Performance-Related Tests and Specifications for Cold In-Place Recycling: Lab and Field Experience

Todd Thomas
Koch Pavement Solutions
4027 E. 37th St. North
Wichita, KS 67220
telephone 316/828-6737
fax 316/828-7385
thomast@kochind.com

Arlis Kadrmas
Koch Pavement Solutions
4027 E. 37th St. North
Wichita, KS 67220
telephone 316/828-8994
fax 316/828-7385
kadrmasa@kochind.com

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Todd Thomas, Koch Pavement Solutions, 4027 E. 37th St. North, Wichita, KS 67220, telephone 316/828-6737, fax 316/828-7385, thomast@kochind.com

Arlis Kadrmas, Koch Pavement Solutions, 4027 E. 37th St. North, Wichita, KS 67220, telephone 316/828-8994, fax 316/828-7385, kadrmasa@kochind.com

ABSTRACT

Cold in-place recycling (CIR) is a cost-effective treatment for deteriorated pavements, and a recent FHWA policy statement recommends recycled materials be considered for all paving projects. A survey of 38 state departments of transportation by the Rocky Mountain User Producer Group found that many routinely use the technique, but there are some problems with performance reliability, specifically pointing to the lack of a uniform, defined design procedure, and problems with raveling, thermal cracking, compaction problems, low early strength and extended curing time. Other agencies are reluctant to try CIR because of those problems. Much recent asphalt research focuses on lessening risks of early pavement failures through the use of performance type specifications. When an improved technology for emulsion cold in-place recycling was developed, researchers also developed performance-related test methods to improve the reliability of the process and give agencies more confidence in trying CIR. A laboratory raveling test run on Superpave Gyratory Compactor prepared samples simulates the raveling that can occur on the newly recycled pavement, and is used as part of an engineered design process as well as specifying raveling resistance and early strength. The Indirect Tensile Test developed for Superpave design is modified to design and specify CIR resistance to thermal cracking. The data from these tests for numerous projects is given, and compared for a side-by-side trial of the new CIR and conventional methods. Since 2000, over 1280 lane-kilometers of pavements in 17 states have been successfully recycled using the new performance-related specifications.

Key Words: Cold In-Pace Recycling, Indirect Tensile Test, Raveling Test, Performance-Related Specifications

INTRODUCTION

Approximately 48.7 percent of U.S. rural interstate mileage and almost 60 percent of urban interstate mileage is rated in fair to poor condition.(1) At the same time, highway funding is not sufficient to maintain the current state of the U.S. highway system, let alone upgrade those roads and highways in unacceptable condition. Sources of quality aggregates are dwindling, and permits for new quarries are difficult to obtain. Many highway departments have found emulsion cold in-place recycling (CIR) to be a cost-effective solution.(2)(3)(4) A recent policy statement by FHWA states that "Recycling and reuse can offer engineering, economic and environmental benefits. 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."(5) CIR can be used to remove thermal and reflective cracks, to re-establish crowns, maintain clearances, improve poor aggregate gradations, reuse existing materials, and minimize the need for new materials, as well as strengthen the pavement. A New Mexico study of 45 CIR projects estimated an average saving of $7074 in construction costs per lane-km ($11,384 per lane-mile), and $7524 per lane-km in life cycle costs ($12,109 per lane-mile).(6)

A recent survey by the Rocky Mountain User Producer Group of 38 states showed that while many states are using CIR with success, they are plagued with some consistency problems. One of the biggest concerns was the lack of standard design and testing methods. In many locations, off-the-shelf materials and generalized procedures have been routinely used for recycling all types of bituminous pavements. Some agencies perform no design due to problems correlating to the field process. Specific improvement areas identified by the survey included raveling, minor segregation, isolated rutting, extended curing time, compaction problems, thermal cracking and disintegration under traffic.(7)

Traditionally, paving materials (including the emulsions used for CIR) have been specified by material physical properties such as viscosity, penetration, and asphalt content. While many of these component properties affect performance, it has long been recognized that these specifications alone do not always yield the desired performance. The Strategic Highway Research Program (SHRP) was initiated to improve the effectiveness of laboratory test methods in predicting field performance(8) and develop "Performance Based" specifications.(9) European highway agencies have adopted sophisticated laboratory testing equipment, such as rutting testers,
designed to mimic pavement failure conditions as closely as possible. While the Superpave system developed by SHRP made many improvements in both measuring fundamental properties of asphalt and predicting field performance, it still does not always accurately predict the performance in the field. In response, there has been a proliferation of efforts to develop “Performance”, “Performance Based”, “Performance Modeled”, and “Performance-Related” specifications. Because of confusion about these terms, standard definitions were developed and published in a National Cooperative Highway Research Program (NCHRP) synthesis. “Performance-Related Specifications” (PRS) use surrogates for the fundamental engineering properties that have been found to have had reasonable success in predicting performance. While not as foolproof as the performance or performance based specifications, PRS are amenable to timely and cost-effective design and acceptance testing, and greatly reduce the risk of failures when compared to the use of material physical property specifications such as penetration and viscosity. While not giving absolute answers, these performance-related tests can be very effective at ranking materials and predicting field failures, and therefore at lowering the risks associated with new materials and techniques. By using performance-related specifications, agencies open the door for innovative products, as well as for competition in the marketplace to meet those performance criteria while improving quality and lowering overall system costs.

Until recently, there have been no performance-related specifications for CIR, and some agencies have not used such recycling practices because of lack of confidence in CIR performance. When an improved chemistry emulsion was developed to give higher early strength and improved coating and film thickness, there was no way to adequately characterize the improved properties. To address the lack of confidence and the problems enumerated in the Rocky Mountain User-Producer Group survey, a new partial depth process has been developed for emulsion CIR that includes a defined sampling protocol, performance-related specifications, an engineered design protocol with performance-related testing of laboratory prepared samples, quicker field compaction and construction specifications. The new process, which considers the millings as “black rock”, or in other words does not consider the old asphalt as part of the binder for the recycled mix, was described in an earlier publication. The performance-related specifications include a new raveling test, thermal cracking testing, strength tests, and moisture susceptibility testing. The specifications also include requirements for the construction equipment and practices, as well as quality control and quality assurance. The new design procedure and specifications have been used on numerous partial depth CIR field projects since 2000.

THE PERFORMANCE-RELATED TESTS

Raveling (or disintegration under traffic) and low temperature cracking were two of the problems identified by the Rocky Mountain User Producer Group survey. The Indirect Tensile Test developed by the Strategic Highway Research Project was adapted for the emulsion recycled mixes, and a new raveling test was developed to simulate resistance to raveling.

Thermal Cracking – The Indirect Tensile Test (IDT)

For performance based tests and specification of thermal cracking temperature of the CIR lab prepared samples, the indirect tensile test (IDT) is used with some modifications. Thermal cracking has been a problem on cold recycling using fly ash, lime and low emulsion contents. Cored samples are taken from the pavement to be recycled, crushed by a laboratory jaw crusher, blended to the medium field gradation, pre-wet and mixed at the design emulsion content, which is determined by volumetrics. The mixes are then compacted damp in 150-mm diameter molds to ±1% of design air voids (the design air voids are very similar to the voids measured in the field) using the Superpave Gyratory Compactor (SGC). For a more accurate comparison of test results and test repeatability, the specimens are cured at 60°C for 48 hours, then checked every 2 hours until there is no more than 0.05% change in mass. Samples are tested at 10°C intervals bracketing the LTPPBind specification temperature for the climate and depth in the pavement structure. A minimum of two specimens are run at each of three temperatures bracketing the critical cracking temperature. The critical cracking temperature is the intersection of the calculated pavement thermal stress curve (derived from the tensile creep test) and the tensile strength line (derived from the results of the tensile strength test). To meet the specification, the cracking temperature predicted by the IDT must be less than or equal to the pavement temperature given for that climate area and pavement depth by LTPPBind. Some of the cold in-place recycled mixes have had hot mix overlays, while others were merely covered with a surface treatment such as a chip seal, depending upon the pavement structural needs. Therefore, the depth in the pavement varies from project to project. Testing may be run as low as –40°C.
**IDT Results**

Figure 1 illustrates how the cracking temperature is determined. It also shows the predicted cracking temperatures for conventional (using standard HFMS-2P emulsion) and the new process CIR (which uses the improved chemistry emulsion and the engineered design protocol) for a project done in Blue Earth County Minnesota. The predicted cracking temperature is 4°C lower for the new process than for the conventional CIR. Table 1 gives laboratory data for several projects using this performance based test. In all cases the predicted cracking temperature of the design mix was lower than the expected pavement temperature at the depth in the pavement where the recycled mix will be, as predicted by the LTPPBind software at 98% reliability. Table 1 also gives the data for field cores taken from two of the field trials. While these results are slightly higher cracking temperatures than the lab prepared samples, they are still well within the specification limits for the climates where the pavements were placed. No significant cracking has been noted to date on any of the projects designed using the performance based IDT test. The sections placed had overlays ranging from 37 to 200mm (1.5 to 4 in), and they are continuing to be monitored for performance.

**The Raveling Test**

One of the problems cited by the Rocky Mountain User Producer group study was raveling of the recycled pavement shortly after placement. While not a universal problem, raveling has led many agencies to be reluctant to use CIR. A newly developed test adapts the wet track abrasion test,(20) where a specimen is mounted on a Hobart mixer and subjected to abrasion by a free floating rubber hose. At ambient temperature, 150-mm specimens are prepared and compacted to 20 gyrations using the Superpave Gyratory Compactor then allowed to cure at ambient laboratory conditions for 4 hours. Typical air voids are slightly higher than the field measured voids of 9 to 14%. Air voids are not routinely measured in this procedure to eliminate errors from too much handling of the specimens. The method differs from wet track abrasion in that there is no ring weight and the testing is run dry. The test is run for 15 minutes, or until the sample disintegrates too much to continue the test. Figure 2 shows the equipment set up and specimens after testing.

**Laboratory and Field Raveling Test Results**

Table 2 gives raveling test results for several projects, all of which meet the specification for a maximum 2% mass loss. Table 3 compares raveling results using the new process CIR and an emulsion typically used for CIR on two field projects that had both conventional and new process CIR test sections. These were the only projects that had control sections using conventional CIR. The specimens shown in Figure 2 are from the test sections in Blue Earth County, MN, represented by data in Table 3. From this test, the conventional CIR had a predicted higher susceptibility to raveling, especially in the first one or two days after placement. In fact, there was minor raveling on the conventional test section, and no evidence of raveling on the new process section. Figure 3 shows the raveling that occurred on the conventional CIR section, which corresponded to a 25.7% mass loss in the raveling test. Figure 3 also shows the new process CIR section, which did not ravel, and which had a 1.6% mass loss on the raveling test. The raveling results are improved with the new process CIR because the new chemistry used to manufacture the emulsion results in a more cohesive mix, reducing or eliminating raveling. Raveling has not been a problem with any of the new process CIR projects constructed to date, and, in fact, one project, K-140 in Kansas, was left open to traffic for up to 90 days before being overlaid and exhibited no raveling during that period.

**THE PERFORMANCE-RELATED SPECIFICATIONS**

Table 4 gives a summary of the performance specifications used for the new CIR process, including requirements for moisture resistance and strength. To specify resistance to moisture, the new process CIR mixtures are tested using a retained Marshall Stability test adapted from AASHTO T-283. For this test, the voids in the samples are vacuum saturated to 55-75%, submerged in a water bath at 25°C for 23 hours, and placed for 1 hour in a 40°C water bath before testing. The air void content of both lab specimens and field compaction is typically 9 to 14%. The percent retained strength is calculated from the Marshall Stabilities before and after the water conditioning. On the Blue Earth County, MN project, the conventional CIR had a retained strength of 42%, while the new process CIR had a retained strength of 83%. The higher asphalt content of the new process and the improved chemistry of the emulsion result in better adhesion and cohesion.

Early strength is an important component of the new process CIR. CIR has not been widely used on high traffic volume roads because of long user delays while the emulsion is curing. The new process has an emulsifier chemistry that breaks and cures more quickly, giving the earlier strength needed for early compaction and traffic return. A Marshall stability on 100-mm Superpave Gyratory Compactor prepared specimens is used for testing
stability. The Marshall stability was chosen for this testing because of the vast experience and available data from this method. The authors recognize that a better method for determining strength using the standard 150-mm specimens should be used and are currently working on developing a new method.

On the comparative project in Blue Earth County, Minnesota, the new process CIR samples exhibited superior performance on raveling, thermal cracking and moisture susceptibility testing than conventional emulsion CIR.\(^{(21)}\) Falling weight deflectometer testing showed higher moduli for the new CIR. On this project, as well as projects in Arizona and Washington, field stiffness testing showed quicker early strength, enabling quicker traffic return.

Since 2000, more than 1280 lane-km of roads have been successfully recycled using these specifications. Projects have been successfully placed in Arizona, California, Colorado, Florida, Georgia, Iowa, Idaho, Illinois, Kansas, Minnesota, Montana, Nebraska, New Mexico, Nevada, South Dakota, Texas and Wyoming. After successful trial projects, these specifications have now been adopted by the Kansas and Minnesota Departments of Transportation, Tazewell County in Illinois and the Western Federal Lands office.

CONCLUSIONS

An engineered design procedure using performance-related tests coupled with performance-related specifications has been successfully used on numerous cold in-place recycling projects throughout the U.S. A newly developed raveling test correctly predicted raveling on a project in Minnesota using conventional CIR process and materials, and correctly predicted the new process CIR would not ravel. Indirect tensile testing has been used to specify maximum cracking temperatures for these projects, and no major cracking has been detected on any of the projects built under these specifications. The oldest of the projects have now been in place for two years. Stabilities and moisture resistance testing has also been used as part of the specifications. The field projects will continue to be monitored with time, and additional performance-related tests such as rutting resistance in the Asphalt Pavement Analyzer are being evaluated in the laboratory.

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REFERENCES


19. AASHTO TP 9.


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FIGURE 2 Raveling Test Setup and Specimens After Testing.
FIGURE 3 Raveled Conventional CIR Section and New Process CIR Test Section Without Raveling in Minnesota.
<table>
<thead>
<tr>
<th>Project Location</th>
<th>LTPPBind 98% Reliable Low Temperature at depth of recycled mix, °C</th>
<th>IDT Predicted Cracking Temperature from Laboratory Prepared Samples, °C AASHTO TP 9-96</th>
<th>IDT Cracking Temperatures from Field Cores, °C AASHTO TP 9-96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phillips County, KS, US 36</td>
<td>-22</td>
<td>-35.0</td>
<td></td>
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<td>Fort Sumner, NM, US 60</td>
<td>-19</td>
<td>-29.2</td>
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<tr>
<td>Buchanan County, IA, Highway 20</td>
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<td></td>
</tr>
<tr>
<td>Tazewell County, IL, Washington Rd</td>
<td>-21</td>
<td>-35.0</td>
<td></td>
</tr>
<tr>
<td>Blue Earth County, MN, Highway 10</td>
<td>-30</td>
<td>-34.0</td>
<td>-32.0</td>
</tr>
<tr>
<td>Washington DOT, State Route 270</td>
<td>-23</td>
<td>-26.0</td>
<td>-30.0</td>
</tr>
<tr>
<td>Project Location</td>
<td>Raveling Test Mass Loss, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>----------------------------</td>
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<td></td>
</tr>
<tr>
<td>Phillips County, KS, US 36</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fort Sumner, NM, US 60</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa DOT, Buchanan County, IA, Highway 20</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tazewell County, IL, Washington Rd</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue Earth County, MN, Highway 10</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington DOT, State Route 270</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tazewell County, IL, Muller Rd</td>
<td>1.9</td>
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<td></td>
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<td>Mitchell County, IA, A-23</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia DOT, US41 / SR 11</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado DOT, I-70</td>
<td>1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bureau of Indian Affairs, MT Route 8</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Arrowhead, CA, North Bay Peninsula Rd</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 3  Raveling Test Results for Conventional and New Process CIR mixes

<table>
<thead>
<tr>
<th>Location</th>
<th>New Process CIR</th>
<th>Conventional CIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Earth County, MN, CSAH 20</td>
<td>1.6%</td>
<td>25.7%</td>
</tr>
<tr>
<td>WA SR 270</td>
<td>1.5%</td>
<td>16.0%</td>
</tr>
<tr>
<td>Property</td>
<td>Criteria</td>
<td>Purpose</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Compaction effort, Superpave Gyratory Compactor</td>
<td>1.25° angle, 600 kPa stress, 30 gyrations</td>
<td>Density Indicator</td>
</tr>
<tr>
<td>Density, ASTM D 2726 or equivalent</td>
<td>Report</td>
<td>Compaction Indicator</td>
</tr>
<tr>
<td>Marshall stability, ASTM D 1559 Part 5, 40°C</td>
<td>1,250 lb min.</td>
<td>Stability Indicator</td>
</tr>
<tr>
<td>Retained stability based on long-term stability</td>
<td>70% min.</td>
<td>Resistance to moisture damage</td>
</tr>
<tr>
<td>Raveling Test, Ambient or 10°C, new procedure</td>
<td>2% max.</td>
<td>Resistance to raveling</td>
</tr>
<tr>
<td>Indirect Tensile Test, AASHTO TP9-96, Modified</td>
<td>LTPPBind temperature for climate &amp; depth</td>
<td>Resistance to cracking</td>
</tr>
</tbody>
</table>
Conventional CIR Thermal cracking temperature = -30°C

New CIR Thermal cracking temperature = -34°C

FIGURE 1 Indirect Tensile Test Thermal Cracking Temperatures for Conventional (HFMS-2P) and New Process Cold In-Place Recycling in Minnesota.
FIGURE 2 Raveling Test Setup and Specimens After Testing.
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