INDIANA DEPARTMENT OF TRANSPORTATION
DIVISION OF MATERIALS AND TESTS

MIX DESIGN PROCEDURE FOR COLD RECYCLING (CR) WITH ASPHALT EMULSION
ITM No. 592-23

1.0 SCOPE

1.1. This method covers the procedure for mix design of Cold Recycled pavements with asphalt emulsion, which includes Cold In-Place Recycling (CIR) and Cold Central Plant Recycling (CCPR).

1.2. This ITM may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.0 SIGNIFICANCE AND USE

2.1. This ITM is used to determine the appropriate mix design for an individual asphalt roadway by ensuring the sampled material with corresponding mix design meets specification requirements.

2.2. This ITM is used to perform the mix design procedure for Cold Recycling with Asphalt Emulsion.

3.0 REFERENCES.

3.1. AASHTO Standards

T 11 Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
T 27 Sieve Analysis of Fine and Coarse Aggregates
T 49 Standard Test Method for Penetration of Bituminous Materials
T 59 Testing Emulsified Asphalts
T 166 Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
T 209 Theoretical Maximum Specific Gravity (Gmm) and Density of HMA
T 245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
T 312 Preparing and Determining the Density of Hot Mix Asphalt by Means of the Superpave Gyratory Compactor

3.2. ASTM Standards

D7196 Standard Test Method for Raveling Test of Cold Mixed Emulsified Asphalt Samples

4.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department's Standard Specifications, Section 101.

4.1. CIR – Cold In-place Recycling

4.2. CCPR – Cold Central Plant Recycling

4.3. CR – Cold Recycling, comprised of Cold In-place Recycling and Cold Central Plant Recycling

4.4. RAP – Reclaimed Asphalt Pavement

4.5. Constant mass – Shall be defined as the mass at which further drying does not alter the mass by more than .05 percent in 2 hours.

4.6. Base Material – Aggregate type material directly below a bituminous pavement

4.7. Mix Design Blend – The selected proportions, by weight, of RAP, aggregate base and/or other additional materials to be used throughout the mix design that accurately represents the chosen depth of treatment, material proportions and material type encountered during CR construction.

4.8. Design gradation – The selected percentage of sized material used in a specimen set for mix design. Use the following sieves: 1-1/2", 1", 3/4", 1/2", 3/8", #4, #8, #16, #30, #50, #100, #200.

5.0 APPARATUS.

5.1. Laboratory, capable of maintaining room temperature 77±9°F (25±5°C)

5.2. Mechanical shaker with the appropriate screens to size material based on the gradations provided.

5.3. 100 mm Superpave Gyratory mold

5.4. Mechanical Bucket Mixer with a bowl measuring 10-12 inches in diameter shall be used. The bowl should be capable of rotating on its axis at 50 to 75 revolutions per minute. The mixer shall use a paddle which makes contact with the bottom of the bowl and shall rotate on its axis at twice the bowl rotation rate, in the opposite direction of the bowl rotation.

5.5. Laboratory Crushing Machine, capable of crushing sampled material to pass the

1.25 inch sieve. If required by pavement sample type. Field millings do not require further crushing.

5.6. Conditioning Chamber, capable of maintaining a temperature of 50± 2˚F (10±1˚ C), at specified humidity, if required.

5.7. Forced Draft Oven, of appropriate size, capable of maintaining temperatures of 104±4°F (40±2° C) and 140± 2˚F (60± 1˚C). Shall be equipped with racks containing slots or holes for circulation of air.

5.8. Scale, capable of showing a reading to the nearest 0.1 gram.

5.9. Miscellaneous lab equipment; scoops, pans, mixing bowls, containers

5.10. Vacuum system, capable of subjecting contents to partial vacuum of 25.0 to 30.0 mm of Hg.

6.0 SAMPLING.

6.1. A mix design shall be performed with the materials to be encountered during construction, including in-place pavements, surface treatments, stockpiled RAP, additional aggregate, aggregate base, asphalt emulsion and other additives. If construction materials change significantly between the time of sampling and construction, additional mix designs shall be performed to establish a representative mix for the project.

6.2. Samples of the existing pavement are collected as cores, test pits, milled RAP, or stockpile samples of RAP. Prepare samples in the laboratory to simulate the specific construction process applied in the field.

6.3. Pavement samples are cut in the laboratory to the appropriate depth to represent field treatment, unless milled or stockpiled RAP is provided. For CCPR mix design, if additional processing of CCPR stockpiles is required during construction, such as scalping, screening or crushing, the sample material shall be processed similarly in the laboratory.

6.4. The composition of in-place pavement should be examined. Location and placement of collected pavement samples shall accurately reflect minor variations in the pavement and form a representative sample of the entire project. Each mix design requires a minimum sample size of 350 lbs.

6.5. Samples from significantly different pavement sections or stockpiles shall be grouped separately, with separate mix designs performed for each. Examples of these variations include: large patches, and significantly different asphalt mixes.

6.6. Shoulder thickness shall be verified. If shoulder thickness is inconsistent or

insufficient, consult with the Agency for possible recycling treatment exceptions.

7.0 PREPARATION OF TEST SPECIMENS.

7.1. Sample Preparation Procedure

7.1.1. Pavement samples shall be cut to a depth that accurately represents the CR treatment to take place, also accounting for pre-milling that may take place in the field.

7.1.2. Sampled pavement shall be crushed using a laboratory crusher or other methods. All material shall be crushed to pass the 1.5 inch sieve, although care should be taken to avoid fracturing the aggregate. Heat shall not be applied to the sampled pavement during the crushing process.

7.1.3. Ensure materials, including RAP, aggregate base and/or other additional materials are stored and prepared separately. Prior to batching specimens ensure material has been dried in a forced draft oven and thoroughly mixed.

7.1.4. Materials containing bituminous material shall be dried to constant mass at 104±4°F (40±2° C) in a forced draft oven. Materials without bituminous material may be dried at temperatures up to 230±9°F (110±5° C) in a forced draft oven.

7.1.5. Using Laboratory Screen Shaker, screen and separate sized material to prepare for batching procedure.

7.2. Asphalt Emulsion Content Selection

7.2.1. Mix designs shall be performed using an asphalt emulsion that meets all requirements detailed in Table 1.

Table 1. CR Asphalt Emulsion Material Specification

Test	Procedure	Minimum	Maximum
Viscosity, Saybolt Furol, at 77˚F (25˚C), SFS	AASHTO T 59	20	100
Sieve Test, No. 20 (850 µm), retained on sieve, %	AASHTO T 59		0.10
Storage Stability Test, 24 hr, %	AASHTO T 59		1
Distillation Test, Residue from distillation% (See Note 1)	AASHTO T 59	64.0	
Oil Distillate by volume, %	AASHTO T 59		1
Penetration, 77˚F (25˚C), 100 g, 5 s, dmm	AASHTO T 49	50	200

Note 1—Modified AASHTO T 59 procedure – distillation temperature of 350 ±9°F (177 ±5°C) with a 20 minute hold.

7.2.2. Select at least three asphalt emulsion contents in increments of 0.5 to 1.0 percent within a suggested range of 1.0 to 4.0 percent by dry weight of RAP.

7.3. Batching Procedure

7.3.1. Select the design gradation for two specimen sets. Design gradations shall be selected according to the gradation of at least two of the three gradation bands detailed in Table 2. The gradation bands selected shall be the two that best match the field gradation expected by the CR type. For CCPR mix designs, when mix design materials are collected from a pre-existing stockpile, the mix design may be completed with a single gradation set, using a design gradation that best matches the anticipated construction gradation.

7.3.2. For a CR treatment that incorporates materials other than RAP, batch the percentage, or mix design blend, by weight, of RAP, aggregate base and/or other additional materials for each specimen in a set. Ensure a representative sample is obtained from the additional incorporated materials when batching specimens.

7.3.3. The design gradation of each specimen within a specimen set shall be identical for wash gradation, Theoretical Maximum Specific Gravity, and Marshall Stability Testing specimens. Only material passing the 1-inch sieve shall be used to manufacture specimens when using 100mm gyratory molds.

Table 2. CR Dry Batched Mix Design Blend Gradation Criteria

Sieve Size		Percent Passing		
		Fine	Medium	Coarse
1 1/2 in.	37.5 mm	100%	100%	100%
1 in.	25 mm	100%	100%	85-100%
3/4 in.	19 mm	95-100%	85-96%	75-92%
No. 4	4.75 mm	55-75%	40-55%	30-45%
No. 30	600 µm	15-35%	4-14%	1-7%
No. 200	75 µm	1-7%	0.6-3%	0.1-3%

Note 2—The design stated on the final report may not necessarily conform to the above gradations. It possibly will diverge outside of the above ranges to reflect aggregate degradation and what is expected under field conditions.

7.3.4. Batch the following specimens from the sized material for the selected asphalt contents according to each design gradation.

a. Prepare 2 washed gradation specimens for each design gradation with a minimum of 2500g specimens for each gradation. Tested according to Washed Gradation Sieve Analysis Procedure in 8.1

b. Prepare 4 Theoretical Maximum Specific Gravity Specimens for each design gradation. Two specimens each will be tested at the highest selected asphalt emulsion content and at the lowest selected asphalt emulsion content. Minimum weight requirement for Theoretical Maximum Specific Gravity Specimens is 2500 g per specimen, using only material passing the 1" sieve. Prepared according to Theoretical Maximum Specific Gravity Specimen Preparation in 8.2

c. Prepare 4 pills per selected emulsion content for each design gradation for Marshall Stability Testing. 1000 g or more per specimen is typical, using only material passing the 1" sieve. The total specimen weight shall be the amount that will produce a 60 to 65 mm tall specimen using a 100 mm diameter gyratory mold,

using 30 gyrations.

d. Prepare 2 raveling pills per selected asphalt emulsion content ~~at~~ only when selected gradation follows medium gradation band. 2500 g or more per specimen is typical. The total specimen weight shall be the amount that will produce a 65 to 75 mm tall specimen using a 150 mm diameter gyratory mold, using 20 gyrations.

7.4. Mixing Procedure.

7.4.1. Mixing occurs at room temperature. One specimen shall be mixed at a time. Design Moisture Content shall be the amount of water added to the mixture during coating procedure. The Design Moisture Content chosen for each selected asphalt emulsion content represents the in-situ moisture and additional water combined during CR construction. The design moisture content does not include water in the asphalt emulsion, and is typically 1.5 to 3.0 percent by dry weight of material. Any other additives are combined in a manner and order similar to field production.

7.4.2. Record design moisture content selected for each gradation.

7.4.3. Using a mechanical bucket mixer, begin mixing batched material at 50-75 revolutions/minute.

7.4.4. Add design moisture content to batched material.

7.4.5. Mix for no less than 60 seconds.

7.4.6. Add asphalt emulsion to mixer.

7.4.7. Mixing time with asphalt emulsion shall be 55±5 seconds.

7.5. Theoretical Maximum Specific Gravity Specimen Preparation.

7.5.1. After mixing procedure detailed in 7.4, spread and transfer each specimen to individual shallow containers.

7.5.2. Cure in a 140±2˚F (60±1˚C) forced draft oven, for at least 16 hours but no more than 48 hours. Care should be taken not to over-dry the specimens.

7.5.3. Remove specimens from oven once reaching constant mass.

7.5.4. After curing, gently break up clusters that have formed in the specimen. Care should be taken to avoid fracturing aggregate.

7.5.5. Let cool to room temperature before continuing to Theoretical Maximum Specific Gravity Test procedure detailed in 8.2.

7.6. Marshall Stability and Raveling Test Specimen Conditioning Procedure-CCPR Only

7.6.1. If preparing a CIR specimen, skip conditioning procedure and immediately proceed to pill preparation in 7.7.

7.6.2. If preparing a CCPR specimen, immediately after mixing procedure detailed in 7.4, transfer material into an individual container measuring 4 to 7 inches (100 to 175 mm) in height and 6 inches (150 mm) in diameter.

7.6.3. Place container in a 104±4˚F (40±2˚ C) forced draft oven for 30±3 minutes.

7.6.4. Upon removal from oven, immediately proceed to pill preparation in 7.7.

7.7. Marshall Stability Pill Preparation.

7.7.1. Superpave Gyratory Compactor shall be prepared in accordance with AASHTO T 312, preparation of apparatus. Use the following machine settings: 1.16˚ internal angle, 87 psi (600 kPa) ram pressure, 30 gyrations. Only final specimen height is to be monitored.

7.7.2. Compact specimens using the Superpave gyratory compactor with a 100mm diameter, room temperature mold.

7.7.3. Extrude pill from mold immediately after compaction.

7.7.4. Cure compacted pills in a 140±2˚F (60±1˚C) forced draft oven, at least 16 hours but no more than 48 hours.

7.7.5. Remove pill from oven once reaching constant mass. Let cool to room temperature before continuing.

7.8. Raveling Pill Preparation.

7.8.1. Superpave Gyratory Compactor shall be prepared in accordance with AASHTO T 312, preparation of apparatus. Use the following machine

settings: 1.16˚ internal angle, 87 psi (600 kPa) ram pressure, 20 gyrations. Only final specimen height is to be monitored.

7.8.2. Compact material in the Superpave gyratory compactor using a 150 mm diameter, room temperature mold.

7.8.3. Extrude specimen from mold immediately after compaction.

7.8.4. Place on a flat surface.

7.8.5. Condition compacted specimens in conditioning chamber for 4 hours± 5 minutes at 50±2˚F (10±1˚ C), at specified humidity if required.

7.8.6. Begin Raveling Test Procedure per 8.4.

8.0 PROCEDURE.

8.1. Washed Gradation Sieve Analysis.

8.1.1. Perform Sieve Analysis on washed gradation specimens in accordance with AASHTO T 11 and T 27 with the following exception:

Washed gradations shall be dried at no greater than 104±4˚F (40±2˚ C) in a forced draft oven.

8.1.2. Remove specimens from oven once constant mass is reached.

8.1.3. Record gradation results for each gradation at the following sieves 1-1/2”, 1”, 3/4”, 1/2”, 3/8”, #4, #8, #16, #30, #50, #100, #200. Ensure sample gradation is within recommended gradation bands limits

8.1.4. Calculate Total % of Material Passing for the recorded sieves per AASHTO T 27.

8.2. Theoretical Maximum Specific Gravity Test Procedure.

8.2.1. Theoretical Maximum Specific Gravity Specimens shall be prepared according to Mixing Procedure per 7.4 and Theoretical Maximum Specific Gravity Specimen Preparation per 7.5.

8.2.2. Determine and record Theoretical Maximum Specific Gravity of each specimen in accordance with AASHTO T 209.

8.2.3. Calculate and Record the Average Theoretical Maximum Specific

Gravity for each asphalt emulsion content measured.

8.2.4. Calculate Average Theoretical Maximum Specific Gravities for remaining asphalt emulsion contents using interpolation of the measured Maximum Theoretical Specific Gravities.

8.3. Marshall Stability Testing Preparation and Procedure.

8.3.1. Measure and record pill heights to be used for Stability calculation.

8.3.2. Determine and Record Bulk Specific Gravity (Gmb) of each specimen in accordance with AASHTO T 166.

8.3.3. Calculate and Record % Air Voids of each specimen in accordance with AASHTO T 269.

8.3.4. Dry and Moisture Conditioned Marshall Stability Pills are to be conditioned and tested concurrently. Moisture Conditioned specimens shall be conditioned using Vacuum Saturation.

8.3.5. Moisture Conditioned Pill Procedure.

a. Using the vacuum system in accordance with AASHTO T 209, place specimen in vacuum container using a spacer to support specimen 1 in. (25mm) above bottom of container.

b. Fill container with water to a level at least 1 in. (25 mm) above top of specimen.

c. Apply vacuum for a short time (typically 5 to 15 seconds).

d. Release vacuum.

e. Remove specimen from water and record mass of container and water

f. Damp dry the specimen by blotting it with a damp towel and record saturated surface dry (SSD) mass.

g. Calculate the volume of air voids, Va, as follows:

$$Va = \frac{Pa \times E}{100}$$

Where:

Va = volume of air voids, cm^3
Pa = percent air voids as determined in 8.4.3
E = volume of the pill, cm^3

h. Calculate degree of saturation of the specimen as follows:

$$S' = \frac{100(B' - A)}{V_a}$$

Where:

S' = degree of saturation, %.
B'= mass of the SSD pill after partial vacuum, g
A = mass of the dry pill in air, g
Va = Volume of air voids, cm^3

If degree of saturation is below 55%, repeat previous steps to reach appropriate degree of saturation. If saturation is above 75%, sample is damaged and must be discarded.

If saturation is between 55 and 75 percent, proceed to the following step.

i. Immediately submerge correctly saturated specimens in a 77 ±2˚F (25 ±1˚C) water bath for 23 hours.

j. Transfer specimens into a 104±4˚F (40±2˚ C) water bath for one hour.

k. See step 8.3.7 for testing of conditioned specimens.

8.3.6. Dry Pill Procedure.

a. Ensure dry specimens are at constant mass prior to conditioning.
b. Dry specimens are conditioned in a forced draft oven at 104±4˚F (40±2˚ C) for 2 hours prior to Marshall Stability Testing.

8.3.7. Marshall Stability Testing. Follow procedure for testing Marshall Stability in accordance with AASHTO T 245, except as previously noted for specimen preparation, compaction and conditioning.

8.4. Raveling Test.

8.4.1. Immediately after conditioning is complete, record the mass of each specimen.

8.4.2. Proceed directly to testing of specimen in accordance with ASTM D7196 test procedure using an abrasion time of 15 minutes.

8.4.3. Follow calculation for % Mass Loss in accordance with ASTM D7196.

8.4.4. Calculate Average % Mass Loss for each asphalt emulsion content tested.

9.0 CALCULATIONS.

9.1. Marshall Stability Calculations

9.1.1. Using the previously measured height of each pill, calculate corrected maximum load (Marshall Stability) for each Marshall Stability pill as detailed in AASHTO 245 Table 2.

9.1.2. Calculate and Record average corrected maximum load (Average Stability) at each asphalt emulsion content for moisture conditioned and dry pills separately.

9.1.3. Calculate and Record Retained Marshall Stability (%) for each asphalt emulsion content at each gradation using the following equation:

$$Retained\ Marshall\ Stability\ \% = \frac{Average\ Moisture\ Conditioned\ Specimen\ Stability}{Average\ Dry\ Specimen\ Stability}$$

9.2. Selecting a Final Design Asphalt Emulsion Content.

9.2.1. Select and Report one asphalt emulsion content per design gradation that meets or exceeds all mix design requirements detailed in table 3.

Table 3. CR with Asphalt Emulsion Mix Design Requirements

CR Test	Passing Criteria
Marshall Stability, lbs (kg), AASHTO T 245	1250 lbs (567 kg) minimum
Retained Stability, %	70% minimum
Raveling Test, 50˚ F (10˚ C), %, ASTM D7196	2.0% maximum
Additional Additive(s) (See Note 3) Cement, %	1.0% maximum
Emulsified Asphalt[1] Emulsion to Cement Content Ratio	3:1 minimum

Note 3—Report shall include type/gradation and producer/supplier.

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10.0 REPORT. All mix design test results shall be reported to the Department per Table 4. All additional additives and bituminous material shall be reported to the Department.

Table 4. Reported Results

Cold Recycling with Emulsified Asphalt- Mix Design Requirements		
Initial Selected Criteria	**Test Purpose**	**Reported Results**
Tested Asphalt Emulsion Contents (%)	Establish a complete dataset	Each Content selected
Design Moisture Contents (%)	Dispersion of Asphalt Emulsion	Each Content selected
Gradation Bands	Match field gradation	Each Band selected
Test Method	**Test Purpose**	**Reported Results**
Washed Gradation, AASHTO T 11, T 27	Ensure proper lab pulverization	Average for each material tested
Superpave Gyratory Compaction, 1.25˚ external angle, 87 psi (600 kPa), AASHTO T 312	Standardize Lab Compaction Effort	Report Compliance for all compacted specimens
Rice (Maximum Theoretical) Specific Gravity, AASHTO T 209	Laboratory Density Indicator	Average at each Asphalt Emulsion Content Tested
Bulk Specific Gravity (Density), AASHTO T 166		
Air Voids, AASHTO T 269, %		
Marshall Stability, lbs (kg)	Strength Indicator	
Retained Stability, %	Moisture Damage Resistance	
Raveling Test, 50˚ F (10˚ C), %	Raveling Resistance	
Additional Additive(s) (See Note 4) Coarse Aggregate Fine Aggregate RAP Cement, %		Report Quantities
Emulsified Asphalt (See Note 4) Distillation Residue, % (See Note 5) Residue Penetration, dmm Optimum Emulsion Content, % Emulsion to Cement Content Ratio		Report Results
Final Selected Criteria	**Test Purpose**	**Reported Results**
Final Design Asphalt Emulsion Content (%)	Select Highest Performing Asphalt Emulsion Content	Content for each Design Gradation

Note 4—Report shall include type/gradation and producer/supplier
Note 5—Modified AASHTO T 59 procedure – distillation temperature of 350±9˚F (177±5˚C) with a 20-minute hold.