Recommended
Mix Design Guidelines
For
Full Depth Reclamation (FDR)
Using Cement or Cement Kiln Dust (CKD)
Stabilizing Agent
FDR202

12/22/2016

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 HMA shall be crushed, mixed with the desired percentage of underlying material and cement or cement kiln dust (CKD) stabilizing agent and other additives, as necessary. The mixture shall then be tested in accordance with the procedures and requirements of Table 3 and the additional procedures and requirements of Table 4 when desired.

User Note: The mix design parameters provided in Table 2 are minimum parameters and should be parts of all FDR mix designs. The optional test parameters provided in Table 3 are recommended when an Owner Agency wants a higher level of reliability or when the desired level of risk, traffic, and length of the project justify the increased cost.

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 base or poor drainage areas. 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 including base material from the areas to be reclaimed. The purpose of the samples is for mix design, to determine if the thickness of the existing pavement is suitable for the recycle depth proposed and 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, subgrade or concrete; 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 samples at various locations along the pavement to assess the consistency of the underlying pavement conditions. Include samples near the centerline, between wheel paths, and at the pavement edge. If FDR is to be performed on the paved 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 or auger sampling, milled areas to be reclaimed, 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. For example, if there are areas of major distresses (i.e. large patches, rutted areas); a separate sample is recommended for design and analysis.

2.1 Core or Auger Sampling

Core or auger 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.

When using core sampling techniques, 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 reclaiming depth plus an additional 6-inches (150-mm), shall be obtained at each sample location. For core samples 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 diameter and thickness shall be recorded for each core location and provided to the mix design laboratory.

For auger sampling place the sample in a container and record the job number and sample location on the container in indelible ink. Similar to the coring log, a log summarizing the date, station, offset, and auger diameter and depth shall be recorded for each sample location and provided to the mix design laboratory.

Either core or auger samples shall be obtained using a pattern that results in a representative sample of the pavement to be reclaimed including at or near lane lines, within and between wheel paths, at the pavement edge and within shoulders if shoulders are to be reclaimed. 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)**.

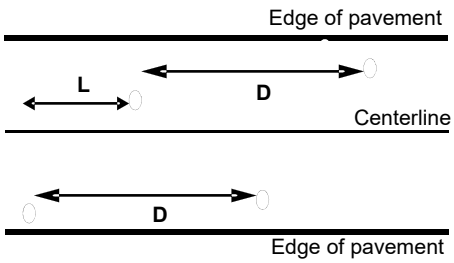

Diagram 1a – Staggered (offset) sampling.

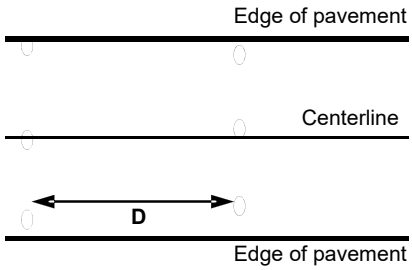

Diagram 1b – Crossroad sampling.

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 reclaimed, 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 samples 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 samples 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 sampling 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 sampling should be in the shoulder if the shoulder is getting recycled.
At least 25% of the sampling should 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 sampling should be in the shoulder if it is getting recycled or within 3-feet (1 m) of gutter.
At least 25% of the sampling should 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 samples 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 samples 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 to be milled shall 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 shall 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 should 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, the pavement to be milled shall 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 shall 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 should be removed prior to sampling.

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) 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

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. After sampling and filling the holes, the roadway shall be cleaned of all loose debris.

3. Full Depth Reclamation Mix Design

3.1 Laboratory Temperature and Humidity Control

Each laboratory performing mix designs shall have heating, ventilation, and air conditioning (HVAC) equipment that maintains a room temperature of 68 to 86 °F (20 to 30 °C) and relative humidity of less than 60 percent.

3.2 Sampling and Processing

A minimum sample size of 350 lbs. (160 kg) is needed for each mix design. Samples of the recycled layer thickness shall be obtained as described in sections 2.1, 2.2 or 2.3. Each layer shall be examined to confirm thickness and material.

If cores or pavement slabs of the asphalt mix were obtained, a laboratory milling machine shall be used to model the gradation expected during reclaiming operations. 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 gradations shall be chosen to match the expected field gradation as closely as possible. The entire sample material 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.

A washed gradation (AASHTO T 11 & T 27 or ASTM C117 & C136) of the RAP and granular layers shall be performed and the combined gradation calculated. The combined gradation shall meet the requirements of Table 2. The plasticity index (PI) (AASHTO T 90 or ASTM D4318) shall be performed and reported on the combined materials. Washed gradations of RAP or combined RAP and granular material shall be dried at 104 °F (40 °C).

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

Table 1 – GRADATION OF PROCESSED (PULVERIZED) MATERIALS	
Sieve Size	**Minimum Percent Passing**
3 in. (75 mm)	100
2 in. (50 mm)	95
No. 4 (4.75 mm)	55

3.3 Mixing and Compaction

Select the anticipated or median cement/CKD content and thoroughly mix the cement/CKD with the required amount of material to be reclaimed and compact the sample in accordance with AASHTO T 134 (ASTM D558) to determine optimum moisture content (OMC) at peak dry density. OMC shall be defined by a best-fit curve from a minimum of four points.

Choose three cement/CKD contents in 1 to 2% increments that will bracket the design cement/CKD content. Recommended cement/CKD content percentages are based on the classification of the materials but generally range for cement from 2.0 to 5.0%.

Mixing of test specimens shall be performed with a laboratory mixer or by hand. The RAP and granular material shall be thoroughly mixed with cement/CKD first, then mixed with the optimum moisture determined in accordance with AASHTO T 134 (ASTM D558). Aggregate material and cement/CKD shall be mixed at a temperature of 68 to 79 °F (20 to 26 °C). If other materials are added, such as lime, then they shall be introduced in a similar manner as they will be on the project. For example, if lime is incorporated a day or more before cement/CKD addition, then it shall be added to the wet aggregate a day or more before mixing with cement/CKD. If lime is incorporated as slurry, then it shall be incorporated as slurry in the laboratory.

After mixing, loose specimens shall be stored individually in sealed plastic containers of 4 to 7 in. (100 to 175 mm) height and 6 in. (150 mm) diameter. Specimens shall be stored at 77 ± 9 °F (25 ± 4 °C) for 30 ± 3 minutes. No further mixing or aeration shall occur during this time.

Following the 30-minute storage, specimens shall be compacted at room temperature 77 ± 9 °F (25 ± 4 °C). Compact three samples at each cement/CKD content in accordance with AASHTO T 134 (ASTM D558). Specimens shall be extruded from molds after compaction so as not to damage the specimens. Record the weight of each specimen.

3.4 Curing after Compaction

Specimens shall be cured for 7 days in a moist room or cabinet capable of maintaining a temperature of 73.4 ± 3 °F (23.0 ± 1.7 °C) and a relative humidity of not less than 96%.

3.5 Unconfined Compressive Strength Measurements

After the 7-day moist cure period remove the specimens from the moist room or cabinet and record the weight of the specimens. Immerse the specimens in a water bath at 77 ± 2 °F (25 ± 1 °C) for 4 hours. Remove each specimen from the water bath and determine the unconfined compressive strength of each sample in accordance with ASTM D1633. Record the unconfined compressive strength as the average strength at each cement/CKD content.

3.6 Cement/CKD Content Selection

The cement/CKD content selected shall result in the mixture meeting the design requirements of Table 2.

Table 2 FDR with Cement/CKD or CKD Mix Design Requirements

Test Method	FDR	Test Purpose
Gradation for Design Millings, AASTHO T 11 & T 27 (ASTM C117 & C136)	Report	
Plasticity Index, AASHTO T 90 (ASTM D4318)	PI < 20	Suitability of stabilizing agent
Maximum Dry Density and Optimum Moisture Content, AASHTO T 134 (ASTM D558)	Report	Optimum Moisture Content for Density and Compaction
Design Moisture Content	Report	Compaction
Wet Density of Specimens Before and After Curing Period	Report	Density Indicator
Unconfined Compressive Strength, ASTM D1633	250 – 500 psi (1,725 – 3450 kPa)	Strength Indicator
Stabilizing Agent/Additional Additive(s)[1] Cement CKD Coarse Aggregate Fine Aggregate RAP Lime %	 Report Report Report Report Report Report	

Notes: 1. Report shall include type/gradation and producer/supplier.

3.7 Optional Testing Parameters

For a higher reliability mix design, one of the two durability tests shall be conducted:

User Note: The procedures provided in Table 4 are recommended for inclusion when an Owner Agency wants a higher level of reliability or when the desired level of risk, traffic and length of the project justify the increased testing cost.

***Vacuum Saturation Test*:**
Determine the durability of the mix according to the vacuum saturated strength testing procedure of ASTM C593.Test specimens made at the design cement/CKD content and at plus 2% cement/CKD.

***Freeze-Thaw Test*:**
Determine the durability of the mix according to AASHTO T 136 (ASTM D560). Test specimens made at the design cement/CKD content and at plus 2% cement/CKD.

Note: ASTM D560 was withdrawn in 2012; however, many manuals and Owner Agencies still reference this test procedure.

TABLE 3 – RECOMMENDED OPTIONAL FDR MIX DESIGN REQUIREMENTS

Test Method	FDR	Test Purpose
Vacuum Saturation Test (ASTM C593)	350 psi (2.4 MPa) Min. Compressive Strength	Durability Indicator
Freeze-Thaw Test, AASHTO T 136 (ASTM D560)	Max. 14% weight loss after 12 cycles	Durability Indicator

3.8 Report

All mix design test results shall be reported to the Owner Agency.
The report shall contain the following minimum information:

- Gradation of RAP granular material and combined gradation
- Plasticity Index (PI) of combined material
- Maximum dry density and optimum moisture content from AASHTO T 134 (ASTM D558)
- Dry density, moisture content and unconfined compressive strength at each cement/CKD stabilizing agent content
- Wet density of compressive strength test specimens before and immediately after moist curing period
- Optimum cement/CKD stabilizing agent content as a percentage of dry materials
- Laboratory mixing method
- Application means of stabilizing agent, e.g. dry or slurry form
- Cement/CKD stabilizing agent designation, supplier name and location and certificates of compliance
- Amount and type of any additional additive(s) as a percentage of dry materials
- Additive supplier name, location and certificates of compliance
- Application means of additive, dry or slurry form
- Dry density and optimum moisture conditioned at recommended cement/CKD stabilizing agent and recycling additive contents

The following optional test results shall be reported if applicable:

- Compressive strength of vacuum saturated specimen tested in accordance with ASTM C593
- Total mass loss of specimen tested in accordance with AASHTO T 136 (ASTM D560)