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Manual of

Laboratory Mix Design Procedure for Cold In-place Recycling using Foamed Asphalt (CIR-foam)

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1. APPARATUS

The following sets of laboratory equipment are required to carry out the laboratory mix design of foamed asphalt mixtures:

1.1 Laboratory Asphalt Foaming Equipment (Wirtgen WLB 10)

Laboratory mix design using foamed asphalt requires a laboratory foamed asphalt unit capable of producing foamed asphalt at a rate between 50g and 200g per second. The method of production should closely simulate that of a full-scale production of foamed asphalt. The equipment should have a thermostatically controlled asphalt tank capable of holding a mass of 10 kg of asphalt binder at the specified temperature from 150°C to 200°C, within a range of ± 5°C. In addition, a low-pressure compressed air supply of 0 – 500kPa with an accuracy of ± 2 kPa should be included in the apparatus. The equipment should have specialized expansion chamber for adding cold water to the hot asphalt, varying in percentage from 0% to 5.0% (by mass of asphalt binder) with an accuracy of ± 0.2%. Finally, the equipment should be designed so that the foam can be discharged directly into the mixing bowl of an electrically driven laboratory mixer with a capacity of at least 10kg.

1.2 Gyratory Compactor

Gyratory compactor meets all ASTM and AASHTO requirements. External angle of gyration should be 1.25° and gyration rate should be 30 rpm. The consolidation pressure should be set at 600kPa. It should be equipped to compact a specimen with a diameter of 101.6 mm.

1.3 Modified Proctor Test Equipment

The hand compact hammer should meet ASTM and AASHTO standards and equipped with a loosely-fitting guide sleeve to control drop height without restricting free fall. The mold should be 152mm in diameter and 116.44mm in height with a detachable extension collar and base plate.

1.4 Sample Conditioning Devices

- Oven with fan-forced-air circulation system reaching up to 200°C with the accuracy of 0.1°C.
- Aluminum volumetric container and a vacuum pump with a maximum vacuum capacity of 760 mm Hg.
- Water bath with a temperature controller ranging from 0 to 80°C.

1.5 Testing Equipment

The standard Marshall testing equipment should have a loading capacity of 5,000lbs at a rate of 50.8mm per minute. The breaking head of indirect tensile strength has upper and lower stainless steel loading strips (W x L = 12.7mm x 76.2mm) with concave contact surface having 58.8 mm radius of curvature, equal to curvature of standard nominal 100mm diameter.

1.6 Other Miscellaneous Devices

- Digital caliper to measure up to 150mm with resolution of 0.01 mm.
- Balance to weigh up to 20 kg with an accuracy of 1g.
- Thermometer to measure a temperature from 0°C to 200°C with the accuracy of ± 0.1°C
- Spatula with a blade of approximately 150mm in length

2. OPTIMUM FOAMING CHARACTERISTICS

The objective is to determine the optimum percentage of water needed to produce the best foam properties for a given asphalt binder. The optimum water content is determined by achieving the maximum expansion ratio and half-life of the foamed asphalt. Expansion ratio is defined as the maximum volume over its original volume and half-life is defined as the time in seconds for foam to become a half of its maximum volume.

2.1 Calibration of Asphalt Foaming Equipment

First, check the asphalt binder discharge rate, normally set at 100g/second (Wirtgen WLB 10). If it does not discharge 100g / second, adjust the water flow rate following Eq. 1.

$$Q_{H_2O} = \frac{Q_A \times P_{H_2O} \times 3.6}{100} \qquad \text{(Eq. 1)}$$

Where:

Q_{H_2O} = Water flow-through volume (ℓ/h)

P_{H_2O} = Asphalt flow-through volume (g/s)

Q_A = Water content (%)

3.6 = Calculation factor

2.2 Foaming Test Process

2.2.1 Fill water tank and connect the pressured air hose to the air tank.

2.2.2 Heat asphalt to the appropriate temperature, ranging from 160°C to 200°C and maintain it for at least 5 minutes before starting the foaming process.

2.2.3 Set air pressure at 400kPa and water pressure at 500kPa. Water pressure must be higher than air pressure by 100kPa.

2.2.4 Measure expansion ratio and half-life for water content from 1.0% to 4.0%, at 1.0% increments. In five seconds, the foaming equipment produces foamed asphalt and discharges it into a container with a diameter of 27cm (500g of asphalt binder). To determine the expansion ratio, measure the maximum height of the foamed asphalt in this container using a graduated dipstick. Then divide the maximum expansion volume (V_{max}) by the original asphalt volume

(V_{min}). The half-life is defined as the duration in seconds it takes for foamed asphalt to change from the maximum expansion to its half as shown in Figure 1.

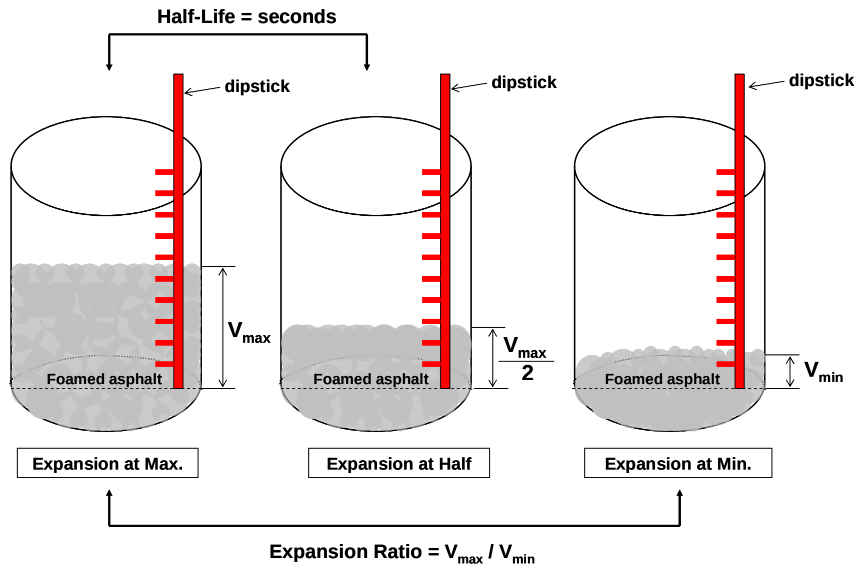


Figure 1. Illustration of expansion ratio and half-life

2.2.5 Plot expansion ratio and half-life against foaming water content. For each level of foaming water content from 1.0% to 4.0% at 1.0% increments, three measurements of expansion ratio and half-life should be made. The average of the three test results should then be plotted against water content as illustrated in Figure 2. The optimum foaming water content is determined at the intersection of the two graphs of expansion ratio and half-life versus water content.

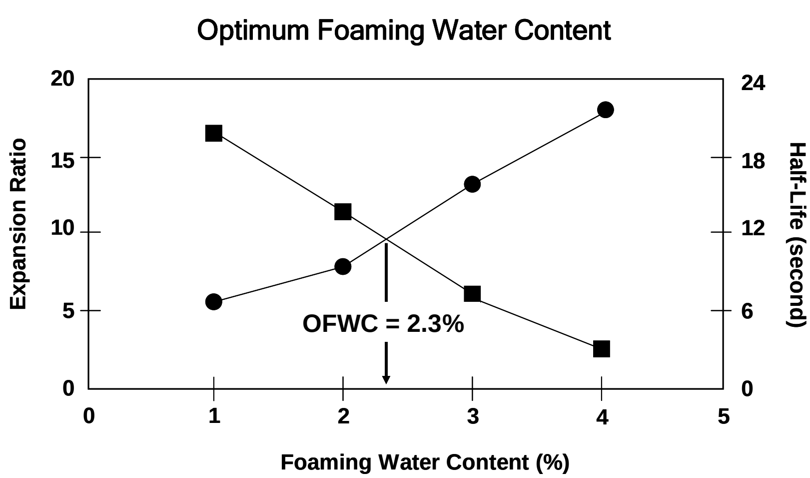


Figure 2. Expansion ratio and half-life plotted against foaming water content

3. RAP SAMPLE PREPARATION

To determine the field gradation, the sieve analysis should be performed using the RAP materials collected from the field. The RAP materials larger than 25mm should be discarded. To produce the laboratory specimens of the field gradation, the remaining RAP materials should be divided into five stockpiles retained on each of the following sieves, 19mm, 9.5mm, 4.75mm, 1.18mm and the ones passed 1.18mm sieve and re-blended.

4. OPTIMUM MOISTURE CONTENT FOR RAP MATERIAL

The optimum moisture content during mixing and compaction is considered as one of the most important mix design criteria for CIR-foam mixtures. The modified proctor test should be conducted in accordance with the ASTM D 1557 “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (2,700 kN-m/m^3)”.

5. COMPACTION METHOD

To simulate the compaction level in the field, 30-gyration of Superpave gyratory compactor should be used to produce CIR-foam test specimen with a diameter of 100mm.

6. CURING CONDITION

To create a representative sample from the CIR-foam pavements in the field, the compacted foamed asphalt specimens should be cured in the oven for three days at 40°C.

7. SAMPLE SATURAION AND CONDITIONING

The cured specimen should be placed under water at 25 ºC for 30 minutes and, to achieve the 100% saturation level; a vacuum of 20 mmHg should be applied for 30 minutes. The saturated specimen is then placed under water for additional 30 minutes.

8. TESTING METHOD

The indirect tensile strength test should be performed on three saturated CIR-foam mixtures for each of five foamed asphalt contents ranging from 1.0% to 3.0% at 0.5 increments.

9. DETERMINATION OF OPTIMUM FOAMED ASPHALT CONTENT

The optimum foamed asphalt content (FAC) is determined where the maximum indirect tensile strength is obtained.

10. STEP BY STEP MIX DESIGN PROCEDURE

Based upon the critical mix design parameters identified, the laboratory mix design procedure of CIR-foam mixtures is developed.

Step 1. RAP Preparation

1.1 Prepare cold water for mixing with RAP materials.
2.2 Prepare RAP materials of 4500-gram for a set of three gyratory specimens.

Step 2. Mixing

2.1 Put RAP materials and 85% of its optimum moisture content into a bowl. Start mixer slowly at the speed level 2 using dough hook and mix for approximately 30 seconds.
2.2 Set the optimum foaming water content and spray the foamed asphalt to wet RAP materials and mix for 30 seconds.

Step 3. Compaction

3.1 Weigh foamed asphalt mixture of 1150g and place it into 101.6mm-gyratory mold. Once the mixture is in the mold, the edges should be spaded 10-15 times and the center spaded 5-10 times. Do not use paper or release discs.
3.2 Compact the foamed asphalt mixture by applying 30 gyrations of the Superpave Gyratory compactor with an external angle of 1.25°, gyration rate of 30 rpm, and consolidation pressure of 600kPa.
3.3 Extrude the competed specimen from the gyratory mold immediately.
3.4 Prepare 15 specimens, 3 specimens for each of five different foamed asphalt contents ranging from 1.0% to 3.0% at 0.5% increments.

Step 4. Curing

4.1 Place the compacted foamed asphalt specimens in the oven at 40°C.
4.2 Cure the compacted specimens for three days.
4.3 After oven curing, allow specimens to cool to room temperature. This takes about two hours, but can be reduced to 15 minutes if a fan is used.

Step 5 Measure Volumetric Characteristics

5.1 Measure dry weight of foamed asphalt specimens after curing is completed.
5.2 Calculate bulk specific gravity G_{mb} following the ASTM D 1188.
5.3 Measure theoretical specific gravity following the ASTM D 4123.
5.4 Compute air void.

Step 6. Vacuum Saturation of Specimens

6.1 Place foamed asphalt specimens in 25°C water bath for 30 minutes, saturate at a vacuum of 20 mmHg for 30 minutes, and then place the specimens in water bath for additional 30 minutes.

Step 7. Indirect Tensile Strength Test

7.1 Perform indirect tensile strength testing following the ASTM D 2041.

7.2 Calculate the average indirect tensile strength of three specimens for five different foamed asphalt contents.

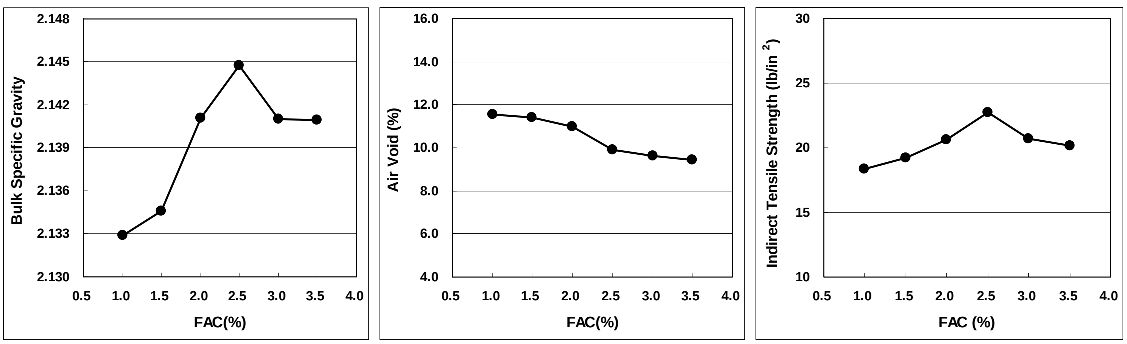
Step 8. Optimum Foamed Asphalt Content

8.1 Plot the following three graphs as shown in Figure 3.

(1) Bulk Specific Gravity vs. Foamed Asphalt Content (FAC)

(2) Air Void vs. Foamed Asphalt Content (FAC)

(3) Indirect Tensile Strength vs. Foamed Asphalt Content (FAC)



(a) G_{mb} vs. FAC (b) Air Void vs. FAC (c) ITS vs. FAC

Figure 3. Plots of ITS, Air void and G_{mb} vs. FAC

8.2 Determine the optimum foamed asphalt content (FAC), which gives the maximum indirect tensile strength value as shown in Figure 4.

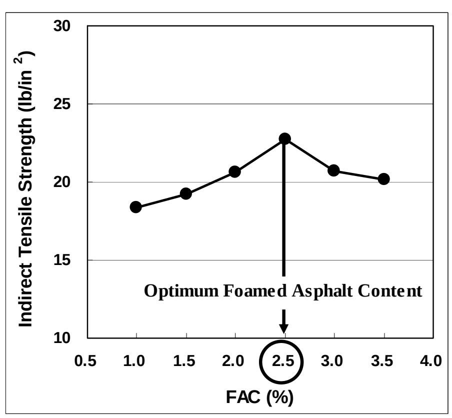


Figure 4. Determination of optimum foamed asphalt content

APPENDIX:

The attached pictures would help a user to understand how to follow the CIR-foam mix design process in the laboratory.

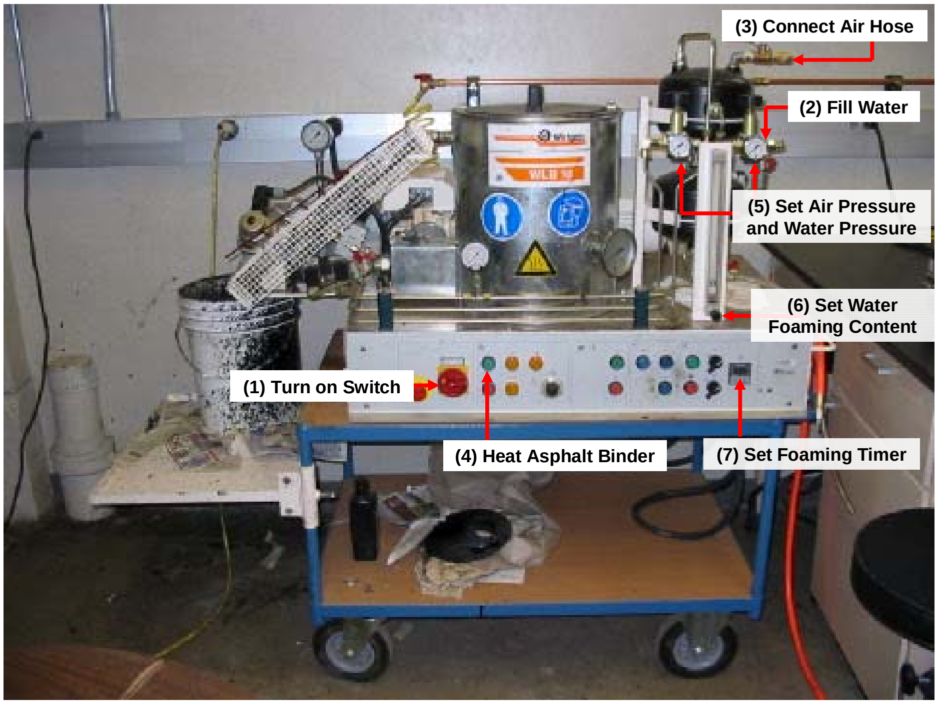
I. Foaming Test Process Using Laboratory Foaming Equipment

II. RAP Preparation

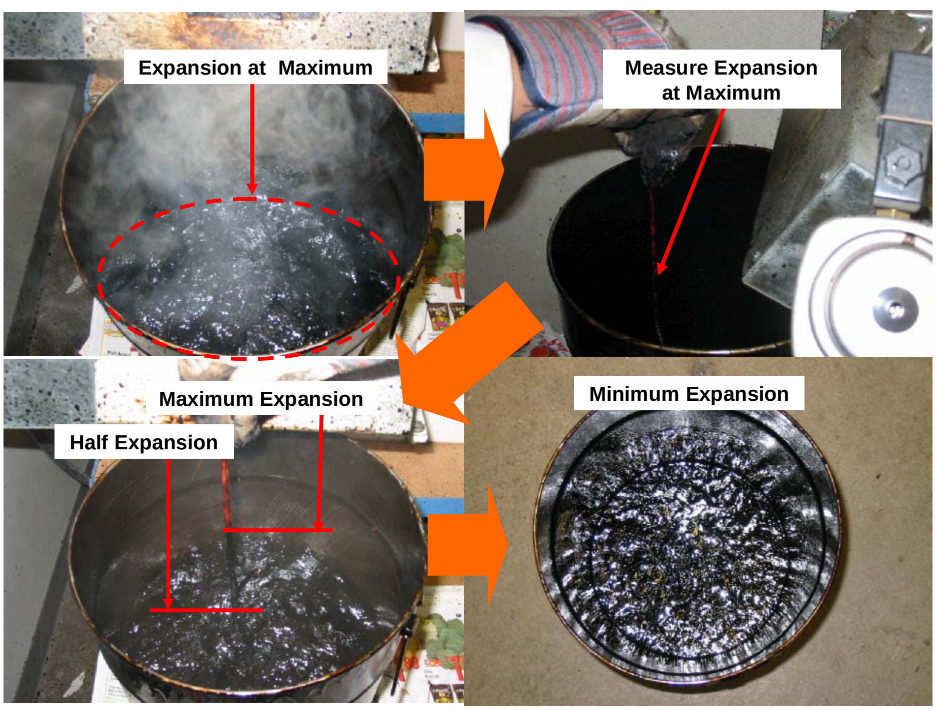
III. Step by Step Mix Design Procedure

I. Foaming Test Process Using Laboratory Foaming Equipment

Preparation of Foaming Test

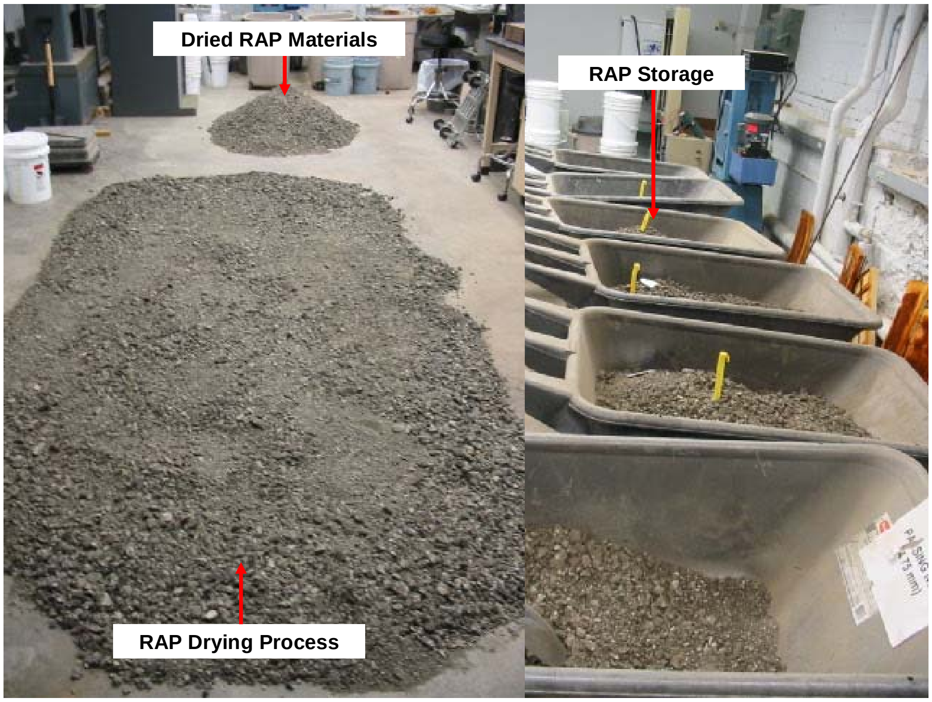


Measurement of Expansion and Half-Life

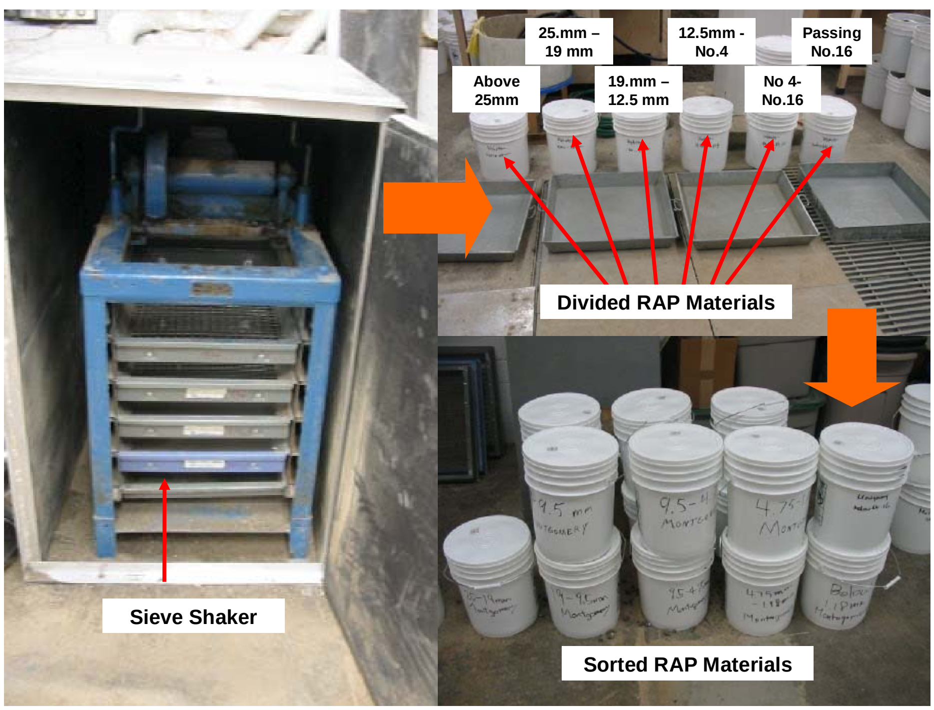


II. RAP Preparation

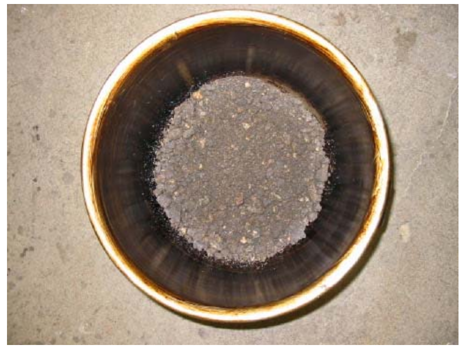
RAP Drying Process

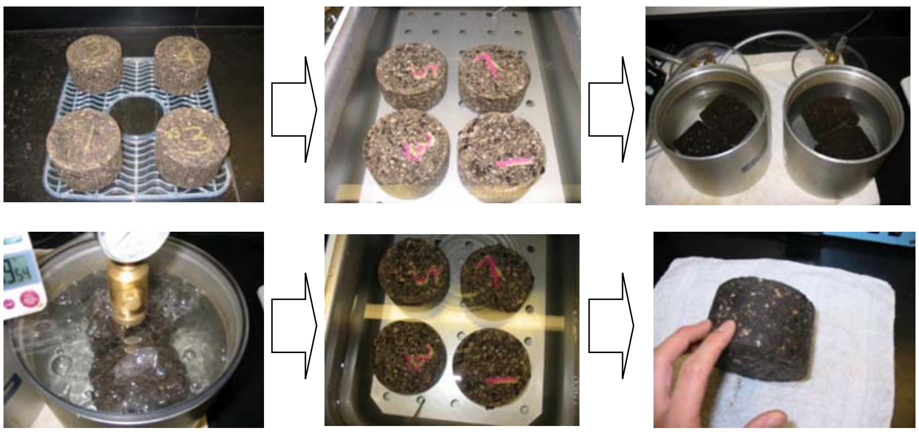
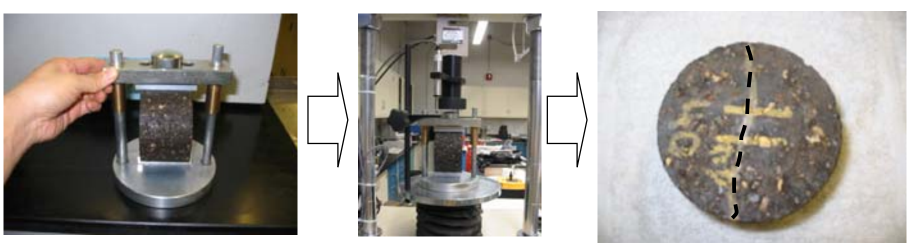


Sorting RAP Materials



III. Step by Step Mix Design Procedure

 	**RAP Preparation (STEP 1)**
 	**Mixing (STEP 2)**
 	**Compaction (STEP 3)**
 	**Curing (STEP 4)**

	**Volumetric Characteristic (STEP 5)**
	**Saturation Process (STEP 6)**
	**Indirect Tensile Strength (STEP 7)**