

**Recommended  
Mix Design Guidelines  
For  
Cold Recycling Using Foamed (Expanded) Asphalt  
Recycling Agent  
CR202**

03/25/2023



**NOTICE**

It is not intended or recommended that these guidelines be used verbatim within a specification. Owner Agencies should use them to help establish their particular project specification. Owner Agencies should understand that all geographical areas and pavement rehabilitation/preservation projects are unique and the availability of materials and equipment may vary as well. ARRA assumes no liability for utilization of these guidelines by any individual or entity. Contact ARRA for answers to questions and for a list of ARRA member Contractors and Suppliers.

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## 1. General

A mix design with foamed asphalt shall be performed with the materials to be encountered during construction of the Cold Recycling (CR) which includes Cold In-place Recycling (CIR) or Cold Central Plant Recycling (CCPR). When the materials change significantly additional mix designs shall be performed to establish representative mixes for the entire job. Representative samples of the asphalt pavement shall be obtained from the roadway for CIR and CCPR or from a stockpile for CCPR and delivered to an AASHTO accredited or Owner Agency approved laboratory experienced in foamed asphalt cold recycled mix designs, where the asphalt pavement samples shall be crushed, if required, and mixed with foamed asphalt recycling agent and additives, as necessary and then, at a minimum, tested in accordance with the procedures and requirements of **Table 1**.

User Notes: Sampling and mix designs for CR are different than for heated asphalt mixtures (HMA and WMA), and not just in the tests that are performed or the properties that are targeted. HMA and WMA designs are based on blending two to five aggregates in certain proportions to obtain desired outcomes, such as air voids and voids in mineral aggregate. If aggregate properties change through a season or year to year, the blend is adjusted at the plant or a new design is performed. Making adjustments to achieve target properties is not only possible but even required. With CR, however, the nature of the construction process does not allow for quick adjustments. Therefore, understanding the variability of the road and designing for it prior to construction is important.

The more that is known about the roadway and terrain the better one can deal with any design and constructability issues that may arise. A site analysis captures many elements that can affect the end performance of cold recycled pavements that a mix design cannot. For example, a mix design will not account for a soft or failing base, nor will it take into account the fact that sections of the roadway only receive two hours of sunlight a day. The sampling crew should describe all abnormal occurrences so as to provide the engineer a thorough understanding of in-situ conditions.

## 2. Sampling Procedures for In-place Materials

### 2.1 Sampling of Reclaimed Asphalt Pavement Materials

Samples of asphalt pavement shall be obtained 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.

User Note: The level of sampling for a cold recycled project is dependent on many factors including the selected reliability of the design, level of risk, length of the project and testing required. The composition of the whole project is important. Samples for mix design and analysis are required for each major difference in observed material types. For example, if one area is composed of aged, oxidized, dense graded HMA overlay and another area is composed of an open graded HMA on top of a less distressed, dense graded HMA, two sets of samples are recommended for design and analysis. Another example would be if one area contains a single chip seal and another has multiple seals.

For CIR and CCPR where the project schedule does not permit obtaining samples from the stockpile, samples shall be obtained from the full depth of the pavement to be recycled. Samples shall be obtained and separated for individual mix design analysis if visual observations indicate greater variation in materials within a segment (i.e. large patches, high binder content mixes). The depth of asphalt layers to aggregate base, subgrade or concrete; 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.

Samples may be obtained as cores or milled RAP from the areas to be recycled.

Core samples shall be obtained to the underlying base or subgrade soil. If a core breaks off prior to penetrating the underlying materials, coring shall continue to the bottom of the pavement for thickness measurement purposes. On retrieval, each core shall be measured to the nearest 1/8-inch (3-mm) and then placed in a separate container and labeled. A coring log summarizing the date, station, offset, and core thickness shall be recorded for each core location and provided to the mix design laboratory.

Milling of material may be conducted provided the cold planer (milling machine) produces a consistently graded RAP similar to the RAP gradation expected during recycling operations. Only millings that represent the pavement to be recycled shall be collected. If a portion of the existing pavement surface is planned to be milled and removed during construction, the pavement shall be milled in a similar manner and removed prior to milling for sampling purposes. Milling and sampling shall only be to the planned recycle depth. The material may be obtained from one test location for each mix design. For example, if a pavement change exists within the limits of the roadway, one test location should be designated for each area.

*User Note: If the project calls for 2 inches (50 mm) of existing pavement to be milled and removed, then the top 2 inches (50 mm) of pavement shall be milled and removed prior to milling for sampling purposes. CIR treatments are usually specified as a milling depth rather than a compacted layer thickness, whereas CCPR depths are normally specified as final compacted thickness. CR materials will not compact to the original milled thickness. This difference in thickness is referred to as a "fluff factor." Typical fluff factors are 10-15% but vary due to materials, methods and environmental conditions.*

Sufficient usable material, up to 350 lbs. (160 kg) shall be obtained. Usable material is defined as the length in the core that corresponds to the recycling depth from the existing pavement surface or the recycle depth after pre milling. Cores shall be cut at the planned recycling depth and only that portion to be recycled shall be used for mix design purposes. Equation [1] may be used to determine the number of cores needed for each 350 lbs. (160 kg) per mix design at a core unit weight of 145 pcf (2.324 g/cm<sup>3</sup>). For different mix design weight requirements or unit weights of cores, the number of cores should be proportioned. When using equation [1] only consider the depth of recycle. Remaining material below the depth of recycle shall be trimmed and not used for mix design purposes.

#### English Units

$$CMD = [5,311] / [(D^2) (CRMD)] \quad [1a]$$

where:

CMD = number of cores per mix design

D = core diameter (in)

CRMD = cold recycle milling depth (in)

#### SI Units

$$CMD = [83,881,233] / [(D^2) (CRMD)] \quad [1b]$$

where:

CMD = number of cores per mix design

D = core diameter (mm)

CRMD = cold recycle milling depth (mm)

User Note: For example, if a 3-inch (75-mm) depth of recycle is proposed and the pavement has a unit weight of 145 pcf (2.324 g/cm<sup>3</sup>) then the following number of 6-inch (150-mm) diameter cores are needed:

$$CMD = [5,311] / [(6)^2(3)] = 49.2 \text{ or } 49 \text{ cores}$$

$$CMD = [83,881,233] / [(150)^2(75)] = 49.7 \text{ or } 50 \text{ cores}$$

Conversely, if the actual pavement is thinner than the recycle depth additional cores are needed. A weighted average of the thickness of the milled pavement can be used with the above equations to determine the number of cores.

Cores shall be obtained using a pattern that results in a representative sample of the pavement to be recycled including at or near lane lines, within and between wheel paths, at the pavement edge and within shoulders if shoulders are to be recycled. The roadway shall be sampled in accordance with staggered or offset sampling (as illustrated in **Diagram 1a**) or crossroad sampling with no offset (as illustrated in **Diagram 1b**).

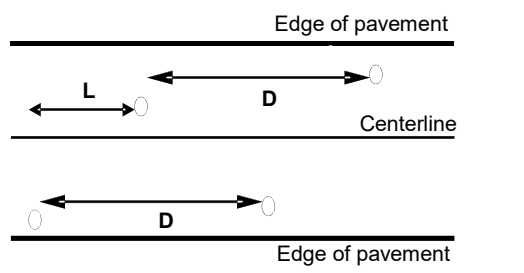


Diagram 1a – Staggered (offset) sampling.

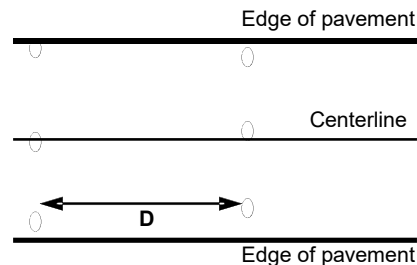


Diagram 1b – Crossroad sampling.

The minimum rate of coring shall be as follows:

D – \_\_\_\_\_ mile maximum (\_\_\_ km)

L – \_\_\_\_\_ mile maximum (\_\_\_ km)

At least \_\_\_% of the cores shall be in the shoulder, if it is getting recycled, or within 3 feet (1 m) of gutter.

At least \_\_\_% of the cores shall be on or within 3 feet (1 m) of centerline.

User Note: Select the type of sampling pattern preferred. With staggered or offset sampling the cores are obtained in one lane at a prescribed sampling rate of D and offset a distance L in the adjacent lane. With crossroad sampling, all cores across both lanes are obtained at a prescribed sampling rate of D with no offset between lanes.

Typically L=D/2

User Note: The rate of coring is also based on determining the uniformity of projects. Unless overridden for a particular project the following guidelines should be a **minimum**:

#### Highways or Airports

D – 1 mile maximum (1.6 km)

L – 0.5 mile maximum (0.8 km)

At least 15% of the cores shall be in the shoulder if the shoulder is getting recycled.

At least 25% of the cores shall be on or within 3 feet (1 m) of centerline.

#### Arterial and Industrial Streets

D – 2,000 feet maximum (600 m)

L – 1,000 feet maximum (300 m)

At least 25% of the cores shall be in the shoulder if it is getting recycled or within 3-feet (1 m) of gutter.

At least 25% of the cores shall be on or within 3 feet (1 m) of centerline.

#### Residential Streets

Streets less than 250 feet long (75 m), one core when grouped with other streets to obtain the quantity of material required for mix design.

Streets 250 feet to 500 feet (75 m to 150 m) long, two cores when grouped with other streets to obtain the quantity of material required for mix design. One within 3 feet (1m) of gutter the other within 3 feet (1 m) of centerline.

Streets over 500 feet (150 m) long, three cores when grouped with other streets to obtain the quantity of material required for mix design. One within 3 feet of gutter (1 m), one within 3 feet (1 m) of centerline, the third between the two.

## **2.2 Safety**

Proper personal protective equipment (PPE) shall be used on all sampling projects. Only personnel trained to operate core drills shall perform coring. Traffic control shall be performed by qualified, experienced personnel.

## **2.3 Shipping**

Samples shall be shipped in sturdy containers (plastic or metal buckets or small strong plastic tubs) or on pallets with each sample clearly marked. Cardboard boxes shall not be used. A copy of the sampling log, protected in a sealed container, shall be included with shipment of samples.

## **2.4 Filling Sample Holes**

Each sample hole shall be filled in accordance with the procedures described below. After sampling and filling the holes, the roadway shall be cleaned of all loose debris.

A high quality cold patch material shall be used to fill core or milling holes. The cold mix shall be compacted flush with a tamping rod, sledge or Marshall hammer. Approximately the same amount of cold patch, i.e. 350 pounds (160 kg), will be required.

## **3. Stockpile Sampling for CCPR**

If sampling is not required for in-place materials, RAP samples for CCPR may be obtained from the stockpile to be used for construction of the CCPR material. Sufficient usable RAP, up to 350 lbs. (160 kg) shall be obtained for the mix design.

### 3.1 Stockpile Sampling of Reclaimed Asphalt Pavement Materials

Obtain a representative sample of the stockpile in accordance with AASHTO R 97, section 5.11. Remove at least 4 inches from the surface before sampling, per section 5.11, as mixtures in a stockpile may develop an oxidized crust.

### 3.2 Safety

Proper personal protective equipment (PPE) shall be used on all sampling projects.

### 3.3 Shipping

Samples shall be shipped in sturdy containers (plastic or metal buckets or small strong plastic tubs) or on pallets with each sample clearly marked. Cardboard boxes shall not be used. A copy of the sampling log, protected in a sealed container, shall be included with shipment of samples.

## 4. Foamed Asphalt Cold Recycle Mix Design

A mix design shall be performed with the materials to be encountered during construction of the cold recycling.

### 4.1 Testing Parameters

The mix design for foamed asphalt CR shall meet the minimum recommended parameters listed in Table 1.

**TABLE 1 – MINIMUM COLD RECYCLING MIX DESIGN REQUIREMENTS FOR FOAMED ASPHALT**

Test Method	Criteria	Property
Asphalt Content of RAP <sup>a</sup> AASHTO T 308 (ASTM D6307), Optional	Report Only	Quantity of Existing Binder
Gradation of Unextracted RAP <sup>a</sup> AASHTO T 11 <sup>b</sup> & T 27 (ASTM C117 <sup>b</sup> & C136)	1.25-inch (31.5 mm) maximum Per Table 2	Maximum Particle Size
Foaming Properties of Asphalt <sup>c</sup>	Minimum Expansion 8 times Minimum Half Life 6 seconds	Foaming Properties
Modified Proctor <sup>d</sup> AASHTO T 180 (ASTM D1557)	Report for Use in Sample Preparation & Compaction Control	Maximum Dry Density & Optimum Moisture Content
Bulk Specific Gravity of Compacted, Cured Specimens <sup>e</sup> AASHTO T 166 (ASTM D2726)	Report Only	Density as Compacted
Maximum Theoretical Specific Gravity <sup>f</sup> AASHTO T 209 (ASTM D2041)	Report Only	Maximum Specific Gravity
Air Voids of Compacted, Cured Specimens <sup>e,f</sup> AASHTO T 269 (ASTM D3203)	Report Only – Recycling agent content should not be adjusted to meet an air void content.	Compacted Air Voids
Indirect Tensile Strength <sup>e,g</sup> AASHTO T 283 (ASTM D4867)	Minimum 45 psi (310 kPa) <sup>h,i</sup>	Cured Strength
Tensile Strength Ratio based on Moisture Conditioning <sup>e,g,j</sup> AASHTO T 283 (ASTM D4867)	Minimum 0.70 <sup>k</sup>	Resistance to Moisture Induced Damage
Ratio of Residual Asphalt to Cement	Minimum 2.5:1.0 (refer to CR101 or CR102)	Prevent Rigid Behavior
PG Grade of Foamed Asphalt Recycling Agent AASHTO M 320	Not polymer modified. Select low temperature PG grade of recycling agent to meet requirements for location of	Resistance to Low Temperature Cracking

	project and depth in pavement structure.	
<b><i>Evaluation of Existing Binder (Optional)</i><sup>l</sup></b>		
Recovery of Binder from RAP <sup>m</sup> AASHTO T 319 (ASTM D5404) or ASTM D1856	Used for Penetration Testing	Recovery of Binder
Penetration of Bituminous Materials AASHTO T 49 (ASTM D5)	Report Only	Softness of Existing Binder

**NOTES:**

<sup>a</sup> For cores from in-place materials, a laboratory milling machine shall be used to model the gradation expected during recycling. For CCPR where samples are obtained from the preprocessed stockpiles the samples shall be used directly. If additional processing of CCPR stockpiles will be required, such as scalping or crushing/screening, the samples shall be processed in a similar fashion.

As an alternative, the mix design for CR shall be performed by screening and crushing with a laboratory crusher and then recombining the RAP in accordance with the gradation criteria of **Table 2**. The selected gradation shall be chosen to match the expected gradation as closely as possible. If the CR is to be conducted using cold planers (milling machines) operating in a down cutting mode, then the fine or medium gradation shall be used. For cold planers operating in the up cutting mode the medium or coarse gradation shall be used. The entire sample material shall be crushed to 100% passing the 1.25-inch (31.5- mm) sieve; however, only the material passing the 1-inch (25-mm) sieve shall be used to manufacture test specimens with 4-inch (100-mm) molds. RAP shall be dried to a constant mass at 104 ± 4 °F (40 ± 2 °C) prior to mixing.

**TABLE 2- COLD RECYCLING GRADATION REQUIREMENTS**

Sieve Size	Fine Gradation	Medium Gradation	Coarse Gradation
	Percent Passing		
<b>1.25" (31.5 mm)</b>	100	100	100
<b>3/4" (19 mm)</b>	95 – 100	93 - 97	83 - 87
<b>No. 4 (4.75 mm)</b>	60 – 70	48 - 52	38 - 42
<b>No. 30 (600-µm)</b>	20 – 30	8 - 12	3 - 7
<b>No. 200 (75-µm)</b>	1 – 7	1 – 3	0.5 – 2

<sup>b</sup> If a washed sieve analysis is desired, the samples should be dried to a constant mass at 104 °F (40 °C) prior to performing the sieve analysis.

User Note: Drying to a constant mass at 104 °F (40 °C) could take several days.

<sup>c</sup> The temperature and percentage of water addition shall be determined that produces the best foam properties (maximum expansion ratio and half-life) for a particular source of asphalt. Expansion Ratio is a measure of the viscosity of the foamed asphalt, calculated as the ratio of the maximum volume of the foam relative to the original volume of asphalt. Half-life is a measure of the stability of the foamed asphalt, calculated as the time taken in seconds for the foam to collapse to one-half of its maximum volume.

Expansion ratio and half-life shall be determined by heating the asphalt in the laboratory foaming unit until the required temperature is achieved and stabilized during testing, typically starting at 320°F (160°C). The

discharge rate of the asphalt shall be calibrated and the timer shall be set on the laboratory foaming unit to discharge a known amount of asphalt. The water flow-meter shall be set to achieve the required water injection rate, normally starting with 2 percent by mass of the asphalt. 500 grams of foamed asphalt shall be discharged into a steel drum preheated to  $\pm 135^{\circ}\text{F}$  ( $\pm 75^{\circ}\text{C}$ ) of the asphalt temperature at the calculated spray time. Immediately after the foam discharge stops, a timer shall be started and the maximum height of the foamed asphalt shall be measured with a calibrated dipstick. The maximum height measured with the calibrated dipstick shall be recorded as the expansion ratio. The time in seconds required for the foamed asphalt to reach one-half of its expanded volume shall be recorded as its half-life. The above procedure shall be repeated three times or until similar readings are achieved.

The above procedure shall be repeated for three water injection rates. Typically, values of 2%, 3% and 4% by mass of asphalt should be used.

A graph shall be plotted of the expansion ratio versus half-life at the different water injection rates on the same set of axes. The optimum water addition shall be selected as an average of the two water contents required to meet these minimum criteria.

*User Note: All procedures are normally reproduced for two other asphalt temperatures, typically  $340^{\circ}\text{F}$  ( $170^{\circ}\text{C}$ ) and  $360^{\circ}\text{F}$  ( $180^{\circ}\text{C}$ ). The temperature and optimum water addition that produces the best foam is then used in the mix design procedure. The minimum acceptable foaming properties are an expansion ratio of 8 and a half-life of 6 seconds.*

<sup>d</sup> If the RAP material does not produce a well-defined moisture-density curve then use an optimum moisture content between 3 and 4%.

<sup>e</sup> Mixing of test specimens shall be performed with a mechanical bucket mixer or with a laboratory size pugmill. RAP and any recycling additives shall be thoroughly mixed with 75% of the optimum water content determined in accordance with AASHTO T 180 (ASTM D1557), then mixed with the foamed asphalt recycling agent. A minimum of three foamed asphalt recycling agent contents that bracket the estimated recommended recycling agent content shall be selected, typically 1.5 to 3.0 percent. Foamed asphalt shall be applied with a properly calibrated foaming apparatus at the optimum half-life and expansion ratio. After adding the foamed asphalt recycling agent the entire mixture shall be mixed at room temperature  $77 \pm 9^{\circ}\text{F}$  ( $25 \pm 5^{\circ}\text{C}$ ) for 30 seconds or until uniformly mixed. Additional mix water may be used to bring the mixture to the optimum moisture content as determined in accordance with AASHTO T 180 (ASTM D1557). The mixture shall be blended until uniform. The specimen shall be compacted immediately or transferred to an air-tight container and immediately sealed for compaction to occur as soon as possible.

*User Note: If excessive moisture is extruded from the SGC mold during compaction, the total water content may be reduced to 75% of the optimum moisture content determined in accordance with AASHTO T 180 (ASTM D1557).*

Specimens shall be compacted at room temperature,  $77 \pm 9^{\circ}\text{F}$  ( $25 \pm 4^{\circ}\text{C}$ ). Specimens shall be compacted using either 4-inch (100 mm) or 6-inch (150 mm) diameter molds. Four-inch (100 mm) diameter specimens shall be compacted to  $2.5 \pm 0.1$  inch ( $63.5 \pm 2.5$  mm) tall using either 75 blows per side by a Marshall hammer or with 30 gyrations using a Superpave gyratory compactor (SGC) at  $1.25^{\circ}$  angle, 87 psi (600 kPa) stress. Six-inch (150-mm) diameter samples shall be compacted to  $3.7 \pm 0.1$  inch ( $95 \pm 5$  mm) tall with 30 gyrations using the SGC at  $1.25^{\circ}$  angle, 87 psi (600 kPa) stress. Molds and Marshall compaction hammer shall not be heated. A total of 6 specimens at each foamed asphalt recycling agent content shall be prepared for indirect tensile strength testing, 3 for cured specimens and 3 moisture condition cured specimens. If paper



disks are used, the paper disks shall be placed on the top and bottom of the specimen before compaction and shall be immediately removed after compaction. Specimens shall be extruded from molds within 24 hours after compaction in a manner so as not to damage the specimens. Specimen heights shall be determined according to AASHTO T 245 (ASTM D6927) or may be obtained directly from the readout if the SGC is used.

After removal from the molds, specimens shall be placed in a forced draft oven with ventilation on sides and top. Each specimen shall be placed in a small container to account for material loss from the specimens. Specimens shall be cured at  $104 \pm 2$  °F ( $40 \pm 1$  °C) to constant weight for at least 16 hours but not more than 72 hours. Constant weight is defined as 0.05% change in weight in 2 hours. After curing, specimens shall be cured at ambient temperature a minimum of 12 hours to a maximum of 24 hours.

<sup>f</sup> Two additional specimens, mixed in accordance with **note e** above, shall be prepared for Theoretical Maximum Specific Gravity according to AASHTO T 209 (ASTM D2041) with the exception that loose RAP foamed asphalt mixtures shall be cured in an oven at  $104 \pm 2$  °F ( $40 \pm 1$  °C) to constant weight for at least 16 hours but not more than 72 hours. Constant weight is defined as less than a 0.05% change in weight in 2 hours. Agglomerates which will not easily reduce with a flexible spatula shall not be broken. Both specimens shall be tested at the highest foamed asphalt recycling agent content in the design and back calculated for the lower recycling agent contents. The optional dry-back procedure of AASHTO T 209 (ASTM D2041) may be required to account for the effect of uncoated particles.

<sup>g</sup> Compacted and cured specimens shall be brought to test temperature by placing each specimen in a leak-proof bag and submerging in a water bath at  $77 \pm 2$  °F ( $25 \pm 1$  °C) for 30-45 minutes immediately prior to testing in accordance with AASHTO T 283 (ASTM D4867). This testing shall be performed at the same time that moisture-conditioned specimens are tested.

<sup>h</sup> When recycling RAP with rounded aggregate, a sandy gradation, or softer binders (recovered penetrations greater than 30) 45 psi (310 kPa) may not be achievable without a recycling additive. In such instances a minimum of 34 psi (225 kPa) may be acceptable. The Owner Agency will determine whether the specification needs to be reduced or whether an additive shall be used according to the pertinent additive sections of *CR101 - Construction Guidelines for Cold In-Place Recycling Using Bituminous Recycling Agents* and *CR102 - Construction Guidelines for Cold Central Plant Recycling Using Bituminous Recycling Agents*.

<sup>i</sup> Minimum values to be obtained are for mix design only; for field construction, refer to *CR101* and *CR102*.

<sup>j</sup> Moisture conditioning shall be conducted on 3 compacted, cured specimens at each foamed asphalt recycling agent content by applying a vacuum of 2 psi to 10 psi (13 to 67 kPa) or absolute pressure 10 to 26 inches (254 to 660 mm) of Hg partial pressure for a time duration required to vacuum saturate specimens to 55 to 75 percent. Percent saturation shall be calculated by comparing saturated surface dry mass with dry mass in air. Specimens shall then be submerged in a  $77 \pm 2$  °F ( $25 \pm 1$  °C) water bath for 24 hours and indirect tensile strength determined in accordance with AASHTO T 283 (ASTM D4867) immediately after removal from the water bath. Tensile Strength Ratio shall be defined as the average moisture conditioned specimen strength divided by the average dry specimen strength.

<sup>k</sup> The Tensile Strength Ratio may be reduced to 0.60, provided the moisture condition indirect tensile strength exceeds the minimum dry strength requirement.

<sup>l</sup> **User Note: The existence of soft (high penetration) or high asphalt cement content recovered binders can impact mixture performance and make it difficult to meet minimum mix design requirements. Knowing**

recovered recycling agent properties provides the engineer, Contractor and Owner Agency with valuable information for use in evaluating mix design results, selecting recycling agents and additives, and alerting the Contractor to constructability issues.

<sup>m</sup> 3.3 lbs. to 6.6 lbs. (1,500 to 3,000 g) of RAP shall be used to recover binder.

#### **4.2 Report**

The report shall contain the following minimum information:

- RAP binder content (optional)
- Penetration of recovered binder from RAP (optional)
- Gradation of RAP, and corrective aggregate when required
- Density, maximum specific gravity, air void content, indirect tensile strength level of saturation, retained tensile strength ratio at each foamed asphalt recycling agent content
- Recommended water content range as a percentage of dry RAP
- Optimum foamed asphalt recycling agent content as a percentage of dry RAP
- PG grading of asphalt binder, supplier name and location and certificates of compliance
- Amount and type of recycling additive as a percentage of dry RAP
- Ratio of asphalt content of recycling agent to cement, if used
- Application means of foamed asphalt recycling additive
- Compaction method used to prepare strength specimens