CHAPTER 13 IN-PLACE RECYCLING

13.1 OVERVIEW

This chapter covers in-place recycling as an alternative maintenance option for hot mix asphalt (HMA) pavements. The specific goal of this chapter is to provide information on the materials, design, and construction of cold in-place recycling (CIR) and hot in-place recycling (HIR). The major topics include:

- Materials
- Mix Design
- Construction
- Quality Control
- Troubleshooting

Although this chapter focuses on CIR and HIR, it is recognized that there are other alternatives to recycling pavement materials. For example, HMA and other materials such as chip seals and previous overlays might be removed from the existing pavement surface by milling and then used elsewhere such as an addition to HMA at a central plant. Although this is a good and ongoing practice, it is not the subject of this chapter on surface recycling. In addition, other materials such as crushed portland cement concrete may be returned to the same project and laid down in the same manner as for the CIR process.

Because of the success of surface recycling, it has become increasingly a choice for maintenance rather than just for rehabilitation or reconstruction. The functional performance of pavements can be improved, since the top few inches are reworked and can correct such deficiencies as rutting, raveling, and surface cracking, thus improving the ride quality as well as structural integrity. Surface recycling is not recommended when the underlying pavement layers are structurally deficient.

This chapter is limited to the broader features of in-place recycling in order to provide a general understanding of the concept, with enough detail so that the reader may gain a good feel for the concept along with the steps required to achieve a successful project. Additional more detailed information may be found in the references.

13.1.1 Cold In-Place Recycling

The CIR process removes a portion of an existing asphalt pavement by milling, and then replaces it with reworked asphalt mix with additives. Typically, the steps include:

- Milling the existing asphalt layers to some partial depth
- Typical depth is 3 inches, but ranges from 50 to 100 mm (2 to 4 inches)

- Size the reclaimed material, mix with additives, and repave
- If needed, add virgin material before relaying the recycled mix

As the name implies, CIR is accomplished without heating any of the components, before or after placement. Depending upon the structural requirements of the overall pavement and its intended use, the CIR typically receives a wear course such as a chip seal or HMA overlay. Note that CIR is contrasted to full depth reclamation (FDR), which often incorporates the entire pavement section and may incorporate a substantial amount of underlying base material, for example. Also note that a CIR pavement will require time to dry (aerate) the free moisture from the mix as well as cure the asphalt emulsion before final compaction and placement of a wearing course on top.

CIR is often used on low traffic volume roads or secondary roads where a central hot mix plant may not be convenient for obtaining new HMA for an overlay (FHWA 2003). It can also be used on high volume roadways as a repair to the existing pavement and a mitigation layer for cracking in conjunction with a HMA overlay. This process is effective in restoring or improving the cross section profile, crown, cross slope drainage, as well as removing cracked pavement (Khandall and Mallick, 1997). Success will depend on careful evaluation of the existing pavement to determine the cause of distress and recognize the limits of CIR, and that it will not restore a deficient subgrade, for example.

13.1.2 Hot In-Place Recycling

The HIR process is not unlike CIR, except that heat is used to soften the existing asphalt surface. The softened asphalt surface is mechanically loosened, mixed as necessary with recycling agent, aggregate, or additional HMA, and then re-laid, without removing it from the pavement site (Button, et al 1994). HIR is effective at correcting surface distress that is limited to the top 25 to 50 mm (1 to 2 inches) but depending on the process and extent of cracking, may extend to 3 inches. The process is effective for correcting minor surface rutting, corrugations, raveling, flushing, loss of surface friction, minor thermal cracking, and minor load associated cracking (Button, et al, 1994). Note that HIR should be used only if the underlying pavement layers are structurally sound.

The HIR process can be performed as either a single-pass operation that combines the restored pavement surface material with virgin material, or as a two-pass operation, in which the restored pavement surface material is re-compacted and the application of a new wearing surface follows at a later time. Three different processes are commonly used in HIR, including:

- Surface recycling, including heater-scarification
- Repaving and remixing
- Remixing

These are described in some detail under the section on Construction.

13.2 MATERIALS

13.2.1 Project and Materials Selection

In Chapter 3 there is a detailed description and discussion of how a project is selected for maintenance or rehabilitation. It is important that all the available data and resources are utilized to determine the most appropriate method for a given project. Figure 13-1 is a summary of the process (Epps, et al 1980) and incorporates the existing pavement condition, including tests to help with the cause analysis, the past history of this project as well as other projects that might have used the same materials in the vicinity, thus could experience the same problems.

A key part of this process shown in Figure 13-1 is the sampling and evaluation of materials used in the asphalt pavement that needs rehabilitation. For the more detailed evaluation of the recycling option, this chapter addresses the surface recycling, either hot or cold. For both CIR and HIR, the proper selection of materials is dependent on a thorough evaluation of the existing in-place materials. It is important to identify the characteristics of the existing pavement materials so that the correct types and amounts of additives can be determined (i.e., recycling agents and/or binders) and the need for additional materials such as virgin aggregate can be ascertained (FHWA, 2001, Kendalh, et al, 1997). A more thorough treatment of this subject can be found in Ref. 2.

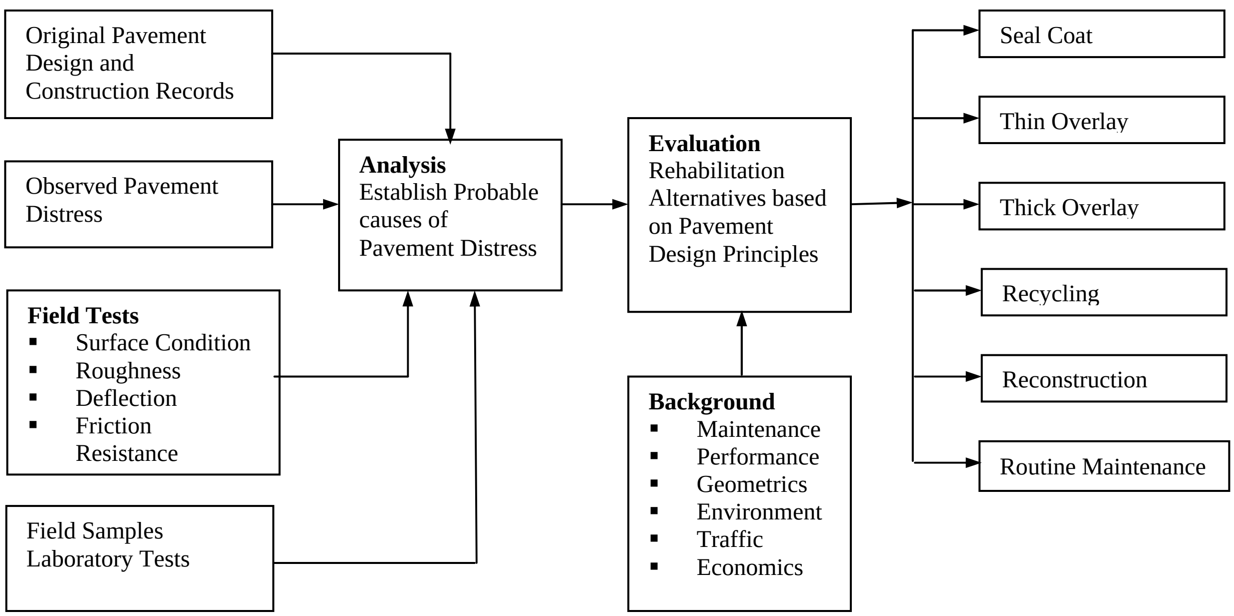

Figure 13-1 Summary of process to arrive at the best option for pavement rehabilitation (Epps, et al, 1997)

13.2.2 CIR Materials

A thorough understanding of all the materials that make up a CIR project is important to its success. Of primary concern is the existing asphalt pavement and its condition, and when it is removed from the surface, and then becomes reclaimed asphalt pavement (RAP). Other materials will then be added in order to make up the desired combination that will serve its intended use. These materials will include added aggregate, new HMA if any is needed, and asphalt additives.

Reclaimed Asphalt Pavement (RAP)

RAP is the milled asphalt pavement that is removed from its original position or depth of layers in the pavement, and will be used for the CIR mixture. Samples of RAP are obtained from core samples obtained during the preliminary stages of project evaluation. The properties of the RAP are determined by detailed laboratory testing, but the core samples will also be used to evaluate the uniformity of the RAP along the project roadway, and note any changes that may have resulted from past designs and maintenance that may have occurred at different times. In addition, the depth of the pavement to be recycled is critical for successful field construction, so that unexpected problems can be avoided. For example, if the planned depth of CIR is 3 in, and the existing pavement depth varies from 2 ½ in to 5 in thick, a large portion of the underlying material would be incorporated into the mixture and cause variability of the recycled mixture. Good records of the core samples should include any visual observations, photographs, and trimming the samples to the depth to be recycled, and then testing of the material for the design of the final CIR pavement mixture. Typical testing should include at least the following:

- aggregate gradation of the RAP
- large projects may warrant additional testing and evaluation as follows:
    - Moisture content if samples are obtained using dry coring or cutting
    - Asphalt binder content
    - Dry and retained strength of the recycled mixture for moisture sensitivity evaluation
    - Raveling potential of the recycled mixture based on observation of the original pavement

The above information will be used as the starting point to determine what additives or other materials will be required to design a mixture with the desired characteristics for the newly recycled pavement. For example the primary concern may be to correct an existing mix deficiency such as flushing, or to generally upgrade the material to meet new standards. The mix design should follow Caltrans Lab. Procedure # 8, METHOD OF TEST FOR DETERMINING THE PERCENT OF EMULSIFIED RECYCLING AGENT TO USE FOR COLD RECYCLING OF ASPHALT CONCRETE. This method is available at: www.dot.ca.gov/hq/esc/Translab/fpmlab.htm.

New Aggregate

Although not often added, some projects may require the addition of virgin aggregate in order to reduce the average binder content because of flushing, for example. Or, there may be a desire to improve the strength or thickness of the recycled layer. The new aggregate may be from the same or different source as the original pavement, but will need to meet all material specifications including quality, and especially gradation in order to complement that in the RAP to meet the final gradation of the combined materials (ARRA 2001). An alternative to new aggregate might be RAP from another project that has been sized to meet the needs of the project at a nearby central plant.

Recycling Additives for CIR

There are myriad material options for additives to improve the properties of the CIR pavement. The option selected may be determined in the laboratory by making trial mixtures using different additives for comparison. The goal is to change or improve the quality of the binder in the RAP, but also may be for aiding compaction. Because the CIR is mixed at ambient temperatures, the choices must be compatible with this limitation, but the opportunity is good for utilizing a material(s) that will work well. A summary of these options is shown below (FHWA 2001, ARRA 2001).

Asphalt Emulsions

The most common binder for CIR is asphalt emulsion, available in several types and grades. Those that have found success in CIR include medium and slow setting, both cationic and anionic types, as well as anionic high-float emulsions. However, the use of medium set and high float emulsions in California are limited due to environmental concerns. Some may be combined with other modifiers such as polymers to improve properties of the mixture.

Recycling Agents

For CIR, recycling or rejuvenating agents are usually combined with an asphalt emulsion. These combinations are typically custom blended by the suppliers, usually to fit a particular material (RAP) and also the location, because of climatic concerns. The idea is to simultaneously restore desirable asphalt binder properties and at the same time add more binder for improving the mixture or to make up the difference when new aggregate is added. A cautionary note is that either the portion of new binder or recycling agent may not be appropriate for the particular RAP if used simultaneously resulting, for example, in too soft a binder or too much binder, without the ability to make changes on the run.

Cutback Asphalts

Caltrans no longer specifies cutback asphalt for several reasons. In past years, in the 1930s, cutback asphalts were the binder of choice for cold in-place recycling because they were stable and readily mixed with a wide range of aggregates and RAP. But they are now on the way out because of environmental concerns of release of hydrocarbons into the atmosphere; many government agencies no longer allow their use. There is also safety concern because of their low flash point, and the potential for causing fires on the jobsite.

Foamed Asphalts

An alternative method of adding asphalt binder to CIR mixtures is by foaming the asphalt to provide a means of coating the RAP and aggregate. This system requires a means of injecting hot asphalt cement (not asphalt emulsion or cutback) and water together in a chamber to produce a foaming action. The expansion of the foam results in a condition that allows it to disperse, wet, and coat the RAP-aggregate materials with asphalt. Because the asphalt cement, which is paving grade and is not liquid at ambient temperature, quickly reverts to its semi-solid state, the binder tends to cement particles together rather than coat them. As such it is not particularly suited to rejuvenating or restoring asphalt binder properties, particularly the fine fraction.

Chemical Additives

There are several types of mineral or chemical additives that have proven beneficial to the construction and performance of CIR materials and pavements. Liquid anti-strip additives are an effective material in reducing water sensitivity. Dry materials, such as fly ash, portland cement, and lime have all been used, typically in a slurry form to reduce dust, for use in providing early setting and curing of asphalt emulsions, as well as early strength gain to overcome the effects of wet weather and/or the need to overlay the CIR pavement earlier than would normally be practical. The idea is that the cement, for example, absorbs the water contained in the asphalt emulsion, resulting in quicker setting and faster breaking and curing. Using this approach can also reduce the tendency for early rutting during the cure period, especially for poorly graded or rounded aggregate mixtures.

13.2.3 HIR Materials

In a manner similar to that for CIR, each project must be evaluated to determine the specific properties of the in-place pavement condition and RAP and any other materials anticipated to be used in the final recycled mixture. Determination of the mechanisms that caused the distress will be important to solving the problem and preventing the distress from returning in the future. Once the problem is assessed, then this information is used in the material selection and design of the recycled mixture.

The needs for the change or procedure for HIR will affect the construction methods, and possibly the equipment to be used as well. More specific information follows.

Reclaimed Asphalt Pavement (RAP)

Core sampling, using random location techniques is a common method to obtain samples of the existing pavement that will represent the project to be recycled. However, Caltrans prefers to take cores every 2,000 feet in an alternating pattern. For CIR, the preferred spacing is 1,500 feet. In a manner similar to that used for CIR, the HIR pavements must be evaluated using the methods outlined for evaluation in Chapter 3. Assessment of cracking, rutting, and other pavement defects will assist the engineer to determine the best method for designing the new recycled mixture. Once the cores have been measured and photographed, they should be trimmed, utilizing the topmost portion that is equal to the depth of recycling for the source of RAP to be used in the mix design. Tests on the material from the core samples should include at least the following:

- Bulk specific gravity or density
- Field moisture content (this will have an influence on the rate of production in the field)
- Asphalt binder content
- Properties of aggregate recovered from the RAP, including gradation, shape and angularity, etc
- Properties of the recovered asphalt binder, including the PG grading, and also other properties such as penetration, viscosity, temperature susceptibility, etc
- Maximum theoretical specific gravity of the existing mix, using crumbled core samples, for example
- Volumetric properties including air voids, voids in the mineral aggregate, and voids filled with asphalt

This information provides a starting point for the engineer to evaluate the existing state of the pavement and use it to assist in re-designing the mix to achieve the desired properties.

Asphalt Binder

The asphalt binder provides the best opportunity to change the properties of not only the binder itself, but the total behavior and durability of the recycled HMA. Recycling agents can be used to modify the existing asphalt binder to improve the performance and/or simply restore the original properties as needed (ARRA 2001).

HIR Recycling Agents

Recycling agents for HIR mixtures are typically hydrocarbons that will alter the binder in the existing pavement mixture to have physical and chemical properties that are beneficial to the performance of the pavement (ARRA 2001). The purpose of adding recycling agents is intended to:

- Restore the aged asphalt binder properties to a consistency level appropriate for construction purposes and the intended end use of the recycled mixture
- Provide sufficient additional binder to coat the RAP and any added aggregate
- Provide sufficient asphalt binder to satisfy the mix design requirements

Recycling agents may include materials such as soft asphalt binders, specialty products, and on occasion, asphalt emulsions (ARRA 2001). Soft asphalt binders are typically less expensive than other options, but have limitations in that they must be added to the RAP as a coating on virgin aggregate in order to get good dispersion. Specialty recycling agents are more commonly used and are more aggressive in their ability to alter the binder in RAP, and thus activate old binder that may be tightly bound to the aggregate. The choice of agent will depend on what the mix designer is attempting to achieve in the recycled mixture. One philosophy might be to assume the existing binder on the RAP is part of the aggregate, and that the new additives will not activate the binder in the RAP. Another approach is to attempt to restore original properties to the aged binder. It is generally agreed that recycling agents must have at least the following properties (ARRA 2001):

- Be easy to disperse in the recycled mixture
- Be compatible with the aged asphalt binder to avoid separation such as syneresis or exudation of paraffins from the binder. Also, if the recycling agent contains modifiers such as polymers, they must also be compatible with the asphalt in the RAP
- Able to disperse the asphaltenes in the aged asphalt binder
- Capable of altering the properties of the aged asphalt binder to the desired level.
- Are uniform and consistent from batch to batch
- Resistant to excessive hardening during the hot mixing phase to ensure long term durability
- Be low in volatile organic compounds or contaminants to minimize smoking and volatile loss during construction as well as reduce long term aging.

New Aggregate

Although rarely used in practice, new aggregates can be introduced during the HIR process in order to modify the gradation, and improve stability or stiffness as well as possibly correcting an over-asphalted mixture. This decision will be based on the performance of the original HMA pavement, and within the limit of the construction equipment’s ability to accommodate additional materials (ARRA 2001). More likely, new HMA would be the practical method to achieve improved gradation of the final mix.

New HMA

On occasion, it may be desirable to add virgin HMA from a hot mix plant in order to improve the mix performance and/or provide a thicker layer as well as smooth high and low areas, as is done in pre-leveling. This change may be part of the HIR process of repaving and remixing. Similar to the addition of virgin aggregate, the gradation of the new HMA will need to be compatible with the RAP, as well as the rejuvenated binder in the original pavement. This can be done by remixing the RAP and the HMA into an integral blended layer. Alternatively, the new HMA might be placed on top of the just-placed recycled mix.

New Technologies

Variations on a theme have been proposed in the past, with only modest success. One idea is a system to transform an existing asphalt pavement to a two-layer pavement with open-graded mix on the top. This idea from Japan is called HITONE and uses HIR equipment to heat in place, but then separates the RAP into two size fractions. The finer fraction, essentially a mastic, is placed back on the roadway, followed by the coarser open graded fraction as a friction course that may also serve as a drainage layer and be quieter under traffic. This system has not been tried in the U.S. yet.

Warm Mixes

One of the difficulties with HIR is the ability to heat the RAP to sufficiently high temperatures in order to compact it back into a dense layer. Multi-phase heaters and scarifiers have been developed to overcome this problem, but in cool or windy weather, reaching adequate compaction temperature and maintaining it is not easy. There is a considerable move afoot to introduce additives and methodology that will allow HMA to be readily compacted at less than traditional temperatures and this concept could be extended to HIR.

13.3 MIX DESIGN

13.3.1 Philosophy of Mix Design

With both CIR and HIR, the establishment of the appropriate quality and gradation of aggregate for the intended purpose of load capacity, traffic, friction, durability, etc., must be done in conjunction with the practices in place for the class of road. Once that is done, then the purpose of the design is to put as much asphalt binder as possible into the mix to provide waterproofing and durability, but not so much that there is loss in stability and stiffness required to carry the intended traffic. The quality of the final mix in place should have sufficient compactability so that the required density can be achieved. CIR has the disadvantage of requiring additional fluids (water) to reduce the mix mass viscosity for compaction at ambient temperatures. HIR has the challenge of getting the recycled HMA heated sufficiently to achieve adequate compaction.

13.3.2 Cold In-Place Recycling Mix Design

The basic concepts of mix design for CIR are similar for most highway agencies, but there is no universally adopted procedure. Caltrans has established a mix design for CIR projects. It is a work in progress and is expected to be updated as State experience is developed. A summary of the key steps are presented below.

1. Obtain samples of RAP from the field. As briefly discussed above, core samples are taken from the existing pavement, both at the centerline and at the edge of the pavement, to determine the various characteristics of the existing layers and thickness of HMA. Care must be exercised to evaluate the uniformity of thickness and changes along the centerline of previous paving operations. The preferred method of obtaining samples for mix design is by using a milling machine that will produce samples similar to what will be achieved during construction
2. Determine RAP properties. Laboratory tests are conducted using the RAP core samples to determine the properties of the existing mixture. These properties include the gradation of the milled or crushed (if milling is not an option) RAP, moisture content, asphalt binder content, aggregate properties. This information is the basis for determining the properties and amount of added material, if any, to improve the recycled mixture.
3. Select the amount and gradation of new aggregate. In some cases, new aggregate may be needed to correct a mix that is over-asphalted, or to improve the stiffness and stability. Also, if there is insufficient material to make up the needed thickness of the recycled layer, then new aggregate or virgin HMA will be required. Although one option would be to mill deeper into the existing pavement, there may not be sufficient pavement thickness for this purpose.
4. Select type and grade of recycling additive. The most common recycling additives for CIR are asphalt emulsions or emulsified recycling agents because they are liquid at ambient temperatures, and can be readily dispersed in the recycling mixture. Some versions of these additives include

other modifiers such as polymers, used to provide enhanced setting and performance properties to the binder. Other mineral additives such as lime or portland cement are added to accelerated the setting and provide early stiffness, as well as improve water susceptibility such as stripping.

5. Estimate the amount of recycling additive. Past experience has shown that CIR mixtures that will not have aggregate added (100% recycle) require recycling additives in the range of 2% to as much 4% based on the total mix. The thickness of recycling in the field will also help determine the amount added. The actual starting point of the design will depend on local practice, experience, and other empirical factors. The type and level of activity (ability to soften the existing binder) of the agent will also determine how much of the old aged binder will actually be rejuvenated and become part of the binder system of the newly recycled mixture. The more aggressive, the less recycling agent will normally be required.
6. Determine liquid content for adequate coating. Water is typically added to CIR mixtures in order to provide enough total liquid to coat the aggregate and aid in the compaction of the final mixture. If an asphalt emulsion is used as a recycling agent, then some of the moisture comes from the water fraction of the emulsion. However, this recycling agent may not be sufficient to wet and coat the RAP and new aggregate (if any), so water is also added. This coating evaluation is done in the laboratory by using small samples of RAP and adding the previously-determined amount of agent to the RAP, and then thoroughly mixing in water in small increments, then observing the degree of coating. The optimum amount of coating is then determined by observing the minimum amount of added water that just coats the RAP and aggregate, and when additional water does not improve this coating. Moisture sensitivity and raveling should be evaluated.
7. Establish job mix formula. Following the mix evaluation and testing using compaction vs. total fluids content curves, a job mix formula (JMF) is established as a starting point for field operations. The JMF includes the amount, type and grade of recycling additive, the water to be added, as well as the aggregate requirements.
8. Make field adjustments. At the start-up of a project, the JMF is used to set the mixture parameters. It is recognized, however, that adjustments will need to be made for weather, variation in the RAP, and changed demand for recycling agent materials. Fine tuning of the mix may include adjusting the water content or even the recycling agent if observations show that coating is not optimum. Compactability is also very important when evaluating the mix during start up.

13.3.3 Hot In-Place Recycling Mix Design

As indicated earlier, the goal of HIR mix design is to restore the properties of the aged asphalt pavements to that of a new pavement, or at least as near as possible. To achieve this goal, the aged binder must be evaluated to determine the effect of oxidation over time. In addition, the effects of traffic on the pavement mixture due to densification and reduction in air voids must be evaluated. The mix design shall conform to Asphalt Institute Manual Series Number 2 (MS-2), Appendix A, “Mix Design Using RAP” using California Test 367 to perform Step 5.

In a manner similar to that shown for CIR, the summary is provided below.

1. Evaluate the existing HMA and determine mix properties. As indicated in the Materials section, the specific characteristics of the existing materials must be identified so that the type and amount of recycling agent as well as the need for virgin aggregate can be determined. Core samples must be carefully examined to identify the thickness of different pavement layers, previous surface treatments, interlayer geotextile paving fabrics, specialty mixes, evidence of material failure such as stripping, disintegrating aggregate or mixture, retention of moisture, and any tendency to delaminate (FHWA 2003). Once the core samples have been examined, they must be prepared as

outlined under the Materials section. In addition to cores, actual millings from the field equipment or a small milling machine used for this purpose might be generated in order to help determine how the HMA will behave under real construction procedures, and to provide materials for the mix design.

2. Determine the method for rejuvenating the asphalt binder. The next step of the mix design for HIR is to conduct laboratory testing of the original HMA to determine the best method to rejuvenate the aged binder. Three methods of rejuvenating have been successful, and these options are: a) use a recycling agent only, b) use a soft grade of new asphalt cement, or c) use a combination of recycling agent, new asphalt binder, and new aggregate. In lieu of this last option, virgin HMA could be considered for an addition to improve the mix and/or add more material for a thicker pavement layer. It is imperative that the nature and reactivity of the recycling agent be understood so as to avoid undesirable consequences after the project is complete.
   Select the type and amount of recycling agent. Traditionally, this step has been to determine the viscosity of the aged asphalt, and then add sufficient agent to restore the original or desired properties. However, more information may be required to predict the future behavior and longevity of the recycled pavement by using the Performance Graded (PG) system developed for Superpave. The tests used in the PG grading system are intended to match not only the material properties, but the climate or location where the binder will perform well. Using viscosity alone may mislead the designer as to expected performance. The steps or process to achieve this phase of the mix design consist of the following:

   - Obtain representative field samples
   - Extract and recover aged asphalt binder, and determine a) binder content, b) viscosity and penetration of the binder, and c) other properties necessary to grade the original binder in the PG procedure, if desired
   - Use viscosity blending chart to determine the amount of recycling agent required to rejuvenate the aged asphalt binder
   - Make adjustment in the field to the recycling agent application rate based on mix appearance and QC/QA test results during HIR construction

3. Prepare and test mix specimens in the laboratory. Mixtures are made up in the laboratory, to include a range of RAP, recycling agents, new aggregates, new asphalt binder, and possibly new HMA. Test specimens are made for evaluating mixture properties. Tests normally used in mix design procedures such as stability, stiffness, water sensitivity, and others are used to determine the optimum combination(s).

4. Establish job mix formula. Once all laboratory analysis of materials has been completed, the information is available to establish the job mix formula which includes the optimized properties and meets any economical goals or limitations.

   The JMF should include the following information:

   - Asphalt binder content (%), penetration at 25ºC and viscosity at 60ºC of the asphalt binder contained in the asphalt pavement to be recycled using ASTM Method D-2172. Alternatively, the properties used to classify asphalt binder using the PG system may be used.
   - Gradation of the aggregate in the asphalt pavement to be recycled (after extraction of binder) using California Test 202
   - Gradation of aggregate and percent asphalt of the virgin HMA added to the mixture
   - Proposed asphalt binder grade, source, and properties (as specified in Section 92, "Asphalts" of the Standard Specifications)

- Source and properties of the aggregates, as specified in these special provisions, proposed for use in virgin hot mix asphalt
- Source, type, amount, and properties of recycling agent per Section 92 or 94 of the Standard Specifications
- Aggregate gradation (including recycled pavement plus virgin hot mix asphalt) and asphalt content of the recycled asphalt concrete mixture (including recycled pavement, virgin hot mix asphalt, and recycling agent)
- Stability and volumetric analysis information of the recycled mixture as described in California Test 367
- Penetration at 25ºC and viscosity at 60ºC and 135ºC of the binder in the combined recycled mixture (includes recycled pavement, virgin hot mix asphalt, and recycling agent)

13.4 CONSTRUCTION

13.4.1 Cold In-Place Recycling Construction

The construction process, sequence of operations, and the equipment type for CIR are usually dictated by the specifications, the contractor's experience, and the specifics of the project. All pavement evaluation work needs to be completed prior to a contract being awarded, except mix design which is done as part of the contract. The Caltrans construction specifications for CIR are in Reference 13. The CIR construction process includes as least the following operations:

- Preparation of the construction area
- Surface pulverization and sizing of the RAP
- Addition of new aggregate if necessary
- Addition of new RAP if necessary
- Addition of new asphalt binder/recycling agent
- Mixing
- Placement
- Aeration
- Compaction
- Curing
- Application of pavement wearing surface

A general view of the construction process is shown in Figure 13-2. There are several possible arrangements of equipment and process details that can be selected by the contractor, but Figure 13-2 shows that some choices such as a single-unit train combines several operations. All steps or operations may not be necessary on some projects.

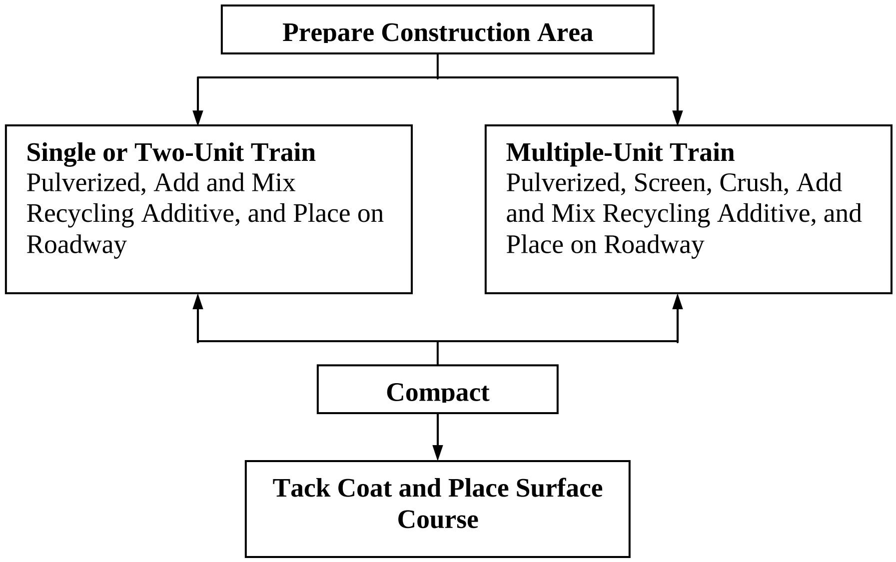

Figure 13-2 CIR construction flow chart (ARRA 2001)

Preparation of the Construction Area

Prior to construction, the pavement should be evaluated to identify any areas where material properties or pavement thickness appear to be non-uniform. Any areas displaying insufficient support, such as localized soft areas, must be corrected prior to recycling due to the risk of damage to construction equipment or premature failure following construction. Weak material should be removed and replaced with suitable patching material. Portions of the project that were noted in the preliminary evaluation and mix design phases should be identified on the roadway and the field personnel made aware of these changes (ARRA 2001). For example, the current CIR project may span more than one prior project where asphalt materials were different.

Construction Process

The process of CIR construction combines the several steps, including milling, material sizing, adding aggregates/HMA/recycling agents, mixing, and laydown. There are two methods that are typically used in the CIR process, including:

- Single unit train
- Multi-unit train

These methods are described in the paragraphs below, and largely come from ARRA, 2001.

Single Unit Process Train

The single unit train does all the steps with a single piece of construction equipment, including removing the asphalt pavement to the required depth and cross-slope, sizes the RAP, blends all additives with the RAP, and places the material back on the roadway. Traditional single unit trains do not contain the equipment to screen and crush the RAP. Single unit machines must contain a breaker bar or some other means of sizing the RAP. A schematic of a single unit full depth recycling machine is shown in Figure 13-3 and can be compared to the single unit CIR recycling train shown in figure 13-4.

A single unit CIR train may actually contain more than a single piece of equipment, but because they act in tandem, are essentially "single units". In the unit shown in Figure 13-3, the first component mills and mixes the existing pavement surface with recycling agent and deposits the recycled mix in a windrow on the roadway. A separate paving machine follows closely behind the recycling machine, picks up the windrowed material and lays it back down on the roadway in the final configuration for the pavement surface. Note that although there is a truck with the asphalt emulsion recycling agent, and a compactor, these are still considered part of the single unit.

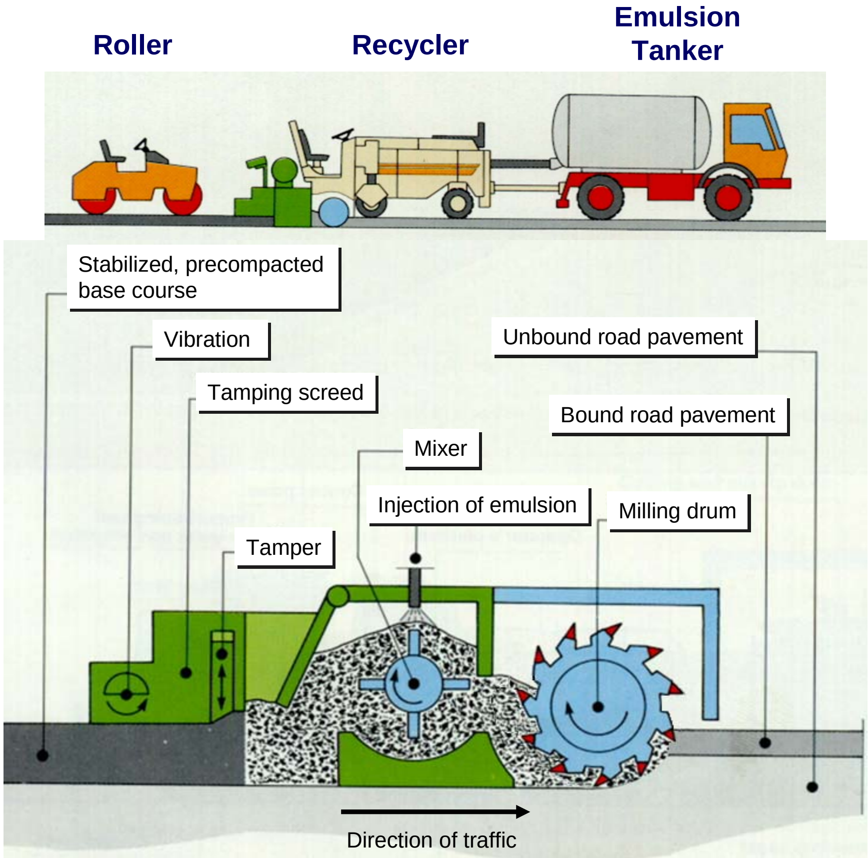

Figure 13-3 Schematic of Single Unit Full Depth Recycling (FDR) Train (Kandhal, et al 1997)

New materials such as aggregates or other dry additives such as lime may be spread on the existing roadway ahead of the unit prior to milling. The milling machine then can pulverize the existing material as well as mix all ingredients in a single operation. Two other single unit machines are shown in Figures 13-4 and 13-5.

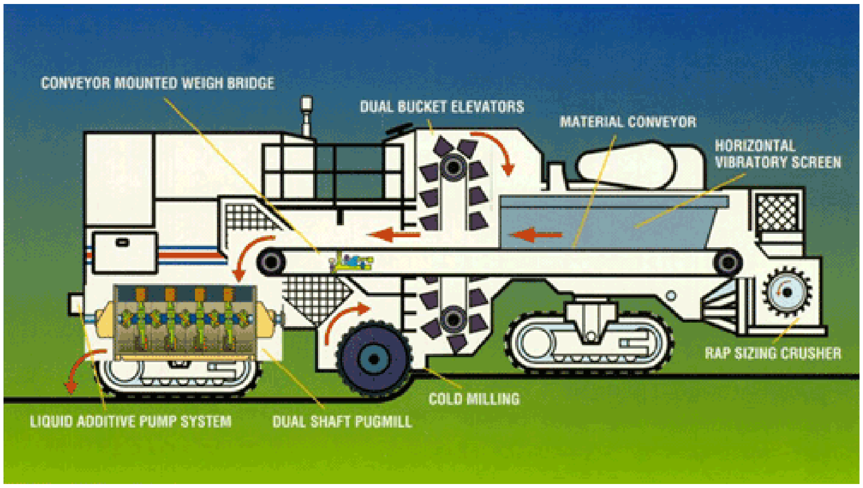

Figure 13-4 A Variation of a Single Unit CIR Train (Kandhal, et al. 1997)

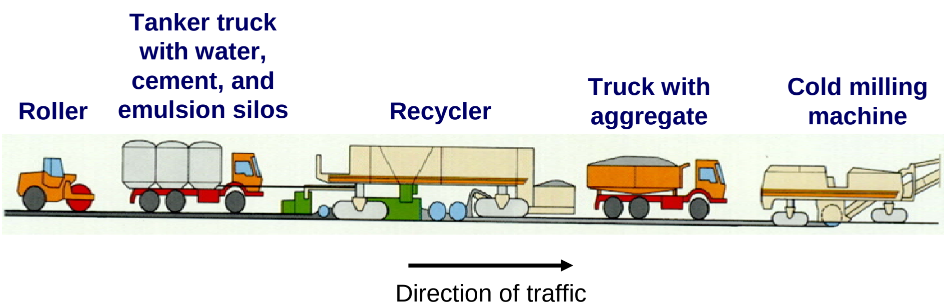

Figure 13-5 A Multi-Unit Train that Allows for Addition of Virgin Aggregate (Kandhal, et al, 1997.)

The single unit trains have the advantage of simplicity of operation and high production volume. It is also easier to operate in tight quarters such as urban streets with short turning radii due to its short configuration.

Two-Unit Train

Many CIR trains incorporate pugmill mix-pavers as an integral part of the train. The two units include a large, full-lane width milling machine and a pugmill mixer-paver. One of these units is shown in Figure 13-6. These trains are essentially large cold mix pavers with the added feature of a metered pugmill in the chassis. The milling machine removes the RAP, and the sizing of the RAP is similar to the single unit. The RAP is deposited directly into the large pugmill of the mixer-paver, and has the ability to be weighed on the feeder belt, and then the liquid recycling agent/asphalt emulsion proportioned accordingly. The completed mix then goes directly into the spreader-auger system and placed in its final form.

Advantages of the two-unit CIR system is more accurate proportioning that results in a more uniform mix, simplicity of operation, and high production capacity. It is also relatively short, and can be used effectively in urban areas and where turning space is limited.

Figure 13-6 Two-Unit CIR Train in Operation (FHWA 2003)

Multi-Unit Trains

The configuration of a multi-unit CIR train is longer than other trains, and consists of a milling machine, a trailer mounted screening and crushing unit, and a trailer mounted pugmill mixer (in many cases, the screening, crushing, and the pugmill mixer are all combined in one unit) a pick-up conveyor, and a paving machine. A sketch of a typical train is shown in Figure 13-7. The milling machine cuts the pavement to the desired depth and profile as well as cross slope shape, then deposits the RAP into a crushing and screening unit. All material is passed over the screens and oversized material is sent to the crusher, which is usually an impact type, then the crushed material is returned to the screening unit for resizing. From the screens, the RAP goes into the pugmill mixer on a conveyor weigh belt that weighs the RAP. The liquid recycling agent is added at the pugmill using a computerized metering system that is locked into the feed belt for accurate measurement and control. The recycling agent is pumped into the twin shaft pugmill for thorough blending of the agent and RAP. Experience has shown that these computerized systems have a high degree of quality control and high productivity. From the pugmill, the completed mixture is deposited into a windrow or directly into the hopper of the paver. A windrow elevator is typically used to place the mix into the paver rather than be locked to the train, providing flexibility in speed and operation of the paver. The final step for the CIR train is to place the recycled mix on the roadway.

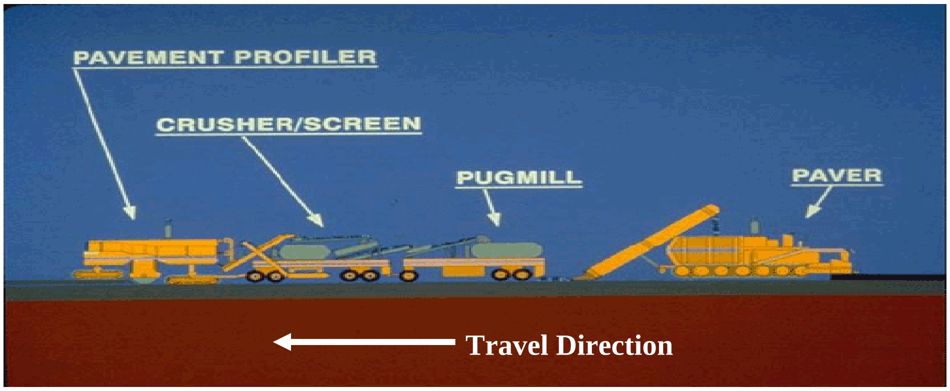

Figure 13-7 Schematic of Multi-Unit CIR Equipment Train (Kandhal, et al 1997)

The multi-unit CIR trains have been found to provide the best process control, uniformity, and production, often more than two miles per day. A disadvantage is its length and difficulty in operating in urban streets, as well as complex traffic control.

Aeration, Compaction, Curing, and Surfacing

As noted in the discussion of mix design for CIR, additional fluids are added to the mixture to promote good mixing, coating, and compaction. But this added moisture, particularly any added water and the water that is part of the asphalt emulsion must be allowed to evaporate once the pavement is in place. Aeration also improves stability after placement, so that compaction equipment is more effective. The rate of evaporation will depend on many factors, but probably the most important is the weather, with CIR being most successful when it is dry and warm. The factors that impact the rate of evaporation include the type of asphalt modifier, gradation or permeability of the aggregate, and weather factors such as temperature, wind velocity, humidity, and shade from trees. Minimizing additional fluids in the design and construction process will also speed up the aeration process, and may even allow placement with a conventional paving machine. (Kandhal, et al 1997)

CIR mixes are stiffer than HMA mixes and require additional compaction effort. Heavy pneumatic and vibratory drum steel compactors must be used to break down the mix, and even with these, it is not feasible to achieve the same densities as with HMA. The best procedure is to determine the optimum amount of total fluids early in the construction process. It is recommended that compaction commence as the asphalt emulsion begins to “break”, or turn from brown to black. The time for the mix to break will vary with the type of emulsion or recycling agent, and/or the weather, but typically the target will be from 10 minutes and up to 2 hours. It is advisable to work closely with the supplier of the emulsion in order to obtain best results on any given project. When finally compacted, the total air voids in CIR mixes are typically much higher than for HMA mixes, often in the range of 9 to 15 percent (Kandhal et al 1997 and ARRA 2001). While these voids may not be desirable for pavement performance, they do enhance the ability of the mix to dry. Further reduction in air voids is obtained in many cases by re-rolling after curing and prior to the surface application

Compaction of CIR is an important part of the construction process, because poor compaction can lead to premature failure or poor performance in terms of smoothness, load capacity, resistance to rutting and shoving, and disintegration. Typically, a combination of vibratory steel wheeled and pneumatic rollers are used to get to the final density. Breakdown rolling is usually accomplished with a steel drum roller in the static mode to seat the mix into place and provide a relatively smooth starting point, before the pneumatic compactor gets onto the mat. The heavy pneumatic roller will further seat the mix into its maximum density, but will distort the mix, especially along the edges of the mat if it has not been seated with the steel drum roller. Under the action of the heavy (25 tons) pneumatic-tired roller, the mix will continue to break down and increase density, but may leave tire marks in the surface. Roller marks can be removed by finishing compaction with a vibratory steel wheeled roller. The optimum compaction and rolling patterns should be established early on a project using a test strip, experimenting with the type of roller and number of passes to achieve maximum density (ARRA 2001).

The CIR pavement will have a high load carrying capacity because of rock-to-rock contact, but the high void content will cause premature damage such as raveling if a wearing surface is not applied when the curing process is complete. The compacted CIR pavement must be adequately cured before a wearing course is applied. The curing period is typically two days to two weeks depending on environmental condition prior to applying a wearing course, and traffic speed may be controlled during this period to reduce damage. However in many instances a fog seal is applied at the end of each recycling day to minimize raveling.

Similar to the aeration process, the curing process is the continuation of the evaporation of water and volatiles in the asphalt emulsion as well as water from the mixture. Aeration is the removal of free water that was added for compactability that can readily evaporate from the air voids. Curing is the process of the asphalt emulsion converting from the emulsified state through removal of water and other fluids. As the water in the asphalt emulsion evaporates, the dispersed asphalt particles then coalesce into a continuous asphalt film that coats the aggregate. When curing is complete, the mixture has reached its near maximum strength and it is appropriate to apply the wearing course. The initial curing period may vary from a few days up to two or more weeks, and the strength gain will continue with time, depending on factors such as:

- Temperature, both day and night
- Permeability
- Rain and/or humidity levels
- Moisture content of the recycled mix
- Level of compaction and in-place voids
- Moisture content of the subbase, and shoulders

The curing period may be dictated by the need to place the road back into service, impending poor weather, and other factors. Selection of the materials and recycling additives will play a key role in determining an acceptable or desirable curing time.

The primary purpose of the wearing course is to protect the CIR pavement, providing an umbrella to shed water off the surface and onto the shoulders and drainage system and to prevent the abrasive action of vehicle tires from degrading the surface. For roads with low traffic volumes, single or double chip seals have been shown to be effective. However, some roads may require fog seal only if the traffic is low, and curing is adequate. For higher volumes of traffic, HMA overlays have been used, typically in the range of one to two inches thick.

13.4.2 Hot In-Place Recycling Construction

In a manner similar to that for CIR, the HIR process has variations, depending on the type or extent of surface recycling desired. These methods were largely developed as innovations by contractors, and then adopted by agencies such as Caltrans, who then wrote specifications to attain the desired results. There are three processes that are currently utilized: surface recycling (also called heater-scarification), repaving, and remixing. Currently Caltrans only has a HIR specification for remixing. A future specification may be developed for repaving. There is need to improve the air quality associated with HIR, and a future specification may include this requirement. All of these methods are aimed at heating the surface of the existing HMA and then restoring the damaged or worn surface to new-like condition.

Surface Recycling (Heater Scarification)

Surface Recycling (also known as heater scarification) is the earliest form of HIR and was widely used in the 1950s, 1960s, and early 1970s. It is a simple process in which the surface of the old pavement is heated, scarified with a set of scarifying teeth, mixed with a recycling agent, then leveled and compacted (8). Scarification depths of up to 1 in were possible, but more commonly, effective scarification was limited to about ½ to ¾ in. No new aggregate or other materials were added during the process, but a new wearing course was often added later. Figure 13-8 is a schematic of a typical heater-scarifier equipment set up.

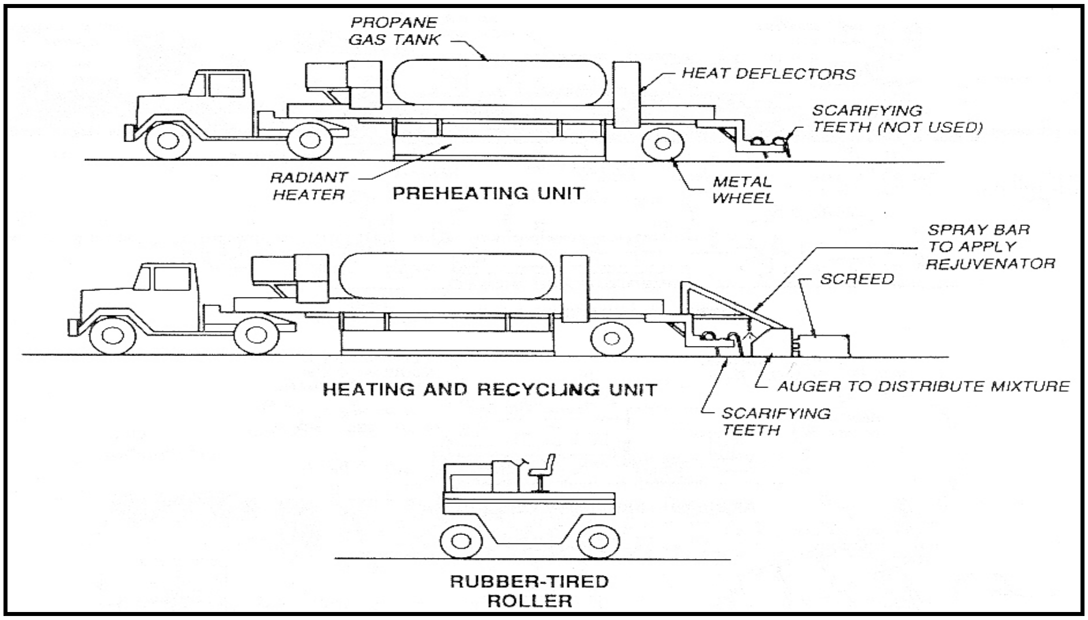

Figure 13-8 Surface Recycling Process (Heater-Scarification) (Button et al, 1994)

Early attempts at heating using direct flames were not particularly successful because it caused smoking and excessive hardening of the asphalt binder. Later methods utilized infra-red heaters fired by propane gas, and proved to be better at minimizing the problems with direct flame. One or more heater units were used in tandem to gradually raise the surface temperature of the pavement so that the scarifying teeth could scrape through the surface. Mix temperatures up to 300°F were possible when using two pre-heaters. The scarifying teeth on this type of equipment were usually spring-loaded tines that could ride over obstructions such as man-hole covers, but they had limited ability to dig very deep into the warmed pavement since the temperature decreased with depth. The combination of normal asphalt aging and additional hardening from heating typically required that a liquid recycling agent be added to soften and restore the binder properties. Blending the recycling agent into the loosened surface mix was a challenge without additional stirring and mixing. Most surfaces restored using heater scarification were overlaid with new HMA as a final wearing surface.

Repaving

Repaving is a process where the existing pavement is heated, scarified, or milled to a depth of up to 2 in, and the millings mixed with a rejuvenating agent. This recycled material is then placed as a leveling course and followed up with a HMA wearing course, forming a hot thermal bond between the existing and new layers. These two operations can be completed in a single pass using special equipment, or, using a two-pass process including a heater-scarifier and conventional paving equipment. Figure 13-9 shows an example of a single pass repaving equipment train.

Current repaving practice is to preheat the existing pavement surface to about 375 °F using infrared pre-heaters as well as heaters in the repaving unit as well. The heat-softened pavement material is then removed to a depth of about ¾ in, depending upon how efficient the heater is at penetrating and softening the asphalt. Some repaving machines utilized a milling head that allows the process to mill deeper than might be accomplished using a scarifier only. For the machines with milling capability, there is usually the option to adjust the depth and cross-section of the pavement during the operation, as well as adjust the milling head to avoid obstacles such as manhole covers.

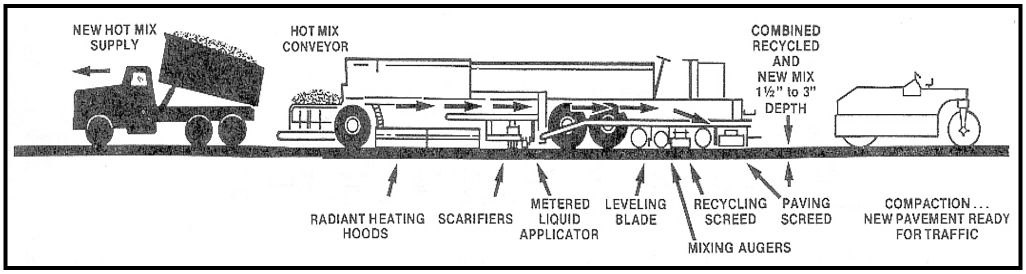

Figure 13-9 Single-Pass HIR Repaving Train (Button, et al 1994)

The amount of rejuvenation of the old asphalt pavement material is determined in the laboratory, then applied in the field, by spraying directly onto the roadway, onto the windrow, or directly into the mixing chamber. This predetermined rate of rejuvenator is set in the machine, and locked into the rate of forward progress so that a uniform mix results. Mixing of the recycling agent is usually accomplished on the roadway surface by augers that transfer milled material into a windrow, and then also auger the material into a new shape and levels the recycled mix. The new HMA material is then added and spread with a second screed directly on top of the recycled layer. The goal is to bond the new HMA layer to the recycled pavement surface, and this is readily accomplished if the recycled layer can be maintained hot (~215 °F). Weather and forward progress of the repaving process will usually affect the success to a significant degree. Depending on the design of the repaving equipment, a well-shaped and uniform lift thickness may be constructed using manual or automated controls. Repaving has been shown to be a practical method to restore and old asphalt pavement in a single pass of the equipment.

Remixing

The remixing method of HIR is used when the pavement requires additional aggregate or HMA to improve the gradation or thickness of the recycled pavement. The depth required to correct defects such as cracking is also a consideration. Heating the existing pavement up to about 230 °F (average for the material) or higher is feasible when the existing pavement is reasonably dry, the weather is warm, and the wind is minimal. Each unit in the paving train usually has a heater (propane or diesel fueled), including a heater on the remixing unit. The heaters and the remixing units are usually full lane width, and may range up to 40 ft long. Depending upon how many heater units are used, the HIR may range up to 200 ft long, and require considerable space to operate. Figure 13-10 shows one arrangement for a remixer train.

Most remixer units use rotary milling heads to remove the surface of the existing pavement rather than tines. Less power is required for warmed pavements as compared to cold milling operations. It is difficult to heat the pavement to a depth of 2 in, the usual target depth for this HIR process. Heat penetration into the existing pavement is inefficient and slow, and may overheat the surface. Some equipment manufactures have developed staged milling (two-step is most common) process where each pre-heater has a milling head and removes only a portion of the heated pavement, say 1 in. Following units will also heat and remove 1 in, until up to 3 in depth has been achieved. This staged process is gentler on the RAP, and does not break aggregate, nor take as much power where each layer is warmed sequentially, and higher mix temperatures may be attained. The heated RAP is then typically mixed with a recycling agent in a pugmill in the final remixer unit. Figures 13-10 and 13-11 are examples of this process and there are other configurations used by contractors.

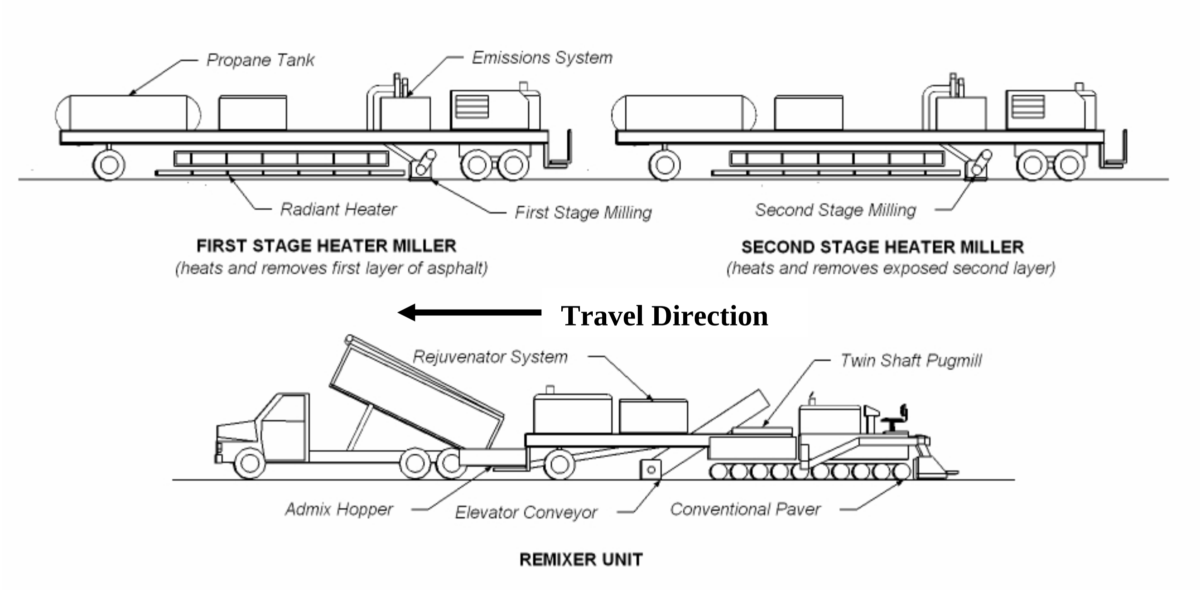

Figure 13-10 Example of a Remixing Process HIR Train (Wiley 2007)

Figure 13-11 Example of a Remixing HIR Train in Action (Wiley 2007)

The virgin HMA is usually received in the hopper of the paving machine following the remixer unit. However, some trains are set up to deposit the HMA in a windrow ahead of the remixer in order to take advantage of the added mixing, and also to increase the average temperature the recycled mix from the higher-temperature. Early systems have attempted to do all of the mixing on the pavement surface after milling, but this practice was not particularly successful. Multi-step heating and milling and stirring on the grade, coupled with a pugmill has been more effective.

Re-laying the recycled mixture has been accomplished by two different methods. The first method has the paving machine snugged up close behind the remixer unit and the recycled material drops directly into the paver hopper. In the second method, the recycled mixture is dropped into a windrow behind the remixer unit, and then picked up using a conveyor to deposit it into the paving machine, where it is laid in the same manner as new HMA, then compacted.

One of the restrictions of the remix process is that the volume of virgin HMA that can be added is limited to 20% in order to preserve grade elevations with respect to adjoining shoulders. One efficient method developed that enables increased volumes of virgin HMA to be added (up to 50%). In this process, a narrow center strip is first cold-milled from the road surface to provide space for temporarily holding the RAP just removed. Not only can increased amounts of hot virgin HMA be added to improve gradation and binder properties, but the heat transfer from these materials reduces the temperature that must be applied to the existing road surface. An example of this approach is shown in Fig. 13-12.

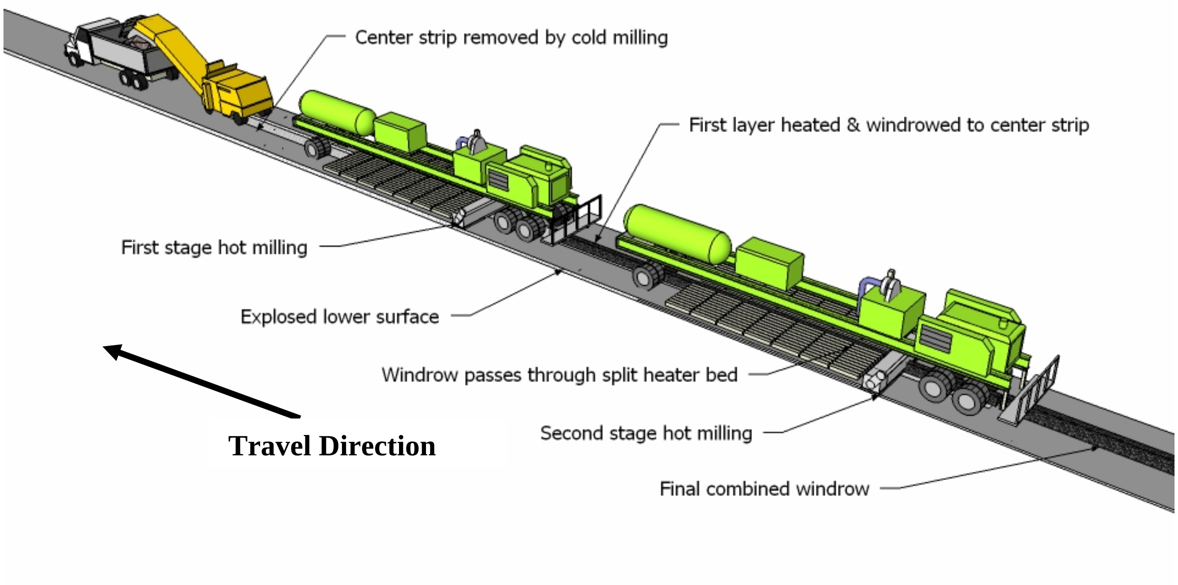

Figure 13-12 Example of Remixing HIR where the amount of virgin HMA can be increased by milling a trench to accommodate the HMA, providing additional heating. (Wiley 2007)

13.5 Quality Control

13.5.1 Quality Control of CIR

Quality control is essential to any successful CIR project, and good practice must be followed regardless of the specifications. The need for consistency and uniformity in all aspects of a project is constant in order to achieve the anticipated results of good quality, strength, and durability. Observation and experience have shown that several areas of poor practice are most often responsible for poor projects (Grogg, et al 2001).

- Poor control of added asphalt binder or recycling agent. Inconsistent amount of recycling agent will result in too soft of a mix when too much is added and too hard when insufficient agent is added. Inadequate bonding of the binder and aggregate may also occur when insufficient agent is added
- Inconsistent mixing of all materials that may be caused by factors such as too fast of forward progress
- Poor compaction and resulting inadequate density
- Placement of a tight seal or dense-graded wearing course too soon after construction. Good weather is required to properly dry and cure the CIR mix before it is covered with an overlay or seal coat. If the surface is placed too soon, water can be trapped in the pavement, leading to

accelerated stripping and rutting due to lack of strength. Even under good conditions, this process may take up to two weeks to get the moisture content down to a desirable level of less than .5 percent

- Depth of recycling. Surface recycling is intended to remove only a partial depth of HMA, leaving a layer for bonding with the recycled mix. If the depth of milling is too great, there will be a loss of bonding if the milling cuts through the HMA and into the unbound base course, but more importantly, there will result variable mix properties
- Wet weather. If there is significant rain following CIR construction, and before curing has concluded, the asphalt emulsion may wash off the aggregate with serious loss of bonding and ultimately project failure

Variability in the HMA along the length of a roadway is inevitable, ranging from patches to change in design or thickness from previous projects or contracts. A good QC plan should be able to accommodate these variables encountered in CIR:

- Gradation of aggregate, binder content, and moisture content of RAP
- Amount of recycling agent to be added
- Extent of patching, and other anomalies in the roadway
- Nature and amount of distress such as cracking or other deterioration
- Final compacted density of recycled pavement

A good QC plan should also be able to identify the target levels of variability and provide guidance on how to address the variables when encountered during construction. The plan should be flexible and nimble enough to allow for changes "on the fly" as they are encountered. In order to meet the Caltrans specifications and for quality control, there are specific actions that are required.

A given project should be divided into lots of 3000 sq yd, and the CIR operations should include the following factors:

1. Measure the actual recycle depth at each end of the milling drum every 300 ft along the roadway.
2. Measure the amount of emulsified recycling agent used to an accuracy of 0.5 % of the dry weight of recycled material shown in the JMF, by recording the amount used for each lot and comparing to that computed for the dry mass of processed RAP.
3. Measure the in-place density of the compacted recycled material using a nuclear density gauge when possible.
4. Sample the recycled material behind the screening equipment and test for gradation. For every third sample taken, determine the wet field gradation for sieves from 25 to 4.74 mm, and compare to the design, then adjust the emulsified recycling agent accordingly. Note that the fine fraction passing the 4.74 mm sieve is the most important for controlling the binder content.
5. The contractor is required to provide specific information for each lot as part of the Contractor Quality Control program of Caltrans, including:
   - Length, width, and depth of cut, and calculated mass of RAP processed.
   - Amount of emulsified recycling agent used, and compared to the amount of RAP processed.
   - Amount of any dry additives used and compared to the amount of RAP processed.
   - Maximum particle size in the RAP, prior to adding emulsified recycling agent.
   - Nuclear gage readings of in-place density at random locations.

- Plot the compaction rolling (passes) vs. density, containing the time and location of the test strip, which is used for relative compaction comparisons.
- Record of the ambient and compacted recycled surface temperatures.

13.5.2 Quality Control of HIR

The requirements for quality control of HIR are similar to those for conventional HMA. However, due to the wide variation in HIR construction equipment and methods, any generic QC plan will need to be adapted to accommodate local conditions and specifications, such as those of Caltrans. As an example, a QC plan for a project using the heater scarifier method will have only one component, while a quality plan for a remixing or repaving project will have two components: one for the HIR portion of the project, and one for the admix or HMA added to the integral overlay portion of the pavement. In general, experience has shown that the following areas need to be addressed in the QC plan for HIR projects (ARRA 2001).

- Heating of the existing HMA pavement
- Treatment depth
- Addition of recycling agent and admixture
- Placement of recycled mix
- Compaction of recycled mix

These five areas of concern regarding QC are discussed in the following sections.

Heating of the Existing HMA Pavement

Heating of in-place HMA is probably one of the greatest challenges. Getting heat into a dense layer of pavement is difficult when one must balance the rate of heating and softening with the rate of production. Oxidation or age hardening of the asphalt binder in the existing HMA needs to be minimized while at the same time ensuring that:

- Any excess moisture has been removed. Many older asphalt pavements have water trapped in the voids and considerable energy is required to evaporate the water before the mixture can be heated above the heat of water vaporization temperature (212 °F)
- The asphalt pavement is softened sufficiently so that it can be scarified and/or milled without excessive aggregate breakage. Although some equipment is designed with lower powered milling heads, they may not be able to mill to the desired depth. Other equipment is designed with more powerful milling heads that will essentially cold mill to the required depth (2 in, for example), and then use the heating units to heat the loosened HMA on the roadway surface, being more efficient in heat transfer. Still others will heat and remove the HMA in stages, heating and milling, with each pass of a heater/miller
- The recycling agent and admix can be thoroughly mixed in
- An adequate temperature has been attained and maintained for compaction of the final mix

Because of the variable nature of the HIR process regarding forward speed, materials composition, and need for recycling agent, it is difficult to determine the uniformity and compliance with specifications on a continuous basis. Although overheating and aging the asphalt can be measured in the laboratory on samples collected from the jobsite, it is not practicable to do so “on the fly”. There are really no rapid tests for this purpose. However, there are a few observations and indicators that may be useful to help achieve the desired results:

- Emissions are good indicators as to what is happening during heating. Those that are white and dissipate quickly are from the vaporization of water in the HMA
- Blue or black smoke emissions indicates that some overheating or combustion is occurring, usually the more volatile hydrocarbons in the binder. Corrective action is required immediately, including one or more of the following: increasing forward speed, decreasing the intensity of applied heat by turning the burners down, or raising them off the pavement surface
- Observation of scorched or charred pavement surface
- Excessive temperature variations across the mat

Heating of the pavement surface should be as uniform as possible in both the longitudinal and transverse directions. This helps to ensure that the temperature, treatment depth, and compaction is uniform. Monitoring the temperature during the HIR process is necessary on a constant basis, in order to optimize uniformity. Some equipment have on-board thermocouples or thermometers that measure temperature, reliability and durability of these instruments is often in question. More useful are the hand held infrared heat guns that that can be used at any point in the HIR process, allowing the operator better control. But the heat gun measures temperature only at the surface, so material must be moved aside in order to get a better assessment of overall temperature.

Temperatures should be checked and monitored continually at several locations within the HIR process. The locations to monitor and for making immediate adjustments will depend on the equipment configuration, but should include at least the following:

- After each pre-heating unit
- Prior to final heating
- Prior to final mixing
- Immediately behind the paver screed

Treatment Depth

Uniformity of treatment depth is desirable and critical to the consistency of the HIR process. A number of methods have been used to determine HIR treatment depth, with varying degrees of success and include:

- Precision level surveys before and after scarification
- Measurement at the outside edges of the pavement after scarification and/or milling
- Marking out a known area, removing and weighing the loose scarified material, then calculating the depth based on the final density
- Using a probe or dipstick to measure the depth of uncompacted mix behind the paver screed
- Measurements from compacted core samples

Whichever method is use, a number of measurements must be made to represent an average depth. There are exceptions to achieving a uniform depth, for example when the HIR process is used to adjust the cross section of the roadway. The crown may need to be increased or decreased, or the curb may be in need of adjustment as well. In these instances, longitudinal uniformity is desirable, but laterally, the cross slope may be changed as part of the design.

Addition of Recycling Agent and Admixture

The addition of recycling agent is a key part of the QC operation and needs to be linked to the forward progress and treatment depth of the recycling unit. Modern recycling trains have incorporated microprocessors and/or positive displacement pumps to add the liquid recycling agent at the design rate. The set rate will depend on the depth or recycling, and can be set at the beginning of a project, and then adjusted and fine tuned over the first portion of the project. This calibration process would best be done in a test strip prior to beginning a project, but with a long recycling train, this is impractical because of the space required if it is off site. The agent can be linked to the forward speed of the HIR train, but the depth of treatment needs to be constant since there is no sensor to measure depth; the process needs to be monitored manually on a constant basis for uniformity in final results. The accuracy and variations of the addition of agent will have an effect on at least the following factors:

- Asphalt binder content of the recycled mix, including the recycling agent
- Rheology of the binder
- Compaction properties and uniformity
- Void content of the recycled mix
- Strength and durability of the recycled mix

The tolerance for the variation in added recycling agent is typically ±5% of the agent added as specified. The measurement of this rate can be made using a microprocessor or flow meter that accumulates the amount added over time/distance. A further check on application rate can be made by checking the tank manually on a regular basis.

When new HMA, aggregate, or other admixture is added to the RAP, a similar linking of forward progress to the rate of added material is also required. The equipment that can handle this admix material usually also can measure the rate using a microprocessor on a calibrated weigh belt. Tolerance of the rate of application may typically be in range of ±5 % of dry weight of recycled mix. A further check on the rate of admixture can be measured by matching truck weigh tickets to forward progress of the train and calculating the resulting rate of application. The application rates should be checked regularly, such as every hour, in order to keep tabs of the uniformity.

Placement and Compaction of Recycled Mix

Once the recycled mix leaves the HIR recycling and mixing process, it is placed using the same techniques as for new HMA. Some HIR trains have a screed on the last unit, usually with a pug mill, and the mix goes directly onto the roadway or into a hopper where it is spread in the normal manner. Other trains may be followed by conventional paving machines that have their own screeds. When admix material, especially HMA, there is opportunity to reshape the cross section of the roadway to the intended final position. Even though the hot milling of the recycling units attempt to shape the pavement, variations still occur and this final laydown operation provides the opportunity to finish the pavement as designed.

Compaction is accomplished using conventional steel wheeled and pneumatic tired rollers in a manner similar to virgin HMA. A test strip is required to determine the optimum roller combination and passes to achieve the necessary density. With HIR mixes, especially when full depth of 2 in is used, it may take more compactive effort to achieve the desired final density because it is also more difficult to reach and maintain adequate temperature required for compaction. Consequently, a combination of heavy vibratory rollers and pneumatic rollers may be required. Although the temperature and mix stiffness are crucial, an additional factor is the gradation of the aggregate. A combination of the aggregate gradation in the milled RAP (with some aggregate breakage that may not have been observed in laboratory samples) and aggregate in the new HMA must meet the specified gradation for the final recycled mix. It is highly likely that adjustments and fine tuning of the JMF for the HMA mix will be necessary after results from the test strip and early construction behind the recycling train are evaluated. More frequent sampling and testing early in the project is generally necessary to establish the correct proportioning. Density is usually monitored using a nuclear gauge that has been calibrated to the field core samples.

Specific requirements by Caltrans for the Quality Control of HIR projects for the remix method include:

- Measurement of the actual recycle depth on each side of the milling or scarifying machine at least every 100 m along the roadway length
- Following compaction, but prior to opening the roadway to traffic, the relative compacted density must be at least 92 % of theoretical maximum density

Each project must be divided into lots of 3,000 sq m, and the following information provided for each lot:

- Length, width, and depth of cut, and the calculated mass of RAP processed
- Amount of recycling agent used, compared to the amount of RAP processed, in percent
- Asphalt binder content of the in-place HIR mixture based on California Test 382
- Amount of HMA, aggregate gradation in the virgin HMA, and the amount (%) of asphalt binder in the HMA
- In-place density and relative compaction at three locations, using California Test 375, except in Part 5, substitute maximum theoretical density (Rice Method), using California Test 309, test for maximum density (TMD)
- On a daily basis, sample the HIR mixture at a selected location, split the sample, using one split sample for measuring the maximum theoretical density (Rice Method) based on California Test 309; the second split sample is retained by the engineer
- Every other day, sample the HIR mixture from the mat prior to compaction and test for Hveem stability using California Test 366 for information purposes

13.6 TROUBLESHOOTING IN THE FIELD

There is ample opportunity for achieving excellent results when constructing CIR and HIR projects. However, one must be diligent and follow a well thought out QC plan in order reach the intended final goal. Conditions may change, and then the uniformity and balance of the various components of the process may need to be adjusted. For example, a change in the weather, materials encountered, or construction equipment calibration may contribute to the need for continuous fine tuning of the construction process. Because of these factors, it is important to be able to quickly pinpoint what is wrong and to find a solution. A guide to this process of troubleshooting is provided in Tables 13-1 and 13-2, which identify some of the more common problems that the contractor or QC inspector may encounter during a project.

13.6.1 Troubleshooting Guide for Cold-In-Place Recycling

Table 13-1 Troubleshooting guidelines for partial-depth cold in-place recycling (CIR) operations. (ARRA 2001)

Problem	Typical Cause(s)	Typical Solution(s)
Flushing of asphalt at surface after laydown and before compaction	Excessive mix water	Reduce the target water content in the mix
	Excessive asphalt emulsion or recycling additive	Reduce asphalt content
	Inadequate mixing of materials	Hold the material in the mixing chamber longer Increase the blade processing to insure proper distribution of the recycling agent
Mix segregation	Inadequate asphalt coating of the aggregate due to inadequate water content in the mix	Increasing the water content in the mix or use softer grade asphalt in the emulsion
	Variation of existing materials	Add new graded base and redo mix design
Mat raveling after compaction	Too little asphalt emulsion (or recycling additive) in the mix	Increase the amount of asphalt emulsion or emulsified recycling additive in the mix Reprocess the problem areas
Shiny black mat after compaction	Too much asphalt emulsion or emulsified recycling additive in the mix	Reduce the amount of asphalt emulsion or emulsified recycling additive in the mix Reprocess the mix adding virgin material
Poorly graded RAP behind recycling unit and change in existing pavement	Variation in depth of existing materials	Add new graded base to keep constant depth and redo mix design
	Teeth on the milling machine are worn or broken	Change the teeth
	Speed of the operation is too fast	Slow the operation down
Variable depth	Poor control of grade	Repair (or use improved) grade controls
Varying dry and wet spots in RAP	Poor water and/or recycling agent control. Varying existing pavement and gradation changes	Check and calibrate pulverizing and mixing operations
Appearance of fines in RAP material	Milling into subsurface layers	Provide better control of depth. Confirm thickness of existing HMA layer
	Speed of the milling machine too slow	Increase speed of operation
Oversize RAP in the mix	Screen or breaker bar not functioning properly	Repair the screen or breaker bar
New mat stays spongy and/or will not densify	Steel wheel rollers may be sealing the top and causing moisture retention	Use a heavy pneumatic tire roller for breakdown and compaction rolling
	Excess moisture in mix	Confirm liquid contents in emulsion Revise target moisture in mix as necessary

13.6.2 Troubleshooting Guide for Hot-in-place Recycling

Table 13-2 Troubleshooting guidelines for hot in-place recycling (HIR) operations. (ARRA 2001)

Problem	Typical Cause(s)	Typical Solution(s)
Blue or black smoke emanating from the heating units or exhaust	Combustion and removal of hydrocarbons from the asphalt binder	Reduce the intensity of the heating units, raise the heating units from the pavement surface, or increase the forward speed of the heating units or employ additional heating units at a faster speed to allow heat to penetrate. Remove and replace the damaged areas with virgin mix.
Wet appearance of surface after recycling	Excess asphalt binder or recycling agent in mix	Check application rates of asphalt binder and recycling agent
Poor gradation of RAP	Speed of the operation too fast or too slow. Changes in existing pavement	Alter speed of the operation to minimize segregation and add heating units as needed to assure penetration depth is achieved
Variable or insufficient milling depth	Speed of the operation not correlated to the existing surface and ambient temperatures	Alter speed of the operation to match existing temperatures and add heating units as necessary to achieve proper depths
Inadequate density	Inadequate number of rollers, weight, passes, etc.	Check rollers for adequate weight, tire pressure, as well as rolling pattern
	Rolling when mix is too cold	Slow down the operation to allow the rollers to keep pace (or add additional rollers)
	Segregation	Slow down the speed of the operation to allow more time for proper mixing
Spot areas of flash fires or blue smoke	Excessive crack sealant and/or patches	Remove crack sealant prior to HIR operation
	Polymerized small maintenance patch areas	Remove patching material and, if necessary, replace with virgin HMA mix
Cannot achieve required depths of removal without producing blue smoke	Existing asphalt binder may have age hardened to a degree heat will not penetrate to the required depth without burning asphalt	Poor project for this construction method and may need to be canceled or specification requirements altered
Wet spots on the finished mat	Variation of the added asphalt binder or rejuvenating agent	Check and recalibrate the asphalt pump
	Excessive crack sealant	Remove crack sealant prior to operation
	Contamination of the existing surface	Remove contaminated areas and replace with HMA prior to processing
Dry spots in the finished mat	Variability of the added asphalt or rejuvenating agent	Check and recalibrate the asphalt pump

13.7 REFERENCES

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