CHAPTER 15: COLD RECYCLING – MIX DESIGN

Like Hot In-Place Recycling (HIR) and Full Depth Reclamation (FDR), there is no nationally accepted method for the design of Cold Recycling (CR) mixtures, and most agencies that use CR have their own mix design procedures. The Oregon Department of Transportation has an empirical procedure for estimating initial asphalt emulsion content for mixtures with 100 percent Reclaimed Asphalt Pavement (RAP). American Association of State Highway and Transportation Officials/the Associated General Contractors of America/American Road and Transportation Builders Association (AASHTO-AGC-ARTBA) Joint Committee Task Force 38 Report entitled "Report on Cold Recycling of Asphalt Pavements" (Task Force 38) contains mix design procedures for both Marshall and Hveem equipment and many states use it or modified Marshall or Hveem. There is also research underway to adopt Superpave technology to CR mixtures.

The mix design serves as an initial job mix formula, the same as in hot mix asphalt (HMA) construction. Adjustments are generally required for workability, coating, and stability.

Most mix design methods for CR mixes involve the application of asphalt emulsions, emulsified recycling agents or cutbacks as the recycling additive although foamed asphalt and chemical recycling additives have also been used. Three basic theories have been proposed for designing CR mixes with these recycling additives. The first theory assumes that the RAP will act as a black aggregate and the mix design consists of determining a recycling additive content to coat the aggregate. The second theory evaluates the physical and chemical characteristics of the recovered asphalt binder and adds a recycling agent to restore the asphalt binder to its original consistency. The assumption is that complete softening of the old asphalt binder occurs. The third and most prevalent theory is a combination of the first two, where some softening of the old asphalt binder occurs. This theory is referred to as the effective asphalt theory, where the recycling additive and the softened aged asphalt binder form an effective asphalt layer. The degree of softening is related to the properties of the old asphalt binder, recycling additive, and environmental conditions. Because the degree of softening is difficult to quantify, it is recommended that mechanical tests on the CR mix be a part of all mix designs.

Most State Highway Agencies that utilize CR have their own mix design procedures. The procedures range from simple to complex. The simplest methods entail empirical formulas based on the amount and consistency of the recovered asphalt binder to predict an initial recycling additive content. The complex methods include sophisticated testing such as resilient modulus, stability, and moisture sensitivity tests. Testing often includes short-term and long-term curing conditions. Adjustments are made in the field to the initial recycling additive content for optimum performance. The different methods generally address all or a portion of the following steps or procedures, as shown in Figure 15-1. The issues concerning each step of the general procedure are addressed in subsequent sections.

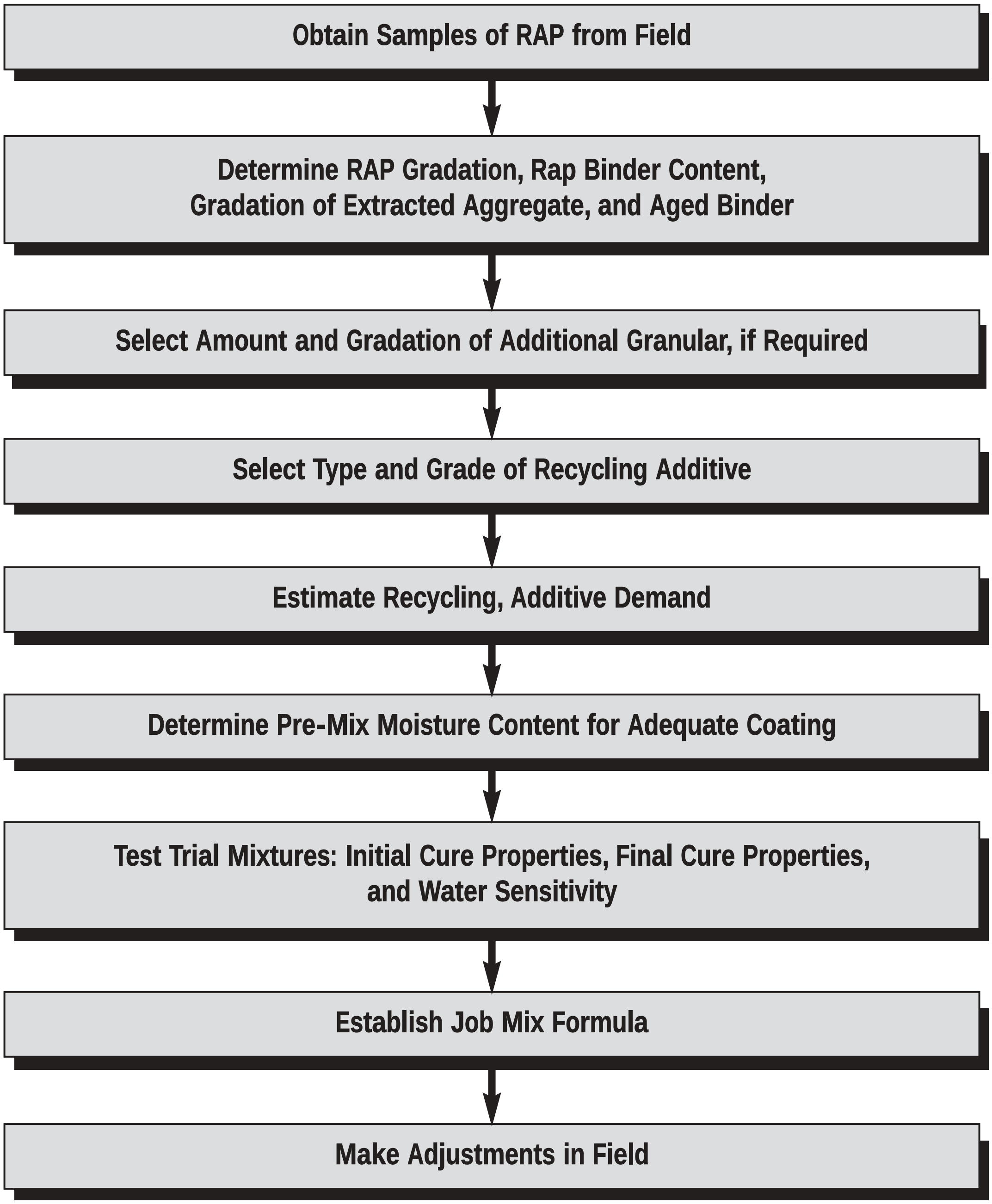


Figure 15-1: CR mix design flow chart

15.1 SAMPLING EXISTING PAVEMENT

Representative samples of the RAP should be obtained and evaluated to properly design a CR mixture. A sampling plan must be developed that adequately determines the physical properties of the RAP along the length of the project. A visual evaluation should be made along with a review of construction and maintenance records, to determine whether significant differences in materials will be encountered. Sections of the roadway with significant differences in materials should be delineated and treated as separate sampling units to ensure representative sampling. Areas with different mixtures and/or extensive maintenance mixtures should not be lumped together for design. After delineating representative sampling units, samples of the pavement should be obtained from each unit, using random sampling techniques. Stratified random samples are usually recommended, where a random sample or samples are obtained from each lot of the sampling area. The number of sampling lots and samples per lot vary with the length of the project and traffic. For larger jobs, length greater than 4 miles (6.4 kilometers), one random sample per lane 5/8 lane mile (kilometer), with a minimum of six samples per project, is often recommended. In urban locations, others recommend sampling frequencies of five samples per 5/8 lane mile (kilometer) or one per block due to the increased variability encounter with urban asphalt pavements.

Samples usually consist of cores. These should be obtained full depth, as the thickness of the pavement after milling must be evaluated to ensure that the remaining pavement can support the weight of the recycling train. It is generally recommended that a minimum of 1 inch (25 mm) and preferably 2 inches (50 mm) of asphalt material or 6 inches (150 mm) of aggregate base remain to support the weight of the recycling train.

The gradation of the RAP and extracted mineral aggregate will have an effect on the selection of the amount of recycling additive and on final mixture performance. Therefore, the importance of obtaining realistic field samples cannot be overemphasized. Representative samples of RAP are required. Field sampling has traditionally been obtained by coring/sawing or small milling machines. The popularity of using small milling machines to obtain field samples is declining since the consistency of the samples between different types of small milling machines is highly variable and it is relatively expensive. The gradation of the samples obtained by small milling machines is not as coarse with smaller maximum particle size and more fines, i.e., passing No. 200 (0.075 mm) sieve size than what is produced by the large milling machines during the CIR process. The current trend is to obtain samples by means of coring, usually 6 inches (150 mm) in diameter, and then subsequently crushing the cores in the laboratory. With field coring and laboratory crushing, the sample gradation more closely resembles what is achieved in the field during the CIR process. Block sampling, by means of sawing, can also be used, but it is usually more expensive than coring. It is important that the full depth of the asphalt bound layers be cored in order to assess its condition. However, only the upper portions of the core, equivalent to the anticipated CIR treatment depth, are used for subsequent analysis. Regardless of the method used to obtain RAP, it is recommended that agencies obtain samples of the RAP during construction to compare to mix design gradations. Based on this database, adjustments in gradations for mix design samples could be evaluated.

15.2 DETERMINATION OF RAP PROPERTIES

The properties of the RAP, extracted aggregate, and recovered asphalt cement should be evaluated. The gradation of the RAP should be determined in accordance with the American Association of State Highway and Transportation Officials (AASHTO) T 27 "Sieve Analysis of Fine and Coarse Aggregate" or the American Society for Testing and Materials (ASTM) C 136 "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate." The asphalt content of the RAP needs to be determined, as well. For smaller projects, where it is not feasible to determine the properties of the recovered asphalt cement, the asphalt content may be determined in accordance with ASTM D 6307 "Test Method for Asphalt Content of Hot Mix Asphalt by the Ignition Method."

For larger projects, it is recommended that the properties of the recovered asphalt cement be determined, to assist in selecting the proper grade of recycling additive. The asphalt content of the RAP should be determined using AASHTO T164 "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures." Other extraction procedures can alter the properties of the recovered asphalt cement. Preheating the RAP for 3 hours at 250°F (120°C) prior to extraction is necessary, to determine the residual asphalt content of mixtures made from cutback asphalts or asphalt emulsions containing solvents.

The aged asphalt binder should be recovered from the RAP using the Rotovap procedure, as outlined in ASTM D5404 "Test Method for Recovery of Asphalt from Solution Using the Rotovapor Apparatus." If the equipment is not available, AASHTO T 170 "Recovery of Asphalt from Solution by Abson Method" may be substituted. The recovered asphalt binder should be tested to determine the effects of aging on the stiffness and consistency. At a minimum, the penetration at 77°F (25°C) and/or the absolute viscosity at 140°F (60°C) should be determined. The recovered penetration and viscosity data are useful in determining the proper grade of recycling additive for CR mixtures.

Current research is focusing on the use of the Superpave binder test property of G*/sin d (see Chapter 5 for an explanation of G* and d) for determining the grade of recycling additive. It is anticipated that the results from this study will be implemented in the future, replacing penetration and absolute viscosity.

15.3 SELECT AMOUNT AND GRADATION OF NEW AGGREGATE

Most CR projects are constructed without the addition of new aggregates, including some with fine gradations. The decision to add new aggregate should not be based on the gradation of the aggregate recovered from the RAP alone, because coarse angular particles of conglomerated fines can be manufactured by cold milling that are not broken down by traffic. However, the addition of new aggregate can be beneficial and justified in some cases, such as when excess asphalt binder is present or when it is deemed desirable to increase the structural capacity of the mix. Mixture testing should be performed to insure that the additional costs incurred result in measurable improvements in performance.

The gradation of the extracted aggregate, recovered from ASTM D 6307 or AASHTO T 164, should be determined, using a washed sieve analysis in accordance with AASHTO T 11 "Materials Finer Than 75-mm Sieve in Mineral Aggregates by Washing" and AASHTO T 27. Based on the gradation of the aggregate extracted from the RAP, the need for new aggregates can be evaluated. Many CR projects consist of upgrading lower volume pavements for higher traffic volumes. Many of these pavements contain local aggregates of lower quality, such as sand and gravel mixtures that may not provide adequate structural capacity. Increasing the percent coarse aggregate and the percent crushed material may improve the structural capacity of the pavement. RAP mixtures with excess asphalt binder can sometimes benefit from the addition of new aggregates, as well.

In areas where good quality coarse aggregates are not available, self cementing type C fly ash or type C fly ash/Portland cement blends, have been successfully utilized as a recycling additive to improve the structural capacity and reduce moisture damage potential of CR mixes.

Besides new aggregates, additional RAP may be added when a thicker section is desired but the depth of milling must be reduced because of the presence of a weak layer. RAP or new aggregate is recommended to prevent a reduction in the depth of the CR layer when roadway widening is undertaken.

New aggregates should be selected so that the blend of the new aggregate, and aggregate in the RAP, meets current specifications, in both gradation and quality. The Asphalt Institute has recommendations for aggregates for cold mix, but other agency specifications are suitable, as well. The Asphalt Institute recommends a minimum sand equivalent of 35 percent, a maximum Los Angeles Abrasion at 500 revolutions of 40, and a minimum percent crushed faces of 65 percent. Typical gradations for CR base mixes are shown in Table 15-1.

Sieve	A	B	C	D
Size	Percent Passing			
1.5" (40.0 mm)	100			
1" (25.0 mm)	90-100	100		
3/4" (20.0 mm)		90-100	100	
1/2" (12.5 mm)	60-80		90-100	100
3/8" (9.5 mm)		60-80		90-100
No. 4 (4.75 mm)	25-60	35-65	45-75	60-80
No. 8 (2.16 mm)	15-45	20-50	25-55	35-65
No. 50 (0.300 mm)	3-20	3-21	6-25	6-25
No. 200 (0.075 mm)	1-7	2-8	2-9	2-10

Table 15-1: Gradation Guidelines for CR Combinations of Aggregates from RAP and New Aggregates

Fine aggregates, especially natural sands, should not be added to CR mixtures unless the effect on performance is thoroughly evaluated. The milling process can increase the fines in the mix and the amount depends on many factors, including the type of existing aggregates. Adding new fines could lead to a loss of stability, difficulty in coating the RAP, reduced tolerance for water, and poor dispersion of the recycling additive.

15.4 ESTIMATE NEW RECYCLING ADDITIVE DEMAND

New or additional asphalt binder is necessary to facilitate compaction, improve the cohesion of the mix, and to reduce the viscosity of the aged binder. The recycling additives typically used to supply the new or additional binder are asphalt emulsions, recycling agents or cutback asphalts. The optimum recycling additive content for these additives is typically in the 0.5 to 3.0 percent range for CR mixtures using 100 percent RAP. For most mix designs this new recycling additive content is established based on previous experience or by using empirical formulas. The new or additional recycling additive demand is a starting point for mixture design purposes. For some jobs, the optimum recycling additive content is based on this initial estimate, with changes made in the field by experienced personnel.

The Oregon Department of Transportation has an empirical formula for estimating new or initial asphalt emulsion content, based on their experience. The formula is applicable to mixtures containing 100 percent RAP. The method is based on the gradation, asphalt binder content of the RAP and the penetration and absolute viscosity of the recovered binder. The procedure consists of adjusting a base asphalt emulsion content of 1.2 percent, based on the weight of the RAP, for properties of the RAP and recovered asphalt binder.

15.5 SELECTION OF RECYCLING ADDITIVE

The correct selection of the type and grade of recycling additive is necessary for the proper performance of CR projects. The most common recycling additives for CR mixtures are asphalt emulsions and emulsified recycling agents because they are liquid at ambient temperatures, and can be readily dispersed throughout the mix. Polymer modified versions of asphalt emulsions and emulsified recycling agents have been used to improve early strength, resist rutting, and reduce thermal cracking. Other modifiers, such as Portland cement or lime can also be incorporated to improve properties of the recycled mix. Portland cement or lime, both hydrated and slaked quicklime, has been used in combination with asphalt emulsions to improve early stiffening and improve moisture damage resistance.

15.5.1 ASPHALT EMULSIONS

The most common recycling additives are cationic and anionic mixing grade asphalt emulsions, both medium setting and slow setting, and high float emulsions, with and without polymers. Medium-setting (MS) asphalt emulsions are designed to mix well with open or coarse graded aggregates. They do not break on contact and will remain workable for an extended period of time. High float medium-setting (HFMS) asphalt emulsions are a special class of anionic medium-setting asphalt emulsions. They have a gel structure in the asphalt residue which allows for thicker films on aggregate particles, giving better coating in some instances, such as under high temperatures.

Slow-setting (SS) asphalt emulsions work well with dense graded aggregates or aggregates with high fines content. The slow-setting asphalt emulsions have long workability times to ensure good dispersion with dense graded aggregates. Slow-setting asphalt emulsions are formulated for maximum mix stability.

Some agencies recommend that a medium-setting asphalt emulsion with solvent be used when the penetration of the recovered asphalt binder is less than 30 and that slow-setting asphalt emulsions be used if the penetration of the recovered asphalt is greater than 30. Some agencies, such as the Pennsylvania DOT, use hard residue asphalt emulsions (CMS-2h, HFMS-2h and CSS-1h) when the recovered asphalt binder penetration is greater than 30. Other agencies require polymer modified asphalt emulsions when the recovered penetration is less than 10.

The asphalt emulsion selected should be compatible with the RAP and new aggregate, if utilized. The surface of an aggregate has an electrical charge, with siliceous aggregates having a more negative surface charge and calcareous aggregates a more positive charge. Cationic asphalt emulsions, those designated with a C in front of the grade, contain a negative charge and are selected for use with siliceous aggregates. Anionic asphalt emulsions, no designation before the grade, contain a positive charge and are preferred with calcareous aggregates. When new aggregates are incorporated into the CR mix, the type of asphalt emulsion should be selected based on the charge on the new aggregate. However, the charge on the RAP is not necessarily related to the charge on the surface of the aggregate in the RAP, and the selection should not be based on the type of aggregate alone. For CR mixtures with 100 percent RAP, the asphalt emulsion is selected to optimize coating and initial strength, and control breaking times. Field records from previous projects should be consulted for information on which types and grades of asphalt emulsions have worked well. AASHTO T 59 “Testing Emulsified Asphalts” can be used to evaluate coating as an aid in selecting the recycling additive.

15.5.2 RECYCLING AGENTS

Emulsified recycling agents are the normal means of using a rejuvenator in cold recycling of aged asphalt. The emulsified recycling agent is usually manufactured as a cationic asphalt emulsion. A growing trend is the use of custom or proprietary emulsified recycling agents. Suppliers custom blend recycling agents with various amounts of asphalt emulsion binders. The blended product is designed to restore some of the consistency of the aged asphalt binder while also adding additional asphalt to the mix.

The selection of recycling agent depends on the asphalt demand and on the desired reduction in viscosity of the aged asphalt binder. The effectiveness of recycling agents in reducing the viscosity of the aged asphalt is based on a number of factors. The reactions are complicated and depend on the time and temperature-dependent interaction between the recycling agent and the aged asphalt binder. The rate of softening is a function of the properties of the recycling agent and aged asphalt binder, mechanical effects such as mixing, compaction, traffic, and climatic conditions. Therefore, when determining the amount and type of recycling agent, it is recommended that the mechanical properties of the recycled mix be determined both before and after final curing, rather than simply relying on blending charts based on consistency.

15.5.3 CUTBACK ASPHALTS

Cutback asphalt cements have been successfully utilized in the past but are not currently preferred due to environmental and safety concerns, as the flash point of some cutbacks, could be at or below the CR application temperature. It is also noted that some jurisdictions have restricted or even prohibited the use of cutback asphalts.

15.5.4 FOAMED ASPHALTS

Foamed asphalt cements have been used in the past and there is renewed interest in their use. However, most 100 percent RAP mixtures contain an insufficient amount of fines for use with foamed asphalts.

15.5.5 CHEMICAL ADDITIVES

Type C fly ash, lime and Portland cement, added as a slurry, have been successfully utilized as a recycling additive in CR. These chemical additives can be used to improve early strength gain, increase rutting resistance, and improve moisture resistance of CR mixtures containing rounded coarse aggregates and a high percentage of natural sands. Lime and Portland cement contents used typically used have been 1 to 2 percent by weight of RAP. Fly ash contents in the 8 to 12 percent range have been reported. There is no standard method for determining fly ash content. Mix design methods are available from the American Coal Ash Association.

15.6 DETERMINE PRE-MIX MOISTURE CONTENT FOR COATING

For most recycling additives moisture will be required for adequate coating. The water required for coating is usually greater than that needed to facilitate compaction. The water may be in the RAP as free moisture or may be added to the CR mixture. The water may be added before the addition of the recycling additive, such as at the cutting head for lubrication and cooling or in the pugmill, along with the recycling additive. For slow-setting asphalt emulsions and the anionic grades of medium-setting asphalt emulsions, moisture is required during mixing for adequate coating. High float emulsions and cationic medium-setting asphalt emulsions can contain petroleum distillates and will perform better with drier aggregates than wet aggregates.

Regardless of the recycling additive used, it is recommended that a coating test be performed to determine whether mixing water is needed to disperse the additive. Coating tests generally consist of mixing 2.2 pounds (1000 grams) of RAP with the estimated initial amount of recycling additive and varying amounts of water. Water is added in equal increments, usually 0.5 percent, by weight of the RAP. The water is added and mixed briefly to dampen the RAP, maximum of 30 seconds. The recycling additive is added and the mixture is mixed for an additional 60 seconds. The dispersion is visually evaluated and the lowest moisture content that results in no additional increase in coating is selected. Hand mixing using a spoon and bowl is preferred over mechanical mixing because coating and workability are easily observed. For the typical recycling additives of asphalt emulsions and emulsified recycling agents, the sum of the mix water content, recycling additive and moisture content of the RAP is referred to as the total liquids content. The total liquids content will vary from project to project and must be established during the mix design.

15.7 TRIAL MIXTURES

The amount of mixture testing is dependent on the size and scope of the project. For smaller projects, mixture testing is sometimes omitted, although this is not recommended. There is no one universally accepted mix design method for CR. Some or all of the following procedures are usually preformed.

15.7.1 BATCHING

A representative portion of the RAP should be dried to a constant mass at 230°F (110°C) and the moisture content determined. The moisture content is needed in the coating test. The remainder of the RAP should be sieved over a series of sieves, starting with the maximum sieve size allowed in the specifications and ending with the No. 4 (4.75 mm) or No. 8 (2.36 mm) sieve. Material retained on the maximum sieve size should be reduced in size without creating excess fines or be discarded. Samples of the appropriate size, typically 2.4 pounds (1100 grams) for 4 inch (100 mm) diameter Marshall size samples or 8.8 pounds (4,000 grams) for 6 inch (150 mm) diameter Superpave Gyratory Compactor (SGC) samples, should be batched to the same gradation as the RAP. The number of samples required depends on the level of testing. It is generally recommended that triplicate samples be made at each recycling additive content for testing and evaluation.

15.7.2 MIXING

Prior to mixing the RAP with the recycling additive and mix water, the materials are brought up to the desired mixing temperature. Most mixing is accomplished at ambient temperatures of 68 to 77°F (20 to 25°C), and heating the materials is not required. Some agencies heat emulsified recycling additives to 140°F (60°C) for one hour prior to mixing. Preheating an emulsified recycling additive expedites breaking of the emulsion. The mix water can be heated to the same temperature as the emulsified recycling additive.

For 4 inch (100 mm) diameter Marshall sized samples, approximately 2.4 pounds (1100 grams) of RAP is mixed at the total liquids content previously determined. The recycling additive is varied above and below the initial additive content in 0.7 percent increments. For asphalt emulsions, this results in a change in the residual asphalt content of about 0.5 percent. The mix water is adjusted to keep the total liquids content the same for all samples.

15.7.3 COMPACTION

Mix design samples are compacted using a standard compactive energy. The compactive energy should produce a laboratory compacted sample with a comparable density to field produced mix. Compaction at elevated temperatures 140°F (60°C) using 50 blow Marshall compaction has been used by some agencies. This is somewhat undesirable, as the temperature of the mix never approaches this elevated temperature. Recent work has shown that 75 blow Marshall compaction at field mix ambient temperatures of approximately 100°F (40°C) resulted in densities comparable with field densities. Compaction using the SGC has been shown to work with CR samples. However, the Ndesign number of compaction gyrations must be reduced from those recommended for HMA to reproduce expected field densities. Efforts are currently underway to verify the number of design gyrations.

In the field, CR mixtures are typically compacted as the mixture begins to break. For asphalt emulsions and emulsified recycling agents, this is indicated by a change in color of the mixture from brown to black. Samples compacted at ambient temperatures can be compacted immediately after mixing or allowed to break prior to compaction. Breaking can take up to 2 hours for samples of loose mix placed in a pan. Heating the liquids, as previously described in Section 15.7.2 expedites breaking. For samples compacted at elevated temperatures, the loose mix is placed in an oven at the compaction temperature until the mixture reaches the compaction temperature, 1 to 2 hours. The mix should break during this time. Allowing the sample to break prior to compaction will result in a loss of some of the mix water to evaporation and it will not be available to assist compaction. Newer mix design methods are moving toward compacting samples at ambient temperatures and prior to initial breaking.

Compaction typically follows Marshall procedures AASHTO T 245 "Resistance to Plastic Flow of Bituminous Mixtures Using the Marshall Apparatus" or ASTM D 1559 "Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using the Marshall Apparatus" or Hveem procedures AASHTO T 246 "Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus" or ASTM D 1561"Test Method for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus." As previously discussed, the compactive effort must be adjusted to produce laboratory samples with densities comparable to field densities. Compaction temperatures, mix/material temperatures, and allowing mix samples to break will all effect the compacted density of the samples.

15.7.4 CURING

CR mixtures must lose their excess water and cure, to develop maximum strength potential. Mixture testing can be performed to evaluate initial placement conditions, short-term curing or final strength (final curing). Curing procedures vary by agency. Short-term curing is typically carried out by holding the compacted samples at an elevated temperature of 140°F (60°C) for 2 to 4 hours. The samples are left in their compaction molds and are placed on their sides. Samples can be damaged if removed from the molds too soon.

Long-term curing sometimes consists of holding samples at elevated temperatures of 230°F (110°C) until they reach a constant mass. Other agencies hold the samples at 140°F (60°C) for 24 to 48 hours to simulate long-term curing conditions. Samples can be removed from the compaction molds prior to long-term curing.

15.7.5 STRENGTH TESTING

Prior to strength testing and regardless of the type of curing, the samples usually undergo a bulk specific gravity test. Approximate volumetrics can be determined from compacted specimens, however the volumetrics of voids in total mix (VTM), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA) are often not evaluated because of the difficulty of removing all of the mixing water from cured samples. The bulk density is usually determined by AASHTO T 166 "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens" or ASTM D 2726 "Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures," or by dividing the mass of the sample by the measured sample volume. The bulk density is used to verify compaction of like samples and is used in construction quality control.

Strength testing has consisted of Marshall stability and flow, AASHTO T 245 or ASTM D 1559, Hveem stability, AASHTO T 246 or ASTM D1560, unconfined compression AASHTO T 167 "Compressive Strength of Bituminous Mixtures" or ASTM D 1074 "Test Method for Compressive Strength of Bituminous Mixtures," Indirect Tensile Strength (ITS), ASTM D 4123 "Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures" or Resilient Modulus, ASTM D 4123. There are no firm guidelines or threshold values for strength tests.

The optimum recycling additive content (ORAC) can be selected to optimize one or more of the above strength properties. A second approach to selecting the ORAC is to evaluate the compacted VTM. The VTM of the compacted samples are evaluated by determining the maximum specific gravity of a sample of loose mix at each recycling additive content in accordance with AASHTO T 209 "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures" or ASTM D 2041 "Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures." The VTM is calculated in accordance with AASHTO T 269 "Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures" or ASTM D 3203 "Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures." The Asphalt Institute's publication MS-2 contains a good description of void calculations for asphalt mixtures. The ORAC is selected to give a VTM between 9 and 14 percent and/or at the peak density. The recycling additive content should not be artificially adjusted to reach the suggested VTM range. Suggested mix design procedures are available from the Task Force 38 Report on Cold In-Place Recycling.

In areas where there is a history of moisture susceptibility problems, some type of moisture conditioning test is warranted. AASHTO T 283 "Resistance of Compacted Bituminous Mixture to Moisture Induced Damage" is the most common method used, although others have used the Index of Retained Resilient Modulus (IRRM). The IRRM is determined by dividing the resilient modulus of moisture conditioned samples by the resilient modulus of non-moisture conditioned, samples. The moisture conditioning is typically the same as described in AASHTO T283. Samples for moisture susceptibility testing are compacted to the mix design density, not 7 percent VTM as specified in AASHTO T283. Typical tensile strength ratios (TSR) for CR materials are greater than 70 to 80 percent. Portland cement and lime, both dry and slurry, have been shown to greatly improve TSR.

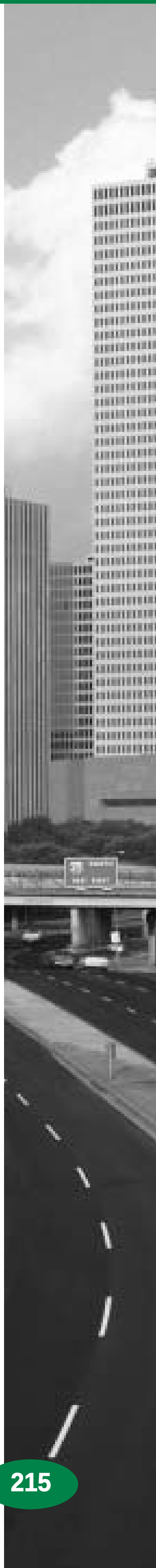
15.8 ESTABLISH JOB MIX FORMULA

At the completion of the mix design, the Job Mix Formula (JMF) is established. The JMF should specify the ORAC, type and grade of recycling additive, the mix water content, and laboratory compacted maximum density at the ORAC. These should be considered as starting points for construction and may need to be adjusted in the field by qualified individuals as conditions warrant.

15.9 FIELD ADJUSTMENTS

Adjustments to the JMF will be required as conditions warrant, and field personnel need the authority to make slight adjustments in mix water content and amount of recycling additive, based on changing field conditions. Slight adjustments in mix water of 1 to 2 percent and/or asphalt emulsion or emulsified recycling agent content of up to 0.5 percent or more could be necessary to ensure adequate dispersal of the recycling additive.

Field conditions that could warrant slight changes in mix water, asphalt emulsion or emulsified recycling agent are changes in the gradation of the RAP and changes in temperature. Changes in gradation of the RAP could result from non-uniformity of the pavement due to maintenance procedures or areas of non-uniformity of the original mix. A lowering of the pavement temperature can result in a coarsening of the RAP gradation and a lower compacted mat density. Increasing the recycling additive content to increase density could lead to an over asphalted mix and cause stability/workability problems. Changes in humidity levels and other environmental factors can effect the breaking of the asphalt emulsion or emulsified recycling agent, and affect dispersion and workability of the CR mixture. However, changes in the recycling additive content due to environmental conditions must be made with care or premature pavement failure could result.



CHAPTER 16: COLD RECYCLING – CONSTRUCTION

Cold recycling (CR) is not a new method of rehabilitating deteriorating roadways. For the past 50 years or more CR which was often called stabilization, has been practiced by various methods. These methods have included rippers, scarifiers, pulvimixers, and stabilizing agents to reclaim the existing surface and underlying materials. Asphalt emulsions, cutbacks and other recycling additives have been added and mixed by spraying the liquid on a windrow and mixing with a blade, with cross shaft mixers, and with various types of traveling plants. The CR material was blade laid and compacted with available compaction equipment.

There are two methods of CR asphalt pavements: Cold In-Place Recycling (CIR) and Cold Central Plant Recycling (CCPR). CIR is faster, more economical, less disruptive, and environmentally preferable because trucking is greatly reduced. CIR is defined as an asphalt pavement rehabilitation technique that reuses existing pavement materials. CIR involves the processing, and treatment with bituminous and/or chemical additives, of the existing asphalt pavement without heat to produce a restored pavement layer. All work is completed while on the pavement being recycled. Transportation of materials, except for the recycling additive(s) being used, is not normally required. The depth of processing is typically 3 to 5 inches (75 to 125 mm). The process is sometimes referred to as partial depth recycling because the underlying materials and or some of the bituminous materials are left intact. In-Place recycling that incorporates untreated base material with the bound material is referred to as Full Depth Reclamation (FDR) and is discussed in Chapters 10 through 13.

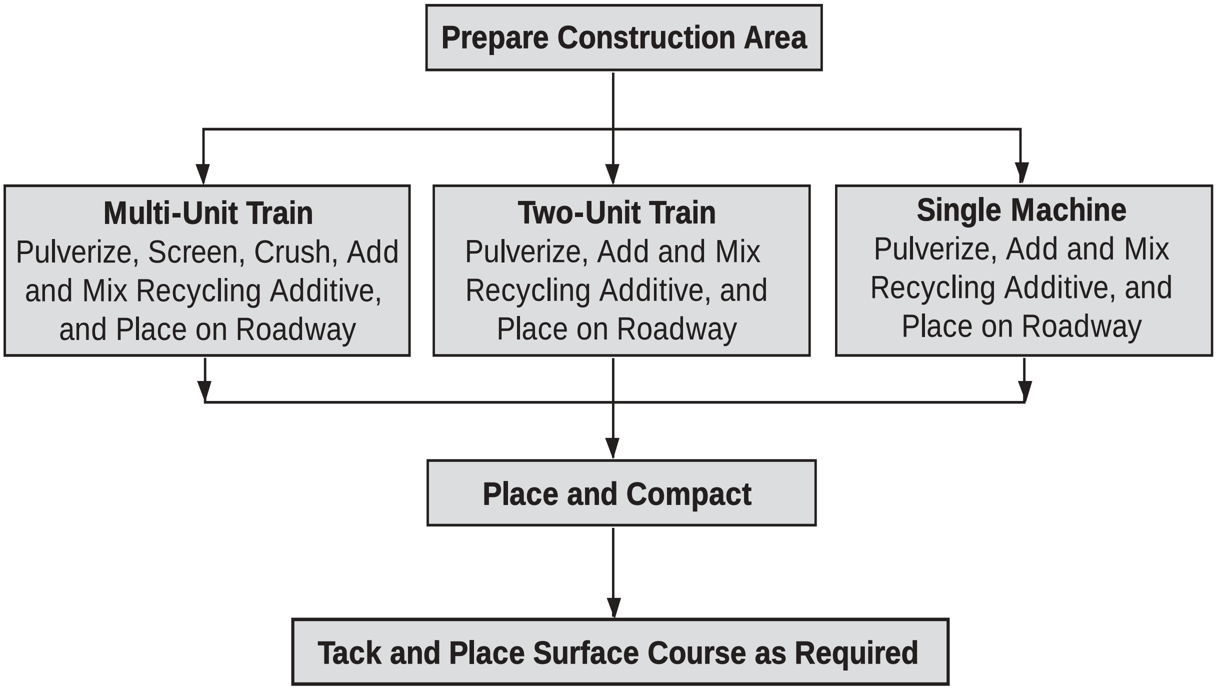


Figure 16-1: CIR construction flow chart

Today, through the innovations of equipment manufacturers, contracting agencies, and contractors, remarkable advancements have been made in the CIR process. The most important advancement was the development of the large cold planing machines. Modern CIR equipment can process up to 2 lane miles (3.2 kilometers) of roadway a day. The result is a stable, rehabilitated roadway at a total expenditure of 40 to 50 percent less than that required by conventional construction methods. The typical construction sequences for CIR are shown in Figure 16-1.

In many locations, high quality Reclaimed Asphalt Pavement (RAP) millings are available and CCPR can produce a high quality, economical paving material, preventing a valuable resource from being land filled. CCPR methods are appropriate when an existing pavement cannot be in-place recycled and must be removed to allow treatment of underlying materials. Typical construction sequences for CCPR are shown in Figure 16-2.

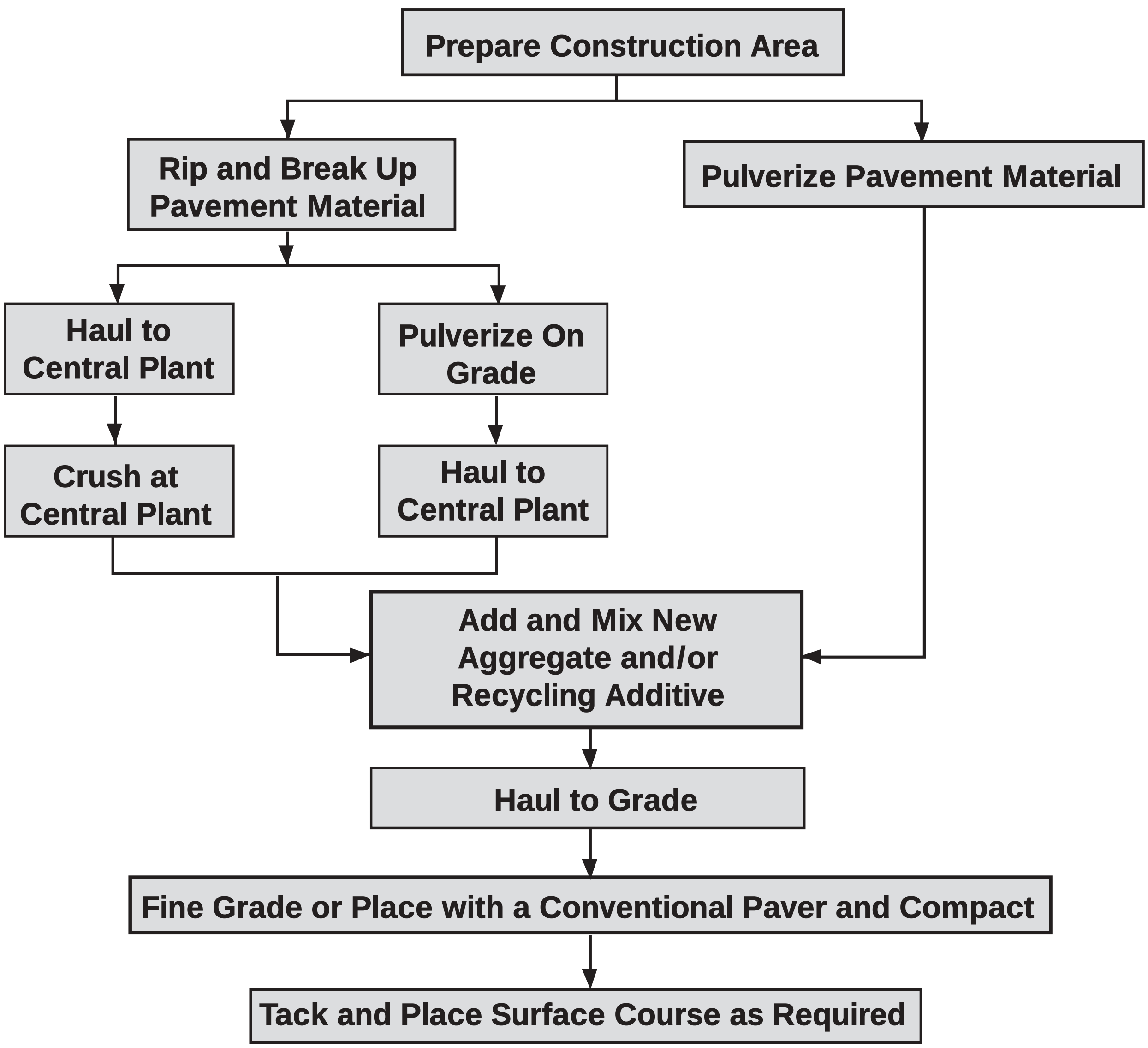


Figure 16-2: CCPR construction flow chart

Figure 16-3: Cold In-Place Recycling Arterial City Streets

The equipment and procedures for each method are discussed in the following sections.

16.1 COLD IN-PLACE RECYCLING METHODS

The use of the CIR train has become the rehabilitation method of choice since the greatest savings occur when trucking costs are eliminated. Both two-unit and multi-unit trains operate with high productivity, excellent quality control, and reliability.

When evaluating a project for CIR, several factors can influence the type of equipment best suited for the project. Milling machines currently used with CIR have 10 to 12 feet (3.0 to 3.7 meters) wide cutting drums with extensions up to 4 feet (1.2 meters) available. Pavements less than 20 feet (6.0 meters) wide could prove difficult to CIR and maintaining traffic could be a problem. Shoulders are often incorporated into the CIR mixture. This prevents existing distress in the shoulder, typically cracks, from propagating into the recycled mix and its overlay. Pavements with shoulders 4 feet (1.2 meters) wide or less can be recycled in one pass by using an appropriate sized extension to the milling machine. A second approach is to use a smaller milling machine to mill the shoulder and deposit the RAP in a windrow in front of the train. Pavements with 6 feet (1.8 meter) shoulders and 12 feet (3.7 meter) lanes, up to 18 feet (5.4 meters) total width, have been recycled in this manner. The windrow and full lane are then recycled in one pass. Shoulders wider than 10 feet (3 meters) can be recycled in one pass.

CIR has been successfully completed on all types of roads, ranging from low volume rural county roads, to city streets, to Interstate highways with heavy truck traffic. However, maintaining traffic through and around the construction zone needs to be considered, especially on roads with limited pavement and or shoulder widths and or few alternate or bypass routes. The single or two-unit trains are usually preferred in urban areas with numerous cross streets and business or residential access.

16.1.1 PREPARATION OF CONSTRUCTION AREA

Prior to construction, areas of non-uniform materials or pavement thickness should be identified. Areas with either insufficient pavement thickness or subgrade strength to support the weight of the recycling train should be identified. These areas of insufficient support must be corrected prior to recycling or risk the cold planing machine or other CIR equipment breaking through the pavement, causing construction delays and added expense. Weak material should be removed and replaced with suitable patching material. Areas of the project that exhibit frost heave should be identified and the frost susceptible materials removed and replaced with suitable patching material. RAP is an excellent choice for patching material. Aggregates may be used, as well. Large areas patched with aggregate could require increases in recycling additive for proper coating. The use of RAP eliminates this concern. Small aggregate patches are acceptable but will result in some uncoated aggregate.

Portions of the project that were identified during mix design as requiring different recycling additive content should be identified and construction personnel made aware of the situation.

16.1.2 RECYCLING TRAINS

16.1.2.1 SINGLE UNIT TRAIN

There are several variations of single unit trains available, with one variation shown in Figure 16-4.

With the single unit train the milling machine cutting head removes the pavement to the required depth and cross-slope, sizes the RAP and blends the recycling additive with the RAP. Single train units do not contain screening and crushing units, making control of the maximum particle size more difficult. Most single unit trains are capable of producing uniform RAP with a maximum size of 2 inches (50 mm) by operating the cutting head in the down cutting mode and controlling the forward speed. The forward speed of the machine can help control the coarseness of the millings since reducing the forward speed results in a finer RAP. Pavements that are badly alligator cracked, make controlling the maximum particle size difficult

A spray bar in the cutting chamber adds the liquid recycling additive. The liquid recycling additive is either self-contained in the unit or provided by a tanker truck which is often towed or pushed by the single unit train. The amount is based on the treatment volume, determined by the cutting depth and width, and the anticipated forward speed of the unit. Single unit trains provide the lowest degree of process control because the recycling additive application rate is not directly linked to the treatment volume. Roadways that are badly distorted due to rutting, edge drop-off, etc. are not good candidates for CIR with the single unit train, because proper recycling additive application rate would be difficult to ensure.

Figure 16-4: Single unit CIR train

Dry additives and or new aggregates can be applied by spreading the material on the pavement ahead of the milling machine prior to milling. One pass of the single unit train is sufficient to adequately pulverize and mix all ingredients. The recycled mix is placed with a screed attached to the cold planer, as indicated in Figure 16-4.

The advantages of the single unit train are simplicity of operation and high production capacity. The single unit train may be preferred over the multi-unit train in urban areas and on roads with short turning radius, due to its short length. The main disadvantages of this method are the limitations on RAP aggregate oversize, limitations on precise material proportioning, and minimal mixing times.

16.1.2.2 TWO-UNIT TRAINS

Many CIR trains now incorporate pugmill mix-pavers as an integral part of the train. These two-unit trains, as shown in Figure 16-5, consist of a large, full lane milling machine and a pugmill mix-paver. The pugmill mix-pavers are predominately cold mix pavers with an integral metered pugmill in the chassis. The milling machine removes the RAP. The two-unit train does not contain crushing and screening unit. Control of RAP maximum size and gradation is the same as with single unit trains. The mix is deposited into the pugmill of the mix-paver. The pugmill contains a feeder belt with a belt scale and a processing computer to accurately control the amount of liquid recycling additive. The mix leaves the pugmill directly into the paving screed auger system. The two-unit train provides an intermediate to high degree of process control, with the liquid recycling additive being added based on the weight of the RAP, independent of the treatment volume and forward speed of the train.

Figure 16-5: Two-unit CIR train

The advantages of the two-unit train are simplicity of operation and high production capacity. The two-unit train may be preferred over the multi-unit train in urban areas and on roads with short turning radius due to its short length. The main disadvantage of this method is the limitation controlling RAP aggregate oversize.

16.1.2.3 MULTI-UNIT TRAINS

The multi-unit train typically consists of a milling machine, a trailer mounted screening and crushing unit and a trailer mounted pugmill mixer, as indicated in Figure 16-6. The milling machine mills the pavement to the desired depth or cross-slope. The milling head can operate either in a down cutting mode which results in a finer RAP gradation or in the up cutting mode which results in higher capacity.

The RAP is deposited into the screening and crushing unit. All material is passed over the screening unit and oversize material sent to a crushing unit, typically an impact crusher. The crushed material is returned to the screening unit for resizing. The maximum size of the RAP is controlled by the opening size of the bottom of two screens.

The RAP proceeds from the screening and crushing unit to the pugmill mixer. A belt scale on the belt carrying the RAP to the pugmill determines the weight of the RAP entering the pugmill. The amount of liquid recycling additive is controlled by a computerized metering system, using the

Figure 16-6: Multi-unit CIR train

mass of material on the belt scale. Liquid recycling additive is added to the pugmill by a pump equipped with a positive interlock system which will shut off when material is not in the mixing chamber. A meter connected to the pump registers the rate of flow and total delivery of the liquid recycling additive introduced into the mixture. A twin shaft pugmill blends the liquid recycling additive and RAP into a homogenous mixture. Trains equipped with computerized metering systems have the highest degree of quality control and the highest productivity, about 2 lane miles per day (3.2 lane kilometers).

The material leaving the pugmill is deposited in a windrow or deposited directly into the paver hopper. The material from the windrow is picked up with a windrow elevator and is placed and compacted using conventional HMA paving equipment.

The multi-unit train provides the highest level of process control. The main advantages of the multi-unit train are high productivity and high process control. The major disadvantage is the length of the train which can make traffic control difficult in urban locations.

16.1.3 FIELD ADJUSTMENTS TO THE MIX

CR is a variable procedure. Changes in the gradation of the RAP result in changes in the workability of the mix. The Job Mix Formula (JMF), optimum moisture, and recycling additive contents developed in the laboratory are starting points for construction. Adjustments in the mix water content or recycling additive content may be necessary to promote good coating and workability. Changes to these values should be made judiciously and only by experienced personnel. Rigid adherence to the original JMF recommendations may result in less than optimum performance.

One of the first things to evaluate is the coating of the mix. Adequate coating is desired. If the mix is not sufficiently coated, the mix water content is increased first. Excessive mix water may cause the asphalt to flush to the surface, retarding curing. Too little mix water results in mix segregation, raveling under traffic or poor density. Reducing the asphalt emulsion one grade softer may improve coating.

If the recycled mix is adequately coated but lacks cohesion, the amount of asphalt emulsion or emulsified recycling additive is increased. Too much asphalt emulsion or emulsified recycling agent will result in an unstable mix, and too little may cause the mixture to ravel, although minor raveling is acceptable. The balling of fines is usually the result of excessive asphalt emulsion or emulsified recycling agent or excessive fines in the RAP.

The following field test has been used to evaluate cohesion. A ball of the material is made by squeezing the material in the fist. If the ball is friable (falls apart after the pressure is released), the mix lacks cohesion. The palm of the hand should contain specks of asphalt, indicating the proper asphalt emulsion or emulsified recycling agent content. If the hand is stained, the asphalt emulsion or emulsified recycling agent content could be too high.

Adjustments to the initial asphalt emulsion or emulsified recycling agent content should be made based on the appearance of the mat after initial compaction. With the proper asphalt emulsion or emulsified recycling agent content, the mat should be brown and cohesive. Excess raveling is an indication of too little recycling agent and a shining black mat is an indication of too much. Adjustments in asphalt emulsion or emulsified recycling agent are typically made in 0.2 percent increments and should only be made by experienced personnel. An increase or decrease in the recycling additive may be followed by an equivalent change in the mix water content to keep the total liquids content the same.

16.1.4 LAYDOWN AND COMPACTION

Either conventional asphalt pavers or cold mix pavers are used to place the mix. Some contractors use pavers with oversize hoppers to allow for RAP surges caused by fluctuations in the existing pavement section. The screed should be operated cold as a heated screed causes RAP to stick, tearing the mat, and will not promote extra density or reduced breaking time. The laydown machine should be operated as close to the milling machine as possible, reducing the fluids necessary for placement and the aeration time required before compaction.

Compaction is accomplished with heavy pneumatic and double drum vibratory steel-wheel rollers. CR mixes are more viscous than conventional HMA and require heavier rollers. It is not possible to compact CR mixes to the same density range as HMA. Well compacted CIR mixes could have a Voids in Total Mix (VTM) in the 9 to 14 percent range or higher.

Compaction commences as the mixture begins to break. If asphalt emulsions or emulsified recycling agents are used this could take from 30 minutes to 2 hours depending on environmental

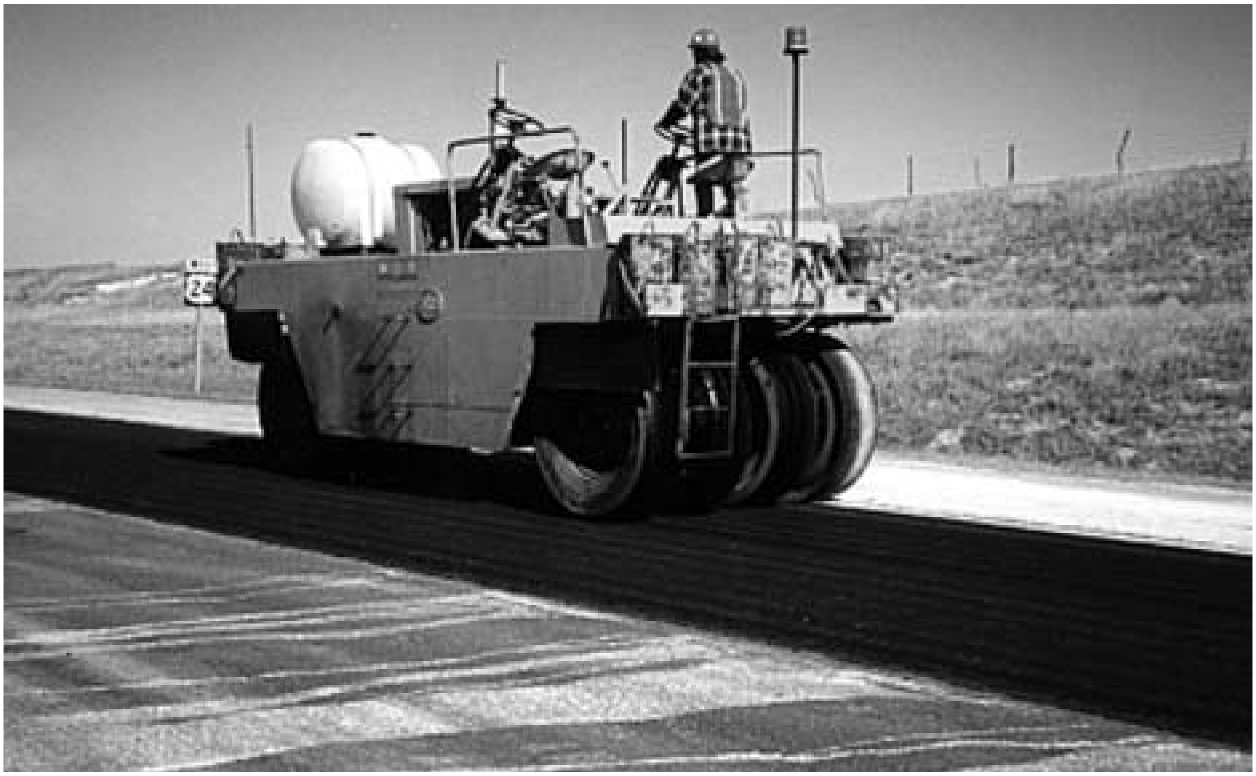


Figure 16-7: Heavy pneumatic tired roller

conditions. The mix will turn from a brown to a black color when the asphalt emulsions or emulsified recycling agent breaks. Some agencies heat the recycling agent and mix water to the 120 to 140°F (50 to 60°C) range to reduce curing or breaking problems in cool or damp conditions. Delaying compaction until after the mixture breaks can cause a crust to form on the top portion of the mixture. The formation of a crust will make compaction difficult and severe roller checking and cracking could result with steel-wheel rolling.

For mixes with type C fly ash, lime, or Portland cement as the recycling additive, rolling commences immediately after placement. A set retarder is often required to prevent rapid set and loss of strength.

Breakdown rolling can be successfully accomplished with either pneumatic-tired or vibratory steel-wheel rollers or a combination of both. Local mix and weather conditions will have an effect on the preference of which method to use. Many contractors begin breakdown rolling with one or two passes of a static steel-wheel roller. This can improve final smoothness of the compacted mat, prevents edge distortion, and prevents excessive distortion of the mat by pneumatic rolling. Additional breakdown rolling is accomplished with heavy pneumatic-tired rollers, 25 tons (23 tonnes) or more, as shown in Figure 16-7.

Breakdown rolling is continued until the roller "walks out" of the mix. This is followed by intermediate rolling with a 12 or more ton (11 tonne) double drum vibratory steel-wheeled rollers. Finish rolling, as shown in Figure 16-8 is with the vibratory steel-wheel roller to remove roller marks. Some report breakdown rolling should not be accomplished with a vibratory steel-wheel

Figure 16-8: Finishing rolling

roller alone due to the possibility of trapping moisture in the mix, delaying curing. For fly ash mixes, breakdown rolling is usually accomplished with a vibratory steel-wheel roller.

Rolling patterns should be established to determine the procedures that result in optimum compaction. Passes with various combinations of rollers should be evaluated. A nuclear density meter can be used to evaluate relative increase in density with roller passes. The number of passes that results in no further increase in density should be selected as the rolling pattern. The relative density of the mat, measured with a nuclear density meter, can be recorded to assist in compaction monitoring.

The rolling procedures should be followed and the recycled mix compacted to minimum of 97 percent of the relative density of the control strip. Difficulty in meeting this density could indicate a change in uniformity of the mixture and a new roller pattern or a new control density is needed.

The following rolling procedure is generally recommended. The longitudinal joint should be rolled first, followed by the regular rolling procedure established in the control section. Initial rolling passes should begin on the low side and progress to the high side by overlapping of longitudinal passes parallel to the pavement centerline. For static rollers, the drive drum should be in the forward position or nearest to the paver except on steep grades where the position may need to be reversed to prevent shoving and tearing of the mat. Drums and tires should be uniformly wetted with a small quantity of water or water mixed with very small amounts of detergent or other approved material, to prevent mixture pickup. Care should exercised in rolling the edges of the mix so the line and grade are maintained.

16.1.5 CURING

The compacted CR mixture must be adequately cured before a wearing surface is placed. The rate of curing is quite variable and depends on several factors. These include day and nighttime temperatures, humidity levels and rainfall activity after recycling, moisture content of the recycled mix before and after recycling, the level of compaction, in-place voids, the drainage characteristics of the material below the CR and the shoulders. Sealing the surface prior to adequate moisture loss may result in premature failure of the CR mix and/ or the surface mix.

Various agencies have differing moisture content requirements prior to placement of the wearing surface and these can be based either on the total moisture in the mix or the increase in moisture content from the pavement prior to recycling. Often curing times, generally 10 days to 2 weeks, are used as the acceptance criteria. It is commonly felt that if a dry cut core can be extracted essentially intact, then the mix has cured sufficiently to place the overlay. In any event, it is generally accepted as preferable to overlay a partially cured mix prior to winter shutdown rather than leave it exposed to the winter. Experience has indicated that these mixes will complete their curing in the following season. The addition of lime has been reported to greatly accelerate the curing process. Rolling with a steel-wheel roller several days after initial compaction, usually referred to as “re-rolling,” is sometimes done to remove minor consolidation in the wheelpaths as a result of densification by traffic. This re-rolling is best completed on warmer days or during warmer periods of the day, such as in the afternoon.

It is generally best to keep traffic off the pavement during curing. However, this can almost never be accommodated. A light application of a fog seal may be necessary to prevent raveling of the mix prior to placement of the wearing surface. The fog seal should consist of a light application of slow-setting asphalt emulsion or the asphalt emulsion used as the recycling additive. The asphalt emulsion should be diluted 50 percent with water prior to application. Typical application rates are between 0.05 to 0.10 gallons/square yard (0.23 to 0.45 liter/square meter). The fog seal will be necessary for fly ash mixtures, as well. Since tire pick-up of the recycled mix can occur, traffic should remain off the fog seal until it has adequately cured.

16.1.6 WEARING SURFACE

Due to the high VTM content, CR mixes need a wearing surface to protect the mixture from intrusion of surface moisture. For pavements with low traffic volumes, single and double chip seals have been successfully employed. For pavements with higher traffic volumes, conventional HMA wearing surfaces have been employed. A tack coat should be applied at a rate similar to the fog seal, to promote good bond between the CR layer and the HMA overlay.

The minimum recommended HMA overlay thickness is 1 inch (25 mm) with 1 1/2 inches (40 mm) preferred. Thin HMA lifts are hard to adequately compact and a poorly compacted surface mix will not protect the CIR from moisture intrusion. The thickness of the HMA overlay should be based on the traffic level and existing roadway strength. Some agencies use the Falling Weight Deflectometer (FWD) to evaluate the pavement section prior to designing the thickness of the HMA overlay. Others assign an “a” coefficient of 0.25 to 0.35 to the CR layer for use with the

Figure 16-9: Urban Cold In-Place recycled mat prior to placement of wearing surface

1986 AASHTO Thickness Design Guide. These coefficients are based on resilient modulus testing but each agency will have to develop their own coefficient.

16.2 COLD CENTRAL PLANT RECYCLING

CCPR may be a viable alternative when stockpiles of high quality (uniform) RAP are available or when it is not possible to in-place recycle the pavement. RAP may be from a nearby milling project or a pavement crushing operation. The RAP is hauled to a central plant or a portable unit can be hauled to the stockpile site.

The central plant may require a screening and crushing unit to control the maximum size of the RAP or a scalping screen may be used to remove oversize RAP. The central plant should have a RAP feed hopper and conveyor belts with a belt scale. The belt scale should be linked to a computerized liquid recycling additive and water system that accurately meters the recycling additive into the pugmill, based on the mass of the RAP. The liquid recycling additives should be metered into the pugmill using positive displacement pumps with interlocks to shut off the supply when the chamber is empty.

Asphalt emulsion and emulsified recycling agent mixes require shorter mixing time than conventional asphalt mixes. Asphalt emulsion mixes can be over-mixed resulting in a loss of asphalt coating caused by the premature breaking of the asphalt emulsion. Undermixing can cause poor coating of the mix. Complete coating of the coarse portion of the RAP or aggregate is not

Figure 16-10: CIR Train set up in a stationary plant mode

necessary at the time of mixing. Further coating takes place during spreading and rolling of the mix.

The screening and crushing unit and pugmill mixer from a recycling train are being utilized as central unit plants, as indicated in Figure 16-10.

Conventional asphalt drum mix plants and batch mix plants have also been utilized on occasion. However, continuous or stabilization plants, as indicated in Figure 16-11 are most often used.

16.2.1 LAYDOWN, AERATION AND COMPACTION

The CCPR mixture is discharged into surge bins, storage silos, deposited into stockpiles or directly into haul trucks for transport to the job site. The use of surge bins, storage silos or stockpiles results in a continuous operation which results in a more uniform mixture and more efficient trucking.

Aeration of the CCPR mix may be required, to reduce the water and volatile content prior to compaction. The laydown and spreading equipment for CCPR mixes are the same as for CIR and conventional HMA. The recycled mix can be placed in a windrow and spread to grade and cross-slope with a motor grader. The motor grader also can assist in aeration of the mix. Jersey spreaders attached to the front end of crawlers or rubber-tired tractors have been used to place the mix. Conventional HMA pavers and cold mix pavers with windrow attachments, the same as for CIR, are typically used. Compaction, curing, and placement of the wearing surface are the same as for CIR.

Figure 16-11: Conventional CCPR plant

CHAPTER 17: COLD RECYCLING – SPECIFICATIONS AND INSPECTION

The current trend in the construction industry is to move away from method specifications, where the owner agency describes in detail not only the scope of the project, but also how to construct the project, and to move toward end result specifications. In a true method specification, the owner agency describes in complete detail all equipment and procedures that must be used to obtain the desired quality of the project. Method specifications require continuous construction monitoring and require that the inspector work closely with the contractor to assure compliance with the specifications. If an inspector is not available, it will be impossible to determine later whether the contractor complied with the specifications. Writing a good set of method specifications requires that the agency preparing the specifications be experienced with all phases of the proposed construction.

With end result specifications, the owner agency tells the contractor what level of performance or end result it expects from the project, and how that performance level or end result will be measured. It is then up to the contractor to decide how to best meet the performance requirements. The contractor could select the construction method and equipment, job mix formula, recycling additives, and construction sequence. At the end of the project, the owner agency would perform testing to assure that the minimum performance level was obtained. Testing is usually statistically based. Therefore, reasonable construction variation of the test properties must be understood and allowed for in the specifications. The major difficulty in preparing end result specifications is in determining what properties to specify and what limits to set. The test properties specified should be directly or at least indirectly related to performance.

Cold Recycling (CR) is a variable process and the properties that relate to performance are not completely established at this time. The variability of the process makes setting statistically based specification limits difficult. The lack of a good understanding of the mix, material, and construction sequences that relate to performance makes selecting properties for testing suspect, as well. Therefore, most CR projects currently use a combination of method specifications and end result specifications.

In combination specifications, the owner agency typically specifies the required equipment and might specify a portion of the construction sequence. The owner agency would provide the job mix formula (JMF) and select the recycling additive and rate or have the authority to approve or modify the contractor's JMF. The minimum requirements for the size, type, and level of automation of the construction equipment are typically specified. The compaction sequence is sometimes specified; however, the contractor is usually required to meet certain testing requirements, as well. Specifying the compaction sequence can inhibit contractor efficiency and innovation. Testing requirements are typically specified for maximum size of the RAP, recycling additive and amount, final in-place density, and smoothness or cross-slope.

17.1 QUALITY CONTROL/QUALITY ASSURANCE

A good Quality Control/Quality Assurance (QC/QA) plan is essential to obtaining a satisfactory CR pavement, regardless of the type of specification used. As with any in-place construction, CR can involve the recycling of pavement sections with variability in gradation and asphalt content, due to areas of major maintenance such as patching and chip sealing. A good QC/QA plan must not be so complex as to prohibit changes due to this inherent variability, yet be sophisticated enough to determine the acceptability of the CR process and identify areas of non-uniformity where changes in the process are necessary.

The required material sampling and testing should be appropriate for the construction methods and should be related to process control and/or final product performance. CR is a variable process and changes in rolling patterns, moisture content, and recycling additive content will be necessary to obtain optimum performance. The testing and acceptance plan needs to be formulated to identify the need for slight changes in the above procedures and flexible enough to allow for changes without redesign of the mixture.

Tables 17-1 and 17-2 show the recommended field sampling and testing plan for CR and the accompanying notes, respectively, developed by the American Association of State Highway and Transportation Officials, the Associated General Contractors of America, American Road and Transportation Builders Association (AASHTO-AGC-ARTBA) Joint Committee Task Force 38 Report entitled "Report on Cold Recycling of Asphalt Pavements." This report is available from AASHTO. The sampling and testing methods refer to American Society for Testing and Materials (ASTM) and AASHTO test methods. Other test methods from other government agencies could be substituted if proven acceptable. Guide specifications, developed by Task Force 38, are included at the end of the chapter. Comments to the test plan are in part from the Task Force 38 Report, as well.

17.2 INSPECTION AND ACCEPTANCE ISSUES

There are issues and concerns that must be fully understood and addressed when dealing with CR. These issues arise due to the inherent variability of recycling and to the special concerns related to compacted moist, cold, bituminous mixtures that are not a part of conventional HMA construction. These issues, as they relate to sampling, testing, and specifications, are discussed below.

17.2.1 RAP GRADATION

Most agencies limit the maximum size of the RAP to 1 1/2 inches (40 mm). Oversized material can result in increased segregation of the mix, excess voids, increased permeability, and difficulty in spreading and compacting the mat. For thin sections of CR, oversize RAP could cause tearing of the mat. A good rule of thumb is for the maximum RAP size to be no larger than 1/3 of the compacted layer thickness.

Table 17-1. Recommended Field Sampling and Testing for Control of CIR

Type of Testing	Purpose of Testing	Frequency	Sample Location & Size
Recommended for Control and Testing			
RAP gradation, 2, 1.5 or 1.25 inch (50, 37.5 or 31.5 mm) sieves	Specification compliance with maximum size determination	Each 1/2 mile (0.8 km) [1,6]	From conveyor belts, windrow or mat, minimum weight of 20 pounds (9.0 kilograms)[2]
Recycling Additive[3] (asphalt emulsion, emulsified recycling additive, Portland cement, fly ash, lime, etc.)	Check on specification compliance	Every load sampled, one test per day	From asphalt tank on recycling unit or transport truck, wide-mouth plastic bottle, 1 quart (1 litre) sample size[1]
Moisture added to the RAP[4]	Adjustment of water content for proper mixing and compacting	Each 1/2 mile (0.8 km) [1,6]	From belt into mixer or after spreading, minimum weight of 20 pounds (9.0 kilograms)[2]
Mat moisture content after curing (asphalt emulsions/ recycling agents only)	To determine when the new asphalt surface can be placed	Each 1/2 mile (0.8 km) [1,6] one each lane	Full cold recycled lift depth sample, minimum weight of 3 pounds (1.4 kilograms)[2]
Recycling additive content	Verify amount of recycling additive and also accuracy of meter readings	Minimum of one per day	By tank gauging, truck weighing or meter readings and RAP weight by belt scale
Recycled material compacted density by rolling control strips[5]	To establish rolling procedures and target density for specification compliance	Minimum of two strips and nuclear density testing each 1/2 mile (0.8 km) [1,6]	Strips at beginning of project and additional if major changes in the recycled mix properties occur, 400 to 500 foot (120 to 150 meter) length
Recycled material compacted density by field compacted specimens[5]	To establish the target for specification compliance	Material sample and nuclear density testing each 1/2 mile (0.8 km)[1,6]	Material sampled from windrow or mat after spreading, minimum weight of 20 pounds (9.0 kilograms)[2]

Table 17-1. (continued) Recommended Field Sampling and Testing for Control of CIR

Recommended for Control and Testing			
Depth of pulverization/milling	For specification or plan compliance	Each 1/8 mile (0.2 kilometer) or additional as needed	Measurements across the mat, adjacent to longitudinal joints and at the outside edge
Spreading depth of recycled material, Cold Central Plant Recycling only	Check of the lift thickness for specification or plan compliance	Each 1/8 mile (0.2 kilometer) or additional as needed	Measurements across the mat, adjacent to longitudinal joints and at the outside edge
Mixing equipment calibration	To assure proper content of the recycling additive(s) and moisture	Prior to beginning of work each year and additional, as required[7]	Material being processed from mixer into a truck and liquids into barrels, tanker or asphalt distributor for weighing by a scale
For Information Only			
Recycled material temperature	To determine the influence of temperature on compaction and temperatures for mix design	Minimum of four each day, two early morning and two late afternoon	Determined for the recycled material when mixing and the mat immediately prior to rolling
Recycled mat smoothness	To develop data on spreading procedures and for possible future specification requirements	Continuously or at selected locations of existing pavement and after cold recycling	By profilograph device (California or other)
Original pavement and recycled material asphalt contents[8]	To determine added and total asphalt contents	Randomly[6]	From selected locations in a stockpile or pavement before recycling and in the recycled mat, minimum weight of 20 pounds (9.0 kilograms)[2]

Table 17-2. Notes for Recommended Field Sampling and Testing, i.e., Table 17-1

1. Additional sampling and testing may be required if major changes in RAP characteristics are observed, such as a much coarser or finer gradation or a noticeable difference in asphalt content or when considerable variability is occurring in the field test results.

2. RAP sampling generally should be in accordance with ASTM D 979 or AASHTO T 168 procedures for Sampling Bituminous Paving Mixtures.

3. Asphalt Emulsion and emulsified recycling agent sampling should be in accordance with ASTM D 140 or AASHTO T 40 for Sampling Bituminous Materials.

4. The moisture content can be determined with ASTM D 1461 or AASHTO T 110 for Moisture or Volatile Distillates in Bituminous Paving Mixtures. Also, the moisture content can be adequately determined by weighing and drying a sample to a constant weight using a forced draft oven in accordance with ASTM D 2216 or AASHTO T 265 or by microwave oven drying according to ASTM D 4643.

5. Target densities for recycled mix compaction are being established by using rolling control strips or by the field compaction of density specimens using Marshall and Proctor compactors and recently gyratory compactors. The compacted density, when determined, normally is measured with a nuclear density/moisture gauge since it is generally not possible to obtain cores during construction. For control strips, backscatter measurement is typically used but for density checks for specification compliance, direct transmission measurement is preferred. The procedures generally followed are in accordance with ASTM D 2950 Density of Bituminous Concrete in Place by Nuclear Methods. The density obtained will be a "wet density" as conversion to a true "dry density" by the gauge is not possible with these types of mixes. A more accurate dry density may be obtained by sampling the recycled mix at the nuclear gauge test location, determining the moisture content by drying and correcting the gauge wet density using the sample moisture content.

6. For each length or lot size quantity specified, materials sampling can be completed on a random basis using the procedures of ASTM D 3665 for Random Sampling of Construction Materials.

7. Based on the mixer computer meter readings and other checks, additional calibration may be required. This calibration may require only checking and adjusting the belt scale system using weights.

8. The asphalt content in cold recycled mixtures can be determined by asphalt extraction using ASTM test methods D 2172 or D4125 or AASHTO test methods T 164 or T 287 or the ignition furnace using ASTM D 6307.

Figure 17-3: Cold Recycling Paver with Integral Pugmill. Microprocessor controlled aggregate and emulsion measuring systems provide accurate proportioning.

17.2.2 RECYCLING ADDITIVE(S) SAMPLING

The recycling additive(s) should be sampled to insure proper type and compliance with specifications. When using an asphalt emulsion as the recycling additive, the specifications should allow for the changing of the asphalt emulsion grade one grade to facilitate field coating and compaction. Changing the asphalt emulsion grade one grade softer can improve compaction and coating when difficulties are encountered with coating and compaction. The moisture content is generally adjusted first, to improve coating rather than adjusting the recycling additive content. Field methods to evaluate coating, and suggested remedial measures, are discussed in Chapter 16, Section 1.3. Changes in recycling additive content should be made judiciously and only by experienced personnel.

17.2.3 MOISTURE ADDITION

Proper moisture control is required for good recycling additive dispersion and CR mix compaction. Chapter 16, Section 1.3 discusses adjustments to moisture content to facilitate coating. Generally, more moisture is needed for dispersion than for compaction. For asphalt emulsions and emulsified recycling agents, compaction should not take place until the mixture begins to break, turning from brown to black in color. It may be necessary to delay compaction of CR mixes with asphalt emulsions or emulsified recycling agents 30 minutes to 2 hours, with the delay dependent on the recycling additive breaking properties, lift thickness, and weather. For final strength gain (curing), this mixing and compaction moisture must leave the mat. It is important that this moisture not be sealed in during rolling.

Figure 17-4: Connected Water (Front) and Emulsion (Rear) Tanks to permit Metered Addition of Both Liquids

17.2.4 RECYCLED MIXTURE MOISTURE CONTENT

CR mixtures with asphalt emulsions or emulsified recycling agents as the recycling additive must properly cure in order to reach their full strength potential. The rate of curing is quite variable and depends on several factors. These include day and nighttime temperatures, humidity levels and rainfall activity after recycling, moisture content of the recycled mix before and after recycling, the level of compaction, in-place voids, the drainage characteristics of the material below the CR, and the shoulders. Placement of a wearing surface on a CR mat with excessive moisture will delay strength gain of the CR and could cause premature failure of the wearing surface.

Various agencies have different moisture content requirements prior to placement of the wearing surface, and these are based on either the total moisture in the mix or the increase in moisture content from the pavement prior to recycling. Samples of the compacted mix are required to determine the moisture content, as nuclear density meters will not give accurate moisture content results with these types of materials. Rather than sample and patch the compacted CR mix, most agencies specify curing times, generally 10 to 14 days. Traffic is allowed on the mat during this time. A light fog seal may be required to prevent raveling of the CR. A light application, 0.05 to 0.10 gallons/square yard (0.23 to 0.45 liter/square meter) diluted 50 percent with water, of CSS-1 or the asphalt emulsion used for as the recycling additive has been reported as satisfactory.

17.2.5 RECYCLING ADDITIVE CONTROL

A proper recycling additive content is required for optimum performance and recycled mix workability. For asphalt emulsions and emulsified recycling agents, excess recycling additive will result in an unstable mix that is subject to rutting and shoving. The balling of asphalt emulsion with fines in the windrow is another indication of excessive recycling additive. Too little recycling additive can result in segregation and surface raveling when opened to traffic. Adjustments to the asphalt emulsion or emulsified recycling agent content should be made in 0.2 percent increments and should only be made by experienced personnel. For chemical additives, such as type C fly ash or Portland cement, too little recycling additive could result in a weak layer and/or poor durability, while too much recycling additive could result in a brittle mixture.

Modern CIR trains have microprocessor controlled weigh measuring systems for asphalt emulsions, emulsified recycling agents and RAP that when properly calibrated, give a very good record of the recycling additive rate. It is possible to determine the asphalt emulsion or emulsified recycling agent content by sampling the mix off the conveyor belt, prior to entering the mixer and by sampling the CR mix discharging from the pugmill. The asphalt content is determined for both samples using either solvent extraction or the ignition furnace. The difference in asphalt contents is the residual asphalt in the asphalt emulsion or the emulsified recycling agent. This residual asphalt content can be converted to an asphalt emulsion content using the residue content of the asphalt emulsion or the emulsified recycling agent.

17.2.6 COMPACTION PROCEDURES

CR mixes are more viscous than conventional HMA and it will not be possible to compact CR mix to the same density range as HMA. Well compacted CR mixes could have voids in total mix (VTM) in the 9 to 14 percent range or higher.

Compaction is accomplished with heavy pneumatic-tired rollers, 25 tons (23 tonnes) or more, and with double drum vibratory steel-wheeled rollers weighing 12 or more tons (11 tonnes). Compaction should begin as the mix begins to break. This is indicated by the mix beginning to turn from brown to black. Delaying rolling until after the mix breaks can result in a crust forming in the top portion of the mat making compaction difficult and causing severe roller checking or cracking.

Breakdown rolling can be successfully accomplished with either pneumatic-tired or vibratory steel-wheel rollers or a combination of both. Local mix and weather conditions will have an effect on the preference of which method to use. Initial breakdown rolling with one or two passes of a vibratory steel-wheel roller in the static mode can improve final smoothness of the compacted mat, prevent edge distortion and prevent excessive distortion of the mat during pneumatic rolling. Additional breakdown rolling is accomplished with heavy pneumatic-tired rollers until the roller "walks out" of the mix. Finish rolling is with the vibratory steel-wheel roller to remove roller marks.

The following rolling procedure is generally recommended. The longitudinal joint should be rolled first followed by the regular rolling procedure established in the control section. Initial rolling passes should begin on the low side and progress to the high side by overlapping of longitudinal passes parallel to the pavement centerline. For static rollers, the drive drum should be in the forward position or nearest to the paver except on steep grades where the position may need to be reversed to prevent shoving and tearing of the mat.

Drums and tires should be uniformly wetted with a small quantity of water or water mixed with very small amounts of detergent or other approved material to prevent mixture pickup. Care should exercised in rolling the edges of the mix so the line and grade are maintained. The roller should be kept 8 to 12 inches (200 to 300 mm) inside the outside edge of the mat on the initial pass when using a pneumatic roller. Constant monitoring of the mat is required when using vibratory compaction, to prevent roller checking or other cracking.

Rerolling after some period of curing may be advantageous when density has been hard to achieve, such as with cool temperatures and coarser RAP gradations. The rolling is usually accomplished with a steel-wheel roller or with a pneumatic roller followed by a steel-wheel roller. Rerolling serves several additional purposes including: removing wheel marks and minor consolidation caused by traffic while the mix is gaining strength; sealing the CR reducing moisture infiltration and; adding additional densification. The mat should be observed during rerolling and rolling ceased if roller checking or cracking occurs. Rerolling thin CR lifts could result in debonding.

17.2.7 COMPACTED MAT DENSITY

In general, the higher the compacted density, the better the material properties of the CR mixture. The gradation of the RAP is not as uniform as the aggregate in HMA and it may not be possible to achieve as uniform a compacted mat (same standard deviation). Because of this, HMA specifications and HMA QC/QA procedures should not be used with CR mixes, as specification compliance will not be achievable.

Three methods are available for determining the target density for compaction of CR mixtures. They are percent of laboratory compacted density, percent of field compacted density, and percent of control strip density. The latter two methods are preferred because percent of mix design density does not address normal changes in RAP gradation that affect the field compacted density.

When using percent of field compacted density, the target density is determined by compacting field samples using the mix design compactive effort and determining the bulk density of the sample. The bulk density is determined on either a dry or a wet mass basis. The wet bulk density is determined either by dividing the wet mass by the measured volume or by the saturated surface dry (SSD) mass minus the submerged mass (SSD basis).

Problems with sample tenderness can be encountered when using the SSD method. The wet density can be converted to a dry density by correcting the wet weight by the measured moisture content of a portion of the sample, or by oven drying the entire compacted sample. A second problem encountered with SSD bulk density determination is inaccurate measurements due to high void contents. AASHTO T 166 "Bulk Specific Gravity of Compacted Bituminous Mixtures using Saturated Surface-Dry Specimens" is not recommended for samples that contain open or interconnected voids or absorb more than 2 percent water by volume during testing. This will usually be the case with CR mixtures. Paraffin coating AASHTO T 275 "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens" or sealing samples with a plastic wrap, either manually or vacuum sealing, has been used with limited success. A FHWA pooled fund study is currently underway to evaluate the use of "Corelok" to establish the bulk specific gravity of porous samples. It is hoped that the results of that study will minimize the difficulties with existing test methods and provide more accurate results. Typical specification requirements using field compacted target densities are 93 to 96 percent compaction, on a wet density basis.

Figure 17-5: Nuclear density meter

The major problem with the field compacted method is determining the proper compactive energy. Many agencies use 50 blow Marshall compaction with the samples heated to 140°F (60°C). Satisfactory results have been obtained although the CR mix will not reach this temperature in the field. Recent work has shown that CR field mix compacted using 75 blow compaction at ambient mix temperatures of 100°F (40°C) resulted in densities equivalent to field compacted densities. There is interest in using the Superpave Gyratory Compactor (SGC) for mix design and field control. As in the case for mix design, whatever compaction level/mix temperature is utilized, it must produce laboratory compacted densities that are achievable in the field.

To avoid the above problems with field compacted samples, many agencies use rolling control strips to determine the target density. The mix is rolled to a minimum number or passes with rollers of specified minimum weights. After the minimum number of passes, the density is monitored with each additional pass using a nuclear density meter. The wet density is recorded. The target density is the density obtained when additional passes result in an increase in wet density of less than 1 pound/cubic foot (16 kilograms/cubic meter). The rolling pattern is the number of passes of each roller that resulted in the target density. Specifications typically require 96 to 97 percent of the target density. The target density may have to be re-established if the uniformity of the mixture changes significantly.

The compacted density of the mat is the wet density, usually determined with a nuclear density meter as shown in Figure 17-5.

The nuclear density meter obtains the dry density by adjusting the wet density for hydrogen atoms. In CR mixtures, the aged asphalt binder and many recycling additives contain hydrogen atoms, as well as the mix water. The reported dry density is the wet density reduced by the hydrogen atoms found in all of these sources, not just the water, resulting in inaccurate readings. The dry density can be determined by obtaining a sample of the mix from the location of the density test and determining the moisture content. The wet density can be corrected to a dry density using this moisture content.

For QC purposes, testing in the backscatter mode can be used, although direct transmission is recommended. There can be a significant difference in density between backscatter and direct transmission, due to the coarse surface texture and lift thickness of CR mixes. For quality assurance and/or specification compliance testing, readings should be made in the direct transmission mode. Nuclear density measurements should be calibrated to the density, from cores from the pavement. This correlation is often not performed because it can be difficult to obtain cores in a timely manner. Several days may be required before satisfactory cores can be obtained. Success has been reported using specimens dry sawed from the CR shortly after placement.

17.2.8 DEPTH OF MILLING

The specifications can either require a constant depth of milling or the grade and cross-slope can be reestablished. It is not possible to do both. The depth of milling may need to be adjusted due to unexpected field conditions, such as a weak base or subgrade, a thinner pavement section, or to be the proper distance from the interface/boundary between two pavement layers. A pavement should be milled to just below the interface between pavement layers, or no closer than 3/4 inch (20 mm) above the interface boundary. Failure to heed these recommendations may result in chunks of the pavement being dislodged by the milling machine.

17.2.9 SPREADING DEPTH/CROSS-SLOPE

The spreading depth only applies to Cold Central Plant Recycling (CCPR). The spreading depth needs to be monitored to provide adequate pavement thickness for load-carrying capacity and for compliance with specification requirements. The cross-slope for all CR should be checked regularly with a level and straight edge behind the paver and after rolling. Typical specifications require no deviation greater than 1/4 inch (6 mm) when using a 10 foot (3 meter) straight edge. The edge of the mat should be rolled first and progress toward the center or high side to prevent excessive edge sloughing.

17.2.10 MIXING EQUIPMENT CALIBRATION

The mixing equipment should be regularly checked to determine whether the proper amount of recycling additive and moisture are being added. Modern two-unit and multi-unit CIR trains have microprocessor controlled weight measuring systems for liquid recycling additives. When properly calibrated a very accurate record of the recycling additive rate is available. Weigh belt scales, liquid metering systems, and other components should be calibrated at the beginning of each job and whenever problems are encountered

17.3 GUIDE SPECIFICATIONS

Many owner agencies have considerable experience with CR and they have developed their own specifications to fit their particular expectations based on local materials and environmental conditions. Based on the significant effect environmental conditions and local materials have on CR performance, specifications from one agency might not be applicable to another agency, in a different location.

The following guide specifications are from the Task Force 38 Report and are based on SECTION "411 Cold Recycled Asphalt Pavement" of AASHTO's Guide Specifications for Highway Construction. Many of the requirements are general in nature due to the universal nature of guide specifications. Local experienced contractors and owner agencies should be consulted for specific recommendations. The specifications should be applicable to CCPR, as well as CIR.

COLD RECYCLED ASPHALT PAVEMENT – GUIDE SPECIFICATIONS

5.1 DESCRIPTION. This work shall consist of cold milling and pulverizing the existing asphalt pavement to a specified depth and maximum size or processing accepted stockpiled asphalt pavement, mixing a recycling agent(s), water and additives with the reclaimed material, and spreading and compacting the mixture.

5.2 MATERIALS. Recycling agent(s) shall include asphalt emulsions or asphalt emulsion rejuvenators. Materials shall meet the requirements of the appropriate specification Subsections:

Portland Cement . . . . .Specifications to be provided by the User Agency
Asphalt Emulsions . . . . .Specifications to be provided by the User Agency
Water . . . . .Specifications to be provided by the User Agency
Quicklime .Specifications to be provided by the User Agency
Fly Ash . . . . .ASTM C 618 and D 5239
Emulsified Rejuvenators . . . . .Specifications to be provided by the User Agency
Blotter Sand . . . . .Specifications to be provided by the User Agency

A. Composition of Mixtures. The cold recycled mixture shall be composed of Reclaimed Asphalt Pavement (RAP), recycling agent(s), and additives as specified. The composition of the mixture shall be established by the Contractor and approved by the Engineer and required shall be the following:

1. The sieve size where 100% passing is required _________ (1.25 inch (31.5 mm) sieve is recommended).
2. The beginning percentage of recycling agent _____, water _____ and additives _______ to be added to the RAP.

The cold recycled mixture shall be sampled for testing for job compliance at the spreading operation.

B. RAP Material. For Cold In-Place Recycling (CIR), the RAP shall be accepted by samples taken from the cold planer's conveyor, if there is no screening and crushing unit, and from the discharge conveyor of the screening and crushing unit if one is being used. RAP shall be accepted from a stockpile if Cold Central Plant Recycling (CCPR), without a screening and crushing unit, is being used and from samples from the discharge conveyor if screening and crushing unit is being used.

C. Recycling Agent(s). These materials shall be accepted under Specifications to be provided by the User Agency.

D. Additives. Additive sources shall be approved by the Engineer.

5.3 CONSTRUCTION REQUIREMENTS

A. Weather Limitations. Cold recycling operations shall be performed with asphalt emulsions when the atmospheric temperature in the shade is 50°F (10°C) and rising and it is not foggy. When using cement or fly ash, the atmospheric temperature in the shade shall be 39°F (4°C) and rising. Recycling operations shall not be performed when rain is occurring or night temperatures are forecast to fall below freezing.

B. Cold Milling Equipment and Mixing Plants. Cold milling equipment shall conform to Specifications to be provided by the User Agency.

A continuous pugmill mixing plant shall be equipped with a belt scale and automatic controls to obtain the proper amount of recycling agent and liquid additives, such as hydrated lime or cement slurry.

C. Hauling Equipment. Trucks used for hauling shall conform to Specifications to be provided by the User Agency.

D. Asphalt Pavers. Self-propelled asphalt pavers shall conform to Specifications to be provided by the User Agency.

E. Rollers. Rollers shall conform to Specifications to be provided by the User Agency except that a minimum of one 25 ton (23 tonne) pneumatic-tired roller and one 12 ton (11 tonne) or larger double drum vibratory steel-wheeled roller shall be provided.

F. Temperature of Recycling Agent. Recycling agent(s) shall be used within the temperature range specified for the mixing of the material being used. If required, the recycling agent(s) shall be heated to within the desired temperature range without overheating.

G. RAP Moisture Content. RAP for the cold recycled mixture shall have water added prior to mixing with the recycling agent(s), as specified or required by the Engineer to provide proper coating/dispersion and compaction.

H. Mixing Operation. The RAP, recycling agent(s) and additives shall be combined in the quantities required by the specifications or as directed by the Engineer. The mixing operation shall result in the RAP being thoroughly mixed with recycling agent(s) and additives, if used.

I. Spreading and Finishing. Asphalt pavers shall be used to spread the cold recycled mixture to the established grade and cross-slope.

The paving operations shall be conducted to protect existing and finished pavement sections. Traffic control and paving operations shall be completed according to the approved traffic control plan unless otherwise approved by the Engineer.

If blotter sand is required to prevent pick-up of the cold recycled mixture by traffic, it shall be applied by a mechanical spreader at a rate of from ____ to ____ (5 to 10 pounds per square yard, (2.7 to 5.4 kilograms per square meter) is recommended).

J. Rolling. After the cold recycled mixture has been spread and any surface irregularities corrected, the mat shall be uniformly compacted without undo displacement and cracking.
The number, weight, and type of roller furnished shall be sufficient to obtain the required compaction of the cold recycled material. The sequence of rolling operations shall provide the specified degree of compaction. The longitudinal joint shall be rolled first followed by the regular rolling procedure. The initial passes for all regular rolling should begin on the low side and progress toward the high side by overlapping of longitudinal passes parallel to the pavement centerline. When using an asphalt emulsion, the initial rolling shall not begin until the asphalt emulsion has started to break (turning from a brown to a black color). The time of beginning initial rolling shall be determined by the Engineer. With Portland cement or fly ash the recycling agent, the initial rolling shall begin immediately after spreading of the cold recycled material and be completed as soon as possible.

Rollers shall be operated at speeds appropriate for the type of roller and necessary to obtain the required degree of compaction and prevent defects in the mat. For static rollers, the drive drum normally shall be in the forward position or nearest to the paver. However, on steep grades, the non-powered drum shall be nearest to the paver, if required to prevent the mixture from shoving and tearing. Vibratory rollers shall be operated at the speed, frequency and amplitude required to obtain the required degree of compaction and prevent defects in the mat.

To prevent picking up of the mixture by rollers, drums and tires shall be uniformly wetted with water or water mixed with very small quantities of detergent or other approved material.

Any pavement shoving or other unacceptable displacement shall be corrected. The cause of the displacement shall be determined and corrective action taken immediately and before continuing rolling. Care shall be exercised in rolling the edges of the cold recycled mixture so the line and grade of the edge are maintained.

A minimum density of _____ percent (88% recommended) of the Maximum Theoretical Density. AASHTO T 209 or a minimum density of ______ percent (93% recommended and method used in determining laboratory density specified) of laboratory specimens made of production materials should be obtained.

When the control strip method of density control is specified, the control strip shall be constructed of mixture produced with the cold recycling equipment and within the pavement section. The Contractor shall select compaction patterns from which the Engineer (assisted by testing results using nuclear gauge or other testing procedures) will select the coverage that provides the specified minimum percent of density (97% minimum recommended). Whenever there is a change in the cold recycled material or compaction method or equipment or unacceptable results occur, a new test control strip shall be constructed, tested, and analyzed. Revised compaction methods will be selected by the Engineer.

K. Joints. Adjacent recycling passes shall overlap the longitudinal joint a minimum of 4 inches (100 mm). Any fillet of fine, pulverized material which forms adjacent to the vertical face of longitudinal joints shall be removed prior to spreading the cold recycled material, except that such fillet adjacent to existing pavement which will be removed by a subsequent overlapping milling need not be removed. The cold recycling widths selected shall not result in longitudinal joints being located in wheelpaths.

L. PAVEMENT SMOOTHNESS. The surface shall be tested with a 10 foot (3 meter) straightedge at locations selected by the Engineer. The variation of the surface from the testing edge of the straightedge between any two contacts, longitudinal or transverse with the surface, shall not exceed ______ (3/16 inch (5 mm) recommended). Irregularities exceeding the specified tolerance shall be corrected by and at the expense of the Contractor by grinding/cold milling or leveling with cold or hot mix asphalt as directed by the Engineer. Following correction, the area shall be retested.

5.4 METHOD OF MEASUREMENT

- In-place cold recycling will be measured by the station along the centerline of the lanes or by the square yard (square meter).
- Water will not be measured for payment.
- Liquid recycling agent(s) will be measured by the U.S. gallon (litre) or ton (tonne). Cement and fly ash will be measured by the ton (tonne).
- Cement, when dry cement or cement slurry is specified, shall be measured by the ton (tonne).
- Quicklime, when hydrated lime slurry is specified, shall be measured by the ton (tonne).
- Blotter sand will be measured by the ton (tonne) or cubic yard (cubic meter) in the truck at the point of usage for the quantity applied on the pavement.

5.5 BASIS OF PAYMENT

Payment for accepted quantities will be made as follows:

Pay Item	Pay Unit
In-Place Cold Recycled Asphalt Material	Station or Square Yard (Square Meter)
Recycling Agent	U.S. Gallon (Liter) or ton (tonne)
Blotter Sand	Ton (tonne) or Cubic Yard (Cubic Meter)
Quicklime	Ton (tonne)
Cement	Ton (tonne)

GLOSSARY OF TERMS

ABRASION: the wearing away of a surface material of a pavement structure by tire friction or snowplow scraping.

ABSOLUTE VISCOSITY: a method of measuring viscosity using the poise (Pascal•second) as the basic measurement unit utilizing a partial vacuum to induce flow in the viscometer. Test temperature of 140°F (60°C) is typical for an asphalt binder.

AGE-HARDENED: decrease in the penetration and/or increase in viscosity of asphalt binder caused by loss of volatiles and oxidization of the asphalt binder during manufacture (predominately during mixing) and subsequent exposure to weather.

AGGREGATE: a hard, inert, granular material of mineral compositions such as sand, gravel, shell, slag or crushed stone.

ALLIGATOR CRACKING: cracks which occur in asphalt pavements in areas subjected to repeated traffic loading which develop into a series of interconnected cracks, with many-sided, sharp-angled pieces, characteristically with an alligator pattern.

ASPHALT: a dark brown to black cementitious material in which the predominating constituents are bitumens that occur in nature or are obtained by petroleum processing.

ASPHALT BINDER (CEMENT): a dark brown to black cementitious material, in which the predominant constituents (+99%) are bitumens which occur in nature or are obtained as residue in petroleum manufacturing, and are used as binder in asphalt-aggregate mixes.

ASPHALT CONCRETE: a high quality mixture of asphalt binder and carefully graded coarse and fine aggregates.

ASPHALT EMULSION: an emulsion of asphalt binder and water that contains a small amount of an emulsifying agent. A heterogeneous system containing two normally immiscible phases (asphalt and water) in which the water forms the continuous phase of the emulsion, and minute globules of asphalt form the discontinuous phase. Asphalt emulsion may be either anionic i.e., electro-negatively charged asphalt globules or cationic, i.e., electro-positively charged asphalt globule types, depending upon the emulsifying agent.

ASPHALT LEVELING COURSE: a layer of asphalt concrete, of variable thickness, used to eliminate irregularities in the contour of an existing pavement surface prior to a superimposed treatment or construction.

ASPHALT PAVEMENT: pavement consisting of asphalt concrete layer(s) on supporting courses such as concrete base (composite pavement), asphalt treated base, cement treated base, granular base, and/or granular subbase placed over the subgrade.

ASPHALT REJUVENATOR: a liquid petroleum product, usually containing maltenes, added to asphalt paving material to restore proper viscosity, plasticity, and flexibility to the asphalt.

ASPHALT-RUBBER: a blend of asphalt binder, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt binder sufficiently to cause swelling of the rubber particles.

ASPHALTENES: the high molecular weight hydrocarbon fraction precipitated from asphalt by a designated paraffinic naphtha solvent at a specified solvent-asphalt ratio.

ATTERBERG LIMITS: soil moisture values used to define liquid and plastic conditions and thus to identify silty, clayey, and organic soils in the Unified Soil Classification System.

AVERAGE ANNUAL DAILY TRAFFIC (AADT): the average daily amount of vehicles in all lanes and both directions in a one year period.

BASE COURSE: a layer of specified or selected material of planned thickness constructed on the subgrade or subbase for the purpose of serving one or more functions such as distributing load, providing drainage, minimizing frost action, etc.. It may be composed of crushed stone, crushed slag, crushed or uncrushed gravel and sand, reclaimed asphalt pavement or combinations of these materials.

BATCH PLANT: a manufacturing facility for producing asphalt concrete that proportions the aggregate constituents into the mix by weighted batches and adds asphalt binder by either weight or volume.

BENKELMAN BEAM: a device for measuring the rebound deflection of a pavement surface, under a standard load, to assess/evaluate its structural adequacy.

BINDER: an adhesive composition of asphalt binder modifies asphalt binder, etc. which is primarily responsible for binding aggregate particles together.

BITUMEN: a class of black or dark-colored (solid, semisolid or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, and pitches are typical.

BITUMINOUS: containing or treated with bitumen.

BLEEDING (FLUSHING): presence of excess asphalt material on the pavement surface caused by too much asphalt binder in the mix, too heavy of an application of an asphalt sealant, excessive crack or joint sealant, and/or low mix air void content. Traffic action and warm temperatures can contribute to the occurrence of bleeding.

CAPE SEAL: a surface treatment where a chip seal is followed by the application of either a slurry seal or micro-surfacing.

CATIONIC EMULSIONS: emulsions where the asphalt binder globules in solution having a positive charge.

CHIP: particles of crushed coarse aggregate that can be one size or uniformly graded.

CHIP SEALING: a surface treatment using one or more layers of chips and asphalt emulsion binder.

CLAY: a cohesive soil composed of very fine particles which is defined by the Atterberg Limits in the Unified Soil Classification System.

COARSE AGGREGATE: that portion of aggregate retained on the No. 4 (4.75 mm) sieve.

COLD IN-PLACE RECYCLING (CIR): a rehabilitation treatment involving cold milling of the pavement surface and remixing with the addition of asphalt emulsion, Portland cement or other modifiers to improve the properties, followed by screeding and compaction of the reprocessed material in one continuous operation.

COLD PLANING (CP): a process which uses equipment where a rotating drum with helical placed teeth grinds up the pavement into pieces to the desired depth.

CONSISTENCY: describes the degree of fluidity or plasticity of asphalt binder at any particular temperature. The consistency of asphalt binder varies with temperature so it is necessary to use a common or standard temperature when comparing the consistency of one asphalt binder with another.

COMPACTION: the densification or compressing of a given volume of material into a smaller volume of a soil or pavement layer by means of mechanical manipulation such as rolling or tamping, with or without vibration.

COMPACTION CURVE: the curve showing the relationship between the dry unit weight (density) and the moisture content of a soil for a given compaction effort.

COST EFFECTIVENESS: an economic measure defined as the effectiveness of an action or treatment divided by the present worth of life-cycled costs.

CRACK FILLER: a material, usually bituminous or silicon-based, used to fill and seal cracks in existing pavements.

CRACK REPAIR: maintenance in which badly deteriorated cracks are repaired through patching operations.

CRACK SEALING: a maintenance treatment in which a crack is filled with a sealant. This may or may not include prior routing and/or drying with hot compressed air.

CROSS SECTION: a profile cut or illustration taken at right angle to the centerline of the longitudinal axis of a roadway.

CRACK TREATMENT: maintenance in which cracks are directly treated through sealing or filling operations.

CRUSHED GRAVEL: aggregate produced from the crushing of gravel, with most particles having at least one crushed face.

CRUSHER: equipment that is used to reduce larger stone and gravel too smaller, usable sizes.

CRUSHED BASE EQUIVALENCY: a measure expressing the contribution of each pavement component in terms of an equivalent thickness of crushed granular base.

CRUSHED STONE: aggregate produced from the crushing of quarried rock, with all faces fractured.

CUPPING: a depression in the pavement profile along crack edges caused by damaged or weakened sub-layers.

CUTBACK ASPHALT: asphalt binder that has been blended with distillates.

DEEP PATCHING: a maintenance treatment where the asphalt concrete and granular layers are removed and replaced with asphalt concrete with or without granular material below.

DEEP STRENGTH PAVEMENT: a flexible pavement with at least 7 inches (175 mm) of asphalt concrete on 6 inches (150 mm) or more of granular base.

DENSE-GRADED AGGREGATE: an aggregate that has a particle size distribution such that when it is compacted, the resulting voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, are relatively small

DENSIFICATION: act of increasing the density of a mixture during the compaction process.

DENSITY: the degree of solidity that can be achieved in a given mixture that will be limited only by the total elimination of voids between particles of mass. The mass of material divided by the volume, expressed as pounds per cubic foot (kilograms per cubic meter).

DISTRESS MANIFESTATION INDEX (DMI): a numerical value representing the cumulative amount of various types and severity of pavement surface distress.

DRAINAGE LAYER: an open graded base, stabilized or unstabilized, for pavements, usually 4 to 6 inches (100 to 150 mm) in thickness, and connected to a positive drainage system.

DRYER: an apparatus that will dry aggregates and heat them to specified temperatures.

DRY MIXING PERIOD: the interval of time between the beginning of the charge of dry aggregates into the pugmill and the beginning of the application of bituminous material.

DRUM MIX PLANT: a manufacturing facility for producing asphalt concrete that continuously proportions aggregates, heats and dries them in a rotating drum, and simultaneously mixes them with a controlled amount of asphalt binder. The same plant may produce cold-mixed bituminous paving mixtures without heating and drying the aggregates.

DUCTILITY: the ability of a substance to be drawn out or stretched thin. Ductility is considered an important characteristic of asphalt binders. In many applications, the presence or absence of ductility is usually considered more significant than the actual degree of ductility.

DYNAFLECT: a device to measure the surface deflection of a pavement under a sinusoidal varying load in order to evaluate its structural adequacy.

EDGE DETERIORATION: secondary cracks and spalls that occur within a few mils (mm) of the edges of a primary crack.

END RESULT SPECIFICATION: the specification of an end result to be achieved in construction, as compared to a method type of specification.

EMBANKMENT: a raised fill structure whose surface is higher than the natural adjoining surface.

EMULSION: an abbreviated term for asphalt emulsion binder which is produced in a high shear mixing device using asphalt binder, water, admixture, and in some cases, distillates.

EQUIVALENT SINGLE AXLE LOAD (ESAL): a concept which equates the damage to a pavement structure caused by the passage of a non-standard axle load to a standard 18,000 pound (80 kiloNewton) axle load, in terms of calculated or measured stress, strain or deflection at some point in the pavement structure or in terms of equal conditions of distress or loss of serviceability.

EROSION: wear caused by the force of wind or moving water.

FALLING WEIGHT DEFLECTOMETER (FWD): a device to measure the surface deflection of a pavement under a dynamic load in order to evaluate its structural adequacy.

FATIGUE: decrease of strength due to repetitive loading.

FAULTING: a difference in elevation between opposing sides of a crack caused by weak or moisture-sensitive foundation material.

FILLER: general term for a fine material that is inert under the conditions of use and serves to occupy space and may improve physical properties.

FINE AGGREGATE: aggregate passing the No. 4 (4.75 mm) sieve and predominantly retained on the No. 200 (0.075 mm) sieve.

FINES: proportion of a soil or clay and silt particles in an aggregate, finer than No. 200 (0.075 mm) sieve size.

FLEXIBLE PAVEMENT: a pavement structure usually composed of one or more asphalt concrete layers over an unbound aggregate or stabilized base and prepared subgrade soil.

FLUSHING: see bleeding.

FRACTURED FACES: an angular, rough or broken surface of an aggregate particle created by crushing, by other artificial means or by nature.

FRICTION: resistance to the relative movement of one body (tire) sliding, rolling or flowing over another body (pavement surface) with which it is in contact.

FRICTION COURSE: open graded mix or surface treatment to improve road surface friction.

FRICTION NUMBER: the ability of an asphalt paving surface, particularly when wet, to offer resistance to slipping or skidding. Aggregates containing non-polishing minerals with different wear or abrasion characteristics provide continuous renewal of the pavement's texture maintaining a high friction number surface.

FROST HEAVE: the rise in a pavement surface caused by the freezing of pore water and/or the creation of ice lenses in the underlying layers.

FULL DEPTH PAVEMENT: a flexible pavement structure which has asphalt concrete layer(s), usually greater than 6 inches (150 mm) in total thickness, placed directly in contact with the subgrade.

GEOSYNTHETIC: woven or non-woven man-made materials designed for such applications as drainage, filtration, separation, and strengthening. They can be subdivided into various groups: geotextiles, geowebs, geocomposites, geogrids or geodrains.

GRADATION: the proportions by the mass of soil, rock, granular or other materials distributed in specified particle size ranges.

GRADE: the elevation of a surface or the slope of the surface.

GRADIENT: the amount of slope along a specific line or route, such as road surface, channel or pipe.

GRANULAR BASE EQUIVALENCY (GBE): a measure expressing the contribution of each pavement component in terms of an equivalent thickness of granular base.

GRAVEL: granular material predominantly retained on the No. 4 (4.75 mm) sieve and resulting from natural disintegration and abrasion of rock or processing of weakly bound conglomerate.

HEAT-PLANER: a device that heats the pavement surface and uses a stationary or vibrating flat steel blade or plate to shear off up to 1 inch (25 mm) of the heated surface.

HEAT-SCARIFIER: a device that heats the pavement surface and uses stationary steel tines/teeth or rotating milling drum to loosen or remove up to 1 inch (25 mm) of the heated surface.

HIGH FLOAT EMULSION: an emulsion with petroleum distillates that have a gel quality imparted by the addition of various chemicals.

HOT MILLER: a device that heats the pavement surface and uses a rotating milling drum that has cutting tools mounted over the cylindrical surface to mill off up to 2 inches (50 mm) of the heated surface.

HOT IN-PLACE RECYCLING (HIR): a rehabilitation treatment used to correct asphalt pavement surface distress involving heating, removal of old asphalt concrete, processing, mixing with new aggregates, new asphalt binder and/or recycling agents, relaying, and compacting to meet specifications for conventional asphalt concrete.

HVEEM METHOD: method to design hot mix asphalt concrete.

INFRARED HEATING: involves heating a pavement using invisible heat rays having wavelengths longer than those of red light, thus direct contact of flame on pavement surface is avoided. Sometimes referred to as radiant or indirect heating.

IMPERMEABILITY: the resistance to passage of air and water into or through a pavement.

IMPERVIOUS: resistant to movement of water or air.

INTERNATIONAL ROUGHNESS INDEX (IRI): a summary statistic which characterizes road surface longitudinal roughness, based on the simulation of a standard quarter car model moving over the longitudinal profile of the road.

KINEMATIC VISCOSITY: a method of measuring viscosity of an asphalt binder using the millimeters squared per second (stoke) as the basic measurement and is related to the absolute viscosity by the specific gravity of the asphalt binder. Test temperature of 275°F (135° C) is typical for an asphalt binder.

LIFE-CYCLE COST ANALYSIS: an investigation of the present and future costs of each repair alternative, taking into account the effects of both inflation and interest rates on expenses over the life of the project.

LIPPING: an upheaval in the pavement profile along crack edges. Lipping may be the result of bulging in underlying Portland cement concrete base or the infiltration and buildup of material in the crack.

LOAD EQUIVALENCY FACTOR: a ratio of relative pavement damage to the number of Equivalent Single Axes Loads (ESAL's) a particular loading on a vehicle axle assembly represents.

LONGITUDINAL: parallel to the centerline of the pavement or laydown direction.

LONGITUDINAL CRACK: a distress manifestation where the crack or crack pattern in the pavement is parallel to the direction of travel.

MAINTENANCE: well timed and executed activities to ensure or extend pavement life until deterioration of the pavement layer materials and subgrades is such that a minimum acceptable level of serviceability is reached, and/or it is more cost-effective to rehabilitate the pavement.

MAINTENANCE MIX: a mixture of bituminous material and mineral aggregate applied at ambient temperature for use in patching holes, depressions, and distress areas in existing pavements using appropriate hand or mechanical methods in placing and compacting the mix. These mixes may be designed for immediate use or for use out of a stockpile at a later time without further processing.

MARSHALL METHOD: a method to design hot mix asphalt concrete.

MARSHALL STABILITY AND FLOW: design properties (resistance and deformation) of asphalt concrete determined from specific laboratory tests on a test specimen.

MAXIMUM SIZE (OF AGGREGATE): in specifications for or descriptions of aggregate, the smallest sieve opening through which the entire amount of aggregate is required to pass.

METHOD BASED SPECIFICATION: a specification involving the methodology or technique to be applied to a construction item, such as number of passes of a certain weight of roller.

MICROWAVE: short electromagnetic waves sometimes used to heat asphalt paving mixtures for recycling.

MILLING: removing the surface of a pavement with a self-propelled machine equipped with a transverse rotating cutter drum.

MINERAL FILLER: a finely divided mineral product at least 70 percent of which will pass a No. 200 (0.075 mm) sieve. Pulverized limestone is the most commonly manufactured filler, although other stone dust, hydrated lime, Portland cement, and certain natural deposits of finely divided mineral matter are also used.

NOMINAL MAXIMUM SIZE (OF AGGREGATE): in specifications for or descriptions of aggregate, the smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

OPEN-GRADED AGGREGATE: an aggregate that has a particle size distribution such that when it is compacted, the voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, remain relatively large.

OVERLAY: a new lift(s) of asphalt concrete placed on an existing pavement to restore the ride or surface friction or strengthen the structure.

PASS: a single passage of a reclaimer, motor grader or roller.

PATCHING: a maintenance treatment to repair failures or replace surface material.

PAVING GRADE: a classification system used to define asphalt binder types used for the production of hot mix asphalt for road, street, highway and other applications.

PAVEMENT: the layers above the subgrade.

PAVEMENT CONDITION INDEX (PCI): a composite measure of surface distress types, severity, and frequency.

PAVEMENT STRUCTURE: the subbase, base, and wearing surface layers.

PAVEMENT MANAGEMENT SYSTEM (PMS): a wide spectrum of activities including the planning or programming of investments, design, construction, maintenance, and the periodic evaluation or performance used to provide an effective and efficient road network.

PENETRATION: consistency of an asphalt binder expressed as the vertical distance that a standard needle penetrates a sample of the material under standard conditions of loading, time, and temperature.

PERFORMANCE BASED SPECIFICATION: a specification involving minimum or maximum levels of performance items at certain ages, such as roughness, surface distress, surface friction or structural adequacy.

PERMEABILITY: a property of a material measured in terms of the rate with which it allows passage of water or air.

PETROGRAPHIC ANALYSIS: a procedure to assess the durable qualities of aggregate through its petrology and structural fabric.

PLASTICITY INDEX (PI): the numerical difference between the liquid limit and the plastic limit of a soil.

PLASTIC LIMIT (PL): the lowest moisture content at which a soil remains plastic.

PLATE LOAD TEST: a method to determine the load bearing capacity of a subgrade, subbase or base, by measuring the deflection of a plate under a static load.

POISE: a centimeter-gram-second unit of absolute viscosity, equal to the viscosity of a fluid in which a stress of one dyne per square centimeter is required to maintain a difference of velocity of one centimeter per second between two parallel planes in the fluid that lie in the direction of flow and are separated by a distance of one centimeter.

POLISHING: the phenomena caused by the abrasive action of vehicle tires on aggregate particles that reduces the frictional properties of the surface.

PORTLAND CEMENT: a hydraulic cement comprised of very fine grains produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates and calcium sulphate.

PORTLAND CEMENT CONCRETE (PCC): the product of mixing Portland cement, mineral aggregates, water, and in some cases additives such as an air entering agent which result in a hardened structural material after hydration.

POTHOLE: localized distress in an asphalt-surfaced pavement resulting from the breakup of the asphalt surface and possibly the asphalt base course. Pieces of asphalt pavement created by the action of climate and traffic on the weakened pavement are then removed under the action of traffic, leaving a hole.

POTHOLE PATCHING: the repair of severe, localized distress in asphalt-surfaced pavements. This maintenance activity is generally performed by the agency responsible for the roadway and is intended to be a temporary repair at best. Pothole patching is not intended to be a permanent repair. Full-depth reconstruction of the distressed areas is necessary for a permanent repair in most instances.

PREVENTIVE MAINTENANCE: major maintenance treatments to retard deterioration of a pavement, such as chip seal, rout and crack seal, etc.

PRIME COAT: the application of low-viscosity liquid asphalt or asphalt emulsion to penetrate and bind a granular base prior to the placement of asphalt concrete.

PROFILE: (longitudinal) a chart line indication of elevations, grades, and distances and usually indicating the depth the cut and height of fill of the grading work commonly taken along the centerline of the proposed road alignment.

PROFILE: (transverse) a cross-sectional plot of surface elevations across a road.

PUGMILL: a device for mixing hot or cold aggregates and reclaimed asphalt pavement with an asphalt binder, recycling agent or stabilizing additive(s) to produce a homogeneous mixture.

QUALITY ASSURANCE (QA): a system of activities whose purpose is to provide assurance that the overall quality control job is in fact being done effectively. It involves a continuing evaluation of the effectiveness of the overall control program with a view to having corrective measures initiated where necessary. For a specific product or service, this involves verifications, audits, and the evaluation of the quality factors that affect the specification, production, inspection, and use of the product or service.

QUALITY CONTROL (QC): the overall system of activities whose purpose is to provide a quality of product or service that meets the needs of users. The aim of quality control is to provide quality that is satisfactory, adequate, dependable, and economic.

RAVELING: the wearing away of a pavement surface through the dislodging of aggregate particles and/or matrix of asphalt binder and fine particles.

RECLAIMED ASPHALT PAVEMENT (RAP): asphalt pavement or paving mixture removed from its original location for use in recycled hot mix asphalt, Cold Recycled mixes or for Full Depth Reclamation.

RECYCLING AGENT: a blend of hydrocarbons with or without minor amounts of other materials that is used to alter or improve the properties of the aged asphalt in a recycled asphalt paving mixture.

RECYCLED HOT MIX ASPHALT (RHM): a mixture of reclaimed asphalt pavement with the inclusion, if required, of asphalt binder, asphalt emulsion, cut-back asphalt, recycling agent, mineral aggregate, and mineral filler.

REHABILITATION: a term in pavement management involving the restoration of pavement serviceability through such actions as overlays.

REJUVENATOR: an additive used in the recycling of reclaimed asphalt pavement.

RIDING COMFORT INDEX (RCI): a measure to characterize the ride quality of a pavement on a scale of 0 to 10.

ROAD FRICTION: a general term related to the frictional or friction number properties of a road surface.

ROUT: a groove cut along a crack in asphalt pavements to act as a reservoir for crack sealant.

RUTTING: a distortion occurring in the wheelpaths of an asphalt concrete pavement.

SAND: granular material passing the No. 4 (4.75 mm) sieve and predominantly retained on the No. 200 (0.075 mm) sieve, either naturally occurring or the product of processing, i.e., manufactured sand.

SAND ASPHALT: a mixture of sand and asphalt binder, cutback or asphalt emulsion. It may be prepared with or without special control of aggregate grading and may or may not contain mineral filler. Either mixed-in-place or plant mix construction may be employed. Sand asphalt is used in construction of both base and surface courses.

SATURATES: a mixture of paraffinic and naphthenic hydrocarbons that on percolation in a paraffinic solvent are not absorbed on the absorbing medium. Other compounds such as naphthenic and polar aromatics are absorbed thus permitting the separation of the saturate fraction.

SCARIFICATION: ripping (usually with grader teeth), reshaping, and recompacting a pavement surface and/or base and/or subbase layer.

SCARIFICATION: removal of the top 1 to 2 inches (25 to 50 mm) of an asphalt pavement using a bank of tines/teeth or a rotating milling drum.

SCREEN: in laboratory work an apparatus, in which the apertures are circular, for separating sizes of material.

SECONDARY CRACK: a crack extending parallel to a primary crack.

SEGREGATION: a deficiency in pavement components where the coarse particles are separated from the fine matrix.

SERVICEABILITY: the ability, at time of observation, of a pavement to serve traffic that uses the facility.

SHALLOW PATCHING: a maintenance treatment where the surface layers(s) of asphalt concrete is removed and replaced with well compacted asphalt concrete.

SHOULDER: the non-travel portion of a road on each side of the pavement.

SHOVING: permanent, longitudinal displacement of a localized area of the pavement surface caused by the traffic-induced shear forces.

SIEVE: in a laboratory work an apparatus, in which the apparatus are square, for separating sizes of material.

SKID NUMBER (SN): a standard test measure of the friction between a tire and a wetted road surface.

SLAB: a load bearing layer of Portland cement concrete, with or without reinforcement, sized to control and minimize shrinkage cracking.

SLURRY SEAL: a surface treatment of asphalt emulsion, sand, Portland cement, and water, placed as a slurry. Single or multiple applications may be used.

SOIL: sediments or other unconsolidated accumulations of solid particles which are produced by the physical and chemical disintegration of rock and which may or may not contain organic matter.

SPRAY INJECTION: repair technique for potholes in asphalt-surfaced pavements and spalls in PCC-surfaced pavements that uses a spray-injection device. Spray-injection devices are capable of spraying heated asphalt emulsion, virgin aggregate or both into a distress location.

STABILITY: the ability of asphalt paving mixture to resist deformation from imposed loads. Stability is dependent upon both internal friction and cohesion.

STABILIZATION: a mechanical, chemical or bituminous treatment designed to increase or maintain the stability of a material or otherwise to improve it's engineering properties.

STABILIZING ADDITIVE: a mechanical, chemical or bituminous additive or material used to increase or maintain the strength, durability or moisture susceptibility of a material or to improve its engineering properties.

STANDARD PROCTOR: a test method where 12,375 foot-pounds per cubic foot (593 Kj/(cubic meter) of compactive effort is used to determine the optimum moisture content and maximum dry density of a soil aggregate.

STOKE: a unit of kinematic viscosity, equal to the viscosity of a fluid in poises divided by the density of the fluid in grams per cubic centimeter.

STRIPPING: a phenomenon in asphalt mixtures, where the asphalt binder film debonds or strips from the aggregate particles in the presence of water.

STRUCTURAL ADEQUACY INDEX (SAI): a measure that uses deflections and Equivalent Single Axle Loads to characterize the structural adequacy of a pavement on a sale of 0 to 10.

STRUCTURAL CAPACITY: the load-carrying capacity of a pavement that can be determined by evaluating the materials and/or layer thickness of the pavement structure or the surface deflections.

STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP): a comprehensive, multimillion dollar research program in the USA and other countries involving research in Long Term Pavement Performance, Asphalt, Concrete, Structures and Highway Operation.

SUBBASE: the layer of select compacted granular material placed on the subgrade and which is overlain by the base of a flexible pavement structure or the Portland cement concrete slab of a rigid pavement structure.

SUBGRADE: the soil prepared and compacted to support a pavement structure.

SUPERPAVE: a general term encompassing the methodology developed in the Strategic Highway Research Program for selecting asphalt binders, for designing hot mix asphalt concrete and for estimating the fatigue, rutting, low-temperature cracking and moisture damage performance of the asphalt concrete.

SURFACE RECYCLING: a general term that describes the Hot In-Place Recycling of the upper portion of an asphalt pavement.

SURFACE TREATMENT: a maintenance or rehabilitation treatment used to seal a road surface, improve its ride or surface friction. Multiple applications of bituminous material and mineral aggregate may be used.

TACK COAT: an application of liquid asphalt or asphalt emulsion to an existing asphalt concrete surface prior to the placement of an asphalt concrete lift or overlay.

TEXTURIZATION: grooving, milling or otherwise abrading the top of a pavement surface.

THERMOPLASTIC (MATERIAL): a material that becomes soft when heated and hard when cooled.

THROW-AND-GO: repair technique for cold-mix patching materials in which material is shoveled into pothole, with no prior preparation of the pothole, until it is filled: compaction of the patch is left to passing traffic, while the maintenance crew moves on to the next distress location.

Throw-and-roll: repair technique for cold-mix patching materials in which material is shoveled into pothole, with no prior preparation of the pothole, until it is filled: the material truck tires are used to compact the patch before the crew moves on to the next distress location.

TRANSVERSE: perpendicular to the pavement centerline or direction of laydown.

TRANSVERSE CRACK: a distress manifestation where the crack is perpendicular to the direction of travel.

TRAFFIC GROWTH FACTOR: a factor used to estimate the percentage annual increase in traffic volume.

TRUCK FACTOR: the number of Equivalent Single Axle Loads (ESAL's) represented by the passage of a truck.

VIRGIN AGGREGATE: new aggregate added to recycled asphalt pavement in the production of recycled hot mix asphalt concrete, Cold Recycled mixtures and for mechanical stabilization using Full Depth Reclamation.

VIRGIN ASPHALT BINDER: new asphalt binder added during recycling to improve the properties of the recycled asphalt concrete.

VOIDS: empty spaces in a compacted mix surrounded by asphalt coated particles.

WARRANTY: guaranteed performance of a work or physical item; e.g. contractor guarantee that pavement rutting on a project will not exceed "x" mils (mm) at "y" years.

WORKABILITY: the ease with which mixtures may be placed and compacted.

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GLOSSARY OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AGC	Association of General Contractors of America
ARRA	Asphalt Recycling and Reclaiming Association
ARTBA	American Road and Transportation Builders Association
ASTM	American Society for Testing and Materials
BARM	Basic Asphalt Recycling Manual
BBR	Bending Beam Rheometer
C	Centigrade
CaO	Calcium Oxide
CBR	California Bearing Ration
CCPR	Cold Central Plant Recycling
CIR	Cold In-Place Recycling
CKD	Cement Kiln Dust
CP	Cold Planing
CR	Cold Recycling
DBC	Design Bitumen Content
DCP	Dynamic Cone Penetrometer
DMI	Distress Manifestation Index
DSR	Dynamic Shear Rheometer
DTT	Direct Tension Tester
ESAL	Equivalent Single Axel Load
F	Fahrenheit
FDR	Full Depth Reclamation
FHWA	Federal Highway Administration

FWD	Falling Weight Deflectometer
GBE	Granular Base Equivalency
GPR	Ground Penetrating Radar
HFMS	High Float Medium-setting asphalt emulsion
HIR	Hot In-Place Recycling
HMA	Hot Mix Asphalt
IRI	International Roughness Index
IRRM	Index of Retained Resilient Modulus
ITS	Indirect Tensile Strength
JMF	Job Mix Formula
LKD	Lime Kiln Dust
LTPP	Long Term Pavement Performance
m	Slope value from Bending Beam Rheometer test
MDD	Maximum Dry Density
mm	Millimeter
MTD	Maximum Theoretical Density
NCHRP	National Cooperative Highway Research Program
OFC	Optimum Fluid Content
OGFC	Open Graded Friction Course
OMC	Optimum Moisture Content
ORAC	Optimum Recycling Additive Content
PAV	Pressure Aging Vessel
PCC	Portland cement Concrete
PCI	Present Condition Index
PG	Performance Grade (asphalt binder)

PMS	Pavement Management System
PrI	California Profilograph Index
PSI	Present Serviceability Index
QA	Quality Assurance
QC	Quality Control
RA	Recycling Agent
RAP	Reclaimed Asphalt Pavement
RCI	Riding Comfort Index
RCR	Riding Comfort Rating
RTFOT	Rolling Thin Film Oven Test
S	Creep Stiffness Value from Bending Beam Rheometer test
SDI	Surface Distress Index
SGC	Superpave Gyratory Compactor
SHRP	Strategic Highway Research Program
SMA	Stone Matrix (Mastic) Asphalt
SN	Structural Number
SQA	Statistical Quality Assurance
SS	Slow-setting asphalt emulsion
SSD	Saturated Surface Dry
TFOT	Thin Film Oven Test
TSR	Tensile Strength Ratio
Va	Air Voids
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate
VTM	Voids in Total Mix

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