Recommended
Mix Design Guidelines
For
Full Depth Reclamation (FDR)
Using Emulsified Asphalt Stabilizing Agent
FDR201A

Revised 1/19/2023

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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 shall be performed with the materials to be encountered during construction of the Full Depth Reclamation (FDR). When the in-place materials change significantly, additional mix designs shall be performed to establish representative mixes for the entire job. Representative samples of the in-place pavement (HMA and underlying materials) shall be taken from the roadway and delivered to an AASHTO accredited or Owner Agency approved laboratory experienced in FDR mix designs where the bituminous surface shall be crushed, mixed with the desired percentage of underlying material, mixed with emulsified asphalt stabilizing agent and additives, as necessary. The mixture shall then be tested in accordance with the procedures and requirements of Table 2.

User Note: Sampling and mix designs for FDR 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. With HMA and WMA 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 FDR, 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.

User Note: The more that is known about the roadway and terrain the better one can deal with any design and constructability issues that arise. A site analysis captures many elements that can affect the end performance of an FDR pavement that a mix design alone cannot. For example, a mix design will not account for a soft or failing base or subgrade, or poor drainage areas, nor will it take into account the fact that sections of the roadway only receive two hours of sunlight a day. It is the responsibility of the sampling crew to describe all road conditions and surrounding terrain so as to provide the engineer a thorough understanding of the in-situ conditions.

2. Sampling Procedures for Full Depth Reclamation Materials

Samples of the pavement to be reclaimed (reclaimed asphalt pavement (RAP) and underlying materials) shall be obtained for the full reclaiming depth of the pavement. The purpose of the samples is for mix design and compatibility of the blend with emulsified asphalt, to determine if the thickness of the existing pavement is suitable for the recycle depth proposed, and to use the sampling location to penetrate the existing pavement for subgrade testing and or analysis, if necessary.

User Note: In addition to collecting material to be reclaimed, it is suggested that material to a depth of 6-inches (150-mm) below the bottom depth of the reclaimed material be obtained and stored separately from the purposed reclaimed material for soil classification purposes. Also, in-situ strength characteristics of this layer should be determined using a dynamic cone penetrometer (DCP) or comparable device.

Additional samples shall be obtained and separated for individual mix design analysis if visual observations indicate greater variation in materials within a segment or if there are areas of major distress (i.e. large patches or rutted areas). The depth of asphalt layers to aggregate base or subgrade; thickness of individual layers; and type of material in the projected reclaimed

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 representative samples from edge to edge in both lanes to ensure sufficient thickness is present. Include samples near the centerline, between wheel paths, and at the pavement edge. If the FDR will be performed on the shoulders, samples shall be taken from them as well. Approximately 350 pounds (160 kg) of materials, of the correct proportion, are required for each mix design.

Samples may be obtained from core sampling (6 inches or greater is recommended), from milled areas to be reclaimed, from test pits or a combination of these methods.

User Note: The level of sampling for an FDR project is dependent upon many factors including the selected reliability of the design, level of risk, length of 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 or for variations in HMA thickness exceeding approximately 2 inches. For example, if there are areas of major distress (i.e. large patches, rutted areas, major grade adjustments such as cuts or fills), a separate sample is recommended. It is not always necessary to perform multiple mix designs. Often, a mix design can be performed on the predominant section and the optimum emulsion and additive content verified for the other pavement sections.

2.1 Core Sampling

Core samples shall be obtained to the underlying base or subgrade soil. If a portion of the existing pavement surface is planned to be milled and removed during construction, the pavement to be milled shall not be included as part of the mix design samples. 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.

Underlying materials (aggregate base and/or subgrade), to the planned recycling depth, plus an additional 6 inches (150 mm), shall be obtained at each core location. Use a bent spoon, hand auger or some other device that prevents asphalt or soil from contaminating the base sample. Carefully scrape the edge of the hole to obtain as much sample as possible. Place the sample in a bag and record the Job Number and core location on the bag in indelible ink. 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.

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)**.

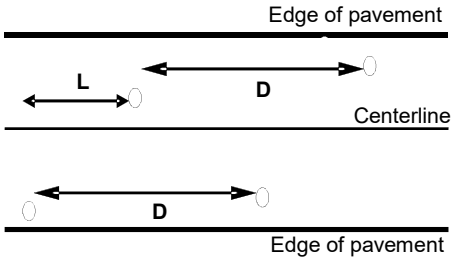

Diagram 1a – Staggered (offset) sampling.

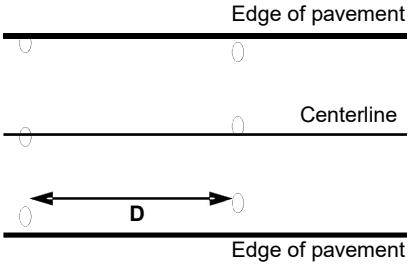

Diagram 1b – Crossroad sampling.

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.

User Note: 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 Milling

Milling of material for sampling purposes may be conducted provided the milling operation only penetrates to the planned reclaiming depth. 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 and not be included as part of the mix design samples. 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.

Cold planing (milling) of the pavement for sampling may be used provided the cold planer produces sufficient coarse RAP to conduct a mix design. Fine millings may not be acceptable to represent the construction-produced millings from a reclaimer.

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.

2.3 Test Pits

Test pits may be used to obtain representative samples of asphalt pavement and underlying materials. Only materials that represent the pavement to be reclaimed shall be collected. If a portion of the existing pavement surface is planned to be milled and removed during construction, that portion of the pavement shall be removed and not included as a part of the mix design samples. 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 removed and discarded prior to mix design.

2.4 Safety

Proper personal protective equipment (PPE) shall be used during all sampling activities. Only personnel trained to operate core drills or saws shall perform coring or slab sawing. Traffic control shall be performed by qualified, experienced personnel.

2.5 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.

2.6 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 to the pavement surface. Approximately the same amount of cold patch, i.e. 350 pounds (160 kg), will be required.

3. Full Depth Reclamation Mix Design –

3.1 Sampling

A minimum sample size of 350 lbs. (160 kg) is needed for each mix design. Samples of the pavement, to the planned recycling thickness shall be obtained as described in sections 2.1,2.2 or 2.3.

3.2 Processing RAP

If cores or pavement slabs of the asphalt mix were obtained, crush the material at ambient or colder temperatures to obtain materials for mix design. Use a jaw crusher, laboratory milling machine or other suitable method to model the shape and gradation expected during reclaiming. As an alternative, the mix design shall be performed by crushing with a laboratory crusher and then recombining the RAP in accordance with the gradation criteria of Table 1. The selected gradation shall be chosen to match the expected gradation as closely as possible. The entire RAP sample shall be crushed to 100% passing the 1.5-inch (37.5- mm) sieve. RAP shall be dried to a constant mass at 104 ± 4 °F (40 ± 2 °C) prior to mixing.

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

TABLE 1- RECOMMENDED FDR RAP GRADATION

Sieve Size	Percent Passing
1.5 in. (38 mm)	100
1 in. (25 mm)	85 - 100
¾ in. (19 mm)	75 - 95
No. 4 (4.75 mm)	30 - 55
No. 30 (600-µm)	5 - 15

3.3 Combined FDR Material

Combine the RAP, batched to the gradation selected in section 3.2, with the underlying material to the proportion found in the field. Perform a washed sieve analysis on a sample of the combined material in accordance with AASHTO T 11 & T 27 (ASTM C117 & C136) except that the material shall be dried at 104 °F (40 °C). Remove all plus 1.5-inch (38-mm) materials for the mix design.

User Note: Drying to a constant mass at 104 °F (40 °C) could take several days. If the percent passing on the No. 200 (0.075 mm) sieve of the combined material exceeds 20 percent, then the use of a stabilizing additive such as cement or lime may be required to meet the mix design requirements.

3.4 Sand Equivalent and Plasticity Index of Combined FDR Material

The sand equivalent, AASHTO T 176 (ASTM D2419), and Plasticity Index (PI), AASHTO T 89 and T 90 (ASTM D4318), shall be performed on a representative sample of the combined FDR materials and reported.

User Note: Mixtures with a sand equivalent value < 30 and/or a PI > 6 typically require the use of a stabilizing additive such as cement or lime to meet the mixture requirements of Table 2.

3.5 Determination of Maximum Dry Density and Optimum Moisture Content

Determine the maximum dry density and optimum moisture content of the combined FDR material in accordance with AASHTO T 180 Method D (ASTM D 1557, Method C), modified Proctor. Use a minimum of four points to determine the maximum dry density and optimum moisture content at peak dry density. If the material does not produce a well-defined optimum moisture content curve, then the optimum moisture content shall be fixed between 4 and 5 percent. This optimum moisture content is the total liquids content (water plus emulsified asphalt) of the FDR mixture.

3.6 Batching FDR Material

Select a minimum of four emulsified asphalt contents, evenly spaced, that will bracket the design emulsified asphalt content. Recommended emulsified asphalt contents should be in 0.5 to 1.0 percent increments covering a range typically between 1 to 4 percent, or greater, by dry weight of FDR material. The following specimens shall be created:

- Six specimens for each emulsified asphalt content selected shall be produced for indirect tensile strength testing
- Two specimens, at the highest or highest and lowest emulsified asphalt content, shall be produced for maximum specific gravity testing.

Samples shall have a weight before addition of water, any additives, and emulsified asphalt to produce a 75 ± 5 mm (2.95 ± 0.20 in.) thick specimen, 150 mm (6 in.) diameter compacted specimens.

3.7 Mechanical Mixing

Mix samples for testing using a mechanical bucket mixer or laboratory-sized pugmill. If any dry additives are in the mixture, add the additives to the dry FDR and mix thoroughly before adding water. For mixtures with a sand equivalent value > 30, use 45 to 65 percent of the total liquids content determined in section 3.5 for the optimum moisture content. For mixtures with a sand equivalent value ≤ 30, use 60 to 75 percent of the total liquids content determined in section 3.5 for the optimum moisture content. If slurry is used, add at the desired solids content by weight of dry FDR material and mix thoroughly. Thoroughly mix the FDR material and any additives with the optimum moisture (water) content for 60 seconds.

Mix the FDR specimens, conditioned at room temperature between 20 and 25°C (68 and 77°F), thoroughly with any additives and water or slurry, and then mix with emulsified asphalt at the expected delivery temperature. Mixing time with emulsified asphalt should not exceed 60 s.

User Note: Before mixing the design samples, prepare trial blends with expected moisture, additives and corrective aggregate, if any, to determine that the emulsified asphalt disperses throughout the blend. If an improvement in dispersion is needed, adjust moisture content, staying within the moisture requirements described in the preceding paragraph. If an improvement is still needed, an emulsified asphalt formula change may be needed.

User Note: During construction stabilizing additives are typically added prior the addition of emulsified asphalt. Cement is the most common additive and is usually spread just prior to emulsion addition but lime, CKD, LKD and fly ash are also used. If lime is incorporated a day or more before emulsified asphalt addition, then it shall be added to the wet aggregate a day or more before mixing with emulsified asphalt. If additives are incorporated as a slurry, then it shall be incorporated as a slurry in the laboratory.

3.8 Curing Before Compaction

After mixing, loose specimens shall be cured individually in plastic containers at 104 °F (40 °C) for 30 ± 3 minutes. Plastic containers shall be 4 to 7 inches tall (100 to 180 mm) and 6 inches (150 mm) diameter. No further mixing or aeration shall occur during this time.

3.9 Compaction

Immediately after curing the specimens shall be compacted at room temperature, 77 ± 9 °F (25 ± 4 °C), to 30 gyrations using a Superpave gyratory compactor (SGC) at 1.25° angle, 87 psi (600 kPa) stress. Samples shall be compacted to 75 ± 5 mm (2.95 ± 0.2 in.) thick using a 150-mm diameter mold. Molds shall not be heated. A total of 6 specimens at each emulsified asphalt stabilizing agent content shall be prepared, 3 for dry 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.

3.10 Curing after Compaction

Specimens shall be extruded from molds after compaction so as not to damage the specimens. Remove the paper disk from the top and bottom of the specimens if used. Place specimens in 60 ± 1°C (140 ± 2°F) forced draft oven with ventilation on sides and top. Place each specimen in a small flat container to account for material loss from the specimens. Cure compacted specimens at 60 ± 1°C (140 ± 2°F) to constant mass but do not heat for more than 48 h and not less than 16 h. Constant mass is defined as 0.05% change in mass or less in 2 hours. After curing, cool specimens at 25 ± 2°C (77 ± 4°F) for a minimum of 12 h and a maximum of 24 h. Specimen heights shall be determined according to AASHTO T 245 (ASTM D6927) or may be obtained directly from the readout of the Superpave gyratory compactor.

Specimens for Maximum Theoretical Specific Gravity shall be cured at the same conditions as the compacted specimens, except they can be tested after cooling a maximum of 24 hours.

3.11 Volumetric Measurements

3.11.1 Bulk Specific Gravity

Determine bulk specific gravity of the specimens using AASHTO T 331 (ASTM D6752). Keep specimens in bags until testing or vacuum saturation is performed. AASHTO T 166 (ASTM D2726) may be used to determine bulk specific gravity if specimens' absorption is less than or equal to 2 percent of water by volume.

3.11.2 Maximum Specific Gravity

Determine Maximum Theoretical Specific Gravity in accordance with AASHTO T 209 (ASTM D2041) or ASTM D6857 except as noted in the Mixing, Compaction, and Curing after Compaction sections. Mix samples according to the mixing section using either the highest emulsified asphalt content or the highest and lowest emulsified asphalt contents in the design. The dry-back procedure of AASHTO T 209 (ASTM D2041) is usually required.

3.11.2.1 *Testing Two Specimens at the Highest Emulsified Asphalt Content*

Test both specimens at the highest emulsified content in the design. Back calculate the theoretical maximum specific gravity for the lower emulsified asphalt contents using the following formulas. Calculate the effective specific gravity of the FDR material from the average measured G_{mm} as:

$$G_{FDR} = (100 - P_{br}) / [(100/G_{mm}) - (P_{br}/G_b)]$$

Where: G_{FDR} = Effective specific gravity of FDR material
P_{br} = Percent residual asphalt content from the emulsified asphalt in the mix
G_b = Specific gravity of the residual asphalt

Calculate the theoretical maximum specific gravity for the lower emulsified asphalt contents using the following formula:

$$G_{mm} = 100 / [((100 - P_{br})/G_{FDR}) + (P_{br}/G_b)]$$

Where: G_{mm} = Theoretical maximum specific gravity at desired emulsified asphalt content
P_{br} = Percent residual asphalt content at desired emulsified asphalt content
G_{FDR} = Effective specific gravity of FDR material
G_b = Specific gravity of the residual asphalt

3.11.2.2 *Testing Specimens at Highest and Lowest Emulsified Asphalt Content*

Test specimens at the highest and lowest emulsified content in the design. Use straight line interpolation to determine maximum theoretical specific gravity at the other emulsion contents.

3.11.3 Air Voids

Determine air voids of all compacted specimens in accordance with AASHTO T 269 (ASTM D3203).

3.12 Indirect Tensile Strength (ITS) Measurements

3.12.1 Dry Cured ITS

For dry cured indirect tensile strength testing, compacted and cured specimens shall be brought to test temperature by either placing each specimen in a leak-proof bag and submerging in a water bath at 77 ± 2 °F (25 ± 1 °C) for 30-45 minutes immediately prior to testing or by placing each specimen in an oven at 77 ± 2 °F (25 ± 1 °C) for 2 hours immediately prior to testing. Test

samples in accordance with AASHTO T 283 (ASTM D4867). This testing shall be performed at the same time that moisture-conditioned specimens are tested.

3.12.2 Conditioned, Cured ITS

For conditioned, cured indirect tensile strength testing, moisture conditioning shall be conducted on 3 compacted, cured specimens at each stabilizing agent content by applying a vacuum of 2 psi to 10 psi (13 to 67 kPa) 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. For indirect tensile strength testing (AASHTO T 283 or ASTM D4867), 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.

3.13 Emulsified Asphalt Content Selection

The emulsified asphalt content selected shall result in the mixture meeting the design requirements of Table 2.

Table 2 FDR with Emulsified Asphalt Mix Design Requirements, Combined materials

Test Method	Criteria		Property
	FDR Type 1[1]	FDR Type 2[1]	
Gradation for Design Millings, AASTHO T 11 & T 27 (ASTM C117 & C136)	Report	Report	
Sand Equivalent, AASHTO T 176 (ASTM D2419, Method B)	Report	Report	Suitability of material for emulsified asphalt stabilization
Plasticity Index, AASHTO T 89 & T 90 (ASTM D4318)	Report	Report	Suitability of material for emulsified asphalt stabilization
Modified Proctor, AASHTO T 180 (ASTM D1557, Method C)	Report	Report	Optimum Moisture (Total liquids) Content
Design Moisture Content (Section 3.7)	Report	Report	Dispersion of Emulsion and for Density and Compaction Control
Bulk Specific Gravity (Density), AASHTO T 311 or T 166 (ASTM D6752 or ASTM D2726)	Report	Report	Density as Compacted
Maximum Theoretical Specific Gravity, AASHTO T 209 (ASTM D2041) or ASTM D6857	Report	Report	Maximum Specific Gravity
Air Voids of Compacted, Cured Samples, AASHTO T 269 (ASTM D3203)	Report Only – Stabilizing agent content should not be adjusted to meet an air void content.	Report Only – Stabilizing agent content should not be adjusted to meet an air void content.	For Calculation of Percent Saturation
Indirect Tensile Strength, AASHTO T 283	40 (276) Minimum	35 (241) Minimum	Cured Strength

(ASTM D4867), psi (kPa)			
Conditioned Indirect Tensile Strength, AASHTO T 283 (ASTM D4867), psi	25 (172) Minimum	20 (138) Minimum	Moisture Resistance
Ratio of Residual Emulsified Asphalt to Cement	Minimum 2.5:1.0	Minimum 2.5:1.0	Prevent Rigid Behavior
Additional Additive(s)[2]			
Coarse Aggregate	Report	Report	
Fine Aggregate	Report	Report	
RAP	Report	Report	
Fly Ash	Report	Report	
Cement %	Report	Report	
Lime	Report	Report	
Emulsified Asphalt[2]			
Distillation Residue, %	Report	Report	
Residue Penetration, mm	Report	Report	
Optimum Emulsion Content, %	Report	Report	

Notes: 1. FDR Type 1 for mixtures containing <8 percent passing No.200. FDR Type 2 for mixtures containing ≥8 percent passing No. 200 or for all gradation mixtures.

3.14 Report

All mix design test results shall be reported to the Owner Agency. All additional additives and bituminous material shall be reported to the Owner.

The report shall contain the following minimum information:

- Gradation of RAP, granular material and combined gradation
- Sand equivalent and PI of combined material
- Maximum dry density and optimum total liquid content from AASHTO T 180 (ASTM D1557)
- Design Moisture Content (Section 3.7)
- Density, maximum specific gravity, air void content, dry and moisture conditioned indirect tensile strength and level of saturation at each emulsified asphalt stabilizing agent content
- Optimum emulsified asphalt stabilizing agent content as a percentage of dry materials
- Density, air void content, dry and moisture conditioned indirect tensile strength at recommended moisture, emulsified asphalt stabilizing agent and recycling additive contents
- Emulsified asphalt stabilizing agent designation, supplier name and location, emulsified asphalt residue content and certificates of compliance
- Amount and type of recycling additive as a percentage of dry materials
- Ratio of residual emulsion asphalt content of stabilizing agent to cement
- Application means of stabilizing agent
- Emulsified asphalt stabilizing agent supplier name and location and certificates of compliance