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METHOD OF TEST FOR DETERMINATION OF THE TARGET CEMENT CONTENT FOR IN-PLACE FULL-DEPTH RECYCLING OF ASPHALT PAVEMENTS USING CEMENT

A. SCOPE

This test method describes the procedure for determination of the target cement content for in-place full-depth recycling of asphalt pavements using cement (FDR-C). FDR-C is a process in which all of the asphalt concrete section and a predetermined amount of underlying materials are treated with cement. This test method is divided into the following parts:

1. Obtaining field samples
2. Mix design
    a. Preparation of materials for lab tests
    b. Determination of minimum cement content
    c. Determination of optimum moisture content and maximum dry density
    d. Determination of optimum cement content
3. Reporting of results

B. REFERENCE

AASHTO M 231	Standard Specification for Weighing Devices Used in the Testing of Materials
AASHTO R 76	Standard Practice for Reducing Samples of Aggregate to Testing Size
ASTM C109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)
ASTM D1557-12	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lb/ft^3 (2,700 kN-m/m^3))
ASTM D1633-17	Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders

ASTM E11	Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves
CT 105	Calculations Pertaining to Gradings and Specific Gravities
CT 202	Method of Test for Sieve Analysis of Fine and Coarse Aggregates
CT 206	Method of Test for Specific Gravity and Absorption of Coarse Aggregate
CT 216	Method of Test for Relative Compaction of Untreated and Treated Soils and Aggregates
CT 226	Method of Test for Determination of Moisture Content of Soils and Aggregates by Oven Drying

C. SIGNIFICANCE AND USE

This practice outlines standard procedures for determining optimum moisture content and optimum cement content of in-place recycled asphalt pavements. Its purpose is to produce FDR-C materials that satisfies mix design requirement.

D. APPARATUS

1. Modified Proctor Rammer and Mold: A compaction rammer and 4 in. (100 mm) split mold conforming to ASTM D1557.
2. Compression Testing Machine: A mechanical or hydraulic testing machine as specified in ASTM D1633 to provide an accurate rate of strain of 1.3 mm/min (0.05 in./min) or a rate of stress of 70 to 210 kPa/s (10 to 30 psi/s).
3. Balance: A balance or scale accurate to 0.1 g and having a minimum capacity of 5 kg. conforming to AASHTO M 231, Class G2.
4. Straightedge: A metal straightedge minimum 250 mm (10 in.) in length which conforms to the straightness and edge requirements of ASTM D1557.
5. Sieves: Woven-wire cloth sieves that meet the designations required by the specifications and have square openings conforming to ASTM E11. Sieves: 3 in., 2 in., 1.5 in., #4.
6. Metal Pans: Pans having a surface area of 75 to 100 in^2, approximately 2 in. deep.
7. Sieve Shaker: A mechanical sieve shaking device that conforms to the requirements specified in California Test 202.

8. Mixer: A pugmill style mixer or equal device capable of mixing up enough quantity of samples for the mix design.
9. Ovens: A forced draft oven with free circulation of air capable of maintaining a range of temperatures between 40°C ± 0.5°C and 60°C ± 1°C (104°F ± 1°F and 140°F ± 3°F).
10. Calipers: Calipers with accuracy to measure the length and diameter of test specimens to the nearest 0.01 mm (0.004 in.).
11. Thermometer: Thermometer capable of measuring temperatures from 0°C to 50°C (32°F to 120°F) with a minimum accuracy of 0.5°C.
12. Capping Plates: Shall be glass plates at least ¼ in. (6 mm) thick, 6 in. (150 mm) square, and the working surfaces shall not depart from a plane by more than 0.002 in. (0.05 mm) in 6 in. (150 mm).
13. pH Meter: A pH meter equipped with reference electrode and low-sodium error glass pH-sensitive electrodes (or combination electrode) and a meter capable of displaying 0.01units pH at 0.02 pH resolution over a range from 0 to 14. The meter must have a pH set-point of 12 or allow for "user selectable" calibration. Calibrate the pH meter in accordance with the manufacturer's instructions.
14. Plastic or Glass Beakers: Six 200 mL (or larger) beakers
15. Containers: Airtight containers capable of holding 1.5 kg to 25 kg (3 lb to 50 lb) of recycled pavement materials.

E. MATERIALS

1. Reclaimed asphalt pavement (RAP)
2. Aggregate base, subbase material, and native material
3. Supplemental aggregate base or supplemental fines if required in the design
4. Cement
5. Water
6. Distilled water
7. High-Strength Gypsum Cement Paste mixed with water at a ratio not to exceed 0.30 and develop a minimum compressive cube strength of 2000 psi at 2 hours, using 2 in. (50 mm) molds, as described in paragraph 5.3 of ASTM C109.

F. OBTAINING FIELD SAMPLES FOR MIX DESIGN

Samples of the pavement to be recycled shall be obtained for the full recycling depth of the pavement including base material from the areas to be recycled.

The purpose of the samples is for mix design and to determine if the thickness of the existing pavement is suitable for the recycle depth proposed.

Additional samples shall be obtained and separated for individual mix design analysis if visual observations indicate a variation in materials within an area of major distress (i.e., large patches or rutted areas). The thickness of individual layers and type of material in the projected recycled depth shall be determined. If differing material types are observed, samples shall be obtained at each differing material type location and a mix design shall be conducted for each material type. Obtain samples at various locations along the pavement to assess the consistency of the underlying pavement condition. Include samples near the centerline, between wheel paths, and at the pavement edge. If FDR-C is to be performed on the paved shoulders, samples shall be taken from them as well. For a new structural section or any change in existing pavement section that requires a new mix design, perform pavement sampling. Approximately 350 pounds of material should be collected for each mix design.

Minimum sampling frequency shall be as follows:

Highways:

- 0.2 mile maximum between samples in the same lane.
- 0.5 mile offset of cores in adjacent lane.
- Shoulder shall not be sampled if shoulder is not getting recycled.
- At least 15 percent of the sampling shall be in the shoulder if the shoulder is getting recycled.
- At least 25 percent of the sampling shall be on or within 3 feet of the centerline.

Arterials and Rural Roads

- 2000 foot maximum between samples in the same lane.
- 1000 foot offset of cores in adjacent lane.
- Shoulder shall not be sampled if shoulder is not getting recycled.
- At least 25 percent of the sampling shall be in the shoulder if the shoulder is getting recycled or within 3 feet of the gutter.
- At least 25 percent of the sampling shall be on or within 3 feet of the centerline.

Option 1: From pavement cores or slabs

Cores: Use a combination of full-depth cores and mechanical removal (augering) or hand removal to the prescribed recycling depth to acquire sufficient material for the mix design. Large diameter cores (> 8 in) are recommended. Record each material layer thickness and final depth of excavation.

Slabs: Excavate a test pit approximately 3 ft by 3 ft (0.9 m by 0.9 m) to the depth specified in the project plans for in-place recycling.

Separate asphalt pavement cores/slabs from the unbound materials. Clean the surface of cores/slabs and remove any residuals. If the project requires pre-milling prior to FDR-C, remove the top undesired wearing coarse from the cores/slabs. Break down or crush the asphalt pavement cores/slabs using a laboratory milling machine, a jaw crusher, or an equivalent device. The milling/crushing method shall model the gradation of recycled asphalt pavement (RAP) expected from reclaiming operations during construction.

The following table provides material mass for an 8-in diameter core of each material. The layer thickness in the table represents the existing layer thickness for asphalt mix and aggregate base, and the layer thickness for native soil is the difference between the designed FDR-C thickness and the combined layer thickness of asphalt mix and aggregate base. The number of cores needed for each material will be estimated based on: total material required for mix design, percentage of each material determined by thickness ratio, and material provided by each material core.

TABLE 1.

Mass Estimates in Pounds (lb) for Each 8-inch Core Based on Layer Thickness

Material	Unit Weight (lb/ft^3)	Layer Thickness (in)											
		1	2	3	4	5	6	7	8	9	10	11	12
Asphalt mix	150	4	8	13	17	22	26	31	35	39	44	48	52
Aggregate Base	130	4	7	11	15	19	23	26	30	34	38	42	45
Native Soils	110	3	6	10	13	16	19	22	26	29	32	35	38

Option 2: From the milled pavement

Samples can be obtained by milling the existing asphalt pavement provided the milling operation only penetrates to the planned recycled depth. If the project requires pre-milling prior to FDR-C, pre-mill the sampling area to the specified depth. Milling depth shall be consistent with the project design and the milling method should provide materials that: 1) are representative of FDR materials produced during construction; and 2) have the gradation that matches the expected field gradation as closely as possible.

Excavate sufficient materials from the milled section and record the layer thickness of each material type.

G. PREPARING SAMPLES FOR MIX DESIGN

Obtain representative samples of any supplemental materials that will be added during FDR-C operations (e.g., aggregate base to increase thickness or supplemental fines to improve gradation). Dry the sampled materials and any supplemental materials to a constant mass. Drying may be performed by any means that does not heat the aggregate in excess of 140°F (60°C) or cause degradation of the particles.

1. For materials obtained using Section F, option 1:
   a. Determine the dry density of the RAP, base(s) and underlying soils in accordance with ASTM D 1557, Method B.
   b. Calculate the percent masses of RAP and unbound materials that represent FDR-C section to be recycled. If pre-milling is specified prior to FDR-C, deduct the pre-mill depth from the existing asphalt layer to determine the proportion of RAP to be incorporated into the mix. Use layer thickness(s), dry density of the RAP, the base(s) and soils to calculate the percent masses of each material for the designated recycling depth.
   c. Thoroughly blend crushed RAP and unbound materials based on the calculated percent masses determined in the previous step. The combined material is then considered as the "recycled material" and will be used for mix design in this laboratory procedure.

      Note: If supplemental materials will be added during FDR-C operations, add the same amount of materials to the blended sample and mix them thoroughly.

2. For materials obtained using Section F, option 2:

   If supplemental materials will be added during FDR-C operations, add the same amount of supplements to the material obtained from the milling process and mix them thoroughly. The final mix is considered as the "recycled material".

H. MIX DESIGN

H.1 GRADATION

Reduce the amount of recycled material to sample size in accordance with AASHTO R 76. Perform sieve analysis on the reduced material in accordance with California Test 202. The gradation of recycled material shall meet the requirements specified in Table 2.

TABLE 2.
Recycled Material Gradation Requirements

Sieve Size (in.)	Sieve Size (mm)	Requirement (% passing)
3.0	75	100
2.0	50	95 – 100
1.5	38	85 – 100
#4	4.75	> 55

H.2 DETERMINATION OF MINIMUM CEMENT CONTENT

The minimum cement content also known as initial consumption of stabilizer (ICS) is the minimum percent cement required to permanently stabilize the recycled material. Determine the minimum percentage of cement as follows:

1. Sieve sufficient amount of recycled material over the 3⁄4-in. (19.0-mm), and No. 4 (4.75-mm) sieves. Determine the percentage of material, by oven-dry mass, retained on the 3⁄4-in., and No. 4 sieves.
2. Select and maintain separate representative samples of recycled material passing the No. 4 sieve and passing the 3⁄4-in. sieve and retained on the No. 4 sieve. Prepare approximately 2 kg (4.4 lb) of recycled material test fraction by removing material retained on the 3⁄4-in. (19.0-mm) sieve and replacing it with an equal mass of material passing the 3⁄4-in. sieve and retained on the No. 4 sieve.
3. Reduce the bulk sample to six 200.0 ± 10.0 g samples in accordance with AASHTO R 76 and place each sample into a 200 mL or larger plastic or glass beaker.
4. Calculate the mass of cement needed to achieve 1, 2, 3, 4, 5, and 6 percent cement by dry mass of the recycled material. Add cement to the beakers and thoroughly mix the recycled material and the cement with a spoon.
5. Add distilled water to sufficiently oversaturate the samples. The material is considered to be oversaturated when the pores are filled with water and free water is observed on the surface. The surface particles do not need to be completely submerged. Maintain the temperature of the mixture at approximately 25 ± 1°C.

6. Mix the samples in the beakers with a spoon for a minimum of 30 seconds until there is no evidence of dry material at the bottom of the beaker. Continue to mix for 30 seconds every 10 minutes.
7. After 60 minutes, make an impression about 25 mm deep into the center of the sample with a scoop or spatula.
8. Place the electrode into the prepared impression and ensure complete contact with the sample with several taps on the sides of the beaker.
9. Record the pH of each sample to the nearest 0.02 of a unit.
10. Determine the lowest percentage of cement at which the pH of sample remains constant and report it as the minimum cement content (i.e., ICS).

H.3 DETERMINATION OF OPTIMUM MOISTURE CONTENT AND MAXIMUM DRY DENSITY

Determine the optimum moisture content and maximum density of cement treated recycled material in accordance with ASTM D1557-12 Method B except for the following:

1. Replace the 3rd sentence in Section 6.1 with:

   The walls of the mold shall be split. Solid wall molds shall not be used.

2. When preparing samples for compaction in accordance with Section 10, use the following scalping technique to obtain test fraction of recycled material required for compaction.

   a. Sieve recycled material over the 3⁄4-in. (19.0-mm), and No. 4 (4.75-mm) sieves. Determine the percentage of material, by oven-dry mass, retained on the 3⁄4-in., and No. 4 sieves.
   b. Select and maintain separate representative samples of FDR material passing the No. 4 sieve and passing the 3⁄4-in. sieve and retained on the No. 4 sieve. Prepare final test fraction of recycled material by removing material retained on the 3⁄4-in. (19.0-mm) sieve and replacing it with an equal mass of material passing the 3⁄4-in. sieve and retained on the No. 4 sieve.
   Note: Using the scalping technique, the percentage by oven-dry mass of material retained on the No. 4 sieve in the test sample shall be the same as the percentage retained on the No. 4 sieve in the original sample.

3. When preparing samples for compaction in accordance with Section 10, add the minimum cement content (determined in Section H.2) plus 1% by dry mass (ICS + 1%) to the final test fraction of recycled material and mix them thoroughly.

H.4 DETERMINATION OF TARGET CEMENT CONTENT

The target cement content is determined from the unconfined compressive strength of the cement stabilized recycled material.

Use three cement contents, starting with the ICS and increasing by 0.5% or 1.0% to determine the optimum cement content. One of the cement contents must be the minimum cement content (determined in Section H.2) plus 1% by dry mass (ICS + 1%).

H.4.1 FABRICATION OF SPECIMENS FOR COMPRESSIVE STRENGTH TEST

1. Prepare recycled material test fraction in accordance with ASTM D1557 Method B and Section H.3, items 1 and 2 of this test method.
2. Determine the amount of material required to fabricate nine compacted specimens.
3. Split a representative sample of sufficient size to generate three specimens from the recycled material in accordance with AASHTO R 76. Place the sample into the mixing tray and add the first cement content by mass of the recycled material. Add the amount of water determined in Section H.3.
4. Mix the material for a minimum of three minutes to ensure uniform stabilization. After mixing, cover the mixing tray with damp cloth to prevent evaporation of the mixing moisture.
5. Determine the mass of FDR-C material needed to achieve the density determined in Section H.3.
6. Split the FDR-C material into three equal samples at the approximate mass determined in Step 5 and place each into a covered container to prevent evaporation of the mixing moisture. Place any unused material into a covered container.
7. Fabricate three compacted specimens at room temperature in accordance with ASTM D1557 Method B with the exceptions specified in Section H.3.
8. Determine the moisture content of the excess material in accordance with California Test 226 halfway through the compaction process.
9. Repeat steps 3 through 8 two more times with the remaining two cement contents.

H.4.2 CURING

1. After removing the specimens from the molds, immediately seal them with two layers of 4-mil plastic. Ensure the plastic is tight around the specimens and seal the seams of the plastic with duct-tape to prevent moisture loss.
2. Cure the wrapped specimens in a forced draft oven at 40 ± 1°C (104 ± 3°F) for seven days.
   Note: during curing, specimens shall not be stacked or touching, and allowance shall be made for air circulation around each specimen.

H.4.3 UNCONFINED COMPRESSIVE STRENGTH MEASUREMENTS

1. Remove the specimens from the oven and allow to cool to ambient temperature (25 ± 2°C). When cooled, remove the plastic wrapping and proceed with the testing.
2. Within 2 hours after removal of specimens from the oven, determine the compressive strength of specimens in accordance with ASTM D1633-17 except for the following:
   a. Modify Section 1.2.1, by replacing "D698" with "D1557."
   b. Disregard sections 6.1 to 6.4.
   c. Replace Section 6.7 with:
      i. Before testing, cap the ends of all compression specimens with gypsum plaster. Capped surfaces shall be plane within 0.002 in. (0.05 mm). tolerance and shall be at right angles to the axis of the specimen.
      ii. Capping plates may be coated with a thin layer of mineral oil or light grease to prevent the capping material from adhering to the surface of the glass capping plate.
      iii. Thoroughly mix the neat gypsum cement and water to form a paste at the established water-cement ratio and use promptly as it will set quickly. Do not exceed the water-cement ratio determined in qualification tests.
      iv. Place the capping plate on a flat, rigid surface. Place an adequate mound of gypsum paste on the capping plate and lower the specimen onto it, applying firm, downward rotating pressure until the paste extrudes out to the bottom perimeter of the specimen. Use a bull's-eye level on top of the specimen to aid with vertical alignment to achieve perpendicular alignment to the axis of the specimen.

v. Repeat the process when capping the top of the specimen. Place a mound of paste on top of the specimen and press the capping plate against the paste with a firm, rotating pressure until the paste reaches the top perimeter of the specimen, again using a bull's-eye level for alignment. Capping plates may be removed within 45 min with gypsum cement pastes without visibly damaging the cap.

d. Replace Section 7.3 with:

Determine the moisture content of one randomly selected specimen from each cement content according to California Test 226.

3. Determine the unconfined compressive strength at each cement content by averaging the test results of three specimens.
4. Select the lowest cement content greater than ICS + 1% that satisfies the compressive strength requirement (i.e., >300 psi and <450 psi), and report it as the target cement content. If the compressive strength at ICS + 1% exceeds 450 psi, select the highest cement content that satisfies the maximum strength requirement (i.e., 450 psi), and report it as the target cement content.
5. Determine the wet density of FDR-C materials in accordance with California Test 216 and report it with your Mix Design. To prepare the samples for California Test 216, use the optimum moisture content and the optimum cement content determined in Section H.3 and Section H.4.3, respectively.

I. **REPORT** - RESERVED

J. HEALTH AND SAFETY

It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Prior to handling, testing or disposing of any materials, testers must be knowledgeable about safe laboratory practices, hazards and exposure, chemical procurement and storage, and personal protective apparel and equipment.

Only personnel trained to operate core drills or saws shall perform coring or slab sawing. Traffic control shall be performed by qualified personnel. Samples shall be shipped in sturdy containers.

End of Text
(California Test 314 contains 11 pages)