
</tr>
<tr>
<td>A Net Mass of Dry Sample in Air (See Table 1),</td>
</tr>
<tr>
<td>C Net Mass of Sample in Water,</td>
</tr>
</tbody>
</table>

Maximum Specific Gravity (Bowl Determination): \[
\frac{A}{A - C} \]

D Mass of Flask (Filled with Water) at 25 C, | g |
E Mass of Flask (Filled with Water and Sample) at 25 C, | g |

Maximum Specific Gravity (Flask Determination): \[
\frac{A}{A + D - E} \]

NOTES: *Measurements and Calculations Should be Accurate to 4 Significant Figures (3 Decimal Places).


Remarks:

CHECKED BY: T. Williams  | Title Lab Supervisor  | Date 5/3/82
MATERIALS ENGINEER: J. Smith  | R. White
RESIDENT ENGINEER: J. Ober

DISTRIBUTION: ☑ CONTRACTOR  ☑ RESIDENT ENGINEER  ☑ MINISTRY  ☐ OTHER (Specify)
1. Scope

1.1 This method describes coating and static immersion procedures intended to determine the retention of a bituminous film by an aggregate in the presence of water. It is applicable to cutback, emulsified, and semisolid asphalt. It should not be used as a measure of field performance because such correlation has not been established (Note 1).

Note 1: No attempt shall be made to evaluate film retention below 95 percent. This is a limitation of the test method and does not intend to imply in any way that an aggregate-bitumen combination failing to retain 95 percent coating by this laboratory test will give unsatisfactory performance in the field. The 95 percent level is used because this is the level that a reasonable degree of reproducibility can be obtained when rating the same sample by visual estimation.

2. Outline of Method

2.1 The aggregate is coated with the bitumen at a temperature appropriate to the grade of bitumen used. In the case of cutback asphalt, the bitumen coated aggregate is subjected to a curing period at 60 C. In the case of emulsified asphalt, the aggregate is coated with bitumen and subjected to a curing period at 135 C. After coating, the coated aggregate is immersed in distilled water for 16 to 18 h. At the end of the soaking period, and with the bitumen-aggregate mixture under water, the total area of the aggregate on which the bituminous film is retained is estimated as above or below 95 percent (Note 1).

3. Apparatus

3.1 Mixing containers, with rounded corners, such as seamless tin cans, with 500 ml (or 16 oz) capacity.
3.2 Scales, with a capacity of 200 g, and accurate to ± 0.1 g.
3.3. Spatula, steel, with a stiff blade approximately 25 mm (or 1 in.) in width and 100 mm (or 4 in.) in length.
3.4 Constant temperature oven, capable of maintaining any temperature between 60 and 149 C within ± 1 C.
3.5 Sieves, standard, woven wire, square hole, of 6.3 mm (1/4 in.) and 9.5 mm (3/8 in.) size, in accordance with Sieves for Testing Purposes (MRDTM 101).

4. Materials

4.1 Aggregates-Test aggregates are required of such size that 100 percent will pass a 9.5 mm (3/8 in.) sieve and is retained on a 6.3 mm (1/4 in.) sieve. The aggregates for the dry coating test (Sec 6.1) shall be washed in distilled water to remove all fines, dried at 135 to 149 C to constant mass, and stored in air tight containers until required for use. Aggregates to be used in the wet coating test (Sec 6.3) shall be brought to a saturated-surface-dry condition using distilled water as described in See 4.1 of Specific Gravity and Absorption of Coarse Aggregate (MRDTM 304).
4.2 Distilled Water-The water used for soaking shall be further boiled or distilled, if necessary, so that its pH is 6.0 to 7.0. No electrolytes of any kind shall be used for pH correction.

5. Procedure

5.1 For dry aggregate coated with cutback asphalts:
5.1.1 Coating-Weigh 100 g of oven dry aggregate at room temperature into the mixing container. Add 5.5 ± 0.2 g of bituminous material, preheated where necessary to the temperature specified in Table 1, depending on the grade of bitumen. Mix the bituminous material and aggregate vigorously with the spatula for 2 minutes (Note 2).

Note 2: For cutback asphalts, grades 3, 4, and 5, the materials in the container may be warmed over a hot plate during the mixing period, to permit effective mixing, but not above the temperature limits specified in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Material, Grade</th>
<th>Temperature, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutback asphalt, 1 and 2</td>
<td>Room Temperature</td>
</tr>
<tr>
<td>Cutback asphalt, 3</td>
<td>35</td>
</tr>
<tr>
<td>Cutback asphalt, 4</td>
<td>52</td>
</tr>
<tr>
<td>Cutback asphalt, 5</td>
<td>68</td>
</tr>
</tbody>
</table>

5.1.2 Curing-Oven cure the coated aggregate for 2 h in the original container at 60 C. The ventilating port of the oven should be open during this curing step. After curing, remix with the spatula while the mixture cools to room temperature, or until the bituminous material ceases to drain off of the aggregate. The bituminous coating must be complete after mixing, no bare spots on the aggregate are permissible.

5.1.3 Water Immersion-Transfer the coated aggregate to a 600 ml glass container. Cover immediately with 400 ml of distilled water at room temperature (approximately 25 C). Soak the bituminous coated aggregate in the water for 16 to 18 h.

5.1.4 Visual Estimation of the Coated Area in Stripping Test-Without disturbing or agitating the coated aggregate, remove any film floating on the water surface. Illuminate the specimen with a shaded lamp, fitted with a 75 watt electric bulb positioned to eliminate glare from the surface of the water. By observation through the water, from above, estimate the percentage of the total visible area of the aggregate which remains coated as above or below 95 percent. Any thin brownish, translucent areas are to be considered fully coated.

5.2 For dry aggregate coated with emulsified asphalts:

5.2.1 Coating-Weigh 100 g of oven dry aggregate into the mixing container. Add 8.0 ± 0.2 g of emulsified asphalt, both materials at room temperature and without stirring. Place in the oven at 135 C for 5 minutes. Take out of oven and stir with the spatula until the aggregate is thoroughly coated.

5.2.2 Curing-Oven cure the coated aggregate as described in Sec 5.1.2 except that the oven temperature shall be 135 C.

5.3 For wet aggregate coated with cutback asphalts:

5.3.1 Coating-Weigh 100 g of the oven dry aggregate at room temperature into the mixing container. Add 2 ml of distilled water. Mix thoroughly with the spatula until the aggregate particles are uniformly wetted. Add 5.5 ± 0.2 g of bituminous material, preheated where necessary to the temperature specified in Table 1, depending on the grade of bitumen. Mix vigorously with the spatula until all aggregate is coated, but for not more than 5 minutes.

5.3.2 Visual Estimation of Coated Area in Wet Aggregate Coating Test-By observation, estimate the percentage of the total visible area of the aggregate coated as above or below 95 percent. Any thin brownish, translucent areas are to be considered fully coated (Note 3).

Note 3: If at least 95 percent of the aggregate area is coated, the curing, water immersion and evaluation steps as described in Sec 5.1.2, 5.1.3, and 5.1.4 may be performed to conclusion of the test.

5.4 For dry aggregate coated with semisolid asphalts:

5.4.1 Coating-Weigh 100 g of oven dry aggregate into the mixing container. When testing asphalts, place the container containing the aggregate in a 135 to 149 C constant temperature oven for 1 h. Heat the asphalt separately to 135 to 149 C. Using a sheet of asbestos paper or other insulating material on the scales to retard chilling, add 5.5 ± 0.2 g of the heated bitumen to the hot aggregate. Warm the spatula blade and mix vigorously with the spatula for 2 to 3 minutes or until the aggregate is completely coated, allowing the temperature of the contents of the container to drop naturally during the mixing. After coating allow the mixture to cool to room temperature (Notes 4, 5, and 6).

Note 4: The bituminous coating on the aggregate must be complete; that is, no bare spots are permissible. If complete coverage is not obtained in the manner described, warm the mixing container gently over a hot plate and continue mixing until coating is complete.

Note 5: In case the bitumen is so fluid that it drains from the aggregate to leave a thin coating, continue mixing while the mixture cools until it becomes tacky.

Note 6: The test with semisolid asphalt is performed with dry aggregate only. No curing is used.

5.4.2 Water Immersion-Transfer the coated aggregate to a 600 ml glass container. Cover immediately with 400 ml of distilled water at room temperature (approximately 25 C). Allow the coated aggregate to remain immersed in the water for 16 to 18 h.
5.4.3 Visual Examination-Estimate the coated area as described in Sec 5.1.4.

6. Report
   6.1 Report the estimated coated area as "above 95 percent" or "below 95 percent."
1. Scope
1.1 This method of test is for compacted bituminous mixtures of the hot-mixed, hot-laid type for use in pavement surfaces and base courses and is intended to provide a measure of the compressive strength of these paving mixtures. This procedure in conjunction with the procedure outlined in MRDTM 415 is commonly referred to as the immersion-compression test.

2. Apparatus
2.1 Molds-Molding cylinders and top and bottom molding plungers shall be as shown in Fig. 1. Molds and plungers of other sizes may be used provided that the diameter of the mold is at least four times the maximum nominal diameter of the largest aggregate size in the mixture to be molded. Molds smaller than 50 mm (or 2 in.) in diameter shall not be used.

2.2 Supports-Temporary supports shall be provided to raise the molding cylinder 25.4 mm (1 in.) during the molding operation. Steel bars 25.4 mm (1 in.) square are suitable.

2.3 Testing Machine-The testing machine may be of any type with sufficient capacity to provide a range of accurately controllable rates of vertical deformation. The rate of vertical deformation for the compression test is 1.3 mm (0.05 in.) per minute per 25.4 mm (1 in.) of specimen height. It may be necessary to test specimens ranging in size from 50 mm by 50 mm (or 2 by 2 in.) to 200 by 200 mm (or 8 by 8 in.). In order to maintain the minimum ratio of specimen diameter to particle size, the testing machine should have a range of speeds from 2.5 mm (or 0.1 in.) per minute for 50 mm (or 2 in.) specimens, to 10 mm (0.4 in.) per minute for 200 mm (or 8 in.) specimens. For central control laboratory installations the testing machine shall conform to the requirements of Verification of Testing Machines (MRDTM 104). The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is spherically seated and the other plain. The spherically seated block shall be mounted to bear on the upper surface of the test specimen and the plain block shall rest on the platen of the testing machine to form a seat for the specimen. The bearing faces of the plates shall have a diameter slightly greater than that of the largest specimens to be tested. The bearing faces, when new, shall not depart from a true plane by more than 0.013 mm (0.0005 in.) at any point and shall be maintained within a permissible variation limit of 0.025 mm (or 0.001 in.). In the spherically seated block, the center of the sphere shall coincide with the bearing face. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

2.4 Oven-The oven for the preparation of hot mixtures shall be capable of being set to maintain any desired temperature from room temperature to 163 C.

2.5 Heating Device-A small hot plate with a variable heating rate, a sand bath, an infrared lamp or an oven shall be provided for supplying sufficient heat under the mixing bowl to maintain the aggregate and bituminous material at the desired temperature during mixing.

2.6 Hot Water Bath-A water bath sufficiently large to hold three sets of 101.6 mm (4 in.) molds and plungers, together with a hot plate of sufficient capacity to maintain the water bath at a temperature just under the boiling point will be required. The hot plate, if electric, shall be provided with a variable controlled rate of heating (Note 2, Sec 5.1).

2.7 Air Bath-An air bath which is capable of either manual or automatic control for storing the specimens at 25 ± 1 C immediately prior to making the compression test.

2.8 Balance-A balance conforming to the requirements of MRDTM 102, Class D shall be provided for weighing the ingredients of the mixture.

2.9 Mixing Machine-The mixture should be prepared in a mechanical mixer. Any type of mixer may be used, provided it can be maintained at the required mixing temperature and will produce a well coated homogeneous mixture of the required size in 2 minutes or less, and further provided that it is of such design that fouling of the blades will be minimized and each individual batch can be retrieved in essentially its entirety including asphalt and fines. Hand mixing may be used, if necessary, but for hot mixtures the time required to obtain satisfactory coating is often excessive and generally the test results are less uniform than when machine mixing is employed.

2.10 Flexible spatulas for scraping the mixing bowl, and stiff spatulas, for spading the specimen in the mold, shall be provided.
3. Preparation of Test Mixtures

3.1 The size of the individual batches shall be limited to the amount required for one test specimen.

3.2 An initial batch shall be mixed for the purpose of "buttering" the mixture bowl and blades. This batch shall be emptied after mixing and the sides of the bowl and blades shall be cleaned of mixture residue by scraping with a small flexible spatula but shall not be wiped with cloth or washed clean with solvent, except when a change is to be made in the binder or at the end of a run.

3.3 A trial specimen shall be molded in order to determine the correct mass of materials to produce a specimen of the desired height. The initial or "buttering" batch may be used for this purpose, if desired.

3.4 In preparing aggregates for making mixtures, a sieve analysis shall be made on each aggregate involved. All coarse aggregates shall be separated individually and recombined in the necessary quantities with the fine aggregates to meet the mixture gradations under study. The weighed aggregate fractions for each batch shall be thoroughly mixed while dry and then brought to a temperature of 163 ± 3 C. The container shall not come in direct contact with a flame or an unshielded hot plate. The bituminous material shall be stirred constantly while being heated. As an alternate method of preheating the bitumen, a paraffin dispenser may be used to hold not more than one day supply at the required temperature throughout a working day. Any residual amount left over at the end of the day must be discarded.

3.5 When the bituminous material has been brought to the desired temperature, the mixing bowl, which shall have been preheated to approximately the temperature of the aggregate, shall be charged with the preheated and dry mixed aggregate, the preheated bituminous material shall be weighed into the aggregate and wet mixing shall be started and continued for not less than 90 s nor more than 120 s. Excessive loss of heat during mixing may be offset by the use of a small hot plate, or sand bath, under the mixing bowl, or an infrared lamp over the mixing bowl. The mixing bowl shall not be in direct contact with a hot plate, if used.

4. Test Specimen

4.1 Generally, the test specimens shall be cylinders 101.6 mm (or 4.0 in.) in diameter and 101.6 ± 2.5 mm (or 4.0 ± 0.1 in.) in height. The size of test specimens has an influence on the results of the compressive strength test. Cylindrical specimens of dimensions other than 101.6 mm (or 4.0 in.) may be used provided that:

4.1.1 The specimen height is equal to the diameter within ± 2.5 percent.

4.1.2 The specimen diameter shall be not less than four times the nominal diameter of the largest aggregate particles.

4.1.3 The specimen diameter shall not be less than 50.8 mm (2 in.), and

4.1.4 The unit rate of deformation shall be constant during the compression test (Sec 6).

5. Molding and Curing Test Specimens

5.1 Laboratory prepared mixtures shall be allowed to cool to molding temperature as quickly as possible after mixing. Mixtures from field projects shall be brought to molding temperature by careful, uniform heating immediately prior to molding (Note 1). Molding temperatures shall be 124 ± 3 C for hot mixtures. Molding temperature is the temperature when the molding pressure is first applied. As soon as the materials have been thoroughly mixed and have reached a suitable temperature within the specified range, approximately one-half of the mixture shall be placed in the molding cylinder which, together with the top and bottom plunger shall have been preheated in the water bath maintained at a temperature just under the boiling point (Note 2). The molds and plungers should be wiped with a clean cloth that has a few drops of oil on it. With the bottom plunger in place and the molding cylinder supported temporarily on the two steel bars, the mixture shall be spaded vigorously twenty five times with a heated spatula, with fifteen of the blows being delivered around the inside of the mold to reduce honeycomb, and the remaining ten at random over the mixture. The remaining half of the mixture shall then be quickly transferred to the molding cylinder and the same spading action repeated. The spatula should penetrate the mixture as deeply as possible. A spatula having slightly curved cross section has been used to advantage. The top of the mixture should be slightly rounded or coneshaped to aid in firm seating of the upper plunger. The mixture shall be compressed between the top and bottom plungers under an initial load of 10.5 kg/cm² (or 150 lb/in.²) to set the mixture against the sides of the mold. The support bars shall then be removed to permit full double plunger action and the entire molding load of 210.9 kg/CM² (or 3000 lb/in²) shall be applied for 120 s. The specimen shall be removed from the mold with an ejection device that provides a smooth uniform rate of travel for the ejection head.

Note 1: Reheated mixtures will show higher compressive strength values than the same mixtures molded promptly after mixing.

Note 2: Instead of preheating the mold and plungers in a hot water bath, an oven may be used provided the heating time is at least 2 h. The temperature of the mold and plungers should be between 93.3 and 135 C when the mixture is placed in the mold.
5.2 After removal from the mold, specimens shall be oven cured for 24 h at 60 °C and thereafter brought to the test temperature of 25 °C by storing in the air bath at 25 °C for not less than 4 h before testing. Specimens that are to be stored dry for more than 24 h, shall be protected from exposure to the air by sealing them in closely fitting, airtight containers.

6. Procedure

6.1 Determine the bulk specific gravity in accordance with the procedure outlined in Method B of MRDTM 411, Bulk Specific Gravity of Compacted Bituminous Mixtures.

6.2 Test the specimens in axial compression, without lateral support, at a uniform rate of vertical deformation of 1.3 mm (0.05 in.) per minute per 25.4 mm (1 in.) of specimen height. For specimens 101.6 mm (4 in.) in height, use a rate of 5.1 mm (0.2 in.) per minute.

7. Report

7.1 Test results and calculations should be reported on MRDWS Form No. 414 and should include the following:
7.1.1 The bulk specific gravity of the specimens.
7.1.2 The compressive strength in kg/cm² (lb/in.²) determined by dividing the maximum vertical load obtained during deformation at the rate specified in Sec 6 by the original cross sectional area of the test specimen. Not less than three specimens shall be prepared for each asphalt increment and the average of the three shall be reported as the compressive strength.
7.1.3 The nominal height and diameter of the test specimen.
### Metric Equivalents

<table>
<thead>
<tr>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(.005)</td>
<td>0.127</td>
<td>3/4</td>
<td>19.0</td>
<td>(3.95)</td>
<td>100.33</td>
</tr>
<tr>
<td>(1/16)</td>
<td>1.6</td>
<td>(1)</td>
<td>25.4</td>
<td>(4)</td>
<td>101.6</td>
</tr>
<tr>
<td>(1/8)</td>
<td>3.2</td>
<td>(1½)</td>
<td>38.1</td>
<td>(4½)</td>
<td>114.3</td>
</tr>
<tr>
<td>(¼)</td>
<td>6.4</td>
<td>(2)</td>
<td>50.8</td>
<td>(6 7/8)</td>
<td>174.6</td>
</tr>
<tr>
<td>(½)</td>
<td>12.7</td>
<td>(2½)</td>
<td>63.5</td>
<td>(7)</td>
<td>177.8</td>
</tr>
<tr>
<td>(9/16)</td>
<td>14.3</td>
<td>(3)</td>
<td>76.2</td>
<td>(7½)</td>
<td>190.5</td>
</tr>
<tr>
<td>(5/8)</td>
<td>15.9</td>
<td>(3 5/8)</td>
<td>92.1</td>
<td>(7 15/16)</td>
<td>201.6</td>
</tr>
<tr>
<td>(3.90)</td>
<td>99.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 1.** Forming Mold and Plunger Showing Tolerances
### Asphalt Content of Bituminous Mixture, Percent by Mass

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Lab Sample No.</th>
<th>Project</th>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Road No.</th>
<th>Road Name</th>
<th>Quantity Represented</th>
</tr>
</thead>
</table>

#### Bulk Sp. Gr. of Bituminous Mixture (MRDTM 411, Method B)

<table>
<thead>
<tr>
<th></th>
<th>1a</th>
<th>16</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Height of Specimen (mm)</td>
<td>102.1</td>
<td>101.4</td>
<td>100.5</td>
</tr>
<tr>
<td>B Diameter of Specimen (mm)</td>
<td>101.4</td>
<td>101.4</td>
<td>101.4</td>
</tr>
<tr>
<td>C Cross Sectional Area of Specimen, ( \frac{3.14 \times B^2}{400} ) cm²</td>
<td>81.03</td>
<td>81.03</td>
<td>81.03</td>
</tr>
<tr>
<td>D Maximum Compressive Load (kg)</td>
<td>8550</td>
<td>8900</td>
<td>8750</td>
</tr>
<tr>
<td>Compressive Strength of Bituminous Mixture, ( \frac{D}{C} ) Kg/cm²</td>
<td>105.5</td>
<td>109.6</td>
<td>108.0</td>
</tr>
</tbody>
</table>

Average: 107.8

### Asphalt Content of Bituminous Mixture, Percent by Mass

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Lab Sample No.</th>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Road No.</th>
<th>Road Name</th>
<th>Quantity Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td></td>
<td>5/8/82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Bulk Sp. Gr. of Bituminous Mixture (MRDTM 411, Method B)

<table>
<thead>
<tr>
<th></th>
<th>1a</th>
<th>16</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Height of Specimen (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B Diameter of Specimen (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Cross Sectional Area of Specimen, ( \frac{3.14 \times B^2}{400} ) cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Maximum Compressive Load (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive Strength of Bituminous Mixture, ( \frac{D}{C} ) Kg/cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average: 6.5

### Asphalt Content of Bituminous Mixture, Percent by Mass

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Lab Sample No.</th>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Road No.</th>
<th>Road Name</th>
<th>Quantity Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td></td>
<td>5/8/82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Bulk Sp. Gr. of Bituminous Mixture (MRDTM 411, Method B)

<table>
<thead>
<tr>
<th></th>
<th>1a</th>
<th>16</th>
<th>1c</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Height of Specimen (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B Diameter of Specimen (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Cross Sectional Area of Specimen, ( \frac{3.14 \times B^2}{400} ) cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Maximum Compressive Load (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive Strength of Bituminous Mixture, ( \frac{D}{C} ) Kg/cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average: 6.5


Remarks:

CHECKED BY: T. Williams  TITLE Lead Inspector  DATE 5/8/82
MATERIALS ENGINEER: J. Smith  (CONSULTANT)
RESIDENT ENGINEER: J. Dunbar  (CONTRACTOR)

DISTRIBUTION: X CONTRACTOR  X MINISTRY
☐ RESIDENT ENGINEER  OTHER (Specify)
1. **Scope**

1.1 This method covers measurement of the loss of cohesion resulting from the action of water on compacted bituminous mixtures containing paving grade asphalts. A numerical index of reduced cohesion is obtained by comparing the compressive strength of freshly molded and cured specimens with the compressive strength of duplicate specimens that have been immersed in water under prescribed conditions.

2. **Apparatus**

2.1 One or more automatically controlled water baths shall be provided for immersing the specimens. The baths shall be of sufficient size to permit total immersion of the test specimens. They shall also be so designed and equipped as to permit accurate and uniform control of the immersion temperature within ± 1°C. They shall be constructed of or lined with copper, stainless steel, or another nonreactive material. The water used for the wet storage of the specimens shall be either distilled or otherwise treated to eliminate electrolytes. The bath shall be emptied, cleaned, and refilled with fresh water for each series of tests.

2.2 A manually or automatically controlled water bath also shall be provided for bringing the immersed specimens to the test temperature of 25 ± 1°C. Any convenient pan or tank may be used provided it is of sufficient size to permit total immersion of the specimens.

2.3 A balance and a water bath with suitable accessory equipment will be required for weighing the test specimens in air and in water in order to determine their densities, the amount of absorption, and any changes in specimen volume resulting from the immersion test. The balance and water bath described in MRDTM 411, Bulk Specific Gravity of Compacted Bituminous Mixtures, will serve this purpose.

2.4 A supply of flat transfer plates of glass or metal will be required. One of these plates shall be kept under each of the specimens during the immersion period and during subsequent handling, except when weighing and testing, in order to prevent breakage or distortion of the specimens.

3. **Test Specimens**

3.1 At least six 101.6 by 101.6 mm (4 by 4 in.) cylindrical specimens shall be made for each test. The procedures described in the Standard Method of Test for Compressive Strength of Bituminous Mixtures (MRDTM 414) shall be followed in preparing the loose mixtures and in molding and curing the test specimens.

4. **Determination of Bulk Specific Gravity of Test Specimens**

4.1 Allow each set of six test specimens to cool for at least 2 h after removal from the curing oven described in MRDTM 414. Determine the oven-dry mass, A, of each specimen. Immerse each specimen in water for 1 minute, surface-dry by blotting quickly with a damp towel, and determine the surface-dry mass, B. Without delay, determine the mass, C, of each specimen when immersed in water.

4.2 Calculate the bulk specific gravity of each of the test specimens as follows:

\[
\text{Bulk Specific Gravity} = \frac{A}{B - C}
\]

where:
A = mass of oven-dry specimen in air, g,
B = mass of surface-dry specimen in air, g, and,
C = mass of specimen in water, g.

5. **Procedure**

5.1 Sort each set of six test specimens into two groups of three specimens each so that the average bulk specific gravity of the specimens in the two groups is approximately the same. Test the specimens in group 1 as described in Sec 5.1.1. Test the specimens in group 2 as described in Sec 5.1.2.
5.1.1 Group 1-Bring the test specimens to the test temperature, 25 ± 1°C, by storing them in an air bath (Note) maintained at the test temperature for not less than 4 h and determine their compressive strengths in accordance with MRDTM 414.

**Note:** The 25 ± 1°C water bath may be used as an air bath by storing the samples in sealed plastic bags.

5.1.2 Group 2-Immerse the test specimens in water for 24 h at 60 ± 1°C. Transfer them to the second water bath maintained at 25 ± 1°C and store them there for 2 h. Determine the compressive strength of the specimens in accordance with MRDTM 414.

6. Calculation

6.1 Calculate the effect of water on the cohesive strength of the asphalt mixture as the percentage of the original strength that is retained after the immersion period. It is calculated as follows:

\[
\text{Index of Retained Strength, } \% = \frac{S_2}{S_1} \times 100
\]

where:

\(S_1\) = compressive strength of dry specimens (group 1), and

\(S_2\) = compressive strength of immersed specimens (group 2).

7. Report

7.1 Record test results on Form No. MRDWS 415.
# Effect of Water on Cohesion of Compacted Bituminous Mixtures

**Specimen No.** | 1 | 2 | 3 | 4 | 5 | 6
---|---|---|---|---|---|---
A. Oven-Dry Mass in Air (MRDTM 411), g | 2060 | 2082 | 2062 | 1996 | 2012 | 2006
B. Surface Dry Mass in Air (MRDTM 414), g | 2068 | 2043 | 2076 | 2080 | 2031 | 2027
C. Mass in Water, g | 1192 | 1180 | 1161 | 1166 | 1160 | 1170

**Bulk Specific Gravity**

\[
\frac{A}{B - C} = 2.340
\]

**Index of Retained Strength**

| Specimen No. | Group 2 | Group 1 |
---|---|---|
Average Bulk Specific Gravity | 2.339 | 2.340 |
Compressive Strength (MRDTM 414), Kg/cm² | | 105.5 105.5 105.0 |
S₂, Average Compressive Strength of Dry Specimens, Kg/cm² | | 105.7 |
Compressive Strength (MRDTM 414), at 1 day and 60°C Kg/cm² | 82.5 79.1 81.0 |
S₂, Average Compressive Strength of Immersed Specimens, | 80.5 |

Index of Retained Strength, percent* = \[
\frac{S_2}{S_1} \times 100 = 76.5
\%

**NOTE:** *Report on Form MRODR 400-B Line 9.

**Remarks:**

---

**CHECKED BY:** T. Williams  TITLE Lab Supervisor DATE 5/8/82

**MATERIALS ENGINEER:** J. Smith  **CONSULTANT**  R. White

**RESIDENT ENGINEER:** J. Dunbar  **CONTRACTOR**

**DISTRIBUTION:**  ✗ CONTRACTOR  ✗ RESIDENT ENGINEER  ☐ OTHER (Specify)
Standard Method of Test for
Moisture or Volatile Distillates in Bituminous Paving Mixtures

MRD Test Method 416
(Adaptation of AASHTO T 110-70)

1. Scope
1.1 This method is intended for the determination, by direct measurement, of moisture or volatile fractions of the bitumen in bituminous paving mixtures.

2. Apparatus
2.1 Metal Still-A vertical cylindrical still, similar to that shown in Fig. 1, having a faced flange at the top to which the head is tightly attached by means of a clamp. The head shall be of metal, preferably of copper or brass, and shall be provided with a tubulation 25.4 mm (1 in.) in inside diameter.

2.2 Condenser, of the water cooled reflux glass tube type, having a condenser jacket not less than 400 mm (or 153/4 in.) long with an inner tube 9.5 to 12.7 mm (or 3/8 to 1/2 in.) in outside diameter. The end of the condenser inserted in the trap shall be ground off at an angle of 30 degrees from the vertical axis of the condenser. For mixtures with very volatile solvents, it may be necessary to supplement this water cooled condenser with a second water cooled condenser of approximately the same dimensions.

2.3 Trap, of well annealed glass, of one of the following types depending upon the purpose of the test:
2.3.1 For determination of water in bituminous paving mixtures, a glass trap of 10 or 25 ml capacity shall be used. The trap shall be graduated in 0. 1 ml divisions with a ± 0.05 ml maximum error below 1 ml, and in 0.2 ml divisions with a ± 0.1 ml maximum error above 1 ml, as specified in ASTM E 123, Apparatus for Determination of Water by Distillation.

2.3.2 For determination of the volatile fractions of the bitumen, the trap shall conform to the dimensions shown on Fig.2.

2.4 Solvent-For general use, an aromatic solvent is preferred, since it has high solvency and dispersing power for most bituminous materials. Xylene, or a blend of 20 percent benzol and 80 percent xylene, is recommended. For asphalts and similar petroleum products, a petroleum distillate, 5 percent boiling between 90 and 100 C, and 90 percent distilling below 210 C, may be used.

3. Sample
3.1 The sample shall be representative of the material and shall be of such size as practical to fill the container in which it is transported to the laboratory. For duplicate tests a 2 liter (or ½ gal.) sample is satisfactory.

4. Preparation of Sample
4.1 Thoroughly mix the sample and weigh out an amount estimated to show a percentage of moisture or diluent within the capacity of the trap calibration. Keep the remainder of the sample in its tightly covered container. The weighed sample should be not less than 500 g for normal mixtures. Thoroughly break up this sample to avoid the large lumps, and place it in the still.

5. Procedure for Determination of Moisture
5.1 After the sample has been placed in the still, add 200 ml of the solvent and quickly stir it into the sample. Firmly attach the still cover and assemble the trap and condenser as illustrated in Fig. 1. Apply heat at such a rate that refluxing will start within 5 to 10 minutes after the heat has been applied and the condensed solvent will drip into the trap at a rate of 85 to 95 drops per minute. Continue the distillation until 3 successive readings of the trap at 15 minute intervals show no increase in the amount of water being condensed, except that in no case shall distillation continue for more than 1½ h.

5.2 Record the volume of water in the trap. Calculate and report the percentage by mass of sample taken.

6. Procedure for Determination of Volatile Distillates
6.1 After the sample has been placed in the still, add 350 ml of water and approximately 3 g of sodium carbonate (Na₂CO₃), and quickly stir into the sample. Firmly attach the still cover and assemble the trap and condenser as illustrated in Fig. 1, except that the trap used shall be the dilution trap specified in Sec 2.3.2 and illustrated in Fig. 2.

6.2 Apply heat at such a rate that the water and solvent will begin to reflux in 5 to 10 minutes after the heat has been applied and will drip from the condenser at the rate of 85 to 95 drops per minute. If the sample contains a large amount of
very volatile solvent, it may be necessary to add a second water cooled condenser above the first one, or to reduce the rate of distillation to prevent escape of the solvent.

6.3 Continue distillation until three successive readings of the upper and lower levels of the diluent at 15 minute intervals show no increase in the quantity being collected. Then remove the source of heat and allow the apparatus to stand for ½ h to permit the solvent to cool and separate.

6.4 Record the volume of diluent in the trap. Calculate and report the percentage by mass of sample taken using the specific gravity of the diluent at 25°C. Record the test results on Form No. MRDWS 416.
# Moisture Content and Volatile Distillates in Bituminous Paving Mixtures

**Field Sample No.** 2  
**Lab Sample No.** 82-2422  
**Project.** FCP 285

<table>
<thead>
<tr>
<th>Field Sample</th>
<th>Lab Sample</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>82-2422</td>
<td>FCP 285</td>
</tr>
</tbody>
</table>

**Date Sampled:** 5/5/82  
**Date Received:** 5/7/82  
**Sampled by:** Y. Toha  
**DATE TESTED:** 5/8/82  
**TESTED BY:** F. Monrakah  
**Road No.:** 202-203  
**Road Name:** Damman-Res Tanur  
**Material:** Bit. Wear Cre Class A  
**Title Lab Technician:** 500 T

## Moisture Content

<table>
<thead>
<tr>
<th>Time</th>
<th>Volume of Water in Trap, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00</td>
<td>2.0</td>
</tr>
<tr>
<td>9:15</td>
<td>1.4</td>
</tr>
<tr>
<td>9:30</td>
<td>2.5</td>
</tr>
<tr>
<td>9:45</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Volume of Water in Trap ml $V_1$ = 2.5

### A. Mass of Water in Trap, g $V_1 \times 1$ g/ml = 2.5

### Moisture Content, Percent by Mass,*

\[
\% W_2 = \frac{A}{W_1} \times 100
\]

\[
\frac{2.5}{W_1} \times 100 = 0.49
\]

## Volatile Distillates

<table>
<thead>
<tr>
<th>Time</th>
<th>Volume of Diluent in Trap, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:30</td>
<td>3.0</td>
</tr>
<tr>
<td>1:45</td>
<td>3.4</td>
</tr>
<tr>
<td>2:00</td>
<td>3.6</td>
</tr>
<tr>
<td>2:15</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Volume of Diluent in Trap ml $V_1$ = 3.6

### B. Specific Gravity of Diluent at 25 °C = 0.936

### C. Mass of Diluent in Trap, g $V_1 \times B$ = 3.4

### Volatile Distillates, Percent by Mass,**

\[
\% W = \frac{C}{W_1} \times 100
\]

\[
\frac{3.4}{W_1} \times 100 = 0.65
\]

**NOTE:**  
*Record on MRDTR 400-B, Line 3.  
**Record on MRDTR 400-B, Line 4.

### Remarks:

______________________________
______________________________
______________________________

### Checked by:

<table>
<thead>
<tr>
<th>T. Williams</th>
<th>TITLE Lab Supervisor</th>
<th>DATE 5/8/82</th>
</tr>
</thead>
</table>

### Materials Engineer:

<table>
<thead>
<tr>
<th>J. Smith</th>
<th>(CONSULTANT)</th>
</tr>
</thead>
</table>

### Resident Engineer:

<table>
<thead>
<tr>
<th>J. Dunbar</th>
<th>(CONTRACTOR)</th>
</tr>
</thead>
</table>

### Distribution:

- [x] CONTRACTOR
- [ ] RESIDENT ENGINEER
- [ ] MINISTRY
- [ ] OTHER (Specify)
**1. Scope**

1.1 These methods cover the procedures for sampling mixtures of bituminous materials with mineral aggregate as prepared for use in paving. The samples may be used for either of two purposes:

1.1.1 To represent an average of the bituminous mixture, or

1.1.2 To ascertain the periodic variation in characteristics of the mixture for the purpose of controlling uniformity.

**2. Selection of Samples**

2.1 Materials sampling is equally as important as materials testing. Every precaution to obtain mixture samples that are representative of the bituminous mixture is essential.

2.2 Care shall be taken in sampling to avoid segregation of coarse aggregate and bituminous mortar. Care shall be taken also to prevent contamination by dust or other foreign matter.

2.3 Samples of bituminous mixtures upon which acceptance or rejection is to be based shall be selected by the Engineer or his authorized representative in accordance with the applicable procedure outlined herein.

**3. Size of Sample**

3.1 The size of sample shall be governed by the maximum size of particle of mineral aggregate in the mixture. The minimum size of sample shall conform to the requirements shown in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Nominal Maximum Size of Particles Passing Sieve</th>
<th>Minimum Mass of Uncompacted Mixture</th>
<th>Minimum Area of Compacted Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td>kg</td>
<td>cm³</td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>4</td>
<td>250</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>7</td>
<td>650</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>9</td>
<td>950</td>
</tr>
<tr>
<td>37.5 (1½ in.)</td>
<td>11</td>
<td>950</td>
</tr>
<tr>
<td>50 (2 in.)</td>
<td>16</td>
<td>1450</td>
</tr>
</tbody>
</table>

4. Sampling Plant Mixed Bituminous Mixtures at Place of Manufacture

4.1 A batch discharged from the mixing plant shall be sampled from the pile by means of a scoop or shovel scraped from the bottom to the top of the pile at two points 180 degrees from each other, and reduced to the required size by remixing and quartering (Note 1). If the sample is to represent more than one batch of the mixture, samples shall be taken at regular intervals from subsequent batches in accordance with the above procedure and placed in a suitable container. When the required number of batches have been sampled, the entire amount shall be reduced to the required size by mixing and quartering on a clean, smooth surface. If necessary, the mixture may be warmed to facilitate remixing, but care shall be taken to avoid overheating any part of the sample and only sufficient heat shall be used to permit satisfactory mixing. If samples are taken for the purpose of determining uniformity of the product of the plant, they shall not be mixed but shall be handled separately.
4.2 Samples from a stockpile shall be obtained by combining equal quantities of the mixture taken from holes dug into points near the top, middle, and bottom of the stockpile. Reduction of the sample to the required size shall be as described in Sec 4.1.

**Note 1:** A convenient sampling tube for uncompacted bituminous mixtures may be made by bending the sides of a round point shovel to form a tube approximately 90 mm (or 3½ in.) in diameter.

5. **Sampling Plant Mixed Bituminous Mixtures From Roadway**

5.1 The size of samples of bituminous paving mixtures taken from the finished pavement for determination of mix characteristics shall not be less than the area of pavement surface shown in Table 1 and shall extend the full depth of the course of bituminous mixture being sampled. The sample shall be cut in such a manner as to cause a minimum disturbance of the density of the sample and shall be firmly wrapped and supported during transport to preserve its shape.

6. **Sampling Road Mixed Bituminous Mixtures**

6.1 Samples shall be taken from mixed-in-place bituminous mixtures for the purpose of determining the physical properties of the mixture and the bitumen content of the mix as well as the uniformity of bitumen content, after the bitumen has been thoroughly incorporated.

6.2 If the mixture is in windrows, a representative sample of the windrow at intervals of not more than 150 m (or 500 ft) shall be obtained and tested separately. Samples of the windrow shall be obtained by flattening the windrow at one point into a layer approximately 0.3 m (or 1 ft) thick and coring this layer at three or more equally spaced points to obtain the required size of sample as shown in Table 1.

6.3 If the mix has been bladed into a relatively uniform layer, samples shall be secured at intervals of not more than 150 m (or 500 ft) and if any further indication of the uniformity of the mixture is required, additional samples at each of the 150 m (or 500 ft) intervals shall be obtained at points approximately 0.6 m (or 2 ft) from the edge of the pavement. Care shall be exercised to avoid including material from the subgrade or base on which the pavement is being constructed.

6.4 Samples from the completed pavement shall be taken in the same manner as directed for plant mixed pavement (Sec 5).

7. **Identification of Samples**

7.1 Each sample should be identified by completion of the transmittal form.
Standard Method of Test for
Quantitative Extraction of Asphalt from Asphalt Paving Mixtures

MRD Test Method 418
(Adaptation of AASHTO T 164-80)

1. Scope
1.1 Extraction is the procedure used for separating the asphalt from the mineral aggregates in an asphalt paving mixture. The purpose of the 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 a gradation analysis and other tests on the aggregate as may be desired. Where further tests on the extracted asphalt are desired, a recovery is made. Recovery of the asphalt must be made without changing its properties.
1.2 This method covers procedures for the quantitative determination of asphalt in hotmixed pavement mixtures and pavement samples. Method E is primarily for use in control of hot paving mixtures during construction (Note 1).
1.3 The aggregate remaining may be used for sieve analysis according to MRDTM 419, Mechanical Analysis of Extracted Aggregate.

Note 1: Although bitumen, by definition, is material soluble in carbon disulfide, trichloroethylene is used in this method for safety reasons and also because it does not change the properties of the asphalt for analysis if a recovery is made. 1,1,1 trichloroethane or methylene chloride may also be used.

2. Summary of Methods
2.1 The paving mixture is extracted with a suitable reagent using the extraction equipment applicable to the particular method. The difference between the original mass of the asphalt mixture and the mass of the dry aggregate after extraction is used for determining the proportion of asphalt and aggregate in a mixture. Corrections must be made for the small amount of fine mineral matter passing through the centrifuge bowl filter ring during the extraction. This is done by evaporating and ashing an aliquot portion of the solvent-asphalt solution (except for Method E). Corrections must also be made for water, if present in the asphalt mixture.

3. Apparatus
3.1 Oven, capable of maintaining the temperature at 110 ± 5 C.
3.2 Pan, flat, 300 mm (or 12 in.) long, 200 mm (or 8 in.) wide, and 25 mm (or 1 in.) deep.
3.3 An analytical balance conforming to the requirements of MRDTM 102, Class B.
3.4 A balance conforming to the requirements of MRDTM 102, Class D shall be provided.
3.5 A balance conforming to the requirements of MRDTM 102, Class E, 15 kg capacity or more.
3.6 Hot Plate-Electric, with adjustable heating rate.
3.7 Graduated cylinders, 1000 and 2000 ml capacity.
3.8 Ignition dish, 125 ml capacity.
3.9 Desiccator.
3.10 Muffle furnace or gas burner capable of maintaining temperatures between 500 and 600 C.

4. Reagents (Note 2)
4.1 Ammonium Carbonate-Saturated solution of reagent grade ammonium carbonate ((NH₄)₂ CO₃).
4.2 Trichloroethylene, Technical Grade, Type 1.
4.3 1,1,1 Trichloroethane.

Note 2: These solvents should be used only under a hood in a well ventilated area, since they are all toxic to some degree as indicated in Table 1.
Table 1

Exposure Limits for Extraction Solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Maximum Acceptable Concentration for an 8 h Exposure, PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethylene</td>
<td>200</td>
</tr>
<tr>
<td>1,1,1 Trichloroethane</td>
<td>500</td>
</tr>
</tbody>
</table>

**Caution:** Trichloroethylene and 1,1,1 Trichloroethane in the presence of heat and moisture may form acids that are extremely corrosive to certain metals, particularly when subject to contact over lengthy periods of time. Precautions should be taken to not allow these two solvents to remain in the effluent tanks of aluminum vacuum extractors, even in small quantities.

5. Preparation of Sample and General Requirements for Weighing

5.1 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large flat pan and warm until it can be handled to a maximum temperature of 110 ± 5°C.

5.2 The test sample should normally be the end result of splitting or quartering a larger sample conforming to MRDTM 417, Sampling Bituminous Paving Mixtures. The size of the test sample shall be governed by the nominal maximum aggregate size in the mixture and conform to the amount shown in Table 2 (Note 3).

Table 2

<table>
<thead>
<tr>
<th>Nominal Maximum Aggregate Size</th>
<th>Minimum Mass of Sample, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td></td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>0.5</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>1</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>1.5</td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>2</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>3</td>
</tr>
<tr>
<td>37.5 (1½ in.)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Note 3:** When the required minimum mass of sample is greater than the allowable maximum mass for the method used, divide the sample into equal portions for testing. The mass for calculations will then be the sum of the masses of each test portion.

5.3 Weighing of extraction test apparatus and/or samples shall be done on a balance meeting the requirements of Sec 3.4 when the capacity is sufficient; otherwise, a balance meeting the requirements of Sec 3.5 shall be used.

6. Water Determination

6.1 If the mix is suspected to have more than 0.1 percent moisture, determine the water content of a representative portion of the mixture according to MRDTM 416, Moisture or Volatile Distillates in Bituminous Paving Mixtures.

6.2 Calculate the mass of water in the sample, W₂, by multiplying the moisture content by the mass of the sample.

Method A

7. Apparatus

7.1 In addition to the apparatus listed in Sec 3, the following apparatus is required for Method A:

7.1.1 Extraction apparatus, consisting of a bowl approximating that shown in Fig. 1 and an apparatus in which the bowl may be revolved at controlled variable speeds up to 3600 rpm. The apparatus shall be provided with a container for catching the solvent thrown from the bowl and a drain for removing the solvent. The apparatus preferably shall be provided with explosion-proof features and installed in a hood to provide ventilation.

7.1.2 Filter Ring-A heavy weight, smooth, white, medium fast filter paper of a diameter at least equal to the bowl sealing surfaces outside diameter and to internally exceed the bowl sealing surfaces width by at least 25 mm (or 1 in.).
8. Procedure

8.1 Determine the moisture content of the sample in accordance with Sec 6.

8.2 Weigh approximately a 1000 to 2500 g sample into the bowl.

8.3 Cover the sample in the bowl with trichloroethylene or 1,1,1 trichloroethane and allow sufficient time for the solvent to disintegrate the sample (not over 1 h). Place the bowl containing the sample and the solvent in the extraction apparatus. Dry and weigh the filter ring and fit it around the edge of the bowl. Clamp the cover tightly on the bowl and place a beaker under the drain to collect the extract.

8.4 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 machine to stop, add 200 ml of trichloroethylene or 1, 1, 1 trichloroethane and repeat the procedure. Use sufficient 200 ml solvent additions (not less than three) so that the extract is clear and not darker than a light straw color. Collect the extract and the washings in a suitable graduate.

8.5 Remove the filter ring from the bowl and dry in air. Remove as much of the mineral matter adhering to the ring as possible and add it to the aggregate in the bowl. Dry the ring to constant mass in an oven at 110 ± 5 C. Dry the contents of the bowl to a constant mass in an oven or on a hot plate at 110 ± 5 C (Note 4).

Note 4: The sample shall be dried until further drying at 110 ± 5 C does not alter the mass 0.1 percent, the precision of weighing.

8.6 Record the volume of the total extract in the graduate. Agitate the extract thoroughly and immediately measure approximately 100 ml into a previously weighed ignition dish. Evaporate to dryness on a steam bath or hot water bath. Burn the residue at a dull red heat (500 to 600 C), cool, and add 5 ml of saturated ammonium carbonate, (NH₄)₂CO₃ solution per g of ash. Digest at room temperature for 1 h. Dry in an oven at 110 ± 5 C to constant mass, cool in desiccator, and weigh.

9. Calculations

9.1 Calculate the mass of mineral matter in the total volume of extract as follows (Note 5):

Total Mineral Matter, \( W_4 \) = \( M_m \frac{V_1}{V_1-V_2} \)

where:
- \( M_m \) = mass of mineral matter in the aliquot portion, g,
- \( V_1 \) = total volume of extract, ml, and
- \( V_2 \) = volume of extract after removing aliquot, ml.

9.2 Calculate the percentage of bitumen in the sample as follows:

\[
\text{Bitumen Content, } \% = \frac{(W_1 - W_2) - (W_3 + W_4 + W_5)}{W_1 - W_2} \times 100
\]

where:
- \( W_1 \) = mass of sample, g,
- \( W_2 \) = mass of water in sample, g,
- \( W_3 \) = mass of extracted mineral matter, g,
- \( W_4 \) = mass of mineral matter in extract, g, and
- \( W_5 \) = increase of mass of filter ring, g.

Note 5: Add the increase in mass of the filter ring to the mass of the recovered aggregate and the mineral matter in the recovered bitumen.

Method B

10. Apparatus

10.1 In addition to the apparatus listed in Sec 3, the following apparatus is required for extraction using Method B. Two commonly used alternate configurations of equipment are described in Sec 10.1.1.1 through 10.1.2.5. Other apparatus differing in dimensional details may be used provided it is otherwise in substantial conformity.

10.1.1 Extraction apparatus, alternate No. 1, similar to Fig. 2.

10.1.1.1 Glass jar, cylindrical, plain 150 mm (or 6 in.) OD, 460 mm (or 18 in.) high, made of heat resistant glass.
10.1.1.2 Cylindrical metal frames, two, 125 mm (or 5 in.) OD, and 170 mm (or 6¾ in.) high. The lower frame shall have legs 50 mm (or 1 7/8 in.) high to support the frame above the solvent level. The upper frame shall have stub legs which fit in recesses provided in the top rim of the lower frame or equivalent method of support. Both frames shall contain 2.00 mm to 1.70 mm (No. 10 to No. 12) mesh metal cones having a base of approximately 115 mm (or 4½ in.) in diameter and side length of approximately 170 mm (or 6¾ in.) mounted inside the top rim of each frame. A bail handle may be provided on the inside of the top rim of each frame.

10.1.1.3 Condenser, 160 mm (or 6¼ in.) in diameter, with a truncated hemispherical condensing surface. It shall be equipped with 6.5 mm (or 1/4 in.) ID tubing inlet and outlet assembled so that no lead soldered joint comes in direct contact with the condensing solvent vapor.

10.1.1.4 Filter paper, medium grade, fast filtering, 330 mm in diameter.

10.1.1.5 Asbestos coated wire, 3.2 mm (1/8 in.) thick or similar insulating pad.

10.1.2 Extraction apparatus, alternate No. 2.

10.1.2.1 Glass jar, cylindrical, plain 225 mm (or 8¾ in.), OD 460 mm (or 18 in.) high, made of heat resistant glass.

10.1.2.2 Cylindrical metal frame, 170 mm (or 6¾ in.) OD, and 345 mm (or 13½ in.) high. The frame shall contain a 2.00 mm to 1.70 mm (No. 10 to No. 12) mesh metal cone with a base 165 mm (or 6½ in.) in diameter and 255 mm (or 10 in.) side length, mounted inside the top rim of the frame. A bail handle may be provided on the inside of the top rim of the frame.

11. Procedure

11.1 Determine the moisture content of the sample in accordance with Sec 6.

11.2 Dry and weigh filter paper(s) to nearest 0.5 g. Fold filter on its diameter and fold twice again, one fold being made over the other to make three segments. Open to form a hollow three-ply cone with a single one-ply seam.

11.3 Select the test sample size in conformance with Sec 5 and measure its mass (Note 3).

11.4 Place the sample in the filter paper lined cone(s).

11.5 Pour approximately 600 ml of trichloroethylene or 1,1,1 trichloroethane into the glass jar and place the cone(s) and frame(s) with supporting legs in the jar. The solvent level must be below the tip of the lower cone.

11.6 Place the loaded jar on the electric hot plate and cover the jar with a condenser. Circulate a gentle steady flow of cold water through the condenser. Adjust the heat so that the solvent boils gently and a steady, light flow of condensed solvent runs into the sample in the cone. Take care to adjust the heat so that the filter cone does not overflow. Continue extraction until the solvent running from the tip of the cone appears a very light straw color when viewed against a white background. Shut off the heat but not the condenser water, and allow to stand until cool enough to handle. Direct contact between the glass jar and the hot plate should be avoided by the use of an appropriate insulating pad.

11.7 Remove the frame(s) with filter paper(s) and extracted aggregate from the jar. Dry in air, and then remove filter paper containing sample and place in a tared pan. Dry to a constant mass in an oven at 110 ± 5 C. Subtract the mass of the tared pan and original mass of filter paper(s) and record the difference as the mass of extracted aggregate (Note 6).

Note 6: The mass of filter paper(s) and frame(s) as described in Sec 11.2 may be determined together. In this case, the frame(s), filter(s) and aggregate may be dried without separating as described in Sec 11.7. Subtract the mass of the frame(s) and filter(s) to determine the dry mass of the aggregate.

11.8 When required, transfer the extract to a 1000 ml graduate. Rinse the jar with solvent until clean and add solvent to the extract. Record the total volume. Determine the ash content in the extract as described in Sec 8.6, or as described in the pycnometer method.

12. Calculations

12.1 Calculate the percentage of bitumen as described in Sec 9.2 excluding W4, except when ash is determined, and excluding W5.

12.2 When the total ash in the extract is determined calculate the mass of ash as described in Sec 9.1.

Method C

13. Apparatus

13.1 In addition to the apparatus listed in Sec 3, the following apparatus is required for Method C:

13.1.1 Extraction apparatus, consisting of a metal container, condenser lid, and stand similar to that shown in Figs. 3 and 4.
13.1.2 Basket, for sample as shown in Fig. 3. A 4.75 mm (No. 4) or heavier sieve shall be placed in the basket to support the sample.

13.1.3 Filter cloth, approximately 185 mesh, placed over the 4.75 mm (No. 4) sieve and shaped to completely cover the inside of the basket.

14. Procedure

14.1 Determine the moisture content of the sample in accordance with Sec 6.

14.2 Weigh 3500 to 11,000 g of sample in a basket assembly, tared to the nearest 1 g, and place in the extractor. Pour 1150 to 1250 ml of trichloroethylene or 1,1,1 trichloroethane over the sample.

14.3 Reflux the sample from 1.5 to 3 h until all bitumen is extracted from the aggregate. Shut down the extractor after 1.5 h and inspect the sample. Mix the sample with a trowel and continue extraction to completion (Note 7).

Note 7: The sample is completely extracted when, upon inspection, no discoloration is found either on the aggregate or on the surface of the trowel used to mix the sample.

14.4 Drain the extract from the extractor and wash clean with fresh solvent. Combine the extract and the washings in a 2000 ml graduate. Remove the sample basket, dry in air and then to constant mass on a hot plate at 110 ± 5 C. Determine the ash content in the recovered bitumen as described in Sec 8.6.

15. Calculation

15.1 Calculate the total mass of ash as described in Sec 9.1.

15.2 Calculate the percentage of bitumen as described in Sec 9.2, excluding Ws.

Method D

16. Apparatus

16.1 In addition to the apparatus listed in Sec 3, the following apparatus is required for Method D:

16.1.1 Extraction apparatus, as illustrated in Fig. 5, consisting of an extraction kettle of metal or borosilicate glass, fitted with a perforated basket and condenser top. The underside of the condenser shall be covered with numerous rounded knobs to distribute the condensed solvent uniformly over the surface of the sample. The suspension of the basket shall be arranged to support the basket 12.5 mm (or ½ in.) above the bottom of the kettle, for immersion of the sample in the solvent, and 100 mm (or 4 in.) above the bottom of the kettle for refluxing.

16.1.2 Cloth filter sacks, with an elastic hem for lining the basket.

17. Procedure

17.1 Determine the moisture content of the sample in accordance with Sec 6.

17.2 Insert a filter sack in the extraction basket and weigh these with the tare pan to determine the total tare mass. Weigh into the filter sack approximately a 500 g representative portion of the paving mixture if the maximum aggregate size is less than 12.5 mm (½ in.). For larger size aggregate, use approximately a 1000 g sample.

17.3 Attach the suspension rod to the loaded basket and set the assembly into the extraction kettle. Pour approximately 600 ml of trichloroethylene or 1,1,1 trichloroethane over the sample. Set the condenser cover in place on the kettle. Provide a flow of cold water through the condenser lid. Raise the basket to immersion level, 12.5 mm (1/2 in.) above the bottom of the kettle, for immersion of the sample in the solvent, and 100 mm (or 4 in.) above the bottom of the kettle for refluxing.

17.4 Continue heating with the sample in the immersion position for 15 to 30 minutes and then raise the basket to refluxing level. Increase the heat and maintain active boiling until solvent dripping from the basket appears light straw in color when viewed against a white background. If a stainless steel kettle is used, lift out the basket and the condenser cover assembly for examination of the solvent.

17.5 Remove the extractor from the hot plate and allow to cool for several minutes. Lift out the basket and condenser assembly. Cover the kettle. Remove the filter sack, distribute its contents in the tared pan in which the sample was originally weighed. Place the filter sack and basket on top of the recovered aggregate. Dry on a steam bath and then in an oven at 110 ± 5 C to constant mass. Transfer the extract to a 1000 ml graduate. Wash extractor clean with solvent and add the washings to the extract. Determine the mineral matter in the extract as described in Sec 8.6.

18. Calculations

18.1 Calculate the total mass of mineral matter as described in Sec 9.1.

18.2 Calculate the percentage of bitumen as described in Sec 9.2, excluding Ws.
Method E

19. Apparatus

19.1 In addition to the apparatus listed in Sec 3, with the exception of items 3.8 and 3.10, the following apparatus is required for Method E.

19.1.1 Vacuum extractor, complete with vacuum pump, gasket, rubber tubing, filter paper support plate, and funnel ring, essentially as shown in Fig. 6 (Note 8).

Note 8: Since the piston-type vacuum pump has required excessive time to complete vacuuming, a vane-type vacuum pump is recommended for general use.

19.1.2 Filter paper, medium grade, fast filtering, 330 mm in diameter.
19.1.3 Sample container, approximately 3800 ml (or 4 qt) capacity or greater.
19.1.4 Flasks, two, 4000 ml capacity.
19.1.5 Dial thermometer, 10 to 115 C.
19.1.6 Mixing spoon, approximately 300 mm (or 12 in.) long.
19.1.7 Spatula, approximately 230 mm (or 9 in.) long.
19.1.8 Spatula, approximately 230 mm (or 9 in.) long.
19.1.9 Stiff bristled brush 25 mm (1 in.) wide.
19.1.10 Watchglass, 100 mm (or 4 in.) diameter.
19.1.11 Metal tongs 150 to 200 mm (6 to 8 in.) long.

20. Reagents

20.1 In addition to the reagents specified in Sec 4, the following reagents are recommended:

20.1.1 Methylene chloride, technical grade (Note 9).

Note 9: Provide suitable means for adequate ventilation. Avoid inhalation of vapors. Vent exhaust from the vacuum pump to the outside. Drain the vacuum pump daily. The maximum acceptable concentration of methylene chloride for an 8 h exposure is 500 ppm.

20.1.2 Reagents, as listed in Sec 4.
20.1.3 Diatomaceous silica filtering aid, conforming to ASTM D 604, Diatomaceous Silica Pigment, Type B (not required for fast filtering mixes).

21. Procedure

21.1 Determine the amount of sample required according to Sec 5. Weigh the sample into the tared sample container.

21.2 If the sample temperature is above 93 C, cool to a temperature less than 93 C. The ideal temperature for testing is approximately 60 C. When sufficiently cool, carefully pour 200 ml of solvent over the sample in small amounts to minimize boiling. Add approximately 700 ml of methylene chloride and stir until the bitumen is visually in solution (Notes 10 and 11).

Note 10: If an ultrasonic cleaner is used, prepare the sample in accordance with Sec 21.2, except use the insert tray as the sample container. Fill the tank of the ultrasonic cleaner with water to a level that will approximately match the level of the specimen and solvent in the insert tray. Add approximately 10 ml of wetting agent (such as a dishwashing detergent) to the water in the tank. Place the tray in the cleaner tank and operate the cleaner until all bitumen is in solution.

Note 11: Any of the solvents listed in Sec 4 may be substituted for methylene chloride.

21.3 Place a dry, tared filter paper on the vacuum extractor, taking care to center the filter on the funnel ring, and tighten the wing nuts finger tight.

21.4 When required, weigh approximately 50 g (or 0.1 lb) (record exact mass) of oven dried diatomaceous silica filtering aid (which passes a 0.075 mm (No. 200) sieve) into a 1000 ml flask. Add 500 ml of methylene chloride and swirl until the filtering aid is completely in suspension. Immediately pour the filtering aid solution onto the filter. Start the vacuum pump and let it run until the pad formed by the filtering aid is surface dry and begins to crack slightly.

21.5 When using the filtering aid, place the watchglass on the filter and gently pour the solution from the sample container over it. When the filtering aid is not required, the solution may be poured directly on the filter. Stop the vacuum when all of the solution has been removed.

21.6 Add another 700 ml of methylene chloride to the sample container and stir. Start the ultrasonic cleaner if used. If the watchglass is used, gently pour the solution over it into the extractor.
21.7 Repeat the step in Sec 21.6 until the solution is a light straw color and the aggregate is visually clean. After the last wash, remove the watchglass from the extractor with tongs and wash clinging aggregate particles back into the extractor with the wash bottle. Gently pour the entire sample into the extractor and thoroughly rinse all aggregate particles from the sample container and spoon into the extractor. Carefully spread the aggregate evenly over the filter with the spatula.

21.8 Start the vacuum pump and let it run for a few minutes to expedite drying of the aggregate. Scrape the aggregate away from the side of the funnel ring toward the center of the filter to prevent loss when the ring is removed (Note 12).

Note 12: Instead of the decantation procedure described in Sec 21.5 through Sec 21.8, removal of the bitumen may be accomplished satisfactorily by initially washing the entire contents of the container into the extractor and adding additional washes directly into the extractor.

21.9 Remove the funnel ring and brush any clinging aggregate into the tared drying pan. Carefully pick up the filter paper and aggregate and transfer the aggregate to the drying pan. Brush the aggregate clinging to the filter paper into the pan, then fold the filter and place it in the pan.

21.10 Dry the extracted aggregate and filter to a constant mass (Sec 8.5, Note 4) in an oven at 110 ± 5 C or on a hot plate. When drying on a hot plate stir the sample occasionally and do not heat the sample to a temperature exceeding 60 C. When a moisture correction is required according to Sec 6, aggregate dried on a hot plate to remove the reagent shall be further dried in an oven at 110 ± 5 C to remove the moisture. A moisture correction is not normally required when the sample is heated to temperatures of 60 C or less.

22. Calculations

22.1 Calculate the net mass of the extracted aggregate, W3, by subtracting the mass of the filtering aid when used.

22.2 Calculate the percentage of bitumen, as described in Sec 9.2 excluding W4 and W5 (Note 13).

Note 13: When the extracted aggregate is used for sieve analysis by MRDTM 204, subtract the mass of the filtering aid from the quantity passing the 0.075 mm (No. 200) sieve determined by MRDTM 204.

23. Scope

23.1 As an alternate method to that given in Sec 8.6 for determining the amount of mineral matter in the extract liquid, the following may be used.

24. Apparatus

24.1 Glass bitumenometer, 750 ml and 1500 ml, with stopper and stopper cover.

24.2 Thermostatically controlled water bath capable of maintaining temperature 251 C.

24.3 Balance, 3-5 kg capacity, graduated in 0.1 g increments.

24.4 Thermometer for water bath accurate to 0.1 C. Thermometers accurate to 0.1 C for determining temperature of extract in bitumenometers.

25. Procedure

25.1 Calibrate volume of stoppered bitumenometers using water at 25 C.

25.2 Determine the specific gravity of trichloroethylene. The nominal range for specific gravity of trichloroethylene is 1.454 to 1.457.

25.3 Determine the specific gravity of the asphalt used (MRDTM 407) if unknown.

25.4 Weigh the glass bitumenometer(s) with stopper and cover to the nearest 0.1 g and record.

25.5 Pour the total extract from the extraction container into one or more bitumenometers. Wash the container with trichloroethylene assuring all extract material is placed in the bitumenometer(s). Care should be used in amount of wash solvent so that material can be contained in bitumenometer(s) intended for use. Adjust the volume of material in the bitumenometer(s) to near full condition using extract or trichloroethylene as necessary.

25.6 Place bitumenometer(s) in water bath and bring temperature of extract to a constant 25 C.

25.7 Fill bitumenometer(s) with trichloroethylene to calibrated stoppered full condition. Replace stopper cover and weigh to nearest 0.19.

26. Calculations

26.1 Determine volume of trichloroethylene in the extract from materials in the bitumenometer less the extraction loss from the extraction test.

26.2 Determine the bitumen equivalent which is the difference between the volume of bitumenometer less volume of solvent divided by the bitumen specific gravity.

26.3 Determine aggregate equivalent which is the mass of the extraction loss less the bitumen equivalent.
26.4 The mass of filler in extracted liquid equals the aggregate equivalent adjusted for the weighted average specific gravities of the mineral materials passing through the filter paper.

27. Report

27.1 Record the test results on Form Nos. MRDWS 418A and/or 418B as appropriate.
Fig. 1. Extraction Unit Bowl

<table>
<thead>
<tr>
<th>Metric Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mm</strong></td>
</tr>
<tr>
<td>4.0</td>
</tr>
<tr>
<td>4.8</td>
</tr>
<tr>
<td>5.6</td>
</tr>
<tr>
<td>6.4</td>
</tr>
<tr>
<td>7.9</td>
</tr>
<tr>
<td>9.5</td>
</tr>
<tr>
<td>15.9</td>
</tr>
</tbody>
</table>
Fig. 2. Bituminous Extractor
Fig. 3. Extractor Unit

Metric Equivalents

<table>
<thead>
<tr>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>(3/8)</td>
<td>44.4</td>
<td>(1 3/4)</td>
<td>152.4</td>
<td>(6)</td>
</tr>
<tr>
<td>12.7</td>
<td>(1/2)</td>
<td>76.2</td>
<td>(3)</td>
<td>254.0</td>
<td>(10)</td>
</tr>
<tr>
<td>19.0</td>
<td>(3/4)</td>
<td>95.2</td>
<td>(3 3/4)</td>
<td>304.8</td>
<td>(12)</td>
</tr>
<tr>
<td>25.4</td>
<td>(1)</td>
<td>101.6</td>
<td>(4)</td>
<td>355.6</td>
<td>(14)</td>
</tr>
<tr>
<td>38.1</td>
<td>(1 1/2)</td>
<td>127.0</td>
<td>(5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Stand Made from 1” x 1” x 1/8” Angle Iron

Front Legs Fixed with Single Pin to Allow Legs to Fold Back when Draining the Extractor

Fig. 4. Stand for Extractor Unit

Metric Equivalents

<table>
<thead>
<tr>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>(1/8)</td>
<td>63.5</td>
<td>(2 1/2)</td>
</tr>
<tr>
<td>25.4</td>
<td>(1)</td>
<td>368.3</td>
<td>(14 1/2)</td>
</tr>
</tbody>
</table>
Fig. 5. Extractor Unit

### Metric Equivalents

<table>
<thead>
<tr>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
<th>mm</th>
<th>(in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>1/8</td>
<td>47.6</td>
<td>1 7/8</td>
<td>155.6</td>
<td>6 1/8</td>
</tr>
<tr>
<td>9.5</td>
<td>3/8</td>
<td>58.7</td>
<td>2 5/16</td>
<td>158.8</td>
<td>6 1/4</td>
</tr>
<tr>
<td>12.7</td>
<td>1/2</td>
<td>60.3</td>
<td>2 3/8</td>
<td>165.1</td>
<td>6 1/2</td>
</tr>
<tr>
<td>25.4</td>
<td>1</td>
<td>71.4</td>
<td>2 13/16</td>
<td>187.3</td>
<td>7 3/8</td>
</tr>
<tr>
<td>41.3</td>
<td>1 5/8</td>
<td>88.9</td>
<td>3 1/2</td>
<td>257.2</td>
<td>10 1/8</td>
</tr>
<tr>
<td>42.9</td>
<td>1 11/16</td>
<td>138.1</td>
<td>5 7/16</td>
<td>304.8</td>
<td>12</td>
</tr>
</tbody>
</table>
Fig. 6(a). Vacuum Extractor

Fig. 6(b). Vacuum Extractor

Table of Contents
**Quantitative Extraction of Asphalt from Asphalt Paving Mixtures**

**FIELD SAMPLE NO:** 2  
**LAB SAMPLE NO:** 82-2422  
**PROJECT:** KCI 2-05  
**ROAD NO:** 202-203  
**ROAD NAME:** Damam - Ras Tanura

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Sample Mass, $W_1$</td>
<td>g</td>
</tr>
<tr>
<td>Percent Moisture (MRDTM 416)</td>
<td>%</td>
</tr>
<tr>
<td>Moisture Content, $W_m = A - W_1$</td>
<td>g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral Matter in Extract (Ash Content)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of Total Extract, $V_t$</td>
<td>ml</td>
</tr>
<tr>
<td>B Tare Mass of Ignition Dish</td>
<td>g</td>
</tr>
<tr>
<td>D Mass of Ignition Dish and Ash,</td>
<td>g</td>
</tr>
<tr>
<td>Volume of Extract after Removing 100 ml Aliquot, $V_{e} = V_t - 100$</td>
<td>ml</td>
</tr>
<tr>
<td>Mass of Mineral Matter in 100 ml Aliquot, $M_m = D - B$</td>
<td>g</td>
</tr>
<tr>
<td>Total Mineral Matter in Extract (Ash Content), $W_e = M_m / V_e$</td>
<td>g</td>
</tr>
</tbody>
</table>

### Bitumen Content of Dry Sample

<table>
<thead>
<tr>
<th>Method A</th>
<th>Method B</th>
<th>Method C</th>
</tr>
</thead>
<tbody>
<tr>
<td>E Mass of Dry Filter Ring,</td>
<td>g</td>
<td>24</td>
</tr>
<tr>
<td>Dry Mass of Extracted Mineral Matter, $W_{m} = G - F$</td>
<td>g</td>
<td>1400</td>
</tr>
<tr>
<td>G Mass of Filter Ring with Mineral Matter</td>
<td>g</td>
<td>26</td>
</tr>
<tr>
<td>Increase In Mass of Filter Ring,</td>
<td>g</td>
<td>2</td>
</tr>
<tr>
<td>H Bitumen Content of Dry Sample, Percent* $\frac{(W_i - W_j) - (W_i + W_j + W_k)}{(W_i - W_j)} \times 100$</td>
<td>%</td>
<td>5.7</td>
</tr>
<tr>
<td>Method B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I Mass of Dry Filter Paper(s) and Frame(s),</td>
<td>g</td>
<td>1245</td>
</tr>
<tr>
<td>J Tare Pan Mass,</td>
<td>g</td>
<td>240</td>
</tr>
<tr>
<td>K Dry Mass of Filter Paper(s) and Frame(s), Extracted Aggregate and Tared Pan,</td>
<td>g</td>
<td>2951</td>
</tr>
<tr>
<td>Mass of Extracted Aggregate, $W_{m} = K - (I + J)$</td>
<td>g</td>
<td>1440</td>
</tr>
<tr>
<td>Total Mineral Matter in Extract (Ash Content), $W_t$</td>
<td>g</td>
<td>5.0</td>
</tr>
<tr>
<td>L Bitumen Content of Dry Sample, Percent* $\frac{(W_i - W_j) - (W_i + W_j + W_k)}{(W_i - W_j)} \times 100$</td>
<td>%</td>
<td>5.8</td>
</tr>
<tr>
<td>Method C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Tare Mass of Basket Assembly,</td>
<td>g</td>
<td>1060</td>
</tr>
<tr>
<td>N Mass of Mineral Matter and Basket Assembly After Extraction,</td>
<td>g</td>
<td>2501</td>
</tr>
<tr>
<td>O Bitumen Content of Dry Sample, Percent* $\frac{(W_i - W_j) - (W_i + W_j + W_k)}{(W_i - W_j)} \times 100$</td>
<td>%</td>
<td>5.7</td>
</tr>
</tbody>
</table>

### Other Tests to be Conducted on Extracted Asphalt?

- [ ] Yes  
- [ ] No Tests

### Other Tests to be Conducted on Extracted Mineral Matter?

- [ ] Yes  
- [ ] No Tests

**NOTE:** *Record on MRDTM 400-B Line 1.

**CHECKED BY:** T. Williams  
**TITLE:** Lab Supervisor  
**DATE:** 5/18/82

**MATERIALS ENGINEER:** J. Smith  
**(CONSULTANT)**

**RESIDENT ENGINEER:** R. White  
**(CONTRACTOR)**

**DISTRIBUTION:**
- [X] CONTRACTOR
- [X] MINISTRY
- [ ] OTHER (Specify)

**FORM NO:** MRDWS 418A
# Aggregate Loss Correction by Bituminometer Method

**FIELD SAMPLE NO.** 2  
**LAB SAMPLE NO.** 62-2422  
**PROJECT** FeP 285  
**DATE SAMPLD.** 5/1/82  
**DATE RECEIVED** 5/1/82  
**DATE TESTED** 5/1/82  
**SAMPLED BY** Y. Taha  
**TESTED BY** F. Manroppal  
**TITLES**  
- Project Inspector  
- Lab Technician  
**MATERIAL** Bit. Wear Crs class A  
**QUANTITY REPRESENTED** 500 T  

## Bitumenometer Calibration

- **A.** Mass of Bitumenometer Filled with Water @ 25°C.  
  - **g = 1001.2**

- **B.** Mass of Bitumenometer,  
  - **g = 247.8**

- **C.** Mass of Water (A - B),  
  - **g = 753.4**

- **D.** Density of Water @ 25°C.  
  - **g/cm³ = 0.997077**

- **E.** Volume of Bitumenometer = \( \frac{g}{D} \).  
  - **cm³ = 751.2**

## Specific Gravity of Solvent

- **F.** Mass of Bitumenometer Filled with Solvent @ 25°C.  
  - **g = 1340.8**

- **G.** Mass of Bitumenometer (B),  
  - **g = 247.8**

- **H.** Mass of Solvent (F - B),  
  - **g = 1093.0**

- **I.** Specific Gravity of Solvent = \( \frac{G}{H} \).  
  - **= 1.455**

## Aggregate Correction

- **I.** Specific Gravity of bitumen (from MRDTM 407)  
  - **= 1.615**

- **J.** Mass of original mix Sample  
  - **g = 1001.5**

- **K.** Mass of Extracted Aggregate  
  - **g = 935.3**

- **L.** Mass of Extraction Loss (J - K)  
  - **g = 66.2**

- **M.** Mass of Bitumenometer and Extracted Liquid @ 25°C  
  - **g = 1381.4**

- **N.** Mass of Bitumenometer (B),  
  - **g = 247.8**

- **O.** Mass of Extracted Liquid (M - N),  
  - **g = 1073.6**

- **P.** Mass of Extracted Aggregate (K),  
  - **g = 66.2**

- **Q.** Mass of Solvent (N - K),  
  - **g = 1008.4**

- **R.** Volume of Solvent (J)  
  - **cm³ = 693.2**

- **S.** Volume of Bitumenometer (E)  
  - **cm³ = 751.2**

- **T.** Volume of Solvent (P)  
  - **cm³ = 693.2**

- **U.** Volume of Extraction Loss (E - P),  
  - **cm³ = 58.0**

- **V.** Bitumen Equivalent (IXD)  
  - **g = 58.9**

- **W.** Mass of Extraction Loss (L),  
  - **g = 62.2**

- **X.** Bitumen Equivalent (RI)  
  - **g = 58.0**

- **Y.** Aggregate Equivalent IL - Ri,  
  - **g = 8.3**

- **Z.** Mass of Aggregate in Extraction Liquid (correction) = \( \frac{X}{770} \).  
  - **g = 57.6**

## Remarks:

- 

**CHECKED BY:** T. Williams  
**TITLE** Lab Supervisor  
**DATE** 5/1/82  
**MATERIALS ENGINEER** J. Smith  
**CONSULTANT** R. White  
**CONTRACTOR**  
**RESIDENT ENGINEER** J. Dunbar  
**DISTRIBUTION:**  
- ✗ CONTRACTOR  
- ✗ RESIDENT ENGINEER  
- ❏ MINISTRY  
- ❏ OTHER (Specify)  

Form No: MRDWS 418 B
1. Scope
1.1 This method of test covers a procedure for the determination of the particle size distribution of fine and coarse aggregates extracted from bituminous mixtures, using sieves with square openings.

2. Apparatus
2.1 The apparatus shall consist of the following:
2.1.1 Balance-A balance conforming to MRDTM 102, Class D for samples less than 5000 g and Class E for samples 5000 g or more.
2.1.2 Sieves-The sieves with square openings shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The woven wire cloth sieves shall conform to the requirements of MRDTM 101, Sieves for Testing Purposes.

3. Sample
3.1 The sample shall consist of the entire lot or sample of aggregate determined according to MRDTM 418, Quantitative Extraction of Asphalt from Asphalt Paving Mixtures, from which the asphalt material has been extracted.

4. Procedure
4.1 The sample shall be dried until further drying at 110 ± 5 C does not alter the mass by more than 0.1 percent, the precision of weighing. The total mass of aggregate in the asphalt mixture being tested is the sum of the masses of the dried aggregates and the mineral matter contained in the extracted asphalt. The latter is to be taken as the sum of the mass of ash in the extract and the increase in mass of the filter element as determined in MRDTM 418.
4.2 The test sample after being dried and weighed shall be placed in a container and covered with water. When water is used add a sufficient amount of wetting agent to assure a thorough separation of the material finer than the 0.075 mm (No. 200) sieve from the coarser particles. The contents of the container shall be agitated vigorously and the wash water immediately poured over the nest of two sieves consisting of a 2.00 or 1.18 mm (No. 10 or 16) sieve superimposed on a 0.075 mm (No. 200) sieve. The use of a large spoon to stir and agitate the aggregate in the wash water has been found satisfactory.

Note 1: Wetting agents may include any dispersing agent such as Calgon, Joy, or other detergent, or a soap, which will promote the separation of fine material.
4.3 The agitation shall be sufficiently vigorous to result in the complete separation from the coarse particles of all particles finer than the 0.075 mm (No. 200) sieve and bring them into suspension in order that they may be removed by decantation of the wash water. Care shall be taken to avoid, as much as possible, the decantation of the coarse particles of the sample. The operation shall be repeated until the wash water is clear.
4.4 All material retained on the nested sieves shall be returned to the container. The washed aggregate in the container shall be dried to constant mass at a temperature of 110 ± 5 C and weighed to the nearest 0.1 percent.
4.5 The aggregate shall then be sieved over sieves of the various sizes required by the specification covering the mixture, including the 0.075 mm (No. 200) sieve. The mass of material passing each sieve and retained on the next sieves shall be recorded. The amount passing the 0.075 mm (No. 200) sieve shall be recorded. The summation of the various masses must check with the dried mass after washing within 0.2 percent of the total mass. The mass of dried material passing the 0.075 mm (No. 200) sieve by dry sieving shall be added to the mass of mineral matter in the asphalt and the mass removed by washing in order to obtain the total passing the 0.075 mm (No. 200) sieve. If it is desired to check the mass of material washed through the 0.075 mm (No. 200) sieve, the wash water may be evaporated to dryness or filtered through a tared filter paper which is subsequently dried and weighed. The mass of fractions retained on the various sieves and the total passing the 0.075 mm (No. 200) sieve shall be converted to percentages by dividing each by the total mass of aggregate in the asphalt mixture from Sec 4.1.
5. Report

5.1 The results of the sieve analysis shall be reported as total percentages passing each sieve. Percentages shall be reported to the nearest whole number except for the percentage passing the 0.075 mm (No. 200) sieve which shall be reported to the nearest 0.1 percent. The analysis results shall be recorded and calculated on Form No. MRDWS 204. The final results shall be recorded on Form No. MRDTR 400 B.
1. Scope

1.1 This method covers the procedure for the determination of flash points by the tag open cup apparatus of cutback asphalts having flash points of less than 93.3 °C.

1.2 The flash point indicates the temperature to which the material may be safely heated without danger of instantaneous flash in the presence of an open flame. The flash point of rapid curing and medium curing asphalts is measured by the Tag Open Cup Test. Equipment and procedures used for flash point determination are to allow for indirect heating of the sample as the flash point is below 93.3 °C (Note 1).

Note 1: Specifications commonly designate the Cleveland Open Cup method for asphalt cements and cutback asphalts having flash points above 79.5 °C.

2. Outline of Method

2.1 The sample is placed in the tester and heated at a slow and constant rate. A small test flame is passed at a uniform rate in a level plane across the cup at specified intervals. The flash point is the lowest temperature at which application of the test flame causes the vapor at the surface of the liquid to flash.

3. Apparatus

3.1 Tag Open Cup Tester-This apparatus consists of a glass test cup, copper water bath, thermometer holder, small gas burner, ignition taper, liquid leveling device and draft shield. The apparatus is described in additional detail in the Appendix.

3.2 Thermometer-A Pensky Martens, low range thermometer -5 to 100 °C and conforming to the requirements for Thermometer 9 °C as prescribed in ASTM E 1.

4. Bath Media

4.1 Water bath for flash points up to 79.5 °C.

4.2 Water-glycol solution (1:1) for flash points above 79.5 °C.

5. Assembly and Preparation of Apparatus

5.1 The tag open cup tester shall be placed in a firm and level position on a solid vibration free table. The location shall be free of perceptible draft and the top of the tester shall be shielded from strong light, so that the flash may be easily seen. A room temperature of 25 ± 5 °C should be maintained throughout the test.

5.2 Adjust the horizontal and vertical positions of the ignition taper so that the jet passes on the circumference of a circle having a radius of 152 mm (or 6 in.) and in a level plane 3.2 mm above the upper edge of the cup as measured from the center of the orifice. The jet should pass across the center of the cup. These adjustments should be made only when required, as usually the apparatus is used continuously for a series of tests (Note 2).

Note 2: The filling level gauge is also used as a gauge to adjust the height of the taper.

6. Procedure

6.1 Place the glass test cup in the metal bath and adjust the thermometer holder so that the thermometer is supported firmly in a vertical position halfway between the center and edge of the cup and on a line passing through the center of the cup and the pivot of the taper. Place the thermometer so that the bottom of the bulb is 6.4 mm (or 1/4 in.) above the inner bottom of the cup.

6.2 Fill the metal bath with water, (for samples with anticipated flash points below 79.5 °C, or water glycol solution (for samples with anticipated flash points between 79.5 and 93.3 °C, at a temperature at least 16.5 °C below the probable flash point of the material to be tested. Cool tap water is satisfactory in most instances when water is used, and may be introduced into the chamber between the bath and sample cups until a slight overflow is noted at the overflow spout. The bath should be filled to a level approximately 3.2 mm (or 1/8 in.) from the top of the bath when the test cup is in place.
6.3 Rest the metal filling level gauge on the rim of the cup and fill the cup with material to be tested until the level just touches the pointers of the gauge, this should be approximately 3.2 mm (or 1/8 in.) below the rim of the cup.

**Note 3:** The test sample should be at least 10 °C below the anticipated flash point.

6.4 Light the ignition taper and adjust the test flame to approximately the same size as the comparison bead or the reference hole in the leveling gauge but in no case greater than 4 mm (5/32 in.).

6.5 Apply heat to the bath so that the temperature of the sample rises at the rate of 1 ± 0.3 °C per minute.

6.6 At 10 to 15 °C below the anticipated flash point, adjust the sample level in the test cup. A syringe or medicine dropper provides a convenient means of removing sample from the cup. At successive 1 °C intervals, pass the ignition taper across the sample in a continuous motion so that the time used for each pass is 1 s. Each pass must be in one direction only and the taper should be kept in the “off” position at one or the other end of the swing except when the flame is applied to the sample.

6.7 Record, as the flash point, the temperature read on the thermometer at the time the test flame application causes a distinct flash in the interior of the test cup.

7. **Report**

7.1 Report the lowest temperature, in degrees Celsius, at which the first or initial flash is noted as the Tag Open Cup Flash Point.

---

**Appendix**

**Apparatus**

A.1 The tag open cup tester is shown in Fig. 1. It consists of the following parts, which must conform to the dimensions shown, and have the additional characteristics as noted:

A.1.1 Copper bath, equipped with a constant level overflow so placed as to maintain the bath liquid level 3.2 mm (1/8 in.) below the ridge of the glass cup.

A.1.2 Thermometer holder, supplied with the tester as shown in Fig. 1. It shall support the thermometer firmly in a vertical position.

A.1.3. Glass test cup as shown in Fig. 2, of molded clear glass, annealed, heat resistant, and free from surface defects.

A.1.4 Filling level gauge, for proper adjustment of the liquid level in the cup shown in Fig. 3. This shall be made of suitable metal at least 3.2 mm (1/8 in.) thick, with two projections for adjusting the liquid level in the glass cup to 3.18 ± 0.05 mm (0.125 ± 0.01 in.) below the top edge or rim of the cup. Also, the holes in the leveling gauge may be used to adjust the size of the test flame and for gauging the height of the taper above the edge of the cup.

A.1.5 "Micro" or small gas burner, of suitable dimensions for heating the bath. A screw clamp may be used to help regulate the gas. A small electric heater controlled by a variable power transformer may be used.

A.1.6 Ignition taper, which is a small, straight, blow pipe type gas burner. The tip of the taper should be approximately 1.6 mm (1/16 in.) in diameter. The ignition taper should be maintained in a fixed horizontal plane above the test cup by means of a swivel device so that the test flame passes on the circumference of a circle having a radius of at least 150 mm (or 6 in.). A comparison bead 4.0 mm (5/32 in.) in diameter may be mounted in a convenient spot. If mounted on the ignition taper, a portion of the tip of the taper 1.6 mm (1/16 in.) in diameter shall extend at least 3 mm (or 1/8 in.) beyond the bead.

A.1.7 The apparatus shall be protected from drafts by a draft free fume hood or a suitable shield. Such a shield might consist of two rectangular sheets of noncombustible material, 610 by 710 mm (or 24 by 28 in.), fastened together along the 710 mm (or 28 in.) side, preferably by hinges. A triangular sheet, 610 by 610 by 860 mm (24 by 24 by 34 in.), is fastened by hinges to one of the lateral sheets to form a top when the shield is open. The interior of the draft shield shall be painted a flat black.
Fig. 1. Tag Open-Cup Flash Tester.
Fig. 2. Glass Test Cup

Fig. 3. Filling Level Gauge
1. Scope
   1.1 This standard is concerned with the method of measuring viscosity by Saybolt Universal Viscometer at temperatures ranging from 20 C to 98.8 C.

2. Definition
   2.1 Saybolt Universal Viscosity is the efflux time in seconds of 60 ml of the sample flowing through a calibrated standard orifice under specified conditions.

3. Apparatus
   3.1 Saybolt Universal Viscometer shall consist of the following main parts:
      3.1.1 The viscometer made of corrosion resistant and rust proof metal; the dimensions of which are defined according to those indicated in Fig. 1. Its lower standard tip shall be replaceable as shown in Fig. 2.
      3.1.2 Water bath surrounding the viscometer and equipped with a thermometer.
      3.1.3 Withdrawal tube, Fig. 3.
      3.1.4 Receiving flask of 60 ml capacity, Fig. 4.
      3.1.5 Stop watch graduated to one tenth of a second and is accurate within 0.1% when tested over a 60 minutes interval. Also accurate electric timers can be used.
      3.1.6 Viscosity thermometers.

   3.2 Preparation of Apparatus.
      3.2.1 Before using, clean the apparatus with an effective non-toxic solvent. Put the apparatus away from air drafts and rapid changes in temperature. Keep the sample away from dust or vapours during the test period. Viscosity determinations shall not be made at temperatures below the dew point of the room's temperature.
      3.2.2 Keep room temperature between 20 C - 30 C so that the sample shall not be subjected to great differences in temperature.
      3.2.3 Fill the bath water to a level higher by 6 mm above the overflow of the viscometer. Water may be replaced by other solvents indicated in Table 1.
      3.2.4 The bath liquid shall be adequately stirred while regarding accurately the change in temperature so that it does not change to more than 0.03 C after reaching the test temperature.

<table>
<thead>
<tr>
<th>Temperature, C</th>
<th>Bath Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.1</td>
<td>Water</td>
</tr>
<tr>
<td>25.0</td>
<td>Water or oil of viscosity 50-70 SUS at 37.8 C</td>
</tr>
<tr>
<td>37.8</td>
<td>Water or oil of viscosity 120-150 SUS at 37.8 C</td>
</tr>
<tr>
<td>50.0</td>
<td>Water or oil of viscosity 330-370 SUS at 37.8 C</td>
</tr>
<tr>
<td>54.4</td>
<td>Oil of viscosity 330-370 SUS at 37.8 C</td>
</tr>
</tbody>
</table>

4. Calibration of Viscometer
   4.1 Calibrate the viscometer at periodic intervals by measuring the efflux time at 37.8 C of a standard oil with known viscosity, by following the procedures shown in this standard.
4.2 If the time of the standard oil efflux differs from the certified value by more than 0.2%, then use the following correcting formula:

\[ F = \frac{v}{t} \]

where:
\( F \) = correcting factor,
\( v \) = certified viscosity of the standard, and
\( t \) = efflux time of the standard oil determined by the apparatus at 37.8 C.

4.2.1 This correcting factor may be applied to all viscosity levels and for all temperatures provided that calibration is based on a viscosity standard between 200-600 SUS at 37.8 C.

4.3 Viscometers or orifices, which have differences more than 1% between the efflux time of the standard oil and its certified viscosity, shall not be used for refree testing.

5. Procedure
5.1 If the temperature of the test is higher than the room temperature raise the sample temperature one degree above the temperature of the test, taking care not to heat the sample to a temperature higher than 10 C above its flash point as volatility losses may alter its composition.

5.2 Insert a cork stopper, with a cord attached to it for easy removal, at the bottom of the viscometer.

5.3 Pass the sample through a fine mesh screen and receive it directly in the viscometer until the level is above the overflow rim.

5.4 Stir the sample well until its temperature remains constant within 0.03 C of the test temperature during one minute of continuous stirring. Stirring may be done in a circular motion at 30-50 rpm, by the viscometer thermometer found in the oil. Never adjust temperature by immersing hot or cold bodies into the sample, for this may affect the sample and the precision of the test.

5.5 Remove the thermometer from the sample, then quickly remove the oil from the gallery by the withdrawal tube, until its level becomes below the overflow rim. Do not touch the overflow rim with the withdrawal tube.

5.6 Place the receiving flask facing the stream of oil coming from the viscometer, so that this stream touches the neck of the flask.

5.7 Snap the cork quickly from the viscometer using the attached cord. Then start calculating the time consumed since the oil begins to efflux until it reaches the graduation mark on the neck of the flask.

6. Calculation
6.1 Multiply the efflux time by the calibration correcting factor for the viscometer used.

7. Result
7.1 Report the corrected time in seconds at the test temperature. Report the viscosity values below 200 s to the nearest 0.1 s. Report all values of 200 s or higher to the nearest whole s.

8. References
Fig. 1. Saybolt Viscometer with Universal

Fig. 2. Universal Tip

Fig. 3. Withdrawal Tube for Use with Saybolt Viscometer

Fig. 4. Receiving Flask
Standard Method of Test for
Distillation of Cutback Asphalt Materials

MRD Test Method 422
(Adaptation of AASHTO T 78-80)

1. Scope
   1.1 This method covers a distillation test for cutback asphalt (bituminous) materials.

2. Purpose
   2.1 The distillation test is used to determine the relative portions of asphalt and diluent present in RC, MC and SC cutback asphalt materials. It is also used to measure the amount of diluent that distills at various temperatures for RC and MC liquid asphalts, thus denoting their evaporation characteristics. This, in turn, indicates the relative rate at which the material will cure after application. Asphalt recovered in the test may also be used for other tests to characterize the material. For SC materials, the diluent distilled off at only one temperature is measured, rather than at several temperatures. This is because the diluent in SC liquid asphalts is oily in nature and these materials are not intended to cure in the same manner as RC and MC materials.

   2.2 The test is made by placing a specified amount of sample in a distillation flask connected to a condenser. The sample is gradually heated to a specified temperature and the amount of diluent driven off at various temperatures is recorded. After a temperature of 360°C is reached, the amount of asphalt remaining is measured and expressed as a percent by volume of the original sample.

3. Summary of Method
   3.1 Two hundred ml of the sample are distilled in a 500 ml flask at a controlled rate to a temperature in the liquid of 360°C and the volumes of distillate obtained at specified temperatures are measured. The residue from the distillation, and also the distillate may be tested as desired.

4. Significance
   4.1 This procedure measures the amount of the more volatile constituents in cutback asphalt products. The properties of the residue after distillation are not necessarily characteristic of the bitumen used in the original mixture nor of the residue which may be left at any particular time after application of the cutback asphalt materials. The presence of silicone in the cutback may affect the distillation residue by retarding the loss of volatile material after the residue has been poured into the residue container.

5. Apparatus
   5.1 Distillation flask, 500 ml side arm, having the dimensions shown in Fig. 1.
   5.2 A standard glass jacketed condenser, of nominal jacket length from 200 to 300 mm and overall tube length of 450 ± 10 mm as shown in Fig. 3.
   5.3 Adapter, heavy wall (1 mm) glass, with reinforced top, having an angle of approximately 105 degrees. The inside diameter at the large end shall be approximately 18 mm and not less than 5 mm at the small end. The lower surface of the adapter shall be on a smooth descending curve from the larger end to the smaller. The inside line of the outlet end shall be vertical, and the outlet shall be cut or ground (not fire polished) at an angle of 45 ± 5 degrees to the inside line.
   5.4 A 22 gauge sheet metal shield, lined with asbestos 3 mm thick and fitted with suitable transparent heat resistant nondiscoloring windows, of the form and dimensions shown in Fig. 2, used to protect the flask from air currents and to reduce radiation. The cover (top) shall be made in two parts of 6.4 mm (or 1/4 in.) millboard.
   5.5 Shield and Flask Support-Two 150 mm sheets of 1.18 mm nickel-chromel (16 mesh) wire gauze on a tripod or ring.
   5.6 Heat Source-Adjustable tirrill-type gas burner or equivalent.
   5.7 A graduated crow receiver as illustrated in Fig. 4 (Note 1).

   Note 1: Receivers of smaller capacity having 0.1 ml divisions may be used when low volumes of total distillate are expected and the increased accuracy required.

   5.8 Residue Container-A 240 ml (8 oz.) seamless metal container with a slip on cover, 75 ± 5 mm in diameter and 55 ± 5 mm in height (Note 2).
Note 2: Provide a cover suitable in size and material to extinguish a flame in the 240 ml tin box if the residue flames after pouring.

5.9 Thermometer-ASTM Thermometers 8°C conforming to ASTM Specification E 1, or IP Thermometer 6°C conforming to IP Specifications for Standard Thermometers.

5.10 A balance conforming to the requirements of MRDTM 102 for Class D balances.

6. Sampling

6.1 Stir the sample thoroughly, warming if necessary, to ensure homogeneity before removal of a portion for analysis.

6.2 If sufficient water is present to cause foaming, dehydrate a sample of not less than 250 ml by heating in a distillation flask sufficiently large to prevent foaming over into the side arm. When foaming has ceased, stop the distillation. If any light oil has distilled over, separate and pour this back into the flask when the contents have cooled just sufficiently to prevent loss of volatile oil. Mix the contents of the flask thoroughly before removal for analysis.

7. Preparation of Apparatus

7.1 Calculate the mass of 200 ml of the sample from the specific gravity of the material at 15.6°C. Weigh this amount, within ± 0.5 g, into the 500 ml flask.

7.2 Place the flask in the shield supported by two sheets of gauze on a tripod or ring. Connect the condenser tube to the tubulation of the flask with a tight cork joint. Clamp the condenser so that the axis of the bulb of the flask, through the center of its neck, is vertical. Adjust the adapter over the end of the condenser tube so that the distance from the neck of the flask to the outlet of the adapter is 650 ± 50 mm (Fig. 3).

7.3 Insert the thermometer through a tightly fitting cork in the neck of the flask so that the bulb of the thermometer rests on the bottom of the flask. Raise the thermometer 6.4 mm (or 1/4 in.) from the bottom of the flask using the scale divisions on the thermometer to estimate the 6.4 mm (or 1/4 in.) distance above the top of the cork.

7.4 Protect the burner by a suitable shield or chimney. Place the receiver so that the adapter extends at least 25 mm but not below the 100 mm mark. Cover the graduate closely with a piece of blotting paper, or similar material, suitably weighted, which has been cut to fit the adapter snugly.

7.5 The flask, condenser tube, adapter, and receiver shall be clean and dry before starting distillation. Place the 240 ml residue container on its cover in an area free from drafts.

7.6 Pass cold water through the condenser jacket. Use warm water if necessary to prevent formation of solid condensate in the condenser tube.

8. Procedure

8.1 Correct the temperatures to be observed in the distillation if the elevation of the laboratory at which the distillation is made deviates by 150 m (or 500 ft) or more from sea level. Corrected temperatures for the effect of altitude are shown in Table 1. If the prevailing barometric pressure in ml of mercury is known, correct to the nearest 1°C the temperature to be observed with the corrections shown in Table 2. Do not correct for the emergent stem of the thermometer.

8.2 Apply heat so that the first drop of distillate falls from the end of the flask’s sidearm in 5 to 15 minutes. Conduct the distillation in order to maintain the following drop rates, the drop count to be made at the tip of the adapter:

50 to 70 drops per minute to 260°C, 20 to 70 drops per minute between 260 and 316°C, and not over 10 minutes to complete distillation from 316 to 360°C.

8.2.1 Record the volumes of distillate to the nearest 0.5 ml in the receiver at the corrected temperatures. If the volume of distillate recovered is critical, use receivers graduated in 0.1 ml divisions and immersed in a transparent bath maintained at 15.6 ± 3°C (Note 3).

Note 3: Some cutback asphalt materials yield either no distillate or very little distillate over portions of the temperature range to 316°C. In this case it becomes impractical to maintain distillation rates prescribed in Sec 8.2. For such cases, the rate of rise of temperature should exceed 5°C per minute.

8.3 When the temperature reaches the corrected temperature of 360°C, extinguish the flame and remove the flask and thermometer. With the flask in a pouring position, remove the thermometer and immediately pour the contents into the residue container. The total time from cutting off the flame to starting the pour shall not exceed 15 s. When pouring, the sidearm should be substantially horizontal to prevent condensate in the sidearm from being returned to the residue (Note 4).

Note 4: The formation of skin on the surface of a residue during cooling entraps vapors which will condense and cause higher penetration results when they are stirred back into the sample. If skin begins to form during cooling, it should be gently pushed aside. This can be done with a spatula with a minimum of disturbance to the sample.
8.4 Allow the condenser to drain into the receiver and record the total volume of distillate collected as total distillate to 360 °C.

8.5 When the residue has cooled until fuming just ceases, stir thoroughly and pour into the receptacles for testing for properties such as penetration, viscosity, or softening point. Proceed as required by the appropriate MRDTM method from the point that follows the pouring stage.

**Note 5:** The correction factor is to be subtracted in case the barometric pressure is below 760 mm Hg; and is to be added in case the barometric pressure is above 760 mm Hg.

Correction = (Observed Pressure - 760) × Correction per mm

Example:
Barometric Pressure = 748 mm, Nominal Observation Temperature 260 °C,
Celsius Correction = (748 - 760) × 0.0632 = 0.758
Temperature = 260 - 0.758 = 259 °C (rounded to the nearest 1 °C).

**9. Calculations and Report**

9.1 Asphalt Residue-Calculate the percent residue to the nearest 0.1 percent as follows:

\[ R = \frac{200 - TD}{200} \times 100 \]

where:
R = residue content, in volume percent, and
TD = total distillate recovered to 360 °C in ml.

9.1.1 Report as the residue from distillation to 360 °C, percent volume by difference.

9.2 Total Distillate-Calculate the percent total distillate to the nearest 0.1 percent as follows:

\[ TD, \text{ percent} = \frac{TD}{200} \times 100 \]
Table 1
Corrected Fractionation Temperatures for Various Altitudes, C

<table>
<thead>
<tr>
<th>Elevation Above Sea Level, m</th>
<th>Fractionation Temperatures For Various Altitudes, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>-305</td>
<td>192  227  262  318  362</td>
</tr>
<tr>
<td>-152</td>
<td>191  226  261  317  361</td>
</tr>
<tr>
<td>0</td>
<td>190  225  260  316  360</td>
</tr>
<tr>
<td>152</td>
<td>189  224  259  315  359</td>
</tr>
<tr>
<td>305</td>
<td>189  224  258  314  358</td>
</tr>
<tr>
<td>457</td>
<td>188  223  258  313  357</td>
</tr>
<tr>
<td>610</td>
<td>187  222  257  312  356</td>
</tr>
<tr>
<td>762</td>
<td>186  221  256  312  355</td>
</tr>
<tr>
<td>914</td>
<td>186  220  255  311  354</td>
</tr>
<tr>
<td>1067</td>
<td>185  220  254  310  353</td>
</tr>
<tr>
<td>1219</td>
<td>184  219  254  309  352</td>
</tr>
<tr>
<td>1372</td>
<td>184  218  253  308  351</td>
</tr>
<tr>
<td>1524</td>
<td>183  218  252  307  350</td>
</tr>
<tr>
<td>1676</td>
<td>182  217  251  306  349</td>
</tr>
<tr>
<td>1829</td>
<td>182  216  250  305  349</td>
</tr>
<tr>
<td>1981</td>
<td>181  215  250  305  348</td>
</tr>
<tr>
<td>2134</td>
<td>180  215  249  304  347</td>
</tr>
<tr>
<td>2286</td>
<td>180  214  248  303  346</td>
</tr>
<tr>
<td>2438</td>
<td>179  213  248  302  345</td>
</tr>
</tbody>
</table>

Table 2
Factors for Calculating Temperature Corrections

<table>
<thead>
<tr>
<th>Nominal Temperatures, C</th>
<th>Corrections (Note 5) per 10 mm Difference in Pressure, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>0.514</td>
</tr>
<tr>
<td>175</td>
<td>0.531</td>
</tr>
<tr>
<td>190</td>
<td>0.549</td>
</tr>
<tr>
<td>225</td>
<td>0.591</td>
</tr>
<tr>
<td>250</td>
<td>0.620</td>
</tr>
<tr>
<td>260</td>
<td>0.632</td>
</tr>
<tr>
<td>275</td>
<td>0.650</td>
</tr>
<tr>
<td>300</td>
<td>0.680</td>
</tr>
<tr>
<td>315</td>
<td>0.698</td>
</tr>
<tr>
<td>325</td>
<td>0.709</td>
</tr>
<tr>
<td>360</td>
<td>0.751</td>
</tr>
</tbody>
</table>
9.2.1 Report as the total distillate to 360 °C, volume percent.

9.3 Distillate Fractions:

9.3.1 Determine the volume percentages of the original sample by dividing the observed volume (in ml) of the fraction by 2. Report to the nearest 0.1 percent as the volume percent as follows:

Up to 190 °C
Up to 225 °C
Up to 260 °C
Up to 316 °C

9.3.2 Determine the volume percentages of total distillate by dividing the observed volume in ml by the total distillate in ml to 360 °C and multiply by 100. Report to the nearest 0.1 percent as the distillate, volume percent of total distillate to 360 °C as follows:

Up to 190 °C
Up to 225 °C
Up to 260 °C
Up to 316 °C

9.4 Report test results on Form No. MRDWS 422 (Note 6).

**Note 6:** Where penetration, viscosity, or other tests have been carried out, report with reference to this method as well as to any other method used. Example: Penetration (MRDTM 404) of residue from MRDTM 422.
Fig. 3. Distillation Apparatus

All Dimensions are in Millimeters.

Fig. 4. Crow Receivers of Capacity 25, 50 and 100 ml
Distillation of Cut-Back Asphalt Materials

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>82-2421</td>
<td>FCP 285</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Sampled By</th>
<th>Date Tested</th>
<th>Tested By</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/5/82</td>
<td>5/7/82</td>
<td>Y. Taha</td>
<td>5/10/82</td>
<td>P. Mankupah</td>
<td>Inspector</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Title</th>
<th>Quantity Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC-3</td>
<td>Lab Technician</td>
<td>26 T</td>
</tr>
</tbody>
</table>

| Distillation Temperature, C | 0.190 | 0.225 | 0.260 | 0.316 | 0.360 |

| Distillation Temperature Corrected For Elevation, C (See Table 1) Elev. 1050 m | 1.85 | 2.20 | 2.54 | 3.10 | 3.53 |

| Distillation Temperature Correction For Barometric Pressure, C (See Table 2) = (Pressure – 760) x (Correction/10ml) / 10 | 1.85 | 2.20 | 2.54 | 3.10 | 3.53 |

| Volume of Total Distillate Fractions to 316 C, ml | 0 | 8 | 14 | 40 | |

| Distillation Test Temperature, C (Line B or A + C) | 1.85 | 2.20 | 2.54 | 3.10 | 3.53 |

| Volume of Total Distillate to 360 C, ml (For RC or MC Materials) | – | – | – | – | 5.0 |

| Volume Percent of Total Distillate to 360 C, TD x 100 | – | – | – | – | 2.5 |

| Residue Content, Volume Percent to 360 C, (200 – TD) / 200 x 100 | – | – | – | – | 7.5 |

| Volume Percent of Distillate Fractions of Original Sample, D / 2 | 0 | 4 | 8 | 20 | 25 |

| Distillate, Volume Percent of Total Distillate to 360 C, D / TD x 100 | 0 | 16 | 32 | 80 | 100 |

### Tests On Residue

<table>
<thead>
<tr>
<th>Test Name</th>
<th>MRD TM</th>
<th>Units</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration of Residue</td>
<td>404</td>
<td>0.10 mm</td>
<td>155</td>
</tr>
<tr>
<td>Ductility of Residue</td>
<td>405</td>
<td>cm</td>
<td>125</td>
</tr>
<tr>
<td>Softening Point of Residue</td>
<td>406</td>
<td>C</td>
<td>–</td>
</tr>
<tr>
<td>Saybolt Viscosity of Residue</td>
<td>421</td>
<td>s</td>
<td>–</td>
</tr>
<tr>
<td>Kinematic Viscosity of Residue</td>
<td>408</td>
<td>Cst</td>
<td>–</td>
</tr>
<tr>
<td>Solubility in CCl₄</td>
<td>402</td>
<td>%</td>
<td>99.7</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE**: Record on MRDTR 400 A, Lines 10 through 24

**Remarks:**

---

**CHECKED BY**: T. Williams, Title: Lab Supervisor, Date: 5/11/82

**MATERIALS ENGINEER**: J. Smith

**CONSULTANT**: R. White

**CONTRACTOR**: J. Oumba

**DISTRIBUTION**: ☑ CONTRACTOR ☑ MINISTRY ☑ RESIDENT ENGINEER ☑ OTHER (Specify):
1. Scope

1.1 This method describes a simplified procedure to determine the Flakiness Index and Average Least Dimension of Aggregates. The sieve analysis shall be carried out by the method described in Sec 2 through 4. The Flakiness Index shall be determined by the method described in Sec 5 through 7. The Average Least Dimension shall be determined from Fig. 3.

2. Procedure

2.1 A surface dry sample shall be weighed and the distribution of particle sizes obtained by means of sieves with square openings, using the method prescribed in MRD TM 204. The minimum mass of sample for sieving is summarized in Table 1.

<table>
<thead>
<tr>
<th>Nominal Size</th>
<th>Minimum Mass of Sample, G</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 (1)</td>
<td>10,000</td>
</tr>
<tr>
<td>19 (¾)</td>
<td>5,000</td>
</tr>
<tr>
<td>12.5 (½)</td>
<td>2,500</td>
</tr>
</tbody>
</table>

2.2 After sieving, weigh the material retained on each sieve on a balance sensitive to 0.1 percent of the mass of the test sample. This mass is recorded and the mass passing each sieve is expressed as a percentage of the total mass of the sample.

3. Report

3.1 Results are reported to the nearest 1 percent, and plotted on the grading curve as illustrated in Fig. 1.

4. Median Size

4.1 The median size is that theoretical sieve in mm (in.) through which 50 percent of the material will pass. The median size may be obtained from Fig. 1.

5. Example

5.1 The material used in this example shall consist of all aggregate used in the sieve analysis that falls within the size ranges specified for surface treatments in the General Specifications for Road and Bridge Construction and summarized in Table 2.
### Table 2

**Nominal Aggregate Sizes**

<table>
<thead>
<tr>
<th>Material Class</th>
<th>Nominal Range or Sizes</th>
<th>Passing</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Bituminous Surface Treatment CMA 12.5 (1/2)</td>
<td>12.5 (1/2)</td>
<td>2.36 No. 8</td>
<td></td>
</tr>
<tr>
<td>CMA-1 12.5 (1/2)</td>
<td>12.5 (1/2)</td>
<td>2.36 No. 8</td>
<td></td>
</tr>
<tr>
<td>Double Bituminous Surface Treatment First Course 19 (3/4)</td>
<td>19 (3/4)</td>
<td>4.75 No. 4</td>
<td></td>
</tr>
<tr>
<td>Second Course 12.5 (1/2)</td>
<td>12.5 (1/2)</td>
<td>2.00 No. 10</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3

**Sizes of Slots for Each Aggregate Fraction**

<table>
<thead>
<tr>
<th>Size of Material</th>
<th>Passing (mm)</th>
<th>Retained (mm)</th>
<th>Slot Width (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(alternate)</td>
<td>(alternate)</td>
<td>(alternate)</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>19.0 (3/4 in.)</td>
<td>13.3 (0.525 in.)</td>
<td></td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>12.5 (1/2 in.)</td>
<td>9.5 (0.375 in.)</td>
<td></td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>9.5 (3/8 in.)</td>
<td>6.7 (0.263 in.)</td>
<td></td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>6.3 (1/4 in.)</td>
<td>4.7 (0.184 in.)</td>
<td></td>
</tr>
<tr>
<td>6.3 (1/4 in.)</td>
<td>4.75 (No. 4)</td>
<td>3.3 (0.131 in.)</td>
<td></td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>2.36 (No. 8)</td>
<td>1.8 (0.070 in.)</td>
<td></td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>2.00 (No. 10)</td>
<td>1.5 (0.059 in.)</td>
<td></td>
</tr>
</tbody>
</table>

### 6. Procedure

6.1 Each fraction of material, as shown in Table 2 shall be tested particle by particle for its ability to pass through an appropriate slotted sieve (British Standards Institution 812), or a gauge made by filing an elongated slot of the required width in a sheet of metal at least 1.5mm (1/16 in.) thick. The size of slots required for each fraction is given in Table 3 and illustrated in Fig 2.

### Table 3

**Sizes of Slots for Each Aggregate Fraction**

<table>
<thead>
<tr>
<th>Size of Material</th>
<th>Passing (Mm)</th>
<th>Retained (Mm)</th>
<th>Slot Width (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(alternate)</td>
<td>(alternate)</td>
<td>(alternate)</td>
</tr>
<tr>
<td>25.0 (1 in.)</td>
<td>19.0 (3/4 in.)</td>
<td>13.3 (0.525 in.)</td>
<td></td>
</tr>
<tr>
<td>19.0 (3/4 in.)</td>
<td>12.5 (1/2 in.)</td>
<td>9.5 (0.375 in.)</td>
<td></td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>9.5 (3/8 in.)</td>
<td>6.7 (0.263 in.)</td>
<td></td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>6.3 (1/4 in.)</td>
<td>4.7 (0.184 in.)</td>
<td></td>
</tr>
<tr>
<td>6.3 (1/4 in.)</td>
<td>4.75 (No. 4)</td>
<td>3.3 (0.131 in.)</td>
<td></td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>2.36 (No. 8)</td>
<td>1.8 (0.070 in.)</td>
<td></td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>2.00 (No. 10)</td>
<td>1.5 (0.059 in.)</td>
<td></td>
</tr>
</tbody>
</table>

6.2 The total amount passing the appropriate slotted sieve openings shall be weighed to an accuracy of at least 0.1 percent of the mass of the test sample.

### 7. Determination of Flakiness Index

7.1 The Flakiness Index is the total mass of the material passing the appropriate slotted sieve openings expressed as a percentage of the combined mass of the fractions tested on the sieve.

### 8. Example

8.1 Sieve analysis as follows:
Total Mass of Dry Sample = 10,000 g
The material is a double bituminous surface treatment, first course from Table 2; Fig. 1; the median size is 16 mm (or 0.63 in.).

8.2 Flakiness Index is determined as follows:

<table>
<thead>
<tr>
<th>Material Size</th>
<th>Width of Slotted Sieve</th>
<th>Total Mass, g</th>
<th>Mass Retained on Slotted Sieve, g</th>
<th>Mass Passing Slotted Sieve, g</th>
<th>Flakiness Index, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0-19.0 (1-3/4 in.)</td>
<td>13.3 (0.525)</td>
<td>2080</td>
<td>1500</td>
<td>580</td>
<td></td>
</tr>
<tr>
<td>19.0-12.5 (3/4-1/2 in.)</td>
<td>9.5 (0.375)</td>
<td>6610</td>
<td>4800</td>
<td>1810</td>
<td></td>
</tr>
<tr>
<td>12.5-9.5 (1/2-3/8 in.)</td>
<td>6.7 (0.263)</td>
<td>500</td>
<td>350</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>9.5-6.3 (3/8-1/4 in.)</td>
<td>4.7 (0.184)</td>
<td>370</td>
<td>210</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>6.3-4.75 (1/4 in.-No. 4)</td>
<td>3.3 (0.131)</td>
<td>300</td>
<td>190</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9860</strong></td>
<td><strong>7050</strong></td>
<td><strong>2810</strong></td>
<td><strong>28.5</strong></td>
<td></td>
</tr>
</tbody>
</table>

8.3 Average Least Dimension

8.3.1 On Fig. 3, proceed horizontally from the median size on the vertical axis to the diagonal line representing the Flakiness Index for the sample. From this point of intersection, proceed vertically to the horizontal axis and read off the Average Least Dimension.

8.3.2 For this particular aggregate sample, the median size is 16 mm (0.63 in.), and the Flakiness Index is 33 percent. The broken line on Fig. 3 indicates that the Average Least Dimension (ALD) of this sample is 10.5 mm (0.41 in.), reading to the nearest 0.25 mm (0.01 in.).

9. Report

9.1 Record test results on Form No. MRDWS 423.
Fig. 1. Median Size of Aggregate

25.4 - 19.0 mm  19.0 - 12.7 mm  12.7 - 9.5 mm  9.5 - 6.3 mm  6.3 - 4.75 mm  4.75 - 2.36 mm  4.75 - 2.00 mm
1 - 3/4 in.     3/4 - 1/2 in.     1/2 - 3/8 in.     3/8 - 1/4 in.     1/4 in.     No. 4     No. 4 - No. 8     No. 4 - No. 10

Fig. 2. Slotted Sieve Openings for Testing Aggregates for Elongated Flat Particles
Average Least Dimension in Inches

Median Size – U.S. Standard, Millimeters

Flexibility Index

Average Least Dimension in Millimeters

Median Size – U.S. Square Sieves, Inch

Fig. 3. Chart for Determining Average Least Dimension of Aggregate
Flakiness Index and Average Least Dimension of Cover Aggregates

<table>
<thead>
<tr>
<th>FIELD SAMPLE NO.</th>
<th>LAB SAMPLE NO.</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>B2-2430</td>
<td>FCP 285</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DATE SAMPLED</th>
<th>DATE RECEIVED</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/5/82</td>
<td>5/7/82</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAMPLED BY</th>
<th>TESTED BY</th>
<th>ROAD NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y. Taha</td>
<td>F. Mann-Figah</td>
<td>202-203</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TITLE</th>
<th>DATE</th>
<th>QUANTITY REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proj. Inspector</td>
<td>5/9/82</td>
<td>750 J</td>
</tr>
<tr>
<td>Lab Technician</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mass of Sample (See Table 1) for Sieve Analysis (MRDTM 204), g. Recorded on MRDWS 204.

![Grading Chart]

Median Size of Aggregate, mm: 140

Flakiness Index

<table>
<thead>
<tr>
<th>Material Class</th>
<th>Nominal Range or Sizes (Table 2)</th>
<th>Passed</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off B.F Surf Tnt</td>
<td></td>
<td>19</td>
<td>14.75</td>
</tr>
<tr>
<td>Final Course</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Size</th>
<th>Slotted Sieve Width</th>
<th>Total Mass</th>
<th>Mass Retained on Slotted Sieve</th>
<th>Mass Passing Slotted Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>mm</td>
<td>g</td>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>25.0-19.0</td>
<td>13.3</td>
<td>2080</td>
<td>1500</td>
<td>580</td>
</tr>
<tr>
<td>19.0-12.5</td>
<td>2.5</td>
<td>4610</td>
<td>4800</td>
<td>1810</td>
</tr>
<tr>
<td>12.5-9.5</td>
<td>6.7</td>
<td>500</td>
<td>350</td>
<td>150</td>
</tr>
<tr>
<td>9.5-6.3</td>
<td>4.7</td>
<td>370</td>
<td>210</td>
<td>160</td>
</tr>
<tr>
<td>6.3-3.75</td>
<td>3.3</td>
<td>300</td>
<td>190</td>
<td>110</td>
</tr>
<tr>
<td>Totals</td>
<td>9860</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Flakiness Index = \( \frac{D}{B} \times 100 \) = 28.5 \%

Average Least Dimension = 10.8 mm

CHECKED BY: J. Williams
MATERIALS ENGINEER: J. Smith
CONSULTANT: R. White

RESIDENT ENGINEER: J. Dunbar

DISTRIBUTION: 
CONTRACTOR
RESIDENT ENGINEER
MINISTRY
OTHER (Specify)
Kingdom of Saudi Arabia  
Ministry of Communications  
Materials and Research Department

Standard Method of Test for
Testing Emulsified Asphalt

MRD Test Method 424
(Adaptation of AASHTO T 59-78)

1. Scope
1.1 The methods given under the headings titled Composition, Consistency, Stability, and Examination of Residue cover the examination of emulsified asphalts composed principally of a semisolid or liquid asphalt base, water, and an emulsifying agent. The methods cover the following tests:

<table>
<thead>
<tr>
<th>Test</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition:</td>
<td></td>
</tr>
<tr>
<td>Water Content</td>
<td>2 to 5</td>
</tr>
<tr>
<td>Residue by Distillation</td>
<td>6 to 7</td>
</tr>
<tr>
<td>Identification of Oil Distillate</td>
<td></td>
</tr>
<tr>
<td>by Micro-Distillation</td>
<td>8 to 10</td>
</tr>
<tr>
<td>Residue by Evaporation</td>
<td>11 to 14</td>
</tr>
<tr>
<td>Particle Charge of Emulsified Asphalts</td>
<td>15 to 17</td>
</tr>
<tr>
<td>Consistency:</td>
<td></td>
</tr>
<tr>
<td>Viscosity (Saybolt Furol)</td>
<td>18 to 19</td>
</tr>
<tr>
<td>Stability:</td>
<td></td>
</tr>
<tr>
<td>Demulsibility</td>
<td>20 to 22</td>
</tr>
<tr>
<td>Settlement</td>
<td>23 to 25</td>
</tr>
<tr>
<td>Cement Mixing</td>
<td>26 to 29</td>
</tr>
<tr>
<td>Sieve Test</td>
<td>30 to 32</td>
</tr>
<tr>
<td>Coating</td>
<td>33 to 34</td>
</tr>
<tr>
<td>Miscibility with Water</td>
<td>35</td>
</tr>
<tr>
<td>Modified Miscibility with Water</td>
<td>36 to 39</td>
</tr>
<tr>
<td>Freezing</td>
<td>40</td>
</tr>
<tr>
<td>Coating Ability and Water</td>
<td></td>
</tr>
<tr>
<td>Resistance</td>
<td>41 to 46</td>
</tr>
<tr>
<td>Storage Stability of Emulsified Asphalt</td>
<td>47 to 52</td>
</tr>
<tr>
<td>Examination of Residue</td>
<td>53 to 57</td>
</tr>
</tbody>
</table>

Water Content

2. Apparatus and Materials
2.1 Metal Still-The metal still, Fig. l(a), shall be a vertical cylindrical vessel, preferably of copper, having a faced flange at the top to which the head is tightly attached by means of a clamp. The head shall be made of metal, preferably brass or copper, and shall be provided with a tubulation 25.4 mm (1 in.) in inside diameter.

2.2 Glass Still-The glass still, Fig. l(b), shall be a short neck, round bottom flask, made of well annealed glass, and having an approximate capacity of 500 ml.

2.3 Heat Source-The heat source used with the metal still shall be a ring gas burner of 100 mm (or 4 in.) inside diameter. The heat source for the glass still shall be either a Bunsen or similar-type gas burner or an electric heater.

2.4 Condenser-The condenser shall be a water cooled reflux glass tube type, having a jacket not less than 400 mm (or 15¾ in.) in length, with an inner tube 9.5 to 12.7 mm (or 3/8 to 1/2 in.) in outside diameter. The end of the condenser shall be ground to an angle of 30 ± 5 degrees from the vertical axis of the condenser.

2.5 Trap-The trap shall be made of annealed glass constructed in accordance with Fig. l(c) and shall be graduated in 0.1 ml divisions from 0 to 1 ml, and in 0.2 ml divisions from 1 to 25 ml.

2.6 Solvent-Xylene or other petroleum distillate with 98 percent distillation between 120 and 250 C.
3. Sample

3.1 Obtain a representative sample of the material for test.

4. Procedure

4.1 When the material to be tested contains less than 25 percent water, place 100 ± 0.1 g of sample in the still. When the material contains more than 25 percent water, use a 50 ± 0.1 g sample. Thoroughly mix the sample to be tested with an equal volume of solvent by swirling, taking proper care to avoid any loss of material.

4.2 Connect the still, trap, and condenser by means of tight-fitting corks as shown in Fig. 1 (a) or 1 (b). When using the metal still, insert a heavy paper gasket, moistened with solvent, between the lid and flange before attaching the clamp. Insert a loose cotton plug in the top of the condenser tube to prevent condensation of atmospheric moisture.

4.3 Place the ring burner used with the metal still about 75 mm (or 3 in.) above the bottom of the still at the beginning of the distillation, and gradually lower it as the distillation proceeds. Regulate the heat so that the condensate falls from the end of the condenser at a rate of from 2 to 5 drops/s. Continue the distillation at the specified rate until no water is visible on any part of the apparatus and a constant volume of water is obtained in the trap. Remove any persistent ring of condensed water in the condenser tube by increasing the rate of distillation for a few minutes.

5. Calculation and Report

5.1 Calculate the water content as follows:

\[
\text{Water Content, } \% = \frac{A}{B} \times 100
\]

where:

A = volume of water in trap, ml, and
B = original mass of sample, g.

5.2 Report the result as water mass percent (Water Content), MRDTR 400-C, Line 1.

6. Apparatus

6.1 Aluminum alloy still Fig. 2, approximately 240 mm (or 9½ in.) in height by 95 mm (or 3¾ in.) inside diameter with one 127.0 mm (or 5 in.) ring burner having holes on the inner periphery to fit around the outside of the still.

6.2 Connecting apparatus, consisting of a connecting tube, tin shield, a water cooled condenser of West or Liebig type with a borosilicate glass or metal jacket and a suitable adapter between the condenser and a 100 ml graduated cylinder, all with dimensions as shown in Fig. 3.

6.3 Thermometer-Two ASTM Low Distillation Thermometers, having a range from -2 to 300 C and conforming to the requirements for Thermometer 7 C as prescribed in ASTM Specification E 1.

6.4 Balance conforming to the requirements of MRDTM 102, Class D.

7. Procedure

7.1 Weigh 200 ± 0.1 g of a representative sample of the emulsion in the previously weighed aluminum alloy still, (including lid, clamp, thermometers and gasket, if gasket is used).

7.2 A gasket of oiled paper or asbestos may be used between the still and its cover, or the joint may be ground to a tight fit. Securely clamp the cover on the still.

7.3 Insert a thermometer through a cork, in each of the small holes provided in the cover. Adjust these thermometers so that the end of the bulb of one is 6.4 mm (or 3/8 in.) from the bottom of the still and the bulb of the other is approximately 165 mm (or 6½ in.) from the bottom of the still.

7.4 Place the ring burner around the still about 150 mm (or 6 in.) from the bottom of the still. Apply heat by lighting this burner and adjusting to low flame. Also apply just enough heat from a bunsen burner to the connecting tube to prevent condensation of water in the tube.

7.5 Move the ring burner approximately level with the bottom when the temperature can be read on the lower thermometer, approximately 215 C. Increase the temperature to 260 ± 5 C maintaining it at this temperature for 15 minutes. The total distillation should be completed in 60 ± 15 minutes from the first application of heat (Note 1).

Note 1: The location of the burner at the start of the test is flexible. It may be raised to decrease chance of foam-over or lowered to the middle of the still for emulsion containing no solvent. A change in temperature reading of upper thermometer indicates foam on the bulb. Remove heat until foaming ceases.
7.6 Immediately at the expiration of the heating period, again weigh the still and accessories as described in Sec 7.1. Calculate and report the percentage residue by distillation. Record the volume of oil distillate to the nearest 1/2 ml. Calculate and report the oil distillate as a volume percentage on the total emulsion. Save this oil distillate if identification is desired (Note 2).

**Note 2:** The aluminum alloy still at room temperature, Sec 7.1, weighs 1.5 g more than at 260°C. Correct for this error by adding 1.5 g to the gross mass obtained in Sec 7.6 prior to calculating the percentage of residue by distillation.

\[
\text{Residue, } \% \text{ by (distillation)} = \frac{B}{A} \times 100
\]

where:
A = mass of emulsion before distillation, g, and
B = mass of residue after distillation, g.

7.7 Remove the cover from the still, stir, and immediately pour suitable portions of the residue through a 0.300 mm (No. 50) sieve into a 240 ml (8 oz) tin or into suitable molds and containers for making the required tests. Permit the residue in the molds and containers to cool, uncovered, to room temperature, and thereafter test as described in Sec 52 to 56, Examination of Residue.

**Identification of Oil Distillate by Micro Distillation**

8. **Apparatus**

8.1 Apparatus shall be in accordance with AASHTO T 115 with the following exceptions:
8.1.1 Flask, 10 ml.
8.1.2 Graduated cylinder, 10 ml, graduation interval 0.10 ml.
8.1.3 Condenser, borosilicate glass, 100 mm jacket.

9. **Procedure**

9.1 Redistill a 10 ml sample of the oil distillate under prescribed conditions of AASHTO T 115 using Group 2 Test Conditions in Table 1 with the following exceptions:

| Diameter of hole in flask support, mm (in.) | 19(0.75) |
| Temperature at start of test: |
| Flask and thermometer, not above ambient |
| Graduate and 10 ml charge, not above ambient |

10. **Calculations and Reporting**

10.1 Calculations and reporting shall be in accordance with AASHTO T 115 where applicable (Note 3).

**Note 3:** Better identificaticxi of the solvent contained in the emulsion is possible if a large condenser is used with ice water for the cooling medium during the distillation of the emulsion.

**Residue by Evaporation**

11. **Apparatus**

11.1 Glass Beakers-Low form, of 600 ml or 1000 ml capacity made of borosilicate glass. Other suitable containers of optional form having approximately equivalent diameters may be used.
11.2 Glass rods with flame polished ends with approximate dimensions of 6 mm (or 1/4 in.) diameter and 178 mm (or 7 in.) length.
11.3 Balance, conforming to the requirements of MRDTM 102, Class C.
11.4 Oven, thermostatically controlled, capable of maintaining a temperature of 163°C.
11.5 Sieve-A 0.300 mm (No. 50) sieve conforming to MRDTM 101, Sieves for Testing Purposes.

12. **Procedure A**

12.1 Procedure A shall be used when determination of the percentage of residue only is required.
12.2 Weigh 50 ± 0.1 g of thoroughly mixed, emulsified asphalt into each of three beakers, each beaker having previously been weighed with a glass rod. Place the beakers containing the rods and sample in the oven, the temperature of
which has been adjusted to 163 ± 3 °C, for 2 h. At the end of this period, remove each beaker and stir the residue thoroughly. Replace in the oven for 1 h, then remove the beakers from the oven, allow to cool to room temperature, and weigh, with the rods (Note 4).

**Note 4:** Care must be taken to prevent loss of asphalt from the beaker through foaming or spattering or both. For this reason, 1000 ml beakers are recommended. Also, the placing of beakers and emulsion samples in a cold or warm oven and bringing oven and sample up to a temperature of 163 °C together is permissible.

### 13. Calculation and Report

13.1 Calculate the percentage of residue on each beaker as follows:

\[
\text{Residue,} \% = \frac{B}{A} \times 100
\]

where:
- \(A\) mass of emulsified asphalt, g, and
- \(B\) mass of residue after heating, g.

13.2 Report the percentage of residue by evaporation as the average of the three results.

### 14. Procedure B

14.1 Procedure B shall be used when tests on the residue from the emulsion are required.

14.2 Proceed in accordance with Sec 12.2 using four 50 ± 0.1 g samples. After the calculation for percentage of residue, replace the beakers in the oven until the asphalt residue is sufficiently fluid to pass through a 0.300 mm (No. 50) sieve (usually requiring 15 to 30 minutes). Pour the residue through the 0.300 mm (No. 50) sieve into suitable containers and molds for making such tests as desired, as described in Sec 52 to 56.

### 15. Apparatus

15.1 A 12 V direct current source, a milliammeter, and a variable resistor is required.

15.2 Plates (electrodes)-Two stainless steel plates 25 by 100 mm (or 1 by 4 in.), insulated from each other and rigidly held parallel 12.5 mm (or 1/2 in.) apart.

15.3 Beaker, 150 or 250 ml.

### 16. Procedure

16.1 Pour the emulsion to be tested into the 150 or 250 ml beaker to a height that will allow the electrodes to be immersed approximately 25 mm (or 1 in.) in the emulsion.

16.2 Connect the electrodes, which have been cleaned and dried, to the current source and insert them into the emulsion approximately 25 mm (or 1 in.).

16.3 Adjust the current to at least 8 mA with the variable resistor and start timing with a suitable timing device.

16.4 When the current has dropped to 2 mA, or at the end of 30 minutes, whichever occurs first, disconnect the current source and gently wash the electrodes in running water.

16.5 Observe the asphalt deposit on the electrodes. A cationic emulsion will deposit an appreciable layer of asphalt on the cathode (negative electrode) while the anode (positive electrode) will be relatively clean. This indicates a positive charge.

### 17. Report

17.1 Report the test results in terms of the observed polarity (positive or negative) as defined in Sec 16.5.

### Consistency Test

#### Viscosity

18.1 Viscometer-A Saybolt Furol viscometer conforming to the requirements specified in MRDTM 421, Test for Saybolt Viscosity.

18.2 Sieve-A 0.850 mm (No. 20) sieve.
18.3 Thermometers—ASTM 17 C for tests at 25 C and ASTM No. 19 C for tests at 50 C, conforming with the requirements of ASTM E 1.

18.4 Water bath, capable of maintaining the required testing temperature within the limits specified in Table 2, MRDTM 421.

19. Procedure

19.1 Tests at 25 C—Stir the sample thoroughly without incorporating bubbles and pour 100 to 110 ml (or 3 1/2 oz) into a 120 ml (or 4 oz) bottle and close securely. Place the bottle in the water bath at 25 C for 30 minutes and mix the sample in the bottle by inverting it several times slowly enough to prevent bubble formation. Pour the sample into the viscometer through the 0.850 mm (No. 20) sieve allowing a small portion of flow through the outlet tube to waste. Place the cork in position, fill the viscometer until the liquid begins to over flow the over flow rim and, without disturbing the sample in any manner, determine the viscosity as prescribed in Sec 7.6 and 7.7 of MRDTM 421.

19.2 Tests at 50 C—Clean and dry the viscometer and insert the cork. Stir the sample thoroughly without incorporating bubbles, and then pour approximately 100 ml into a 400 ml glass beaker. Immerse the bottom of the beaker containing the emulsion approximately 50 mm (or 2 in.) below the level of a 71 ± 3 C water bath. Hold the beaker upright and stir the emulsion with a wide circular motion at a rate of 60 rpm with the thermometer to obtain uniform temperature distribution. Avoid incorporation of bubbles. Heat the emulsion in the water bath to 51.4 ± 0.3 C. Immediately pour the emulsion through the 0.850 mm (No. 20) sieve into the viscometer until it is above the overflow rim. Stir the emulsion in the viscometer at 60 rpm with the thermometer until the temperature is attained, avoiding bubble formation. Adjust the bath temperature until the emulsion temperature remains constant for 1 minute at 50 ± 0.05 C. Withdraw the thermometer. Quickly remove the excess emulsion from the gallery with a suction pipet. Determine the viscosity as described in MRDTM 421. Report the results to the nearest full s.

Note 5: While the Saybolt Furol viscometer is not used for petroleum products and lubricants when the time of flow is less than 25 s, this instrument is satisfactory for testing emulsified asphalt when the time of flow is not less than 20 s.

Stability Tests
Demulsibility

20. Apparatus and Reagents

20.1 Wire Cloth—Three pieces of 1.40 mm (No. 14) wire cloth 125 mm (or 5 in.) square, unframed, having wire diameters and openings which conform to MRDTM 10 1.

20.2 Beakers—Three beakers of 600 ml capacity each.

20.3 Rods—Three metal rods with rounded ends, approximately 8 mm (or 5/16 in.) in diameter.

20.4 Buret—A 50 ml glass buret graduated in 0.1 ml intervals.

20.5 Calcium Chloride Solution (1.11 g/liter)—Dissolve 1.11 g of calcium chloride (CaCl2) in distilled water and dilute to 1 liter.

20.6 Calcium Chloride Solution (5.55 g/liter)—Dissolve 5.55 g of calcium chloride (CaCl2) in distilled water and dilute to 1 liter.

20.7 Sodium Diocyl Sulfosuccinate Solution (8.0 g/liter)—Dissolve 8.0 g of Sodium Diocyl Sulfosuccinate in distilled water and dilute to 1 liter, for use with cationic emulsions.

21. Procedure

21.1 Determine the percentage of residue by distillation as described in Sec 7.

21.2 Record the mass of each assembly including beaker, rod, and wire cloth.

21.3 Weigh 100 ± 0.1 g of the emulsified asphalt into each of three 600 ml beakers in the weighed assemblies. Bring the weighed sample of emulsion and the proper reagent to a temperature of 25 ± 0.5 C. Over a period of approximately 120 s, add to each beaker, from a buret, 35 ml of CaCl2 solution (1.11 g/liter) for rapid-setting emulsions or 50 ml of CaCl2 solution (5.55 g/liter) for emulsions other than rapid-setting. While adding the CaCl2 solution stir the contents of the beaker continuously and vigorously, kneading any lumps against the sides of the beaker, to ensure thorough mixing of the reagent with the emulsion. Continue kneading any lumps for an additional 120 s after the addition of the CaCl2 solution (Note 6).

Note 6: When testing cationic emulsions, use 35 ml of dioctyl sodium sulfosuccinate solution (8.0 g/liter) instead of 35 ml CaCl2 solution (1.11 g/liter).

21.4 Decant the mixture of any unbroken emulsion and reagent onto the wire cloth. Rinse the beaker containing the sample and metal rod with distilled water. Knead and break up all lumps, and continue washing the beaker, rod, and wire cloth until the wash water drains clear. Place the wire cloth enclosing the asphalt in the beaker with the metal rod. Place the assembly in an oven at 163 ± 3 C and dry to constant mass. Preliminary heating at lower temperatures to prevent spattering is permissible.
22. Calculation
22.1 Subtract the tare mass of the beaker, rod, and wire cloth from the mass of the dried assembly to obtain the mass of the demulsibility residue. Calculate the demulsibility as follows:

Demulsibility, % = \( \frac{C}{D} \times 100 \)

where:
C = average mass of demulsibility residue from three tests of each sample of emulsified asphalt, g, and
D = mass of residue by distillation in 100 g of the emulsified asphalt.

or

Demulsibility, % = \( \frac{C \times A}{B} \times 100 \)

where:
C = average mass of demulsibility residue from three tests of each sample of emulsified asphalt, g, and
A and B are as defined in Sec 7.6.

Settlement

23. Apparatus
23.1 Cylinder—Two 500 ml glass cylinders, with pressed or molded glass bases and cork or glass stoppers, having an outside diameter of 50 ± 5 mm, and having 5 ml graduations.
23.2 Glass Pipet—A syphon and 60 ml pipet of optional form.

24. Procedure
24.1 Place a 500 ml representative sample in each of the two glass cylinders. Stopper the cylinders and allow them to stand undisturbed at laboratory air temperature, for 5 days. After standing for this period, remove approximately the top 55 ml of emulsion by means of the pipet or siphon without disturbing the balance. Mix each portion thoroughly. Weigh 50 g of each sample into separate tared 600 ml low form glass beakers, and determine the asphalt residue by evaporation in accordance with Sec 11 and 12.

24.2 After removal of the top sample, siphon approximately the next 390 ml from each of the cylinders. Thoroughly mix the emulsion remaining in the cylinders and weigh 50 g into separate tared 600 ml low form beakers. Determine the asphalt residue of these samples in accordance with Sec 11 and 12.

25. Calculation
25.1 Calculate settlement from the average of three tests as follows:

Settlement, % (5 days) = \( \left( \frac{B_b}{A_B} - \frac{B_t}{A_t} \right) \times 100 \)

where:
A_B = mass of emulsified asphalt drawn off of bottom of the cylinder before evaporating for residue, g,
B_B = mass of residue for sample drawn off of the bottom of the cylinder, g,
A_t = mass of emulsified asphalt drawn off of the top of the cylinder before evaporating for residue, g, and
B_t = mass of residue for sample drawn off of the top of the cylinder, g.

Cement Mixing

26. Apparatus
26.1 Sieve—A 0.180 mm (No. 80) sieve and a 76.2 mm (3 in.) diameter 1.40 mm (No. 14) sieve, made of wire cloth conforming to MRDTM 101.
26.2 Mixing Bowl—Glass or metal of approximately 500 ml capacity.
26.3 Stirring Rod—A steel rod with rounded ends, approximately 12.7 mm (or 1/2 in.) in diameter.
26.4 Graduate—A 100 ml graduated cylinder.
26.5 Balance, conforming to the requirement of MRDTM 102, Class C.

27. Cement
   27.1 Portland cement having a minimum specific surface area of 3450 cm$^2$/g.

28. Procedure
   28.1 Dilute the emulsion with distilled water to a residue of 55 percent, as determined by distillation or by evaporation for 3 h at 163 C.
   28.2 Sieve a portion of the cement through the 0.180 mm (No. 80) sieve. Weigh 50 ± 0.1 g of the cement passing the 0.180 mm (No. 80) sieve into an iron dish or saucepan.
   28.3 Bring the ingredients and apparatus to a temperature of approximately 25 C before mixing. Add 100 ml of the diluted emulsion to the cement and stir the mixture at once with the steel rod, using a circular motion at a rate of 60 rpm. At the end of the 1 minute mixing period, add 150 ml of distilled water and continue the stirring for 3 minutes.
   28.4 Pour the mixture through a tared 1.40 mm (No. 14) sieve. Use repeated washing to completely remove material from the mixing bowl. Pour these over the sieve, and rinse the sieve using distilled water held at a height of approximately 150 mm (or 6 in.) until the water is clear. Place the sieve in a tared shallow pan and heat at 163 C and weigh. Repeat the heating and weighing until successive mass measurements differ by no more than 0.1 g.

29. Report
   29.1 Report the mass, g, of the material retained on the sieve and in the pan as the percentage of break in the cement mixing test.

Sieve Test

30. Apparatus and Reagents
   30.1 Sieve-A sieve having a 75 mm (or 3 in.) frame conforming to of MRDTM 101, and having 0.850 mm (No. 20) wire sieve cloth.
   30.2 Pan-A tin box cover or shallow metal pan of appropriate size to fit over the bottom of the standard sieve.
   30.3 Sodium Oleate Solution (2 percent) Dissolve 2 g of pure sodium oleate in distilled water and dilute to 100 ml (Note 6).

Note 6: Replace sodium oleate solution with distilled water in testing cationic emulsions.

   30.4 Balances, conforming to the requirements of MRDTM 102 Class D for weighing the emulsion and MRDTM 102 Class C, for weighing the sieve and residue.

31. Procedure
   31.1 Record the mass of the sieve and pan and wet the wire cloth with the 2 percent sodium oleate solution. Weigh 1 kg of the emulsified asphalt into a suitable container and pour it through the sieve. Wash the container and the residue on the sieve with the sodium oleate solution until the washings run clear. Place the pan under the sieve and heat for 2 h in a 110 ± 5 C drying oven. Cool in a desiccator and weigh the sieve, pan and residue.

32. Calculation
   32.1 Calculate the percentage of sample retained on the sieve as follows:

   \[
   \text{Sample Retained, } \% = \frac{B - A}{C} \times 100
   \]

   where:
   A = mass of sieve and pan, g,
   B = mass of sieve, pan, and residue, g, and
   C = mass of emulsified asphalt poured through the sieve, g.

Coating Test

(This test is applicable only to emulsions containing an asphalt base of semisolid consistency. It is not applicable to the rapid-setting type of emulsions.)
33. Apparatus and Material
   33.1 Sieves-Standard 19.0 mm (3/4 in.) and 6.3 mm (1/4 in.) sieves conforming to MRDTM 101.
   33.2 Spatula-A steel spatula or its equivalent, having a blade approximately 200 mm (or 8 in.) in length.
   33.3 Mixing Bowl-Glass or metal of approximately 500 ml capacity.
   33.4 Stone-A supply of reference stone (hard limestone, trap rock, or other type) which has been washed with water and dried before using. All stone shall pass through the standard 19.0 mm (3/4 in.) sieve and not more than 5 percent shall pass through the 6.3 mm (1/4 in.) sieve. The source of reference stone should be one which is not apt to change.
   33.5 Balance conforming to the requirements of MRDTM 102, Class D.

34. Procedure
   34.1 Weigh 465 ± 1 g of stone into the mixing bowl. Add 35 ± 0.1 g of the emulsion to the stone in the bowl, and mix vigorously with the spatula for 3 minutes.
   34.2 Record whether or not there is appreciable separation of the asphalt base from the water of the emulsion, and whether or not the stone is uniformly and thoroughly coated with the emulsion. The stone is considered thoroughly coated if upon visual inspection, at least 95 percent of the total area of the aggregate is coated with a bituminous film.

Miscibility With Water
   (This test is not applicable to the rapid-setting type of emulsion.)

35. Procedure
   35.1 Gradually add 150 ml of distilled water, with constant stirring, to 50 ml of the emulsion in a 400 ml glass beaker. The temperature should be between 21 and 25 C. Allow the mixture to stand for 2 h; then examine it for any appreciable coagulation of the asphalt content of the emulsion.

Modified Miscibility With Water

36. Apparatus
   36.1 A 50 ml graduated cylinder.
   36.2 A 400 ml Griffin low form glass beaker.
   36.3 Three glass tubes, 7 mm in outside diameter, 5 mm in inside diameter, and 150 mm in length fitted with suitably bored No. 8 corks, adjusted as described in Sec 37. 1.
   36.4 Supporting Strip-A strip of metal or wood, approximately 150 mm in length, 25 mm in width, and 5 mm in thickness, with a hole 10 mm in diameter at the center.
   36.5 Crucibles-Three 15 or 25 ml porcelain crucibles, or three 30 ml beakers of heat resistant glass.
   36.6 A constant temperature oven as described in MRDTM 409.
   36.7 An analytical balance accurate to 0.1 mg, conforming to requirements of MRDTM 102.

37. Assembly of Apparatus
   37.1 Measure 200 ml of distilled water at 20 to 25 C into the 400 ml beaker, place the supporting strip across the top of the beaker. Insert a cork ringed tube through the hole and adjust the position of the cork so that the lower end of the tube is immersed in the water to a depth of 10 mm. Adjust the second tube to a depth of 25 mm. The third tube should be adjusted so that its tip is within 1 to 1.5 mm from the bottom of the beaker.

38. Procedure
   38.1 Measure 50 ml of the emulsion at a temperature of 20 to 25 C into the graduated cylinder and transfer the emulsion to the 400 ml beaker. Wash the graduate with three 50 ml portions of distilled water at 20 to 25 C and add the washings to the beaker. Stir the emulsion and water with a glass rod until uniformly mixed, cover the beaker with a watch glass, and allow the mixture to stand undisturbed for 2 h.
   38.2 Weigh three crucibles or 30 ml beakers, and a watch glass for each, to the nearest 0.1 mg. After the diluted emulsion has stood for 2 h, remove the watch glass and place the supporting strip across the top of the 400 ml beaker. Take a sample of approximately 1 g from the top layer and transfer to one of the crucibles or beakers, using the first or 10 mm depth tube as a pipet. Close the top of the tube with the finger, insert the tube to the proper depth, remove the finger while the emulsion rises in the tube, and then replace the finger on the top of the tube so that when the tube is removed, its contents of emulsion will be pipetted from the beaker. After removal, wipe off the adhering liquid on the outside of the tube with filter paper before transferring the sample to the crucible. Likewise, take samples from the middle and bottom of the diluted emulsion using the second and third tubes, respectively. Cover the crucibles with a watch glass to retard
evaporation. Weigh the crucibles and samples of emulsion. Determine the mass of each of the three samples by difference from their tare mass.

38.3 Remove the watch glasses from the crucibles and place the samples in the oven at 163°C for 2 h, then remove, cool and weigh.

39. Calculation and Report

39.1 Calculate the percentage of asphalt residue in the top, middle, and bottom samples. Report the maximum numerical difference in percentage of asphalt residue between any two of the three samples.

39.1.1 Calculate the percentage of residue in the top sample:

\[
\text{Residue, %} = \frac{C_t - A_t}{B_t - A_t} \times 100
\]

where:
\(A_t\) = tare mass of 30 ml beaker for the sample from the top, g,
\(B_t\) = mass of beaker and diluted emulsion sample from the top, g, and
\(C_t\) = mass of beaker and residue of sample from the top, g.

39.1.2 Calculate the percentage of residue in the middle sample:

\[
\text{Residue, %} = \frac{C_m - A_m}{B_m - A_m} \times 100
\]

where:
\(A_m\) = tare mass of 30 ml beaker for the sample from the middle, g,
\(B_m\) = mass of beaker and diluted emulsion sample from the middle, g, and
\(C_m\) = mass of beaker and residue of sample from the middle, g.

39.1.3 Calculate the percentage of residue in the bottom sample:

\[
\text{Residue, %} = \frac{C_b - A_b}{B_b - A_b} \times 100
\]

where:
\(A_b\) = tare mass of 30 ml beaker for the sample from the bottom, g,
\(B_b\) = mass of beaker and diluted emulsion sample from the bottom, g, and
\(C_b\) = mass of beaker and residue of sample from the bottom, g.

Freezing Test

40. Procedure

40.1 Place approximately 400 g of the emulsion in a clean metal container, such as a 500 ml press top can. 
40.2 Expose the emulsion in the closed container to an air temperature of -17.8°C for 12 (or more) consecutive hours. 
40.3 At the expiration of the freezing period, permit the emulsion to thaw by exposure of the container to ambient temperature. 
40.4 Repeat the freezing and thawing period until the emulsion will have been subjected to three cycles of freezing and thawing. 
40.5 After the third cycle, the emulsion may be homogeneous or may have separated into distinct layers which cannot be rendered homogeneous by stirring at laboratory temperature. 
40.6 Report the results of this test as either "Homogeneous" or "Broken."

Coating Ability and Water Resistance

(This method covers the determination of the ability of an emulsified asphalt to: 1) coat an aggregate thoroughly; 2) withstand a mixing action while remaining as a film on the aggregate; and 3) resist the washing of water after completion of the mixing. The method is primarily intended to aid in the identification of emulsified asphalt suitable for mixing with coarse graded calcareous aggregates. Refer to Note 7 for application of the method to other aggregates.)

41. Apparatus

41.1 Mixing Pan-An enameled kitchen saucepan of approximately 3 liter capacity. 
41.2 Spatula-A steel spatula or its equivalent, having a blade approximately 200 mm (8 in.) in length.
41.3 Sieve-Standard 19.0 mm (3/4 in.) and 4.75 mm (No. 4) sieves conforming to MRDTM 101.
41.4 Constant Head Water Spraying Apparatus-An apparatus for applying tap water at a constant head of 774.7 mm (30.5 in.) (Figs. 4 and 5). The water shall be applied from the apparatus as a low velocity spray.
41.5 Thermometer-A low softening point thermometer having a range of -2 to 80°C and conforming to the requirements of ASTM E 1, Thermometer 15 C.
41.6 Balance conforming to the requirements of MRDTM 102, Class C.
41.7 Pipet, of 10 ml capacity.

42. Materials
42.1 Aggregate-Standard reference aggregate shall be a laboratory washed and air dried limestone aggregate (Note 7) graded to pass the 19.0 mm (3/4 in.) sieve and be retained on the 4.75 mm (No. 4) sieve.

Note 7: Aggregates other than limestone may be used provided calcium carbonate (CaCO₃) is omitted throughout the method. Laboratory washing and air drying shall also be omitted.
42.2 Calcium Carbonate-Chemically pure, precipitated calcium carbonate (CaCO₃) shall be used as dust to be mixed with the standard reference aggregate.
42.3 Water-Tap water of not over 250 ppm CaCO₃, hardness for spraying over the sample.

43. Sample
43.1 The sample shall be representative of the asphalt emulsion to be tested.

44. Procedure for Tests With Dry Aggregate
44.1 Carry out the test at 23.9 ± 5.5°C.
44.2 Weigh 461 ± 1 g of the air dried, graded reference aggregate in the mixing pan.
44.3 Weigh 4.0 g of CaCO₃ dust in the mixing pan and mix the 461 g of aggregate for approximately 1 minute by means of a mixing blade to obtain a uniform film of dust on the aggregate particles (Note 8).

Note 8: The total mass of aggregate and dust shall equal 465 g. If no calcium carbonate is included, the mass of aggregate alone shall be 465 g.
44.4 Weigh 35 ± 0.1 g of emulsified asphalt into the aggregate in the pan and mix vigorously with the spatula for 5 minutes using a tossing action created by a back-and-forth motion in an elliptical path of the spatula. At the end of the mixing period, tilt the pan and permit any excess emulsion not on the aggregate to drain from the pan.
44.5 Remove approximately one-half of the mixture from the pan and place it on an absorbent paper and evaluate the coating.
44.6 Immediately spray the mixture remaining in the pan gently with tap water from the constant head water spraying apparatus to cover the mixture. Then carefully pour off the water. Continue spraying and pouring off the water until the overflow water runs clear. Carefully drain off the water in the pan. Scoop the mixture from the mixing pan onto absorbent paper for evaluation of coating retention in the washing test.
44.7 Evaluate the mixture immediately by visual estimation as to the total aggregate surface area that is coated with asphalt.
44.8 Repeat the evaluation by visual estimation of the coating of aggregate surface area by asphalt after the mixture surface has been air dried in the laboratory at room temperature. A fan may be used for drying if desired.

45. Procedure for Tests With Wet Aggregate
45.1 Proceed in accordance with Sec 44.1 to 44.3.
45.2 Pipet 9.3 ml of water to the aggregate and CaCO₃ dust mixture in the mixing pan, then mix thoroughly to obtain uniform wetting.
45.3 Continue in accordance with Sec 44.4 to 44.8.

46. Interpretation of Results
46.1 Evaluate and report the following information for tests with both dry and wet aggregate:
46.1.1 At the end of the mixing period, record the coating of the total aggregate surface area by the emulsified asphalt as good, fair, or poor, where a rating of "good" means fully coated by the emulsified asphalt exclusive of pinholes and sharp edges of the aggregate, a rating of "fair" coating applies to the condition of an excess of coated area over uncoated area, and a rating of "poor" applies to the condition of an excess of uncoated area over coated area.
46.1.2 After spraying with water, record the coating of the total aggregate surface area by the asphalt as good, fair, or poor.
46.1.3 After air drying in the laboratory, record the coating of the total aggregate surface area by the asphalt as good, fair, or poor.

Storage Stability of Emulsified Asphalt

47. Scope
47.1 This method relates to the ability of emulsified asphalt to remain as a uniform dispersion during storage. It is applicable to emulsified asphalts composed principally of a semisolid or liquid asphalt base, water and an emulsifying agent.

48. Summary of Method
48.1 The method determines the difference in asphalt content of samples taken from the top and bottom of material placed in undisturbed simulated storage for 24 h. The result is expressed as the difference between the average percent of residue from top and bottom samples taken from two storage cylinders.

49. Significance
49.1 This method is useful for determining in a comparatively short time the storage stability of emulsified asphalt. It is a measure of the permanence of the dispersion as related to time, but it is not to be construed to have significance as a measure of other stability aspects involved in use.

50. Apparatus
50.1 Cylinders—Two 500 ml glass cylinders, with pressed or molded glass bases and cork or glass stoppers, having an outside diameter of 50 ± 5 mm and having 5 ml graduations.
50.2 Glass Pipet—A siphon and 60 ml pipet of optional form.
50.3 Balance conforming to the requirements of MRDTM 102, Class C.

51. Procedure
51.1 Bring the emulsified asphalt to room temperature of 21 to 27 C. Place a 500 ml representative sample in each of the two glass cylinders. Stopper the cylinders and allow them to stand undisturbed at laboratory air temperature of 21 to 27 C for 24 h. After standing for this period, remove approximately 55 ml from the top of the emulsion by means of the pipet or siphon without disturbing the balance. Thoroughly mix each portion.
51.2 Tare two 600 or 1000 ml glass or aluminum beakers, each with an appropriate glass rod. Weigh 50 ± 0.1 g of each sample into the beakers. Adjust the temperature of the oven to 163 ± 3 C. Then place the beakers containing the rods and sample in the oven for 2 h. At the end of this period remove each beaker and thoroughly stir the residue. Replace in the oven for 1 h, then remove the beakers from the oven, allow to cool to room temperature, and weigh with the rods (Note 4, Sec 12.2).
51.3 Siphon off the next 390 ml (approximate) from each of the cylinders (Sec 51.1). Thoroughly mix the emulsion remaining in the cylinders and weigh 50 g into separate tared 600 or 1000 ml glass or aluminum beakers. Determine the asphalt residue of these samples in accordance with Sec 51.2.

52. Calculation
52.1 Calculate the storage stability as the numerical difference between the average percentage of asphalt residue found in the two top samples and that found in the two bottom samples as follows:

Storage Stability, % = APRT - APRB

where:

\[
APRT = \frac{C_{t1} - A_{t1} + C_{t2} - A_{t2}}{B_{t1} - A_{t1} + B_{t2} - A_{t2}} \times 100
\]

and,

\[
APRB = \frac{C_{b1} - A_{b1} + C_{b2} - A_{b2}}{B_{b1} - A_{b1} + B_{b2} - A_{b2}} \times 100
\]

where:
APRT = average percent residue in the top,
APRB = average percent residue in the bottom,
A = tare mass of beakers, g,
B = mass of beakers and emulsion sample before heating, g,
C = mass of beakers and residue after heating,
_t = A, B and C values for samples taken from the top,
_b = A, B and C values for samples taken from the bottom,
_1 = A, B and C values for the first test, and
_2 = A, B and C values for the second test.

### Examination of Residue

#### 53. Specific Gravity

53.1 Determine the specific gravity on representative portion of the residue in accordance with MRDTM 407, Specific Gravity of Semisolid Asphalt Materials.

#### 54. Ash Content

54.1 Determine the ash content by placing a 2 to 5 g sample of the residue in a tared porcelain or platinum crucible and weigh the sample to the nearest 0.1 g. Slowly burn off the combustible matter, and finally ignite the residue until the ash is free of carbon matter. Cool the crucible and contents in a desiccator and weigh.

54.2 Calculation-Use the following formula to calculate the ash content:

\[
\text{Ash Content, } \% = \frac{B - A}{C - A} \times 100
\]

where:
A = tare mass of crucible, g,
B = mass of residue and crucible after burning, g, and
C = mass of residue and crucible before burning, g.

54.3 Report the result as percent of ash.

#### 55. Solubility in Trichloroethylene

55.1 Determine the solubility in trichloroethylene on a representative portion of the residue in accordance with MRDTM 402, Solubility of Bituminous Materials in Organic Solvents.

#### 56. Penetration

56.1 Determine the penetration on a representative portion of the residue in accordance with MRDTM 404, Penetration of Asphalt Materials.

#### 57. Ductility

57.1 Determine the ductility of a representative portion of the residue in accordance with MRDTM 405, Ductility of Asphalt Materials.

#### 58. Report

58.1 Record the results of all tests on Form No. MRDTR 400C.
Fig. 1. Apparatus for Determining Water
Fig. 2. Aluminum-Alloy Still.
Fig. 3. Apparatus Assembly for Distillation Test of Emulsified Asphalts
Fig. 4. Constant-Head Flow Tank
Fig. 5. Valve and Nozzle Assembly for Constant-Head Flow Tank
## Emulsified Asphalt

**Field Sample No:** 3  
**Lab Sample No:** BP-2423  
**Project:** FCP 285  
**Date Sampled:** 5/5/82  
**Date Received:** 5/7/82  
**Sampled By:** Y. Taha  
**Date Tested:** 5/8/82  
** Tested By:** E. Mansurah  
**Road No:** 202-203  
**Road Name:** Dammam - Ras Tanura  
**Title:** Lab Technician  
**Material:** CR5-2  
**Quanity Represented:** 25 T

### Composition:

<table>
<thead>
<tr>
<th>Line</th>
<th>Test Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water Content</td>
<td>%</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Residue, Percent by Distillation</td>
<td>%</td>
<td>65</td>
<td>65 min</td>
</tr>
<tr>
<td>3</td>
<td>Residue, Percent by Evaporation</td>
<td>%</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Particle Charge, Positive, Negative</td>
<td></td>
<td>Positive</td>
<td></td>
</tr>
</tbody>
</table>

### Consistency:

<table>
<thead>
<tr>
<th>Line</th>
<th>Test Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Saybolt Universal Viscosity @ 100°C, SSU</td>
<td>s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Saybolt Furol Viscosity @ 122°C, SSF</td>
<td>s</td>
<td>285</td>
<td>200 - 400</td>
</tr>
</tbody>
</table>

### Stability:

<table>
<thead>
<tr>
<th>Line</th>
<th>Test Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Demulsibility</td>
<td>%</td>
<td>6.0</td>
<td>40 min</td>
</tr>
<tr>
<td>8</td>
<td>Settlement (5 days)</td>
<td>%</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Cement Mixing, Percent Break</td>
<td>%</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sieve: Sample Retained</td>
<td>%</td>
<td>0.05'</td>
<td>0.10 max</td>
</tr>
<tr>
<td>11</td>
<td>Coating: Thoroughly Coated, X95%, Uncoated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Uniformly Coated, Yes, No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Miscibility: Coagulation; Yes, No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Modified Miscibility: Residue Difference</td>
<td>%</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Freezing: XHomogeneous, Broken</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Coating Ability and Water Resistance: Wet Aggregate: XGood, Fair, Poor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Coating Ability and Water Resistance: Dry Aggregate: XGood, Fair, Poor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Storage Stability</td>
<td>%</td>
<td>0.1</td>
<td>1 max</td>
</tr>
</tbody>
</table>

### Examination of Residue:

<table>
<thead>
<tr>
<th>Line</th>
<th>Test Property</th>
<th>Unit</th>
<th>Test Result</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Specific Gravity, 25°/25° C (MRDTM 407)</td>
<td></td>
<td>1.055</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Ash Content</td>
<td>%</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Solubility Matter (MRDTM 402)</td>
<td>%</td>
<td>99.0</td>
<td>97.5 min</td>
</tr>
<tr>
<td>22</td>
<td>Penetration (MRDTM 404)</td>
<td>mm</td>
<td>165</td>
<td>100 - 250</td>
</tr>
<tr>
<td>23</td>
<td>Ductility (MRDTM 405)</td>
<td>cm</td>
<td>85</td>
<td>40 min</td>
</tr>
<tr>
<td>24</td>
<td>Other (MRDTM □)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Remarks:

__________________________

**Checked By:** T. Williams  
**Title:** Lab Supervisor  
**Date:** 5/9/82

**Materials Engineer:** J. Smith  
**Consultant:** R. White

**Resident Engineer:** J. Dunbar  
**Contractor:**

**Distribution:**  
- [ ] Contractor  
- [ ] Ministry  
- [X] Resident Engineer  
- [ ] Other (Specify)
1. Introduction

1.1 Bituminous surface treatment is a broad term embracing several types of asphalt and asphalt-aggregate applications, usually less than 2.5 cm (1 in.) thick, to any kind of road surface. The road surface may be a granular base or it may be an existing pavement. Surface treatments applied to an existing pavement surface often are called seal coats. A single surface treatment involves spraying asphalt followed at once by a thin aggregate cover, which is rolled as soon as possible. For multiple surface treatments the process is repeated a second, or even a third time with the aggregate size becoming smaller with each application. The maximum size aggregate for each successive application is about one half that of the previous one. Properly constructed, bituminous surface treatments are economical, easy to place, and long lasting. They seal and add life to road surfaces but each type has one or more special purposes. A surface treatment is not a pavement in itself. Rather, it resists traffic abrasion and provides a water resistant cover over the underlying pavement structure. It adds virtually no load carrying capacity and therefore is not taken into consideration in computing the structural capacity of a pavement. While a surface treatment can provide an excellent surface if properly used, it is not a cure-all to solve all paving problems. An understanding of the advantages and limitations of bituminous surface treatments is essential for best results.

2. Purpose

2.1 Surface treatments are primarily used for the following purposes:

2.1.1 To provide a low cost, all weather surface for light to medium traffic.

2.1.2 To provide a waterproof layer to prevent the intrusion of moisture into the underlying course.

2.1.3 To provide a skid resistant surface. Pavements that have become slippery because of bleeding or wear and polishing of surface aggregates may be treated with sharp, hard aggregate to restore skid resistance.

2.1.4 To give new life to a dry, weathered surface. A pavement that has become weathered to the point where raveling might occur can be restored to useful service by application of a single or multiple surface treatment.

2.1.5 To provide a temporary cover for a new base course. The surface treatment is an appropriate cover for a new base course. The surface treatment makes an excellent temporary surface until the final asphalt courses are placed.

2.1.6 To salvage old pavements that have deteriorated because of aging, shrinkage cracking, or stress cracking. Although the surface treatment has little or no structural strength, it can serve as a stop-gap measure until a more permanent upgrading can be completed.

2.1.7 To delineate shoulders so they will not be mistaken as traffic lanes.

3. General

3.1 Procedures which help insure the successful use of surface treatments include:

3.1.1 All materials to be used should meet the job specifications.

3.1.2 The existing pavement structure should be adequate to support expected traffic loads before the surface treatment is applied.

3.1.3 Construction equipment should be in proper condition. Gauges and meters, aggregate spreader, and spray nozzles should be in proper working condition.

3.1.4 Asphalt and aggregates should be compatible. Select the proper asphalt.

3.1.5 The optimum application rate of asphalt and the correct amount of aggregate cover should be determined.

3.1.6 Conduct work only during proper weather conditions.

4. Asphalt

4.1 To select the proper grade of asphalt for a surface treatment, consideration should be given to:

4.1.1 Temperature of the surface to which asphalt will be applied.

4.1.2 Air temperatures.

4.1.3 Humidity and wind.

4.1.4 Condition of the surface.

4.1.5 Type and condition of the aggregate to be applied.

4.1.6 Equipment to be used.
4.2 One of the keys to good performance lies in the selection of the correct type, grade, and application rate of asphalt. Using the correct grade, the asphalt for surface treatment will:

4.2.1 When applied, be fluid enough to spray properly and cover the surface uniformly.
4.2.2 After application, retain the proper consistency to wet the surface being treated and the applied aggregate.
4.2.3 Cure and develop adhesion quickly.
4.2.4 After rolling and curing, hold the aggregate tightly to the road surface to prevent dislodgement by traffic.
4.2.5 When applied in the right amount, not bleed or strip with changing weather conditions.

4.3 Table 1 shows the types of asphalt for surface treatments. Table 2 gives typical application temperature ranges for the various types and grades.

Table 1
Types and Grades of Asphalt for Surface Treatment

<table>
<thead>
<tr>
<th>Type</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Cements</td>
<td>120/150,</td>
</tr>
<tr>
<td></td>
<td>200/300</td>
</tr>
<tr>
<td>Liquid Asphalts</td>
<td></td>
</tr>
<tr>
<td>Rapid Curing, RC</td>
<td>1,2,4,5</td>
</tr>
<tr>
<td>Medium Curing, MC</td>
<td>2,4,5</td>
</tr>
<tr>
<td>Slow Curing, SC</td>
<td>4,5</td>
</tr>
<tr>
<td>Emulsified (Anionic)</td>
<td>RS-1,RS-2</td>
</tr>
<tr>
<td>Emulsified (Cationic)</td>
<td>CRS-1,CRS-2</td>
</tr>
</tbody>
</table>

Table 2
Temperature Application Ranges for Asphalts

<table>
<thead>
<tr>
<th>Type and Grade</th>
<th>Application Temperature, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Cements</td>
<td></td>
</tr>
<tr>
<td>120/150</td>
<td>160-205</td>
</tr>
<tr>
<td>200/300</td>
<td>135-175</td>
</tr>
<tr>
<td>Liquid Asphalts</td>
<td></td>
</tr>
<tr>
<td>RC,MC, and SC</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>55-100</td>
</tr>
<tr>
<td>2</td>
<td>80-125</td>
</tr>
<tr>
<td>4</td>
<td>100-145</td>
</tr>
<tr>
<td>5</td>
<td>115-170</td>
</tr>
<tr>
<td>Emulsions:</td>
<td></td>
</tr>
<tr>
<td>RS-1, CRS-1</td>
<td>20-60</td>
</tr>
<tr>
<td>RS-2, CRS-2</td>
<td>50-85</td>
</tr>
</tbody>
</table>

4.3.1 Asphalt is a thermoplastic material that becomes more liquid with increasing temperatures. The application temperature should be selected carefully because the ability to spray at a certain temperature is not always the same for similar grade asphalts. The recommended kinematic viscosity range for spraying is 20-120 centistokes. The best method to select a spraying temperature is by use of a temperature/viscosity chart for the specific asphalt to be used.

5. Aggregate

5.1 Any aggregate used in a surface course is subjected to the abrasive action of traffic. If it is not hard enough to resist rapid wear, the pavement may become a skid hazard when wet. Most hard aggregates can be used with success for surface treatments. But all aggregates considered for use should be tested for abrasion wear, MRDTM 309, Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine. Angular particles with rough surface texture and
relatively low absorption will produce the best results. The aggregate selected, however, should also meet job requirements for size, shape, and cleanliness.

5.2 The ideal shape for surface treatment aggregate is cubical. Flat or elongated particles are undesirable. They tend to become aligned on their flat sides and may be completely covered with asphalt when enough is used to hold the cubical particles in place. If all particles are flat, it takes so little asphalt to hold them that adequate quality control becomes difficult.

5.3 Clean aggregate is very important. If the particles are dusty or coated with clay or silt, the emulsified asphalt may not stick. The dust produces a film that prevents the asphalt from adhering to the aggregate.

6. Single Surface Treatment

6.1 A single surface treatment, often called “chip seal,” may be used for one of several reasons:

6.1.1 As an interim measure pending application of a higher pavement type.

6.1.2 To correct surface raveling and oxidation of old pavements.

6.1.3 To provide a water resistant cover over an existing pavement structure.

6.2 The single treatment approach is especially suited for light duty traffic and as an interim maintenance procedure. It also may be used following crack sealing operations. The surface treatment is applied to resist the abrasive forces of the traffic.

7. Multiple Surface Treatment

7.1 Double surface treatments give about three times the service life of a single surface treatment for about 1 1/2 times the construction cost. Because the cover stone for the second layer is smaller, loss of particles from a graded cover aggregate is greatly minimized.

7.2 In a double surface treatment the largest size of stone in the first course determines the surface layer thickness. The second course serves to fill the voids in the mat of the first course aggregate. The extent to which these voids are filled determines the texture and riding quality of the surface treatment.

7.3 A good, long-lasting pavement can be produced by increasing the thickness with more surface treatments, either single or multiple, as traffic conditions warrant.

8. Single Surface Treatment-Design

8.1 The proper rates of application for asphalt and aggregate are required for single surface treatment design. The objective is to produce a pavement surface one stone thick with enough asphalt to hold the aggregate in place, but not so much that it will bleed. The procedure for single surface design utilizes the following principles (Note 1).

8.1.1 When one-size cover aggregate is dropped by a spreader on an asphalt film, the particles lie in unarranged positions. The voids between the particles are approximately 50 percent.

8.1.2 Rolling reorients the aggregate particles and reduces the surface voids to about 30 percent.

8.1.3 Finally, after considerable traffic, the particles become oriented into their densest positions, with all lying on their flattest sides, and the surface voids are further reduced to approximately 20 percent.

8.1.4 Since the particles lie on their flattest sides, the average thickness of a surface treatment is determined from the overall average smallest dimension of the aggregate particles. This is called the Average Least Dimension (ALD) of the cover aggregate. The Average Least Dimension of any approximately one-size cover aggregate can be determined by measuring a number of individual aggregate particles with a caliper or by using slotted screens described in MRDTM 423.

8.1.5 For good performance, the quantity of asphalt binder used should fill about 70 percent of the 20 percent void space (Sec 8.1.3) if the traffic volume is moderate (500 to 1000 vehicles per day). However, the asphalt binder should not fill more than 60 percent of the 20 percent void space if the traffic volume is high (more than 2000 vehicles per day).

Note 1: These principles are based on one-size cover aggregate. Most often, one-size aggregate is not available economically and graded aggregate, which has fewer voids, has to be used. The voids in this material in a loose weight condition will be somewhat less than the 50 percent for one-size aggregate. This means that the ultimate void space in a surface treatment using graded cover aggregate will be less than 20 percent. A correction must be made in the design method for this condition or a bleeding pavement may result.

8.2 These considerations are incorporated in the development of the design equation for the quantity of cover aggregate in a surface treatment.

\[ C = M [(1 - 0.4V) \times HGE] \]
where:

\[ C = \text{cover aggregate applications, kg/m}, \]
\[ M = \text{a multiplying factor based on experience with local conditions of climate, traffic, cover aggregate, etc., and may have a value greater or less than 1.0, which is its normal value,} \]
\[ H = \text{Average Least Dimension (ALD) of cover aggregate, mm, MRDTM 423,} \]
\[ G = \text{bulk specific gravity of cover aggregate, MRDTM 304,} \]
\[ E = \text{wastage factor to allow for cover stone loss, due to whip-off and unevenness of spread, Table 3, and} \]
\[ V = \text{voids in the cover aggregate in loose weight condition,} \]

\[ V = 1 - \frac{W}{100G} \%	ext{, expressed as a decimal,} \]

where:

\[ W = \text{loose unit weight of cover aggregate kg/m}^3, \text{MRDTM 308,} \]

8.3 The quantity of asphalt to be applied is found by the following equation:

\[ B = K \times 0.40HTV + S + A \]

where:

\[ B = \text{asphalt application, liter/m}^2, \]
\[ K = \text{a multiplying factor that must be selected based on experience with local conditions of climate, traffic, cover aggregate, etc., and may have a value either less than or greater than 1.0, which is its normal value,} \]
\[ H = \text{as defined in Sec 8.2,} \]
\[ T = \text{traffic factor from Table 4, V = as defined in Sec 8.2,} \]
\[ S = \text{correction, liter/m}^2, \text{for texture of surface} \]
\[ \text{on which surface treatment is to be placed,} \]
\[ A = \text{correction, liter/ml for absorption of asphalt into cover stone (disregard except for obviously porous stone).} \]
\[ R = \text{residual asphalt, percent expressed as a decimal. The rate of application is the residual binder content required and it applies directly to asphalt cements. If the asphalt material to be used is a liquid type, allowance should be made for the evaporation of solvents from cutbacks or water from emulsions. There are no established asphalt residue correction factors because there are too many variables to consider. Any single set of values would not be valid for all areas or for the same grade of asphalt from different sources. Therefore, the residual asphalt percent should be determined for each job.} \]

### Surface Texture Correction

<table>
<thead>
<tr>
<th>Pavement Texture</th>
<th>Correction, S liter/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black, flushed</td>
<td>(-0.04 to -0.27)</td>
</tr>
<tr>
<td>Smooth, non-porous</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Absorbent-slightly porous, oxidized</td>
<td>(0.14)</td>
</tr>
<tr>
<td>-slightly pocked, porous, oxidized</td>
<td>(0.27)</td>
</tr>
<tr>
<td>-badly pocked, porous, oxidized</td>
<td>(0.40)</td>
</tr>
</tbody>
</table>
Table 3

Aggregate Wastage Factors

<table>
<thead>
<tr>
<th>Percentage Waste Allowed for</th>
<th>Wastage Factor, E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td>2</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>1.03</td>
</tr>
<tr>
<td>4</td>
<td>1.04</td>
</tr>
<tr>
<td>5</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>1.06</td>
</tr>
<tr>
<td>7</td>
<td>1.07</td>
</tr>
<tr>
<td>8</td>
<td>1.08</td>
</tr>
<tr>
<td>9</td>
<td>1.09</td>
</tr>
<tr>
<td>10</td>
<td>1.10</td>
</tr>
<tr>
<td>11</td>
<td>1.11</td>
</tr>
<tr>
<td>12</td>
<td>1.12</td>
</tr>
<tr>
<td>13</td>
<td>1.13</td>
</tr>
<tr>
<td>14</td>
<td>1.14</td>
</tr>
<tr>
<td>15</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Table 4

Traffic Factors for Surface Treatments

<table>
<thead>
<tr>
<th>Traffic Volume (vehicles per day)</th>
<th>Traffic Factor²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 100</td>
<td>0.85</td>
</tr>
<tr>
<td>100 to 500</td>
<td>0.75</td>
</tr>
<tr>
<td>1000 to 2000</td>
<td>0.70</td>
</tr>
<tr>
<td>Over 2000</td>
<td>0.65</td>
</tr>
<tr>
<td>Over 2000</td>
<td>0.60</td>
</tr>
</tbody>
</table>

¹The factors above do not make allowance for absorption by the road surface or by absorptive cover aggregate.
²Percentage (expressed as decimal) of 20% void space in cover aggregate to be filled with asphalt.

8.4 Example: Standard 2.8 mm (No. 7) crushed granite is to be used on a slightly porous pavement for a surface treatment cover aggregate with CRS-2 emulsified asphalt. The quantities of aggregate and emulsion to be applied, for a roadway serving 800 vehicles per day is determined as follows:

Median size of aggregate = 10 mm, determined from MRDTM 423,
Flakiness Index = 20, MRDTM 423,
Average Least Dimension, H = 7.4 mm, MRDTM 423,
Loose unit mass of aggregate, W = 1538 kg/m³, MRDTM 304,
Bulk specific gravity, G = 2.650, MRDTM 309,
Voids in cover aggregate,

\[ V = 1 - \frac{1538}{1000 \times 2.65} = 1 - 0.58 = 0.42 \]

Wastage factor, E = 1.04, Table 3
Traffic factor, T = 0.70, Table 4 (for 800 vpd),
Texture correction, S = 0.13 liter/m²,
Aggregate absorption correction, $A = 0.00$,
Residual asphalt, $R = 0.69$ (CRS-2),
Multiplying factor $M = 1.0$,
Multiplying factor $K = 1.0$.

8.5 Asphalt application;

$$B = K \frac{0.40 \text{ HTV} + S + A}{R}$$
or

$$B = 1.0 \frac{0.40 \times 7.4 \times 0.70 \times 0.42 + 0.13 + 0}{0.69}$$

$$B = 1.45 \text{ liter/m}^2 (0.32 \text{ gal./yd}^2)$$

8.6 Cover aggregate application:

$$C = M \left[ (1-0.4 \times 0.42) \times 10.1 \times 2.65 \times 1.04 \right]$$

$$C = 16.9 \text{ kg/m}^2 (31.1 \text{ lb/yd}^2)$$

9. Multiple Surface Treatments

9.1 Each course is designed as though it is a single surface treatment. For each succeeding course the nominal top size of cover stone should be not more than one-half the size of that for the previously placed course. No allowance is made for wastage. Also, after the first course, no correction is made for underlying surface texture. After the amount of asphalt for each course is determined, the total for all courses is obtained. For double surface treatments, 40 percent of the total asphalt for the first application and 60 percent for the second. For triple treatment, the total quantity should be split 30-40-30. The asphalt and aggregate quantities determined with these equations will suit most field conditions. As indicated by the "M" and "K" multiplying factors, there may be times when an upward or a downward adjustment must be made because of climate, traffic, cover aggregate, or other conditions. In multiple surface treatments, the first course of cover aggregate generally determines the thickness. Subsequent courses partially fill the upper voids in the previously placed courses.

9.2 Following is an example of double surface treatment design:

9.2.1 First course;
Standard 3.35 mm (No. 6) crushed limestone; MRDTM 423 for grading curve,
Median size of aggregate = 15 mm, MRDTM 423,
Flakiness Index = 0.27, MRDTM 423,
Average Least Dimension, $H = 10.1$ mm, MRDTM 423,
Loose unit mass of aggregate, $W = 1506$ kg/m$^3$, MRDTM 308,
Bulk specific gravity, $G = 2.600$, MRDTM 304,
Voids in cover aggregate,

$$V = 1 - \frac{1506}{1000 \times 2.600} = 0.42$$

Traffic factor, $T = 0.65$, Table 4 (for 1500 vpd),
Texture correction, $S = 0.13$
Wastage factor, $E = 1.00$,
Aggregate absorption correction, $A = 0$,
Residual asphalt, $R = 0.65$ (CRS-1),
Multiplying factor $M = 1.0$, and
Multiplying factor $K = 1.0$.

9.2.2 Asphalt application:

$$B = K \frac{0.40 \text{ HTV} + S + A}{R}$$
or

$$B = 1.0 \frac{0.40 \times 10.1 \times 0.65 \times 0.42 + 0.13 + 0}{0.65}$$
B = 1.9 liter/m² (0.42 gal./yd²)

9.2.3 Cover aggregate application:

\[ C = M [(1 - 0.4V) HGE] \]
\[ C = 1.0 \times [(1 - 0.4 \times 0.42) \times 10.1 \times 2.60 \times 1.00] \]
\[ C = 22 \text{ kg/m}² (40.5 \text{ lb/yd}²) \]

9.3 Second course;
Standard 2.36 mm (No. 8) crushed limestone, MRDTM 423 for grading curve,
Median size of aggregate = 6.35 mm, MRDTM 423,
Flakiness Index = 0.27, MRDTM 423,
Average Least Dimension, H = 4.6 mm, MRDTM 423,
Loose unit mass of aggregate, W = 1522 kg/m², MRDTM 308,
Bulk specific gravity, G = 2.60, MRDTM 304,
Voids in cover aggregate,
\[ V = 1 - \frac{1522}{1000 \times 2.600} = 0.41 \]
Traffic factor, T = 0.65, Table 4 (for 1500 vpd),
Texture correction, S = 0
Wastage factor, E = 1.00,
Aggregate absorption correction, A = 0,
Residual asphalt, R = 0.65 (CRS-1),
Multiplying factor M = 1.0, and
Multiplying factor K = 1.0.

9.3.1 Asphalt application:
\[ B = K \times 0.40 \times \text{HTV} + S + A \]
\[ B = 1.0 \times 0.40 \times 4.6 \times 0.65 \times 0.41 + 0 + 0 \]
\[ B = 0.75 \text{ liter/m}² (0.166 \text{ gal./yd}²) \]

9.3.2 Cover aggregate application:
\[ C = M [(1 - 0.4V) HGE] \]
\[ C = 1.0 \times [(1 - 0.4 \times 0.41) \times 4.6 \times 2.60 \times 1.00] \]
\[ C = 10 \text{ kg/m}² (18.3 \text{ lb/yd}²) \]

9.4 The total amount of asphalt for both layers is 1.9 + 0.75 = 2.65 liter/m² (0.42 + 0.166 = 0.59 gal./yd²). Therefore, the quantities of asphalt and cover aggregate to be applied for each application for a double surface treatment are:

<table>
<thead>
<tr>
<th>Course</th>
<th>Emulsion, CRS-1</th>
<th>Cover Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>First application</td>
<td>0.4 x 2.65 = 1.05 liters/m²</td>
<td>22 kg/m²</td>
</tr>
<tr>
<td>Second application</td>
<td>0.6 x 2.65 = 1.60 liters/m²</td>
<td>10 kg/m²</td>
</tr>
<tr>
<td>Total</td>
<td>2.65 liters/m²</td>
<td>32 kg/m²</td>
</tr>
</tbody>
</table>

10. Report
10.1 Record the surface treatment design data on Form No. MRDWS
Single Surface Treatment Design

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>82-2430</td>
<td>FCP 285</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>Date Received</th>
<th>Road No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/15/82</td>
<td>5/17/82</td>
<td>202-203</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampled By</th>
<th>Tested By</th>
<th>Road Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Tahm</td>
<td>E. Maniubah</td>
<td>Damman - Ras Tanura</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title</th>
<th>Quantity Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proj. Inspector</td>
<td>750 T</td>
</tr>
<tr>
<td>Lab Technician</td>
<td></td>
</tr>
</tbody>
</table>

Median Size of Aggregate (MRDTM 423), mm: 10.0
Grade Emulsified Asphalt: CR-2
Flakiness Index (MRDTM 423): 20.0
H Average Least Dimension (MRDTM 423): 7.4
W Loose Unit Mass of Aggregate (MRDTM 308), kg/m³: 15.38
G Bulk Specific Gravity (MRDTM 304): 2.650
V Voids in Cover Aggregate \( V = 1 - \frac{W}{1000XG} \) %: 0.42
Allowable Waste, %: 4
E Waste Factor (Table 3): 1.04
Traffic Volume, vpd: 800
T Traffic Factor (Table 4): 0.70
S Texture Correction, l/m²: 0.13
A Aggregate Absorption Correction, l/m²: 0.0
R Residual Asphalt (Sec. 11.3), %: 0.0
M Multiplying Factor (Sec. 11.2): 1.0
K Multiplying Factor (Sec. 11.3): 1.0
B Emulsified Asphalt Application, \( B = \frac{0.40 \cdot HTV + S + A}{V} \) l/m²: 1.45
C Cover Aggregate Application, \( C = M \cdot (1 - 0.4 \cdot V) \cdot HGE \) kg/m²: 16.9

Double Surface Treatment Design

<table>
<thead>
<tr>
<th>Course</th>
<th>First</th>
<th>Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Size of Aggregate (MRDTM 423), mm</td>
<td>7.31</td>
<td>2.36</td>
</tr>
<tr>
<td>Grade Emulsified Asphalt</td>
<td>CR-1</td>
<td>CR-1</td>
</tr>
<tr>
<td>Flakiness Index (MRDTM 423)</td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td>Allowable Waste, %</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Traffic Volume, vpd</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>H Average Least Dimension (MRDTM 423), mm</td>
<td>10.1</td>
<td>4.6</td>
</tr>
<tr>
<td>W Loose Unit Mass of Aggregate (MRDTM 308), kg/m³</td>
<td>15.06</td>
<td>15.22</td>
</tr>
<tr>
<td>G Bulk Specific Gravity (MRDTM 304)</td>
<td>2.650</td>
<td>2.650</td>
</tr>
<tr>
<td>V Voids in Cover Aggregate ( V = 1 - \frac{W}{1000XG} ) %: 0.42</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>E Waste Factor (Table 3)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>T Traffic Factor (Table 4)</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>S Texture Correction, l/m²</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>A Aggregate Absorption Correction, l/m²</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R Residual Asphalt (Sec. 11.3), %</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>M Multiplying Factor (Sec. 11.2)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>K Multiplying Factor (Sec. 11.3)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>B Emulsified Asphalt, ( B = \frac{0.40 \cdot H \cdot T \cdot V + S + A}{V} ) l/m²</td>
<td>1.9</td>
<td>0.75</td>
</tr>
<tr>
<td>Bₜ Total Emulsified Asphalt Application, ( Bₜ(\text{First}) + Bₜ(\text{Second}) )</td>
<td>2.65</td>
<td></td>
</tr>
<tr>
<td>Emulsified Asphalt Application, First Course, 0.4 × Bₜ l/m²</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>Emulsified Asphalt Application, Second Course, 0.6 × Bₜ l/m²</td>
<td>1.57</td>
<td></td>
</tr>
<tr>
<td>C Cover Aggregate Application, ( C = M \cdot (1 - 0.4 \cdot V) \cdot H \cdot G \cdot E ) kg/m²</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Cₜ Total Cover Aggregate Application, ( Cₜ = C(\text{First}) + C(\text{Second}) ) kg/m²</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:

<table>
<thead>
<tr>
<th>Checked By</th>
<th>Title Lab Supervisor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Williams</td>
<td>R. White</td>
<td>5/10/82</td>
</tr>
</tbody>
</table>

Materials Engineer: J. Smith
Consultant: J. Dumber
Contractor: J. Dumber

Distribution: Contractor, Resident Engineer, Ministry, Other (Specify)
Introduction
Bituminous Plant Mix Friction Courses were developed to overcome some of the problems that were encountered by some users of chip seals, i.e., overshooting, undershooting, loss of chips, etc. They have about the same void content as chip seals. Bituminous Plant Mix Friction Courses have the following advantages over conventional dense graded surface mixes:

1. Good utilization of high quality aggregates because of the high void content and relatively thin layer thickness (13 to 25 mm).
2. Best utilization of the inherent friction properties of the coarse aggregate.
3. Higher pavement friction properties over a range of high speeds. It is essential that the coarse aggregate have good inherent friction characteristics.
4. Marked reduction of splash and spray during wet weather.

1. Scope
1.1 This method of test describes the procedures for determining the job mix composition for Bituminous Plant Mix Friction Courses. These are unique hot asphalt mixes in that they are designed to have an appreciable internal void system, 15 percent in the 152.4 mm (6 in.) by 76.2 mm (3 in.) laboratory compacted specimen. The void system in the actual thin mat layer used, 13 to 25 mm (or 0.5 to 1.0 in.) will usually be about 25 percent. To give this high void content mixture the needed longevity and to offset the oxidizing effects of air and water it is essential that they be carefully designed and constructed. To provide the longevity the laboratory mix design should provide for a very thick asphalt coating on the aggregate. This is accomplished by using a mix temperature corresponding to about 800 centistokes viscosity for the actual asphalt to be used. Typically, this should result in mix temperatures in the range of 110 to 120 C. The minus 0.075 mm (No. 200) sieve material also aids in providing the needed thickness of asphalt coating because of its "thickening" effect on the asphalt. As an aid to dumping and placing this rather harsh mixture, the asphalt should contain 2 ppm silicone.

2. Preliminary Data
2.1 Test coarse and fine aggregates as received for the project for gradation. If mineral filler is submitted as a separate item, it should also be tested for specification compliance. Analyze gradation results to determine if proportions of aggregates and batching operations proposed by the contractor will meet the jobmix formula and the specification limits.
2.2 Determine bulk and apparent specific gravity (MRDTM 304 and 305) for the coarse and fine aggregate fractions (retained and passing the 2.36 mm (No. 8) sieve) for each type of material submitted. Additional specific gravity tests are not warranted when the only distinction between the aggregates are their size or grading. Using this information, mathematically compute the bulk and apparent specific gravity for the coarse and fine aggregate fractions (retained and passing the 2.36 mm (No. 8) sieve) for the proposed job-mix gradation.

3. Asphalt Content
3.1 Determine the surface capacity of the aggregate fraction that is retained on a 4.75 mm (No. 4) sieve in accordance with the following procedure (Note 1). Determine K, from the percent of SAE No. 10 oil retained, which represents the total effect of superficial area, the aggregate's absorptive properties, and the surface roughness:

Note 1: For highly absorptive aggregates, use the procedure described in Sec 3.3.
3.1.1 Quarter out 105 g representative sample of the material passing the 9.5 mm (3/8 in.) sieve and retained on the 4.75 mm (No. 4) sieve.
3.1.2 Dry the sample on a hot plate or in a 110 ± 5 C oven to constant mass and allow to cool.
3.1.3 Weigh out 100.0 g and place in a metal funnel (top diameter 90 mm (3½ in.), height 115 mm (4½ in.), orifice 12.5 mm (1/2 in.), with a piece of 2.00 mm (No. 10) sieve soldered to the bottom of the opening).
3.1.4 Completely immerse the specimen in SAE No. 10 lubricating oil for 5 minutes.
3.1.5 Drain for 2 minutes.
3.1.6 Place funnel containing sample in 60 C oven for 15 minutes for additional draining.
3.1.7 Pour sample from funnel into a tared pan; cool, and reweigh sample to nearest 0.1 g. Subtract original mass and record difference as percent oil retained (based on 100 g of dry aggregate).

3.1.8 Use chart shown in Fig. 1 for determination of $K_c$.
3.1.8.1 If specific gravity for the fraction is greater than 2.70 or less than 2.60, apply a correction to the oil retained, using the formula at the bottom of chart in Fig. 1.

3.1.8.2 Start at the bottom of the chart in Fig. 1 with the corrected percent of oil retained; follow straightedge vertically upward to intersection with the diagonal line; hold point, and follow the straightedge horizontally to the left. The value obtained is the surface constant for the retained fraction and is known as $K_c$.

3.2 Determine the required asphalt content, which is based on the mass of aggregate, from the following relationship:

$$\text{Asphalt, \%} = (2.0 K_c + 4.0) \times \frac{2.65}{(\text{Sp. Gr.}) \text{CA}}$$

where:
$K_c$ = surface constant, and
$(\text{Sp. Gr.}) \text{CA}$ = apparent specific gravity of coarse aggregate.

3.3 For highly absorptive aggregates, use the following procedure for determining $K_c$ and the asphalt content:
3.3.1 Follow the recommended design procedure from Sec 3.1 through 3.1.3.
3.3.2 Follow the instructions in Sec 3.1.4, except immerse the specimen for 30 minutes.
3.3.3 Follow the recommended procedure from Sec 3.1.5 through 3.1.7.
3.3.4 Pour the sample onto a clean, dry, absorptive cloth; obtain a saturated-surface-dry condition; pour the sample from the cloth into a tared pan and reweigh the sample to nearest 0.1 g. Subtract the original mass of aggregate and record the difference as percent oil absorbed (based on 100 g of aggregate).

3.3.5 Subtract the percent oil absorbed value (Sec 3.3.4) from the percent oil retained value (Sec 3.3.3), and obtain the percent (free) oil retained value. This value represents the percent oil retained value that would have been obtained had the aggregate been a nonabsorptive type. The above technique allows one to evaluate the aggregate’s surface and shape characteristics without the overwhelming influence of a large quantity of absorbed oil.

3.3.6 Follow the procedure recommended in Sec 3.1.8 and 3.2. The only exception is that the percent (free) oil retained value is used (from Sec 3.3.5) to obtain $K_c$. Thus, the asphalt quantity determined is the "effective" asphalt content.

3.3.7 Follow the recommended procedure indicated through Sec 4 and 5. Because asphalt absorption is not presently included in the formula for the determination of fine aggregate content, it is particularly desirable that the effects of oil absorption in the $K_c$ test be excluded in the case of the highly absorptive aggregate.

3.3.8 Prepare a trial mixture using an asphalt content equal to or somewhat greater than (try to estimate amount that will be absorbed) the effective asphalt content determined in Sec 3.3.6 and using the aggregate gradation as determined in Sec 3.3.7. Using a suitable technique, such as the test for Maximum Specific Gravity of Asphalt Mixtures (MRDTM 412), determine the actual quantity of asphalt absorbed (in percent, based on total mass of aggregate).

3.3.9 Determine the total asphalt content of the subject mixture by adding the effective asphalt content from Sec 3.3.6 to the absorbed asphalt content from Sec 3.3.8.

3.3.10 Follow the recommended procedure indicated in Sec 6 and 7, using the total asphalt content for all subsequent computations and trials in Sec 3.3.9.

4. Void Capacity of Coarse Aggregate
4.1 Use the following procedure to determine the vibrated unit mass and void capacity of the coarse aggregate fraction (material retained on a 2.36 mm (No. 8) sieve) of the proposed job-mix gradation.
4.1.1 Apparatus
4.1.1.1 Tamper Vibrator—A tamper foot as shown in Fig. 3. A portable vibrating table as described in MRDTM 214 or a portable electromagnetic vibrating rammer as shown in Fig. 2 each having a frequency of 3,600 cycles per minute and suitable for use with 115 V-ac.
4.1.1.2 Mold—A solid wall metal cylinder with a detachable metal base plate and a detachable metal guide reference bar as shown in Fig. 4.
4.1.1.3 Wooden Base—A plywood disk 400 mm (or 15 in.) in diameter, and 50 mm (or 2 in.) thick, with a cushion of rubber hose attached to the bottom. The disk shall be constructed so it can be firmly attached to the base plate of the compaction mold.
4.1.1.4 Timer—A stopwatch or other timing device graduated in divisions of 1.0 s and accurate to 1.0 s and capable of timing the unit for up to 2 minutes. An electric timing device or electrical circuits to start and stop the vibratory rammer may be used.
4.1.1 Dial Indicator-A dial indicator graduated in 0.025 mm (0.001 in.) increments and having a travel range of 75 mm (or 3.0 in.).

4.1.2 Sample
4.1.2.1 Select a 2.27 kg (5 lb) sample of the coarse aggregate fraction from the proposed job-mix formula.

4.1.3 Procedure
4.1.3.1 Pour the selected sample into the compaction mold and place the tamper foot on the sample.
4.1.3.2 Place the guide reference bar over the shaft of the tamper foot and secure the bar to the mold with the thumb screws.
4.1.3.3 Place the mold containing the sample and tamper foot assembly on the vibrating table, or place the vibratory rammer on the shaft of the tamper foot, and vibrate for 15 s. During the vibration period, the operator must exert just enough pressure on the tamper foot assembly to maintain contact between the sample and the tamper foot.
4.1.3.4 Remove the tamper foot and brush any fines from the top of it. Measure the thickness (t) of the compacted material to the nearest 0.0025 cm (0.001 in.) (Note 2).

Note 2: The thickness (t) of the compacted sample is determined by adding the dial reading, minus the thickness of the tamper foot, to the measured distance from the inside bottom of the mold and the end of the dial gauge when it is seated on the guide reference bar with stem fully extended.

4.1.4 Calculations
4.1.4.1 Calculate the vibrated unit mass (X) in g/cm³ as follows:

\[
X = \frac{4w}{\pi d^2 t}
\]

where:
- \(w\) = mass of coarse aggregate fraction, g,
- \(d\) = diameter of compaction mold, cm, and
- \(t\) = thickness of compacted sample, cm.

If \(w = 2267.96\) g and \(d = 15.24\) cm

\[
X = 12.433 \text{ (g/cm}^3) \frac{t}{t}
\]

4.1.4.2 Determine the void capacity (VMA) as follows:

\[
VMA,\% = 100 \left(1 - \frac{X}{U_c}\right)
\]

where:
- \(U_c\) = bulk solid unit mass g/cm³, of the coarse aggregate fraction, i.e., the bulk specific gravity (Sec 2.2) multiplied by 1 g/cm³ (unit mass of water).

4.1.4.3 Calculate the vibrated unit mass (X), lb/ft³ as follows:

\[
X = \frac{6912w}{\pi d^2 t}
\]

where:
- \(w\) = mass of coarse aggregate fraction, lb,
- \(d\) = diameter of compaction mold, in., and
- \(t\) = thickness of compacted sample, in.

If \(w = 5\) lb and \(d = 6\) in., then:

\[
X = 305.58 \text{ lb/ft}^3 \frac{t}{t}
\]
4.1.4.4 Determine the void capacity (VMA) as follows:

\[
VMA, \% = 100 \left(1 - \frac{X}{U_c}\right)
\]

where:

- \(U_c\) = bulk solid unit mass, lb/ft\(^3\) of the coarse aggregate fraction, i.e., the bulk specific gravity, (Sec 2.2), multiplied by 62.4 lb/ft\(^3\) (unit mass of water).

5. Optimum Content of Fine Aggregate

5.1 Determine the optimum content of the fine aggregate fraction using the following relationship:

\[
Y = \frac{\left(\% VMA - V\right) - \left(\% AC\right) X}{\left(\% VMA - V\right) + \frac{X}{U_f}}
\]

where:

- \(Y\) = percent passing the 2.36 mm (No. 8) sieve,
- \(X\) = actual vibrated unit mass of course aggregate (CA) retained on the 2.36 mm (No. 8) sieve, g/cm\(^3\) (lbs/ft\(^3\)),
- \(U_i\) = theoretical bulk dry solid unit mass of fine aggregate passing the 2.36 mm (No. 8) sieve, g/cm\(^3\) (lbs/ft\(^3\)),
- \(U_a\) = unit mass of asphalt cement, g/cm\(^3\) (lbs/ft\(^3\)),
- \(\% AC\) = percent asphalt Sec 3.2,
- \(\% VMA\) = percent voids mineral aggregate Sec 4.1.4.2 or 4.1.4.4, and
- \(U_c\) = theoretical bulk dry solid unit mass of coarse aggregate retained on the 2.36 mm (No. 8) sieve, g/cm\(^3\) (lbs/ft\(^3\)).

Note 3: In the above relationship, asphalt absorption by the aggregate has been assumed to be negligible. Because asphalt absorption requirements are considered in the test for \(K\), (Sec 3.1), the estimated air voids of 15 percent in the mixture will actually be greater by an amount equivalent to the volume of asphalt absorbed, in percent. This condition provides, if anything, an additional safety factor. As an alternative to the use of the mathematical relationship, the design chart shown in Fig. 5 may be used, provided that the assumptions used in developing the chart are satisfied; that is, the specific gravity values (bulk dry) for the coarse and fine aggregate fractions do not deviate beyond the limits of 2.600 to 2.700. If the value thus obtained for fine aggregate content is greater than 15 percent, a value of 15.0 percent shall be used.

5.2 Compare the optimum fine aggregate content (\(Y\)) determined in Sec 5.1 to the amount passing the 2.36 mm (No. 8) sieve of the contractor's proposed job-mix formula. If these values differ by more than 1 percentage point, reconstruct a revised or adjusted job-mix formula using the value determined for optimum fine aggregate content. Recompute the proportions of coarse and fine aggregates (as received) to meet the revised job-mix formula for submission to the contractor.

Note 4: If the proposed and revised job-mix gradations are significantly different, it may be necessary to rerun portions of this procedure.

6. Optimum Mixing Temperature

6.1 Prepare a 1000 g sample of aggregate in the proportions determined in Sec 5. Mix this sample at the asphalt content determined in Sec 3.2 at a temperature corresponding to an asphalt viscosity of 800 centistokes. When the mixture is completely coated, transfer it to a pyrex glass plate, 20 to 23 cm (8 to 9 in.) in diameter and spread the mixture with a minimum of manipulation. Return it to the oven at the mixing temperature. Observe the bottom of the plate after 15 and 60 minutes (Fig. 6). A slight puddle at points of contact between the aggregate and glass plate is suitable and desirable. Otherwise, repeat the test at a lower or higher mixing temperature, if necessary.

Note 5: If asphalt drainage occurs at a mixing temperature that is too low to provide for adequate drying of the aggregate, a harder grade asphalt should be used.

7. Resistance to Effects of Water

7.1 Conduct the Immersion Compression Test (MRDTM 414 and 415) on the designed mixture. Prepare samples at the optimum mixing temperature determined in Sec 6.1. Use a molding pressure of 70.3 kg/cm\(^2\) (1000 psi) rather than the
specified value of 210.9 kg/cm³ (3000 psi). After a four day immersion at 49 C, the index of retained strength shall not be less than 50 percent.

**Note 6:** Additives to promote adhesion that will provide adequate retained strength may be used when necessary.

**8. Report**

8.1 Report the mix design test values on Form Nos. MRDTR 426 A, B, C and D.

---

**Fig. 1. Chart for Determining Surface Capacity (Kc) of Coarse Aggregate**

Material Used: Aggregate - Passing 9.5 mm (3/8 in.), Ret. 4.75 mm (No. 4) Sieve

Oil - SAE 10

Oil Retained Corrected (%) = Oil Retained (%) \( \times \) \[ \frac{\text{Apparent Sp. Gr. of Coarse Aggregate}}{2.65} \]

---
Fig. 2. Vibratory Compaction Apparatus
Fig. 3. Tamper Foot and Extension
Fig. 4. Cylindrical Mold for Testing Granular Materials
Voids (VMA) in Coarse Aggregate retained on 2.36 mm (No. 8) Sieve, Percent

Assumptions Used in Deriving Chart:

- $U_c = 2.65 \text{ g/cm}^3 (165.4 \text{ pcf})$ (sp. gr. = 2.650)
- $U_f = 2.65 \text{ g/cm}^3 (165.4 \text{ pcf})$ (sp. gr. = 2.650)
- $U_a = 1 \text{ g/cm}^3 (62.4 \text{ pcf})$ sp. gr. = 1.000
- $V = 15.0 \text{ percent}$

Fig. 5. Determination of Optimum Fine Aggregate Content
For optimum mixing temp.
only -- Do NOT adjust
asphalt content
A - no drainage
B - slight
C - good
D - acceptable
E - excessive

Fig. 6. Drainage Test Results
Design of Bituminous Plant Mix Friction Courses

AGGREGATES

A. Proposed Proportions (by mass) %

\[
\begin{array}{ccc}
\text{CA} & \text{FA} & \text{MF} \\
70 & 30 & \\
\end{array}
\]

B. Proposed Job Mix Gradation

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Specification Limits</th>
<th>Percent Passing</th>
<th>Job Mix Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td></td>
<td>CA FA</td>
<td></td>
</tr>
<tr>
<td>12.5 (3/8 in.)</td>
<td>100 100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>95-100 100</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>80-90 32 85</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>5-15 4 30</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>2-8 2 18</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>2-5</td>
<td>3.1</td>
<td></td>
</tr>
</tbody>
</table>

C. Specific Gravity-Unit Mass

<table>
<thead>
<tr>
<th>Type</th>
<th>Apparent SG</th>
<th>Bulk SG (dry basis)</th>
<th>Bulk Solid Unit Mass, g/cm³ (lb/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse aggregate</td>
<td>2.60</td>
<td>2.60 (U)</td>
<td></td>
</tr>
<tr>
<td>(retained on 2.36 mm (No. 8) sieve)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>2.40</td>
<td>2.40 (U)</td>
<td></td>
</tr>
<tr>
<td>(passing 2.36 mm (No. 8) sieve)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.6 mm (3/8 in.) to 4.75 mm (No. 4) Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraction</td>
<td>2.81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D. Void Capacity of Coarse Aggregate

\[
\text{Unit Mass, Vibrated, g/cm}^3 \text{ (lb/ft}^3) = 1.7 \\
\text{Voids Mineral Aggregate, (VMA)} = 35.0 (X)
\]

E. \( K_c \) Determination

\[
\begin{align*}
\text{Oil Retention (g oil per 100 g aggregate)} &= 3.5 \\
\text{Oil Retention (corrected, 2.65 SG)} &= 3.3 \\
K_c \text{ (from chart)} &= 1.45
\end{align*}
\]
### Design of Bituminous Plant Mix Friction Courses

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>B2-2431</td>
<td>ECP 285</td>
</tr>
<tr>
<td>Date Sampled</td>
<td>5/5/82</td>
<td></td>
</tr>
<tr>
<td>Date Received</td>
<td>5/7/82</td>
<td></td>
</tr>
<tr>
<td>Sampled By</td>
<td>Y. Taha</td>
<td></td>
</tr>
<tr>
<td>Date Tested</td>
<td>5/9/82</td>
<td></td>
</tr>
<tr>
<td>Tested By</td>
<td>F. Mannan</td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Proj. Inspector</td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Lab Technician</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Min. Agg. &amp; Plant Mix</td>
<td></td>
</tr>
</tbody>
</table>

#### ASPHALT

**A. Specific Gravity - Unit Mass**

Specific Gravity at 25°C = **1.02**

Unit Mass, g/cm³ (lb/ft³) = **1.02** (Uₜ)

**B. Viscosity - Temperature**

Asphalt Grade = **BS-100**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Viscosity (centistokes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>100</td>
</tr>
<tr>
<td>130</td>
<td>250</td>
</tr>
<tr>
<td>120</td>
<td>400</td>
</tr>
<tr>
<td>110</td>
<td>700</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Target: **700 to 900** (700 to 900)

**C. Asphalt Content (AC, %)**

Percent Asphalt (aggregate basis) = **6.5**

\[
2.0 k_c + 4.0 \times 2.65
\]

Apparent SG of Coarse Aggregate

9.35 mm (3/8 in.) to 4.75 (No. 4) Sieve

---

**Checked By:** T. Williams  | Title: Lab Supervisor  | Date: 5/10/82

**Materials Engineer:** J. Smith  | (Consultant)

**Resident Engineer:** J. Dunbar  | (Contractor)

**Distribution:**
- Contractor
- Resident Engineer
- Ministry
- Other (Specify)
MIXTURE DESIGN

A. Optimum Fine Aggregate Content (Y)

Using: Formula: Chart 10.4

Where: 
\[ X = \frac{1.7}{g/cm^3 (lb/ft^3)} \]
\[ U_t = \frac{2.4}{g/cm^3 (lb/ft^3)} \]
\[ U_c = \frac{2.6}{g/cm^3 (lb/ft^3)} \]
\[ U_a = \frac{1.02}{g/cm^3 (lb/ft^3)} \]

Find: 
\[ Y = \text{______} \% \text{ (limit: } 5 < Y < 15\text{)} \]

Remarks:
Target Y at 10% 

B. Optimum Mixing Temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Viscosity (centistokes)</th>
<th>Drainage</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>500</td>
<td>Good</td>
<td>X</td>
</tr>
<tr>
<td>110</td>
<td>900</td>
<td>slight</td>
<td>___</td>
</tr>
<tr>
<td>125</td>
<td>650</td>
<td>Accept.</td>
<td>___</td>
</tr>
</tbody>
</table>

C. Maximum Specific Gravity of Mixture (MRDTM 412)

Specific Gravity (vacuum saturation) = 2.485

Unit Mass (vacuum saturation) = 2.485 g/cm^3 (lb/ft^3)

D. Resistance to Effects of Water (MRDTM 414 and 415)

Air Dry Strength, Kg/cm^2 = 89.7
Wet Strength, Kg/cm^2 = 63.2
Retained Strength, (%) = 70.5  50% minimum
Air Voids, (%) = 17.5  Bulk volume by dimensional measurement.

Remarks:
# Design of Bituminous Plant Mix Friction Courses

**FILL SAMPLE NO:** 11  
**LAB SAMPLE NO:** B2-2431  
**PROJECT:** FCP 285  
**DATE SAMPLED:** 5/5/82  
**DATE RECEIVED:** 5/7/82  
**DATE TESTED:** 5/9/82  
**ROAD NO:** 202 - 203  
**ROAD NAME:** Damman - Ras Tanura  
**SAMPLED BY:** [Name]  
**TESTED BY:** [Name]  
**TITLE:** Project Inspector  
**TITLE:** Lab Technician  
**MATERIAL:** Min. Agg. Blend Mix 5  

## DESIGN SUMMARY

A. Aggregate Proportions (by mass) %  
<table>
<thead>
<tr>
<th>CA</th>
<th>FA</th>
<th>MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>83</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

B. Job Mix Gradation

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Job Mix Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm (alternate)</td>
<td></td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>100</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>96</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>41</td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>10</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>5</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>2.2</td>
</tr>
</tbody>
</table>

C. Asphalt Content

| Aggregate Basis, (%) | = 6.5 |
| Mixture Basis, (%)   | = 6.1 |

D. Mixing Temperature

| Target Value, (C) | = 120 |
| Range            | 115-125 |

E. Additives  
None

F. Recommendations

Accepted [X]  
Rejected [ ]

---

**CHECKED BY:** T. Williams  
**TITLE:** Lab Supervisor  
**DATE:** 5/10/82  
**MATERIALS ENGINEER:** J. Smith  
**R. White**  
**CONTRACTOR:** J. Dunbar  
**DISTRIBUTION:**  
Contractor [X]  
Resident Engineer [A]  
Ministry [ ]  
Other (Specify) [ ]
1. Scope
1.1 This method covers the design and testing of slurry seal mixtures for surface treatment of pavements.

2. Applicable Documents
2.1 MRDTM 204, Sieve Analysis of Fine and Coarse Aggregates,
2.2 MRDTM 301, Sampling Stone, Gravel, and Sand for Use as Highway Materials,
2.3 MRDTM 305, Specific Gravity and Absorption of Fine Aggregate,
2.4 MRDTM 307, Sieve Analysis of Mineral Filler,
2.5 MRDTM 311, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate,
2.6 MRDTM 313, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test,
2.7 MRDTM 401, Sampling Bituminous Materials, and
2.8 MRDTM 424, Testing Emulsified Asphalt.

3. Description of Term
3.1 Emulsified Asphalt Slurry Seal Mixtures-As related to these practices, mixtures of fine aggregate with or without mineral filler, with or without mixing water, uniformly mixed with emulsified asphalt.

4. Design
4.1 Aggregates
4.1.1 The fine aggregate shall consist of natural or manufactured sand, slag, crushed fines or other mineral aggregate that conforms to the quality requirements of the Specifications.
4.1.2 Smooth-textured sand of less than 1.25 percent water absorption shall not exceed 50 percent of the total combined aggregate. (For heavy duty surface requirements, use 100 percent crushed material).
4.1.3 When tested by MRDTM 313, the combined aggregate prior to the addition of any chemically active mineral fillers shall have a sand equivalent of not less than 45.
4.2 Mineral Filler
4.2.1 Mineral fillers are of two types, chemically active and chemically inactive.
4.2.2 Chemically active mineral fillers such as portland cement, hydrated lime, and ammonium sulfate are used to improve the workability, regulate the setting time and, in some cases, to alter the aggregate gradation.
4.2.3 Chemically inactive mineral fillers such as limestone dust, flyash, and rock dust are used mainly to alter aggregate gradation.
4.3 Emulsified Asphalt-The emulsified asphalt shall conform to Grade SS-1h, for emulsified asphalt, or Grade CSS-1h for cationic emulsified asphalt.
4.4 Composition of Slurry Seal Mixtures
4.4.1 A job mixture shall be selected that conforms to the specification limits, and that is suitable for the traffic, climatic conditions, curing conditions, and final use. All materials to be used shall be pretested for their suitability in the mixture as described in Sec 5.
4.4.2 The mixture shall attain an initial set in not less than 15 minutes nor more than 12 h. The setting time may be regulated by the addition of mineral fillers or chemical agents.
4.4.3 The mixture shall be one of three types, whose combined aggregates conform to the gradation requirements of Table 1.
### Table 1

Grading Requirements for Aggregate

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Amount Passing Sieve, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm) (alternate)</td>
<td>Type 1</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>100</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>100</td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>90 to 100</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>65 to 90</td>
</tr>
<tr>
<td>0.600 (No. 30)</td>
<td>40 to 60</td>
</tr>
<tr>
<td>0.300 (No. 50)</td>
<td>25 to 42</td>
</tr>
<tr>
<td>0.150 (No. 100)</td>
<td>15 to 30</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>10 to 20</td>
</tr>
</tbody>
</table>

4.43.1 Type 1 is suitable to seal cracks, fill voids, and correct surface erosion conditions. The residual asphalt content shall be from 10 to 16 mass percent of dry aggregate. It shall be applied at a rate of 3.3 to 5.4 kg/m² (6 to 10 lb/yd²). This type is used on pavements where surface sealing and skid resistance are the primary needs.

4.43.2 Type 2 is suitable to fill surface voids, correct severe surface erosion conditions, and provide a minimum wearing surface. The residual asphalt content shall be from 7.5 to 13.5 mass percent of dry aggregate. It shall be applied at a rate of 5.4 to 8.2 kg/m² (10 to 15 lb/yd²). This type is used on pavements that are severely eroded, or have numerous cracks. It may also be used as wearing surface and sealer on stabilized base courses.

4.43.3 Type 3 is suitable to provide a new wearing surface or build up a crown. The residual asphalt content shall be from 6.5 to 12 mass percent of dry aggregate. It shall be applied at a rate of 8.2 or more kg/m² (15 or more lb/yd²).

4.44 Consistency Test-This test is used to determine optimum mix design for aggregate, filler, water, and emulsion. A flow of 2 to 3 cm (or 1 to 1½ in.) is considered to be the consistency normally required for a workable field mix (Sec 5.1). 4.45 Set Time-This test determines the time required for slurry to reach initial set with paper blot method. A properly designed slurry mix should be set at the end of 12 h. A 1 h set time is considered acceptable for a quick setting slurry (Sec 5.2). 4.46 Cure Time-This test is used to determine initial cohesion of slurry mat and resistance to traffic. A properly designed slurry mix should be completely cured at the end of 24 h after placement (Sec 5.3). 4.47 Wet Track Abrasion Test (WTAT) -This test method covers measurement of the wearing qualities of slurry seal under wet abrasion conditions. Slurry shall show a loss of not more than 800 g/ml (75 g/ft²) (Sec 5.4).

5. Test Methods for Emulsified Asphalt Slurry Seal
5.1 Consistency Test 5.1.1 This test method is used to determine the proper consistency (mix design) for a slurry seal mixture. 5.1.2 The consistency test should be performed as a method of determining the optimum mix design (proper ratio of aggregate, filler, water, and emulsion) as related to proper consistency for pavement surface placement. Several mixes are made using dried aggregate and various ratios of portland cement, or hydrated lime and/or chemical modifier, water and asphalt emulsion. Mix time shall be for no less than 1 minute and not longer than 3 minutes when mixed at 25 ± 1°C.

**Note 1:** Ideal relative humidity for this test is 50 ± 5%. Results will vary at different relative humidity values.

5.1.3 Mold, metal or plastic, in the form of a frustum of a cone 38 mm (1½ in.) in diameter at the top, 89 mm (3½ in.) in diameter at the bottom and 76 mm (3 in.) in height (MRDTM 305).

5.1.4 The center of a 228 by 228 mm (9 by 9 in.) piece of 3 mm (or 1/8 in.) thick metal plate is inscribed with a circle 89 mm (3½ in.) in diameter. Three to four additional circles, each 13 mm (1/2 in.) greater in diameter than the preceding circle, are inscribed on the metal plate around the center circle, Fig. 1.

**Note 2:** Plastic plates are subject to eventual crazing and abrasion loss of the inscribed circles.

5.1.5 The mold as described in Sec 5.1.3 is loosely filled with a test slurry mix and struck off. The mold and contents are then inverted in the center of the metal plate as described in Sec 5.1.4 by placing the inscribed surface of the metal plate on the slurry-filled cone which, while holding cone and plate firmly together, is quickly inverted. The mold is removed and the contents allowed to flow over the inscribed circles until flow of the slurry stops. Project aggregate and emulsion grade are considered essential for proper relevancy of the method. 5.2 Set Time
5.2.1 This test method is used to determine the time required for the slurry mat to reach initial set (resistance to paper blot).

5.2.2 The slurry mix or mixtures that provide the desired consistency shall be repeated to determine their setting characteristics. A mix passing the consistency test is poured onto a 152 by 152 mm (or 6 by 6 in.) asphalt felt pad 13.6 kg (or 30 lb) roofing felt and screeded to 6 mm (or 1/4 in.) thickness using a 6 mm template. At the end of 15 minutes, at 25 ± 1°C and 50 ± 5% relative humidity, a white paper towel or tissue is lightly pressed or blotted on the slurry surface. If no brown stain is transferred to the paper, the slurry is considered set. If a brown stain does appear, repeat the blot procedure at 15 minute intervals. After 3 h of blotting, 30 minute (or longer) blot intervals would be suitable. Record and report the time required to obtain a stain-free blot as the set time.

5.3 Cure Time

5.3.1 Total cure of a slurry mat is obtained when complete cohesion between asphalt-coated aggregate particles occurs. A cohesion testing device is used to measure cure time.

5.3.2 A slurry mix of optimum design obtained from the use of the consistency test (Sec 4.4.4), is screeded onto a roofing felt pad to a thickness not exceeding the height of the largest aggregate fragment present in the mix. A template is recommended to obtain uniform thickness of the slurry mat.

5.3.3 After set of the slurry mat has occurred (Sec 4.4.5), the mat is placed beneath the pneumatically actuated rubber foot (25.4 mm (1 in.) in diameter) of the cohesion tester (Sec 5.3.4) (Note 3). A pressure of 1.97 kg/cm$^2$ (28 psi) is considered to be equivalent to that exerted by an average automobile. The rubber foot is twisted by means of a hand torque tester (Sec 5.3.4) (Table 2). The torque procedure is repeated at 15 to 30 minute intervals until the highest torque reading obtainable remains constant. An undisturbed site on the slurry pad should be selected for each time-interval test. The time required to reach a constant maximum torque or until the rubber foot rides freely over the slurry mat without any aggregate particles being dislodged, is recorded as the cure time.

Note 3: A suitable rubber foot, having a durometer hardness range of 50 to 70, can be cut from a used automobile tire.

<table>
<thead>
<tr>
<th>psi (on gauge)</th>
<th>psi (on foot)</th>
<th>kg/cm$^2$ (on foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>5</td>
<td>.35</td>
</tr>
<tr>
<td>8.9</td>
<td>10</td>
<td>.70</td>
</tr>
<tr>
<td>13.3</td>
<td>15</td>
<td>1.06</td>
</tr>
<tr>
<td>17.7</td>
<td>20</td>
<td>1.41</td>
</tr>
<tr>
<td>22.1</td>
<td>25</td>
<td>1.76</td>
</tr>
<tr>
<td>24.8</td>
<td>28</td>
<td>1.97</td>
</tr>
<tr>
<td>26.6</td>
<td>30</td>
<td>2.11</td>
</tr>
<tr>
<td>31.0</td>
<td>35</td>
<td>2.46</td>
</tr>
<tr>
<td>35.4</td>
<td>40</td>
<td>2.81</td>
</tr>
<tr>
<td>39.9</td>
<td>45</td>
<td>3.17</td>
</tr>
<tr>
<td>44.3</td>
<td>50</td>
<td>3.52</td>
</tr>
</tbody>
</table>

5.3.4 Cohesion tester (Note 4) is a lightweight, portable device which can be adjusted to apply varying pressure to a slurry pad (Fig. 2). Torque can be applied with a torqometer (Note 5). The cohesion tester can be used in the laboratory or field and can be pressured with in-house air, a portable compressor, or a simple bicycle tire pump.

Note 4: Available from Boer Instrument Co. 7520 Larchwood, Woodridge, Illinois, USA 60515.

Note 5: The Model TQX-2FU Torqometer, available from Snap-On Tools Corp., 2115 S. 162nd St., P.O. Box 46, New Berlin, Wis. 53151, USA, has been found suitable.

5.4 Wet Track Abrasion Test

5.4.1 Summary of Method.

5.4.1.1 A slurry mixture of fine graded aggregate, asphalt emulsion and water is prepared to a homogeneous flowing consistency (see consistency test). The slurry is formed into a disk by pouring in the circular opening of a polymethyl methacrylate (PMMA) template resting on a larger circle of 13.6 kg (or 30 lb) roofing felt.

5.4.1.2 After removal of the template, the disk shaped specimen is dried to constant mass at 60°C. The cured slurry is placed in a water bath for 1 h, then mechanically abraded under water with a rubber hose for 5 minutes. The abraded
specimen is washed free of debris, dried at 60 C and weighed. The loss in mass is expressed as g/m² (or g/ft²) and is reported as the wear value (WTAT loss).

5.4.2 Apparatus.
5.4.2.1 Balance, capable of weighing 5000 g to within ± 1.0 g.
5.4.2.2 Planetary type mechanical stirrer, (Note 6), equipped with a 2.27 kg (5 lb) weighted rubber hose holding device (abrasion head) with about 12.7 mm (1/2 in.) free up-and-down movement in the shaft sleeve (Fig. 3).

Note 6: Hobart C-100 stirrer, available from Hobart Manufacturing Co., World Headquarters, Troy, Ohio 45374, USA, has been found suitable.

5.4.2.3 Heavy 3.2 mm (or 1/8 in.) flat bottom metal pan, approximately 330 mm or 13 in.) in diameter with 51 mm (or 2 in.) vertical side walls (20 gauge or heavier) having four equispaced screw clamps capable of securing 285 mm (11¼ in.) diameter specimen to bottom of pan (Fig. 4).
5.4.2.4 Suitable heavy gauge round bottom bowl, to contain the sample during mixing (Sec 5.4.2.2).
5.4.2.5 Long handled serving spoon, of sufficient length to project 100 mm (or 4 in.) or more out of the round bottom bowl during stirring.
5.4.2.6 Disks, supply of 285 mm (11¼ in.) diameter, cut from 13.6 kg (or 30 lb) roofing felt.
5.4.2.7 Equipment, used in specimen preparation such as a special circular polymethyl methacrylate (PMMA) template 6 mm (1/4 in.) thick with a 279 mm (11 in.) diameter circular opening (Fig. 5) and a 305 to 355 mm (12 to 14 in.) short handled window squeegee.
5.4.2.8 Force draft constant temperature oven thermostatically controlled at 60 ± 3 C.
5.4.2.9 Water bath, constant temperature, controlled at 25 ± 1 C.
5.4.2.10 Reinforced rubber hose (Note 7), with a 19 mm (3/4 in.) inside diameter and 31 mm (1 7/32 in.) outside diameter (two braid 21 kg/cm² (300 psi) green oil-resistant cover). The hose shall be cut into 125 mm (or 5 in.) lengths and drilled with two paired 9 mm (1/8 in.) holes aligned on 102 mm (4 in.) centers. Drill holes through convex and concave sides of hose.

Note 7: Uniroyal P-290 general-purpose air hose, available from Uniroyal, Inc., P. O. Box 1126, Wall Street Station, New York, NY 10005, USA, has been found suitable.

5.4.2.11 Wooden prop block or equivalent for supporting platform assembly in position during testing.
5.4.3 Preparation of Test Specimen.
5.4.3.1 The proper ratio of portland cement (or hydrated lime or other additives), water, and asphalt emulsion to the dry mass of the aggregate shall be predetermined in the laboratory or by a functional field mix design previously accepted by the Project Engineer.
5.4.3.2 Quarter a sufficient amount of the air dried aggregate passing a 4.75 mm (No. 4) sieve to obtain at least 800 g in one quarter.
5.4.3.3 Weigh 800 g of aggregate into mixing bowl. Using the spoon, dry mix the mineral filler into the aggregate for 1 minute or until uniformly distributed. Add the predetermined amount of water and mix again for 1 minute or until all aggregate particles are uniformly wetted. Finally add the predetermined amount of emulsion and mix for a period of not less than 1 minute and not more than 3 minutes.
5.4.3.4 Place the opening in the template over the 285 mm (or 11¼ in.) diameter disk of smooth roll roofing. Immediately pour the slurry onto the smooth roll roofing disk (Fig. 8).
5.4.3.5 Squeegee the slurry level with the top of the template with minimum of manipulation (excessive squeegeeing contributes to segregation). Scrape off excess material and discard.
5.4.3.6 Remove the template. Place the molded specimen in the 60 C oven and dry to constant mass (minimum 15 h drying time).
5.4.4 Procedure.
5.4.4.1 Remove the dried specimen from the 60 C oven. Allow to cool to room temperature and weigh.
5.4.4.2 After weighing, place the specimen in the 25 C water bath for 60 to 75 minutes.
5.4.4.3 Remove the specimen from the water bath and place in the 330 mm (or 13 in.) diameter flat bottom pan. Secure the specimen to the pan bottom by tightening the four wing nuts.
5.4.4.4 Completely cover the specimen with at least a 6 mm (or 1/4 in.) depth of water at 25 C.
5.4.4.5 Secure the pan containing the specimen on the platform of the device (Fig. 3). Lock the rubber hose abrasion head on the shaft of the H machine. Elevate the platform until the rubber hose bears on the surface of the specimen. Use the prop block to support the platform assembly during testing (Note 8).

Note 8: Install a fresh section of hose after completion of each test. It is permissible to rotate the hose one half turn after each test run and obtain a fresh section for the next specimen.
5.4.4.6 Switch to the low speed of the machine (approximately 144 shaft rpm at 61 turns of the planetary). Operate the machine for 5 minutes ± 2 s running time.

5.4.4.7 Remove the specimen from the pan after the abrasion cycle and wash off debris. Place the washed test specimen in the 60 C oven and dry to constant mass.

5.4.4.8 The dried specimen is removed from the 60 C oven, allowed to reach room temperature and weighed. The difference between this mass and the mass obtained in Sec 5.4.4.1 is multiplied by 32.9 to express the loss in g/m² (or 3.06 for loss in g/ft²) (wear value) (Note 9).

**Note 9:** The factors 32.9 and 3.06 are used to convert the loss for the actual abraded area, 0.326 ft² to a 1 m² or 1 ft² basis. These values only apply to the Hobart C 100 machine with a 125 mm (5 in.) rubber hose.

5.4.5 Report the wear value (WTAT loss) in g/m² (or g/ft²).

### 6. Report

6.1 Report the design results on Form No. MRDWS 427.
Fig. 1. Cone Consistency Test (Not to Scale)

Fig. 2. Cohesion Tester (Front View)
Fig. 3. Specimen in Place Ready for Test

Pan 330 mm (13" I.D.) (20 Ga)
54 mm (2 1/8)

7.9 mm (5/16") Clearance
6.35 x 508 x 25.4 mm (1/4" x 20 x 1") R.H. Bolts
273 mm (10 3/4 in.)
(To Fit Pins on Hobart Mixer)

9.5 mm 3/8" Hole
Bottom Plate 355.6 mm (14 in.)
Dia. 3 mm (1/8 in.) Steel Plate

Fig. 4. Diagram of Pan

Fig. 5. Squeeging, Slurry into Mold
Fig. 6. Components of Abrasion Head

Fig. 7. Assembled Abrasion Head

Fig. 8. Funnel Flow Consistency Test
## Slurry Seal Design

### Field Sample No.
- 12

### Lab Sample No.
- 82-RA32

### Project
- FCP 285

### Date Sampled
- 5/1/82

### Date Received
- 5/17/82

### Sampled By
- Y. Taha

### Date Tested
- 5/9/82

### Tested By
- F. Manzouh

### Title
- Field Inspector
- Lab Technician

### Materials
- Sand for Slurry Seal
- Aggregate Type

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Asphalt Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
</tr>
</tbody>
</table>

### Consistency Test*

*Only acceptable mixes should be further tested.

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Flow (mm, 20-30 required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
</tr>
</tbody>
</table>

### Set Time Test*

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Set Time (h, 1.2 required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td>4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

### Cure Time Test*

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cure Time (h, 24h max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
</tbody>
</table>

### Wet Track Abrasion Test

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Initial Mass g</th>
<th>Final Mass g</th>
<th>Change in Mass g (A1)</th>
<th>WTAT Loss g/m² (32.9 x A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>15.35</td>
<td>15.09</td>
<td>0.26</td>
<td>8.35</td>
</tr>
<tr>
<td>3</td>
<td>16.38</td>
<td>16.38</td>
<td>0.20</td>
<td>6.58</td>
</tr>
</tbody>
</table>

Acceptable Mixes: Mix #3

### Remarks:

### Checked By:
- T. Williams

### Materials Engineer:
- J. Smith

### Resident Engineer:
- J. Dunbar

### Distribution:
- Contractor
- Resident Engineer
- Ministry
- Other (Specify)