Cold-in-Place Recycling

A. General

Cold-in-place recycling (CIR) is the process of recycling an asphalt pavement in-place with a train of equipment that can range from a single unit to a multi-unit train. In CIR, the existing asphalt pavement is cold milled to produce recycled asphalt pavement (RAP), which is then further processed, placed, and compacted in one continuous operation on the roadway.

The advantages of CIR over other rehabilitation/reconstruction techniques include:
- Conservation of resources
- Energy conservation compared to other rehabilitation/reconstruction processes
- Surface irregularities are corrected
- A portion of existing cracks are removed and reflective cracks mitigated
- Rutting, potholes, and raveling are eliminated
- Base and subgrades are not disturbed
- Pavement cross-slope and profile are improved
- Reduced traffic disruptions and user inconvenience compared to other rehabilitation/reconstruction techniques
- Reduced or no edge drop-offs
- Cost savings compared to other rehabilitation/reconstruction options

B. Pavement Assessment

When determining whether the appropriate rehabilitation method is a CIR project the following information should be evaluated:
- Age of the pavement
- Thickness of the existing pavement
- Delamination or evidence of stripped aggregates
- Grade and type of existing binder
- Gradation of existing aggregate
- Presence of any fabric or other geosynthetic interlayers
- Past pavement condition surveys
- Subbase/subgrade support quality
- Utility interference

Age of the existing pavement is a good indicator of the stiffness of the existing binder and the expected hardness during cold planning. It is also an indicator of the quality of the underlying support structure.

The thickness of the existing pavement affects treatment depth. Generally CIR projects involve depths of 3 to 4 inches with some as thin as 2 inches and some up to 5 inches provided good compaction can be accomplished. Treatment depths should be a minimum of three times the maximum size of the aggregate to aid compaction. CIR treatment depths should extend through delaminated or poorly bonded lifts to prevent those sections from being loosened and removed during the cold planning process thus creating uneven treatment depths.

Knowledge of the existing binder grades affects the mix design for the CIR product. Soft binders or binders containing solvents tend to be less stable, which may signal the need for additives such as cement, lime, or new aggregate. Harder binders may call for additional recycling agents since less activation of the existing binder occurs. Specialty mixtures such as open-graded drainage layers, open-graded friction courses, and stone matrix asphalt will affect the mix design and construction techniques.

If fabric or other geosynthetic interlayers are present, the recycled depth must either extend below the interlayer so that it is removed, or be a minimum of 1 inch above it to prevent tearing of the fabric and delamination of the pavement above the fabric.

In addition to record information, a field inspection is needed to determine the condition of the existing pavement. The current type, severity, and frequency of pavement distress should be documented. Pavements that have structurally sound bases but surface distresses, such as cracking, rutting, and raveling are prime candidates for CIR. The CIR process can be effective in mitigating cracking if the new layer removes about 70% of the depth of the cracks

Two elements of structural capacity need to be evaluated. The first is what pavement thickness should be developed to address the needs of the anticipated traffic mix over the life of the rehabilitation project. Generally, the new CIR layer has structural coefficients of 0.30 to 0.35 per inch. The actual structural coefficient is based on the amount and type of recycling agents and if additives are used. If the traffic mix calls for additional pavement, an asphalt or concrete overlay can be added to address the structural needs.

The second structural element relates to the ability of the remaining pavement structure to support the recycling equipment during the construction process. Pavements with extensive base failures are not good candidates for CIR. The assessment of the load carrying capacity of the remaining pavement and underlying subbase and subgrade becomes more important for thinner sections. Equipment used for CIR is generally heavy and without sufficient structure; the equipment can punch through the remaining material and into the subgrade.

Three means of determining the strength of the remaining pavement include ground penetrating radar (GPR), dynamic cone penetrometer (DCP), and falling weight deflectometer (FWD). It is important to undertake this testing at the same time of year when moisture conditions in the remaining pavement base, subbase, and subgrade are similar to those at the anticipated time of construction.

Field samples from the existing pavement should be collected to obtain representative material throughout the project area. The gradation of the RAP and properties of the mineral aggregate will affect the amounts of recycling agent, additives, and on final mix performance.

The final assessment includes accessibility for the equipment, especially in urban areas. Although the exact equipment to be used by the successful bidder is not known, an evaluation using typical equipment should be made. Such things as small radii, T-intersections, bridges, overhanging vegetation, and many surface utility structures will influence whether CIR is the appropriate rehabilitation technique to apply. Small cold planers may be needed to facilitate the recycling of the entire roadway.

The presence, frequency, and elevation of utility structures needs to be evaluated. Manholes, valves and other structures should be lowered to a point a minimum of 2 inches below the CIR treatment depth; generally involving removal of the casting. A steel plate should then be installed over the manholes. After the CIR treatment and placement of any overlay, the manholes can be adjusted to match the surface elevations. Special treatment of utility structures that cannot be lowered may involve milling the material around the structure with smaller equipment.

C. Mix Design

The mix design is a laboratory procedure that establishes the job mix formula (JMF) to meet the project requirements for long-term service life of the recycled pavement. Mix design procedures that use Superpave principles are the most widely used. The procedures use either Superpave Gyratory Compactor or 75-blow Marshall Compaction. Mixture evaluations should address initial and cured strength, resistance to moisture-induced damage, raveling resistance, and resistance to thermal cracking.

The mix design should include the following steps:

- Obtain samples from the existing pavement
- Determine binder content and gradation of the extracted aggregate
- Crush the materials and determine gradation
- Select type and grade of bituminous recycling agent
- Select type and grade of recycling additive, if required
- Prepare and test specimens
- Establish job mix formula

The JMF should specify the type and grade of bituminous recycling agent, optimum recycling agent content, mix water content, any additive type and quantity, if used, and laboratory compacted maximum density at the optimum moisture content.

D. Recycling Agents and Additives

1. **Recycling Agents:** The correct selection of the type and grade of recycling agent is critical for proper performance of the CIR project. The most common types of recycling agents are emulsified asphalts and foamed asphalts.

   Emulsified asphalt consists of an asphalt binder, water, and an emulsifier. They can be formulated with ingredients to enhance specific mixture properties, to aid production and/ or constructability. Ingredients added can include solvents, cutters, rejuvenating agents, accelerants, retarders, water reducers, polymers, and peptizers. The chemistry of the emulsified asphalt and the reclaimed materials (RAP, granular materials, and water) has a major influence on the stability and breaking-time of the emulsified asphalt. Thus, it is important to confirm the compatibility of the emulsified asphalt with the remaining materials in the mix design process. Emulsified asphalt content typically ranges from 2% to 4% by dry weight of RAP.

   Foamed asphalt is a mixture of air, water, and hot asphalt. It occurs when a small amount of cold water is introduced into hot asphalt binder inside an expansion chamber. The water causes the asphalt binder to expand rapidly into millions of bubbles resulting in a foam. The foaming occurs as the water changes states from a liquid to a vapor and expands from 8 to 15 times its original volume. In the foam state, the asphalt binder's viscosity is greatly reduced and its surface area is greatly increased enabling it to be readily dispersed throughout the recycled materials. Foamed asphalt content typically ranges from 1.5% to 3% by dry weight of RAP.

2. **Recycling Additives:** Chemical additives are used with recycling agents to improve early strength gain, increase rutting resistance, and improve the moisture resistance of CIR mixes. Chemical additives such as cement or lime have been successfully used. Cement can be added in dry or slurry form. Cement contents should be kept low to prevent shrinkage cracking. The typical cement content should be 0.25% to 1.0% with a minimum ratio of asphalt residue to cement at 3 to 1.

   Quicklime or hydrated lime is usually added in slurry form, although hydrated lime can be added in dry form. Lime is typically added at 1.0 to 1.5% by dry weight of RAP.

E. Construction

Prior to initiation of recycling work, the existing roadway should be prepared by removing any excess dirt, mud, vegetation, standing water, combustible materials, oils, raised roadway markings, and other objectionable materials by sweeping, blading, or other approved methods. Paint stripes are typically just recycled into the material.

Traffic loop wires, rubberized crack fill materials, thermoplastic marking materials, and concrete patches should be removed. Utilities should be lowered to minimize stopping of the CIR train.

Depending on the RAP gradation, bulking of the material can be 10% to 15%. If the roadway has vertical constraints, such as meeting the existing curb and gutter elevations, and will involve additional surface thickness, it may be necessary to pre-mill a wedge at the curb or remove and haul from the site material milled across the entire surface width.

Once construction begins, the recycling agent should be metered by weight of RAP using a meter calibrated to within 0.5% of the specified rate. Complete coating of the RAP with emulsified asphalt is not necessary at the time of mixing. Further coating takes place during spreading and compaction.

If foamed asphalt is used, the CIR equipment must contain a heating system capable of maintaining the temperature of the asphalt flow components in order to maintain the expansion ratio. The binder injection system should contain two independent pumping systems and spray bars to apply the foamed asphalt separately from the water needed for compaction.

CIR is a variable process. The JMF provides a starting point but changes in gradation of RAP can occur, resulting in workability impacts. The appearance of the mixture after initial compaction can indicate if adjustments are necessary. Adjustments to mix water, recycling agents, and additive contents may be necessary. These changes should only be made by experienced personnel.

Compaction of CIR mixtures requires more energy than hot or warm mix asphalt. This is due to the high internal friction developed between mix particles, the higher viscosity of the binder due to aging, and cold compaction temperatures. Typically two or three rollers are used with at least one pneumatic roller weighing 22 to 25 tons and at least one double drum vibratory roller weighing 10 to 12 tons. Main compaction rollers should have a drum width of at least 5.5 feet and have working water spray bars to prevent material pickup. When foamed asphalt is used, the compaction commences immediately after placement. Emulsified asphalt mixtures should be compacted as the mixture begins to break, turning from brown to black.

To determine optimum compaction operations, a control strip between 500 and 1,000 feet long should be established. Many contractors begin breakdown rolling with one or two passes of a static drum roller. Pneumatic rollers and vibratory rollers follow up and then the finish rolling is completed with the static double drum roller. The rolling pattern established on the test strip should compact the mixture between 95% and 105% of the target density. The final compacted surface should be free of ruts, bumps, indentations, and segregation of aggregates while conforming to the designed profile and cross-section.

Minimum temperatures for construction are typically set at 55° F. Construction should not proceed if rainy weather is forecasted.

The CIR mixture must adequately cure before secondary compaction is completed, if needed, or the surface course is placed. Curing periods can be as short as a few hours or as long as several weeks depending on temperature, rainfall, humidity levels, type of recycling additive, if used, and which recycling agent was used. The most common curing period is 2 to 3 days.

A light fog seal may be required to prevent raveling of the CIR surface prior to placing the surface course. The fog seal should be composed of emulsified asphalt diluted up to 60% by volume with water. Typical application rates are 0.05 to 0.12 gallons per square yard. If a sand blotter is needed, it should be applied at 2 to 3 pounds per square yard.

If the recycling agent is emulsified asphalt, secondary compaction may be necessary after curing to remove minor consolidation in the wheel path caused by traffic. Secondary compaction is best completed on warmer days when the pavement temperature is above 80° F.

Due the high void content, a surface course is required to be placed over the CIR mixture to protect the mixture from moisture intrusion. For low traffic roadways, seal coats, slurry seals, and microsurfacing can be used. For higher traffic facilities, overlays of either concrete or asphalt are typically used. Prior to placement of any surface treatment, the surface should be cleaned with a power broom or sweeper to remove all loose materials. If the overlay uses asphalt, a tack coat of emulsified asphalt should be applied to provide for good bond. If an unbonded concrete overlay is used an asphalt or geosynthetic fabric interlayer must be used.

F. References

Asphalt Recycling and Reclaiming Association (ARRA). *Basic Asphalt Recycling Manual.* FHWA. Second Edition, 2015.