TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures, and other tools for use in asphalt pavement materials selection, mixture design, testing, construction, and quality control.

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Overview of Project Selection Guidelines for Cold In-place and Cold Central Plant Pavement Recycling

This Technical Brief provides project selection guidelines for the cold recycling techniques of cold in-place and cold central plant recycling. The Tech Brief intends to aid the user in properly selecting candidate projects for using cold pavement recycling. Significant improvements in cold recycling technologies have been made since the 2000s, including improvements in engineering, construction equipment, and test methods, together with improved mix designs, resulting in improved reliability of performance of the final product.

Introduction

Various in-place recycling techniques have been used to rehabilitate and maintain pavements in the United States since the 1930s. Two events of the 1970s rekindled interest in asphalt recycling: the petroleum crisis and the development of large-scale cold planing equipment with easily adjustable milling teeth.

In recent years, the economics and supply of petroleum and high quality natural aggregates have increased the need for cost-effective alternatives to virgin paving materials. Two in-place recycling alternatives include cold in-place recycling (CIR) and cold central plant recycling (CCPR). These methods provide owner agencies with cost effective and sustainable methods to repair their aging asphalt pavements. When applying the **right treatment** to the **right road** at the **right time**, and when properly designed, specified and constructed, these methods can result in cost savings of 30 to 50 percent compared to conventional asphalt operations, thus allowing for more miles of improved roadways from the associated cost savings. In addition, CIR and CCPR have been shown to accelerate project delivery and mitigate construction traffic congestion while including improvements in the overall sustainability of operations.

In spite of economically and environmentally effective technologies being available for decades, many owner agencies have not used these cold recycling techniques. A lack of information on project selection is often stated as the reason. This Tech Brief contains information to help identify the right treatment to the right road at the right time.

To encourage the use of recycling, FHWA published its *Recycled Materials Policy* in 2006 (revised 2015). The policy states:

- Recycling and reuse can offer engineering, economic, and environmental benefits (see figure 1).
- Recycled materials should get first consideration in materials selection.
- Determination of the use of recycled materials should include an initial review of engineering and environmental suitability.
- An assessment of economic benefits should follow in the selection process.
- Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications.

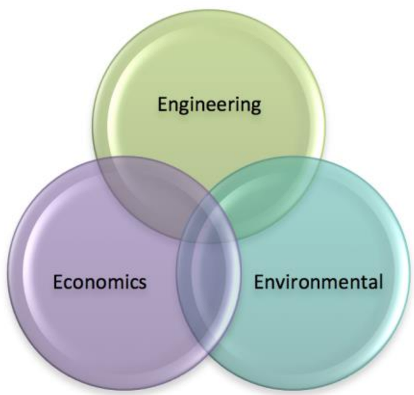

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Figure 1. The three key benefits of recycled/reused materials.

Compared with other rehabilitation techniques such as asphalt overlays (mill and fill) and reconstruction, CIR and CCPR have the following benefits:

- Cost savings
- Reuse and conservation of non-renewable natural resources
- Energy conservation
- Reduction in user delays during construction
- Shorter construction periods (depending of the selected project)
- No disturbance of subgrade soils unless specifically planned
- Improved pavement physical properties by modification of existing aggregate gradation and/or asphalt binder properties
- Preservation of existing roadway geometry and clearances or corrections to pavement profile and cross-slope
- Mitigation or elimination of pavement surface distresses
- Improvement in roadway performance and increase in the structural capacity of the existing pavement structure.

Background

Cold recycling (CR) consists of reclaiming of the existing asphalt pavement and includes cold planing (CP), cold in-place recycling (CIR), and cold central plant recycling (CCPR).

Cold Planing (CP)

Commonly referred to as milling, CP is the construction process that removes portions of the asphalt pavement surface to the depth needed for the operations. CP is typically used before the placement of new materials and will remove surface defects such as raveling, bleeding, shoulder drop-offs, rutting corrugations, and shoving, as well as correction of cross slope and operations to adjust to curb reveals. The materials removed from the existing pavement are called reclaimed asphalt pavement (RAP) and are used by State and local agencies across the country. CP is an integral element of CIR and CCPR.

Cold In-place Recycling (CIR)

CIR is a process in which a portion of the asphalt pavement layers are pulverized, mixed with a recycling agent and repaved in place. CIR occurs within the roadway and uses 100 percent of the RAP generated during the process. Typical treatment depths are 3 to 4 inches (75 to 100 millimeters).

The CIR process commonly uses various recycling agent tankers, CP machines, crushing/screening or sizing units, mixers, pavers, and double drum vibratory and heavy pneumatic rollers. The CIR process can be a single-unit, two-unit or multi-unit CIR train depending on the project's scope. The most common are single- and multi-unit trains, as shown in figure 2. CIR processes can differ in how RAP is removed and sized, the type of recycling agents and additives used, and how the mixture is mixed and placed. Compaction of the mixture is the same for all CIR processes.

Increased depths are possible with two-layer systems that incorporate CCPR processes. Bituminous recycling agents are used and consist of foamed asphalt or emulsified asphalt. Additives such as cement or lime may be used in addition to the recycling agent to improve early strength gain and resistance to moisture induced damage. New aggregate may be added to improve the recycled mixture properties.

Courtesy ARRA

Figure 2. Single and multi-unit CIR trains.

Cold Central Plant Recycling (CCPR)

CCPR is similar to CIR, but the recycling operation occurs at a mobile or central plant location. The asphalt materials are milled, processed, and then repaved using traditional practices. CCPR is used as a base layer in pavement rehabilitation on the same or different projects. Typical layer thickness ranges from 3 to 6 inches (75 to 150 millimeters); however, multiple lifts may be placed. Given that the process controls for CIR and CCPR are expected to be very similar, these two are typically treated similarly in terms of specifications.

Figure 3 shows two CCPR processes in which the asphalt recycling takes place at a central location using a stationary cold mix plant and stockpiled RAP materials. The stationary plant can be either a CIR train minus the CP machine set up in a stationary configuration (shown at left) or a specifically designed plant (shown at right). CCPR plants include a belt scale, a computer controlled recycling agent system, an additive system (if necessary), and a pug mill for mixing of the final product. CCPR mixtures can be immediately transported to the paving operations or stockpiled for later use. Placement of the CCPR mixture on the pavement is conducted with conventional asphalt pavers.

Courtesy ARRA

Figure 3. CIR unit set up as CCPR plant (left) and stationary cold mix CCPR plant (right).

Considerations on When to Apply In-place Recycling Techniques

CR is a pavement preservation or corrective maintenance technique that, when combined with an asphalt overlay, can be classified as major or structural overlay rehabilitation. Figure 4 provides general guidelines of pavement condition for asphalt recycling and reclaiming strategies.

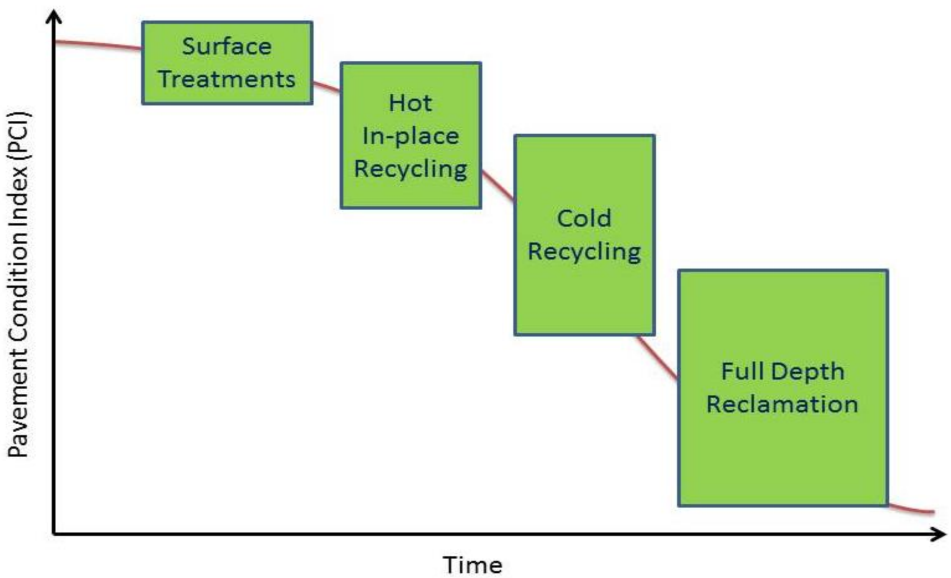

Figure 4: Asphalt recycling and reclaiming strategies for different pavement condition index ranges.[1]

Initial Project Selection Criteria

Appropriate pavement recycling candidate projects should be identified by first obtaining the following information.

Pavement Distress Evaluation

The most important aspects at the onset of any project are proper distress evaluation and detailed project level inspection. Although the CR techniques are powerful preservation and rehabilitation methods, not all pavements are appropriate candidates. In addition, not all asphalt recycling and reclaiming methods are equally suited to treat the various types of pavement distresses.

The Colorado Department of Transportation (CDOT) lists CIR as a total pavement resurfacing and rehabilitation technique that removes existing crack patterns and has these advantages:[2]

- Brand-new interlayering layer utilizing the old surface
- Existing crack patterns are removed
- Previous pavement is rejuvenated

- Bridge clearances and curb heights remain the same
- Hauling excess/milled materials off the project is minimized

CR is generally used with high frequency and high severity, non-load associated distresses (thermal cracking, raveling, etc.). Cracked pavements that are structurally sound and have well-drained bases are the best candidates. For CR to be effective in mitigating cracking, as much of the existing asphalt pavement layer should be treated as possible. The greater the depth of the crack that is removed, the less impact the remaining crack will have on pavement performance. CR can also be used to address load-related distress when used in conjunction with an asphalt overlay to increase the pavement's structural capacity. In addition, CCPR mixtures can be used as a base course in new construction or reconstruction.

Table 1, reconstructed from Table 8.7 of CDOT's *2017 Pavement Design Manual*, shows the pavement distresses that CIR can address.[2] Table 2, reconstructed from Table 10-1 of the *Basic Asphalt Recycling Manual (BARM)*, expands on the distresses that CR can treat depending on the depth of treatment.[1] Unless the causes of the pavement distress are addressed during the CR process, the distresses will be mitigated but they will not be eliminated. As with any pavement treatment, poor drainage must be corrected to ensure adequate performance. CR techniques alone will not address pavement drainage issues or pavements with deep subgrade issues.

The expected design life, performance during the service life, and future maintenance requirements are related to the depth of CR treatment and the type and thickness of the surface course (asphalt overlay or surface treatment).

Table 1. Rehabilitation Techniques Versus Observed Distresses.[2]

Rehabilitation Techniques	Transverse Cracks (minor*)	Transverse Cracks (major)	Longitudinal Cracks (minor*)	Longitudinal Cracks (major)	Fatigue Cracks (minor*)	Fatigue Cracks (major)	Rutting (minor)	Rutting (major)	Reflection Cracks (minor*)	Reflection Cracks (major)	Raveling	Potholes	Polished Surface	Preserves Curb Reveal	Increases Structural Strength	Quick Application
Cold In-Place Recycling	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
Cold In-Place and Chip Seal	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2

*Minor cracks are up to ¼ inch in width.
1 = Rehabilitation technique likely to fix observed distress
2 = Rehabilitation technique has mixed results in fixing observed distress
3 = Rehabilitation technique unlikely to fix observed distress

Table 2. CR Applicability.[1]

Condition		CR Applicability
Surface Defects	Bleeding	Yes
	Pot Holes	Yes
	Raveling	Yes
	Skid Resistance	Yes
Deformations	Corrugations	Yes
	Rutting – Wear	Yes
	Rutting – Mix Instability	Possible, see note a
	Rutting – Deep Structural	Possible, see note b
	Shoulder Drop Off	No
	Shoving	Possible, see note a
Load Associated Cracking	Fatigue – Bottom Up	Possible, see note c
	Fatigue – Top Down	Possible, see note c
	Edge	Possible, see note d
	Slippage	Possible, see note e
Non-Load Associated Cracking	Block	Yes
	Longitudinal	Yes
	Transverse	Yes
	Reflective	Yes
Combined Cracking	Joint Reflection	Possible, see note f
	Discontinuity	Yes
Base/Subgrade Deficiencies	Swells, Bumps, Sags, Depressions	Possible, see note g
Roughness	Ride Quality	Yes
Other Criteria	All Levels of Traffic	Yes, see note h
	Rural	Yes
	Urban	Yes, see note i
	Stripping	Possible, see note a
	Poor Drainage	No, see note j

Notes:

a) Can be corrected with additives such as cement, lime and new aggregate. Needs to be verified by a mix design.
b) Not with CIR but can be addressed with CCPR and correction of the underlying materials.
c) Ensure that structural requirements can be met. CR in conjunction with an asphalt overlay may be needed.
d) Need to provide shoulder confinement after CR.
e) As long as treatment depth exceeds the slippage plane.
f) May not correct but will mitigate.
g) Can be addressed with CCPR and correction of the underlying materials. CIR may not correct but may mitigate.
h) As long as proper pavement structural design is undertaken as part of the process to ensure that the effects of future traffic are taken into account and if the CR mixture is designed to have sufficient early and long term strength. Additives (cement or lime) may be necessary to improve early strength gain.
i) Geometric constraints may influence the type of recycling units used or whether CIR or CCPR is used.
j) Poor drainage must be improved for CR, or any other pavement treatment, to ensure adequate performance.

Traffic

CIR and CCPR techniques were traditionally limited to low to medium traffic volume roadways, but now they have been used successfully on higher traffic volume pavements, including Interstate highways. The Virginia Department of Transportation (VDOT) recently completed two studies of CR on high traffic applications: one on I-81[3] and the other at the NCAT Test Track.[4] The pavement cross-sections for I-81 and the NCAT Test Track are provided in Tables 3 and 4, respectively.

Table 3. VDOT CR Test Sections on I-81[3].

Left Lane	Right Lane (1st 0.40 mile)	Right Lane (Remaining 3.26 miles)
4-inch New AC	4-inch New AC	6-inch New AC
5-inch CIR	8-inch CCPR	6-inch CCPR
Existing Aggregate	12-inch FDR	12-inch FDR
Existing Subgrade	Existing Subgrade	Existing Subgrade

Table 4. VDOT CR Test Sections at the NCAT Test Track[4].

Section S12	Section N4	Section N3
4-inch New AC	4-inch New AC	6-inch New AC
5-inch CCPR	5-inch CCPR	5-inch CCPR
8-inch FDR	6-inch Aggregate	6-inch Aggregate
Subgrade	Subgrade	Subgrade

The I-81 test sections were constructed in 2011 and as of 2016, the left lane has experienced approximately 2.5 million equivalent single axle loads (ESALs) with an International Roughness Index (IRI) of 54 inches per mile and 0.1-inch rut depth[5]. The right lane sections have experienced approximately 10 million ESALs with an IRI of 44 inches per mile and 0.1-inch rut depth.[5] The three test sections at the NCAT Test Track have received over 15 million ESALs with approximately 0.3-inch rut depth and no cracking.[5, 6] In addition to the Test Track, a 5-inch CCPR section with a 3/4-inch hot-mix asphalt (HMA) thinlay was placed on Lee County Road 159 (section L20) as part of NCAT's pavement preservation study. The section has received approximately 0.7 million ESALs with no measurable distress.[6]

Some agencies require minimum HMA overlay thicknesses over CR mixtures based on traffic. However, there should be no upper limit to roadway traffic volumes provided that 1) a pavement structural design is conducted as part of the process to ensure that the effects of future traffic are taken into account; and 2) the recycled material is designed to have sufficient early and long term strength.[7] NCHRP Synthesis 421 contains additional information on agency traffic levels for in-place recycling.[8]

Structural Assessment

Two aspects of structural capacity assessment need to be addressed for the CR techniques. The first is the structural capacity required for anticipated traffic during the design life of the roadway. The second is the ability of the existing pavement structure to support the equipment during construction.

Overlay Thickness Design

If the existing structural capacity of the pavement needs improving, a determination of the required asphalt overlay thickness should be undertaken. Either the *1993 AASHTO Guide for the Design of Pavement Structures* or *AASHTOWare Pavement ME Design* may be used. An owner agency's alternative structural design methods can also be used. The structural layer coefficient ("a" coefficient) of a CR mixture has typically ranged from 0.25 to 0.35[7, 8] with many using 0.30 to 0.35.[2] Recent research from the Virginia DOT has indicated values from 0.36 to 0.44 may be more appropriate.[3, 4] Preliminary results from NCHRP *Project 9-51 Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete for Pavement Design* indicates that CR mixes have dynamic modulus values approximately 50 percent lower than HMA[12] and have similar behavior to HMA base mixes.[5, 12] Completion of NCHRP 9-51 should provide additional guidance for utilization of Pavement ME Design for CR technologies.

Initial Structural Support

Determination of the load-carrying capacity of the existing pavement and underlying materials becomes more important for thinner pavement. Three useful methods of assessing the load-carrying capacity of the pavement structure are Ground Penetrating Radar (GPR), Dynamic Cone Penetrometer (DCP), and Falling Weight Deflectometer (FWD) testing. GPR is an effective device to determine thickness and variability of the pavement structure. DCP provides a measure of a material's in-situ resistance to penetration by driving a metal cone into the ground. The FWD can also be used to assess load-carrying capacity of the existing pavement structure including base, subbase, and subgrade by back-calculating subgrade resilient modulus and effective pavement modulus. Each owner agency will have to establish its own DCP and FWD evaluation criteria based on local conditions.

Field sampling (coring) of the pavement at multiple locations throughout the project's length and width is recommended to evaluate the underlying pavement layers for the determination of the appropriate CR technique. Block sawing or milling with small cold planers have also been used successfully.

Project Length

The total project length is a matter of economics and should be determined by the agency for CIR. The total project length can be any size for CCPR on rehabilitation projects.

Curing

Curing of CR pavements can be an issue if the pavement must be returned to heavy traffic immediately or if environmental conditions are not ideal. Traffic is typically allowed back on the CR mat at the end of the day at a reduced speed to prevent raveling. Many older CIR specifications required minimum cure times of two or more weeks before a surface course could be placed.[9] This was primarily due to the use of solvent bearing emulsified asphalts such as CMS-2 or high float emulsions and the time required for the solvents to fully evaporate from the mixture. Modern emulsified asphalts used for CR are typically solventless, engineered emulsions and cure quickly. The Asphalt Recycling and Reclaiming Association (ARRA) recommends a minimum cure time of three days and a maximum moisture content of 3 percent before placing a surface course.[10] With engineered emulsions, it rarely takes more than a few days for the moisture content to drop below 3 percent except in wet, foggy, cool conditions or when the pavement has high in situ moisture content. In these conditions, ARRA recommends a maximum cure time of 10 days.[10] Foamed (expanded) asphalt CR mixes cure quickly and have been overlaid immediately in rare instances.[11]

Utilities

The presence, frequency, and elevation of utility covers (manholes and valves) must be evaluated during the preliminary project assessment, particularly in an urban setting where CIR recycling is being considered. The BARM contains additional information on addressing issues with existing utilities.[1]

Surface Treatments

Surface treatments (chip seals, slurry seals, micro surfacing) tend to be high in asphalt binder and therefore must be accounted for in the mix design process for CR treatments. Specialty mixtures such as open-graded drainage layers, open-graded friction courses, stone matrix asphalt, etc. will have an effect on mix design as well.

Paving Fabrics, Geosynthetics and Crack Seal

Paving fabrics or geosynthetics can be successfully recycled with CIR, similar to typical asphalt pavement mill and fill operations. CR treatment depths should extend through or stay above the paving fabric to prevent pulling of the fabric and delamination of the mixture. The contractor should be informed of the presence of paving fabrics and excessive crack seal, as additional personnel may be required to remove oversize pieces.

Patches

The presence of large or frequent surface patches increases the variability and decreases the homogeneity of existing materials and resulting CR materials. Excessive patches may be an indication of poor subgrade conditions, which may dictate the appropriate maintenance or rehabilitation technique. If patches are excessive, full-depth reclamation (FDR) or reconstruction may be required. It is an economic decision.

Final Project Selection

After completion of the project level forensic investigation and identifying the failure mechanism, the final treatment selection should be made by assessing all the options with estimated cost, time, and any other project specific constraints such as pavement grade.

CIR methods, as is typical with remixing of in-place materials, have the potential to increase volume up to 10 percent over the specified depth during production. This additional depth of the recycled layer should be accounted for in the final elevation. If the final depth of the recycled layer and asphalt overlay is not acceptable, consideration should be given to either pre-milling the existing pavement or profile milling after the recycling operation has been completed. Depending on project-specific conditions, pavement recycling may or may not be selected. If applied appropriately, pavement recycling is expected to reduce project cost and/or completion time.

Economic Assessment

When undertaking a life-cycle economic analysis, the expected service lives of CR recycling processes generally fall within 6 to 10 years with a surface treatment or 7 to 15 years with an asphalt overlay. The limiting factor for service life of CR treated pavements is typically the service life of the surface course and not the recycled material itself. The effectiveness and performance of CR techniques varies among owner agencies and is dependent on the costs associated with:

- Local conditions
- Climate
- Traffic
- Existing materials to be recycled
- Adequacy of the structural design
- Type and availability of HIR technique
- Quality of materials used
- Quality of workmanship
- Specifications used for the work
- Economy of scale of the project

Summary

The cold recycling techniques of CIR and CCPR are best suited for roadways where the pavement surface is worn and cracked but the subgrade is still firm and in good condition. When applied to the **right road** at the **right time**, the following benefits have been realized:

- Reduction in project time, which reduces delays and inconvenience to road users
- Reduction in the need for material hauling, significantly reducing trucking costs
- Reduction in the need for purchase of new materials, reducing material costs
- Lower initial cost and typically lower maintenance needs compared to traditional methods
- Reduction in reflective cracking compared to traditional mill and overlay treatments

Significant In-place Recycling Resources

- *Basic Asphalt Recycling Manual,* FHWA-HIF-14-001. Asphalt Recycling and Reclaiming Association, Annapolis, Maryland, 2014.

- *Wirtgen Cold Recycling Technology*. Windhagen, Germany, 2015.
- ARRA Construction Guidelines available at www.arra.org
  - *CR101 Recommended Construction Guidelines for Cold In-place Recycling (CIR) Using Bituminous Recycling Agents,* 2017.
  - *CR102 Recommended Construction Guidelines Cold Central Plant Recycling (CCPR) Using Bituminous Recycling Agents,* 2017.

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Project Selection for In-place and Cold Central Plant Pavement Recycling

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