Report No. UT-15.08

COLD IN-PLACE RECYCLE PHASE III, SUPPLEMENTAL— FIELD PROTOCOL: SHORT TERM FIELD STABILITY

Prepared For:

Utah Department of Transportation UDOT Region Three Materials

Submitted By:

Construction Management Engineering Transportation Group (CMETG)

Authored By:

Kevin VanFrank P.E.

Supplemental Report to UT-15.07 May 2015

Utah Department of Transportation - Research Divisi South 2700 West - P.O. Box 148410 - SLC.UT 84114-

Disclaimer Notice

The authors alone are responsible for the preparation and accuracy of the information, data, analysis, discussions, recommendations, and conclusions presented herein. The contents do not necessarily reflect the views, opinions, endorsements, or policies of the Utah Department of Transportation and the US Department of Transportation. The Utah Department of Transportation makes no representation or warranty of any kind, and assumes no liability therefore.

Acknowledgments

Steve Park, P.E., Region Three Materials Engineer, Utah Department of Transportation (UDOT) for the dedication and effort set forth in obtaining funding for the project and visualizing the benefits of cold-in-place recycled pavement construction.

Justin Schellenberg, P.E., Region Three Project Manager, UDOT for funding the project and recognizing the need for appropriate CIR Project management tools.

Howard Anderson, P.E., Engineer for Asphalt, UDOT for championing the Cold-in-Place Recycled Pavement initiative.

Kevin Nichol, P.E., M.P.A., Research Project Manager, UDOT for implementing the Cold-in-Place Recycled Pavement research initiative.

For further information or questions, please contact:

Steve Park, PE Region Materials Engineer Region Three Utah Department of Transportation 658 North 1500 West Orem, Utah 84057

Name	Organization	Title	Email
Lonnie	UDOT Region Two	Region Materials	<u>lmarchant@utah.gov</u>
Marchant	Materials	Engineer	
Kevin	CME Transportation	Senior Engineer	kevin@cmetg.com
VanFrank	Group		
Howard	UDOT Central Materials	Asphalt Engineer	handerson@utah.gov
Anderson	Division		
Scott Andrus	UDOT Central Materials	Engineer for	<u>scottandrus@utah.gov</u>
	Division	Materials	
Kevin Nichol	UDOT Research Division	Project Manager	knichol@utah.gov
Wayne Felix	Independent	Field Engineer	wdf248@gmail.com
Ryan Proctor	Ergon Asphalt and	Technical	<u>Ryan.proctor@ergon.com</u>
	Emulsions, Inc.	Marketing	
		Manager	

Technical Advisory Committee Members

Executive Summary

CIR has become a useful tool in pavement rehabilitation due to cost savings. UDOT wishes to improve the reliability of the process as well as improve the final outcome. A balance is achieved between fracture durability and rutting resistance by controlling void content and added emulsion. This balance is well reflected in the current mix design method but has proven difficult to achieve in the field. Observation of field methods has pointed toward modifications to the mix design procedure as well as to tests providing same-day feedback to the CIR process.

SR 32 is the second field project where a variety of tests were used to control the process consistency and quality as well as the release to traffic conditions. The Dynamic Cone Penetrometer (DCP) along with the Shear Vane test are further validated and a new test protocol using the Marshall Hammer is developed. Recommendations for test thresholds are made.

Recommendations are made for control of both longitudinal and lateral density. Roller patterns are recommended. Emulsion break temperatures are evaluated leading to best compaction practices. Recognition of system sensitivity to temperature results in proposed changes to the mix design procedures. Specification changes are recommended with respect to the pickup machine and paver.

Introduction

The use of CIR to reclaim and rehabilitate pavements has been shown to significantly reduce costs (25% TO 33%) compared to that of reconstruction. The current versions of these tools utilize a solventless emulsion providing for shorter curing times, earlier opening to traffic and reduced volatile organic compounds (VOC) as compared to older methods. UDOT has fully adopted these pavement rehabilitation practices, however the current procedures used to design, control and evaluate the construction of these materials are time consuming and expensive. These control methods have also been unable to prevent project failures due to inadequate timeliness and applicability of test results. Mix design deficiencies have also contributed to difficulties in meeting Department expectations.

The ultimate performance of the CIR material is defined by the in place air voids together with type and amount of emulsion added to the milled material. The design of the material must balance the need of more emulsion to achieve long term performance and reduce raveling with the need for less emulsion to prevent rutting. Current laboratory test procedures can account for this but cannot currently be translated to field applications due to the complexity of the testing. Field control needs to

be based on controlling simple characteristics of the mix and production that affect the ultimate performance and field curing curve.

The SR-32 CIR project scheduled for the summer of 2013 was identified as an excellent opportunity for timely data collection. Through previous efforts, several possible field test protocols have been identified that could be very effective in providing appropriate project control information, giving this research a very high possibility of being successful. These tests include a Dynamic Cone Penetrometer (DCP) and a shear vane tester.

Background

UDOT has been using Cold Recycled Pavements for many years. Older methods involve using a slow- set-low-viscosity (SS1) emulsion or a cutback with rejuvenators to revive the asphalt in the millings. These processes, although successful, have proven unmanageable from a time-to-traffic prospective as well as becoming objectionable under EPA VOC rules.

In 2002, Koch Performance Products filed for a patent wherein a Cold-In-Place Recycled pavement was produced using a Solventless Emulsion. These emulsions moved the solvent level from near 15% to below 1%. A mix design procedure was proposed to balance cracking against rutting behaviors resulting in a durable but stable mix. Without its knowledge, this patent became the basis for the specification adopted by the UDOT.

The use of this specification produced successful CIR projects during the 2004 to 2008 period as Koch's successor, Sem Materials, was the only competitor for CIR projects in the Utah market. Sem Materials provided not only the emulsions but project engineering support for the process. During this period, the applicators were expected to release the project to traffic in a very short period of time. If rutting occurred, the applicator was responsible to reprocess. The applicators complained that they could not get mix design emulsion quantities into the projects without causing rutting. Since they have discretion in the specification to cut the emulsion by up to 0.5%, they did so, resulting in fracture prone pavements. This specification driver was causing the applicators to disregard the mix design and creating friction between the contractor and the Sem Materials field engineers.

Upon Sem Materials 2008 bankruptcy, the Utah market opened to a number of competitors for CIR projects. Suppliers included Sem Materials successors; Ergon Asphalt and Road Science as well as Paramount Asphalt based in Nevada. It soon became obvious that the UDOT specification had grave deficiencies. Department personnel realized that the success of prior projects was primarily due to the sole source and not to control of the project via the specification. Also the previously unrecognized, patented process became troublesome due to project procurement rules. Two projects were done which met specification but failed to meet department expectations made it clear that better design and field control was needed.

This is UDOT's second study to better understand and control the field application of CIR. Previously used field evaluation tools are used to provide rapid feedback to the installer. The goal will be to maximize emulsion addition without creating a rutting condition.

Project Description

SR 32 is a mountain road, connecting US 40 to Francis, Utah. The project runs from the US 40 junction to the Rock Cliff State Park, a distance of 7.75 miles at elevations ranging from 5720 ft. to 9500 ft. The road was paved at the time of construction in 1987 and has been maintained with chipseals. At least two chip seals and possibly three were present on the pavement at the time of reconstruction. These surface treatments were not removed and were included in the recycling operation. The road has a load rating of less than 0.3 million esals.

The rehabilitation treatment chosen was a 3 inch Cold-In-Place (CIR) recycle using solventless emulsion, a 1.5 inch HMA overlay and a double chipseal surface treatment. CIR processing began July 16 and ended July 28. The weather was cool in the morning with lows around 52°F and afternoon highs around 92°F. Afternoons were frequented with thunder showers, some of which were quite heavy. The production was significantly slowed as pavement temperatures climbed above 90°F with some windrow temperatures climbing to 136°F. This reduction in productivity pushed the contractor to move to night work to take advantage of cooler and dryer conditions.

Mix Design was done according to UDOT specification with a coarse gradation and a medium gradation. A 3:1 quick lime slurry was added at the mill head at a rate of 1.5% lime by weight of mix. Coarse mixes required 2.5% added emulsion while Fine mixes required 3.0% emulsion. Adherence to mix design is always troublesome. The contractor is allowed to vary from mix design targets as much as 0.5% without Department input.

Objectives

Objective 1: CIR Oversight for Project

- Task 1. Attend Scoping, Review, Preconstruction and Pre-Paving Meetings
- Task 2. Provide Engineering and Inspection presence on project during calibration and CIR operations
- Task 3. Provide CIR Mix Design in cooperation with Road Science, LLC.

Objective 2: Perform Field and Lab Testing on CIR Materials

- Task 1.Perform field tests on field mix for duration of CIR operations
- Task 2.Perform sampling and laboratory testing of field mix in accordance with current draft
protocols from previous research for duration of CIR operations
- Task 3. Perform other data collection, field or lab testing, or analysis as requested
- Task 4. Document performance of CIR pavement during first week of opening to traffic
- Task 5. Develop correlation between field tests, field performance and laboratory performance.

Task 6. Develop summary report

Deliverables:

- A: List of field test results and suggested revisions to draft FOPs
- B: Interim Report on field data
- C: Interim Report on correlation
- D: Final Report with summary evaluation of tests and proposed FOPs (if successful)

Data Collection

The following sampling and testing protocol was followed:

Item 3, bullet 7; 50 blow Marshall was added to the protocol after the DCP and Shear Vane were unable to isolate flow characteristics.

Field Procedures

- 1. Observe start of paving noting
 - temperatures of surface
 - ambient temperature
 - percentage of lime slurry

- percentage of emulsion
- 2. Coordinate density testing with the contractor QC lab. Set density target.
- 3. Choose 3 locations daily to sample material and perform investigative testing. Take samples from the windrow between the processing machine and the paver.
 - 1 sample bucket for laboratory tests
 - 1 bagged sample for moisture tests
 - GPS locations
 - Ambient Temperature
 - DCP testing in approximately 2 hour intervals during first day with a test the following day. Test protocol was developed in previous studies. Figure 1.
 - Shear testing at the same interval as the DCP tests. Test protocol was developed in previous studies. Obtain ambient and internal mat temperatures. Figure 2. Figure 3.
 - 50 Blow Marshall field test at the same interval al the DCP tests. Test was developed for this project for use in areas exhibiting wet of optimum conditions. Figure 4.
 - Nuclear Density tests at the 3 locations after rolling complete.
- 4. Sample emulsion every day (3-1 quart containers each day)
- 5. Results of gradation tests and setting of emulsion content as results are available from the contractor QC lab.
- 6. Observations of paving operations periodically through the day.
 - Ambient temperature
 - Location
 - Temperature of mix
 - Emulsion percentage
 - Lime percentage
 - Verify that milling tailings that will not be processed are cleaned from corners.
 - Verify milling depth
- 7. Measure the areas processed each day.

Lab Tests each Day

- Moisture tests on 3 samples
- Make 3 pucks out of each bucket sample 1-2 hours after sampling at perform stability tests after 24 hours at 100 degrees.
- Burn and Grade and Rice tests on each of 3 samples



Figure 1: Dynamic Cone Penetrometer





Figure 2: Shear Vane

Figure 3: Shear Vane Test Apparatus



Figure 4: Marshall Hammer

Field and Lab Data

All data reports are found in the appendix.

Observations and Evaluation

The first issue on the project was whether to allow the CIR material to dry to a grey surface prior to compaction. Industry has argued that the material needed to lose water while loose because after compaction, the water would be sealed in. This sealed condition would lead to rutting and delay opening to traffic. The opposing argument was that if the surface was allowed to dry, break would be complete. When the mat is rolled after complete emulsion break, raveling becomes a problem. It was

observed on this project that measured moisture never exceeded 6%. Even when it rained heavily, the compacted material drained rapidly and the emulsion broke properly. An experiment was conducted allowing the material to dry at the surface vs. running breakdown while still wet. Breaking down with vibratory, static and pneumatic rollers was also observed. This RAP structure compacted best when a steel, vibratory roller was used to do the initial compaction prior to primary emulsion break (PEB). This initial operation was followed after PEB with a pneumatic kneading compactor for secondary compaction and finished with a static steel drum. The conclusion on this project was that initial compaction should be done prior to PEB and that final compaction should be completed while viscosities are rising but prior to break completion.

The second issue was whether the emulsion breaks as a function of vibration input from the breakdown roller. Observation of material processed at temperatures around 55°F and vibrated within 10 minutes of paving did not exhibit emulsion break. It appeared that emulsion break was suppressed until temperatures reached 70°F in the pavement. Initial compaction should be done prior to emulsion break so that the system behaves as unbound material. In this way, the optimum moisture condition can be observed under the roller and information can be returned to the processor so that a wet of optimum condition, with its inherent risk of rutting, can be avoided. Intermediate compaction can be done at any time so long as the finish roller completes compaction prior to full emulsion break. Since an understanding of the break rate is not well understood, use of the shear vane test may provide feedback as to the continuing compactability of the system. A probable guideline would look like this: when the shear value is greater than 30 ft lb, release to traffic. When the shear value is greater than 40 ft lb, cease compaction. The compaction "sweet spot" is between 25 and 35 ft lb. Temperature and moisture content clearly effect final compaction operations. Tearing of the mat surface under static roller is an indication that final compaction operations are premature. The 50 blow Marshall procedure resulting in greater than 10 mm depression together with lateral displacement is also a good indicator that the mat is not ready for final compaction.

The third issue involved emulsion deviation from mix design. In reviewing the mix design adjusted targets based on gradation, the applied emulsion approached those targets only when the windrow temperature was below 80°F. When the windrow temperature exceeded this threshold, it was necessary to reduce emulsion targets by 0.1% for each 5°F temperature rise. This reduction was based on several factors. Observations were made of the compactability, bleeding and stability of materials in the windrow (cow pie test) as well as the flow of the material in the paver bin and the stability of the mat during initial vibratory compaction. The indications in the cow-pie-test should be good stability with no bleeding. The material should be brown and fluid in the paver and when the mat crawls and pumps under the vibration, the mat exhibits less stability and rut resistance. The challenge is to keep the binder content as high as possible for cracking durability while remaining dry of optimum for rutting stability. It is believed that as the mat temperature increases, compaction distorts the particles and reduces the available voids. In comparing this project to others, it is clear that this phenomenon is dependent on the RAP binder characteristics. Older, more oxidized binders are less susceptible to this molding than are newer, more pliable binders. High temperatures also cause more rapid emulsion break. Rather than reducing emulsion addition to prevent premature break, the emulsion needs to be adjusted to processing temperatures. The current mix design does not deal with these issues.

The fourth issue is voids. It was observed that the normal gradation structure of the CIR contains approximately 12% void. This changes with milling speed, temperature and pavement condition. Wet gradation and emulsion target adjustment are defined in the mix design as being done in accordance with a Sem Materials procedure. This procedure is no longer available. The document was pursued through the current mix designer and to the original author with no success. Since grading the material wet vs. dry or as conglomerate vs. extracted aggregate can create a great deal of difference

in result, a choice was made to grade the RAP dry as an aggregate. Standard sampling and testing procedures were performed each day with results giving good guidance for cool temperatures. As the temperature warmed above 80°F, it appears that both the shape and size of the conglomerate particles change. The effects of this morphing and welding of particles change the specific surface and void size. This change in pore structure reduces the space available to accommodate moisture in the unbound state and binder in the bound state. It is important to understand the effects of temperature on void availability during mix design, a defect in the current system. Void contents approximating a standard Proctor density on the unbound RAP should be expected. Some reduction of these voids can be achieved with higher processing temperatures but significant reduction would require adding appropriately sized material for better gradation control. Density control can never approximate HMA control due to the varying nature of the processed RAP.

Issue 5 concerns lateral density distribution and mat edge conditions. Using a windrow pickup machine with sufficient power to handle the full windrow at a rate faster than the processing capability is required in specification. On this project, when the paver got behind the CIR process, the operator would raise the pickup device up to two inches above the milled surface so as to catch up with the processer. This was done to assure the emulsion break would not occur in the paver. The result of this operational adjustment was a lateral differential in density and stability. A lateral, particle-size segregation was also observed. Future projects should require demonstration of an excess capacity in the pick-up device of at least 30% over the capacity of the CIR process. It was also observed that when processing against a previously processed mat, a disturbed, unprocessed area was generally present. This condition was also observed on previous projects. This area consists of a 3 to 6 inch wide zone. No new emulsion gets into this area leaving a weak section at the longitudinal joint. The specification needs revision to address this issue.



Figure 5: Lateral Segregation due to Paver Dragging



Figure 6: Lateral Segregation due to Poor Windrow Pickup



Figure 7: Well placed and compacted CIR

Issue 6 involves what indicators can be used to release the mat to traffic. Three tests were used on this project to determine release to traffic. Two of these were previously used on I-84 at Morgan. The Dynamic Cone Penetrometer (DCP) and the Shear Vane were used to measure the stability and

viscosity of the processed mat. In the SR-32 project, a 50 blow Marshall procedure was used to add a flow measurement to the acceptance procedure.

A determination was made on the I-84 project that when fewer than 10 mm per blow was achieved using the DCP, the mat had sufficient stability to resist traffic loads. The DCP picked up both low density and insufficient emulsion conditions (raveling).

A determination was also made on the I-84 project that when resistance to rotation above 30 ft Ib was achieved using the Shear vane, the emulsion had broken sufficiently to resist traffic loads.

These two tests were thoroughly developed and described in the previous UDOT paper "Phase II Short Term Field Stability; 2012".

It was noted on SR 32 that both of the above parameters could be achieved while the pavement contained too much moisture leaving the pavement stable but plastic. The finish roller tended to tear the surface until this condition resolved. Since shear and viscosity are the same phenomenon, the shear vane was unable to discern flow instability when a near fully broken emulsion was present. This is due to the localized nature and high degree of particle displacement surrounding the shear vane tips. A 50 blow Marshall procedure was instituted where less than 10 mm of penetration and no plastic flow was used as a criteria to accept the mat under flow instability conditions. This test measures bulk movement of particles in a large stress influence field where each particle moves a small distance. A Field Operating Procedure was developed and included in the appendix for this test.

Recommendations

1. The pavement behaves as an unbound material prior to emulsion break. In this condition, fluids in the matrix effect compactability. Optimum fluids may be determined using Proctor techniques. At the high level of voids present in processed RAP, fluid drainage is not an issue. Initial compaction should take advantage of these properties and be done before emulsion break initiates. Pre-break initial compaction initiates the drainage process and allows further consolidation to proceed unhindered by high pore pressure. An indication of excess fluid in unbound materials is pumping under the vibratory roller. Although processing at near optimum fluid is desirable, observation of pumping or shoving under the break down roller should be followed by a reduction of fluid in the recycling process. Finish compaction should proceed as viscosity rises during emulsion break. Optimum finish compaction viscosities can be determined using the Shear Vane Test or by observing the behavior of the finish roller as it interacts with the mat. As with all materials, a trained eye can tell a great deal about the material without a formal test. Rapid feedback to the processing operator is critical to the balance between rutting potential and durability. The most rapid feedback is achieved by watching roller/mat interaction.

2. The emulsions used on this project are resistant to chemical and vibratory inputs. They are subject to break beginning around 70°F. When mat temperatures reach this level, either from solar radiation or from ambient conduction, emulsion break initiates. Break accelerates as temperature climbs. At mat temperatures above 85°F, traffic opening can be achieved within three hours of processing. Maintenance of traffic requirements should recognize this behavior. It is unknown if emulsions can be designed for lower temperatures but it is clear from discussions with emulsion producers that they can be slowed for higher temps. It is critical that the emulsion break slowly enough as not to set up in the paver while achieving the 3 hr. post processing stabilities required by department expectations. Specifications can be modified at this time to reflect these findings.

3. Temperature affects the CIR process. Elevated temperatures change particle size and packing characteristics. These phenomena are not addressed in mix design. Further research is necessary in this area for incorporation into the emulsion targets. For the SR 32 project, it was observed that for each 5°F above 85°F, the emulsion target was reduced by 0.1%. This relationship is believed to be dependent on

the RAP and must be individualized for each project. A revision to the mix design process must be made to reflect this behavior.

4. Voids in the direction of the alignment (longitudinal) are a function of pavement condition, milling speed and temperature. Sufficient interconnected voids are necessary to allow fluid drainage from the system. Density targets will be possible to set but difficult to control. Some targeting may be done by measuring compactability at varying temperatures. Target densities could be set at temperature points and achieved within a band. It is important to recognize optimum fluid content and emulsion-break viscosity as drivers in obtaining maximum achievable density. Investigation of these characteristics needs to be added to the mix design procedures.

Voids in the lateral direction should be consistent. Segregation is detrimental to any pavement and should be controlled. Paver condition and control are key to achieving an unsegregated mat. Leaving an unprocessed longitudinal joint needs to be addressed in specification.

The DCP, Shear Vane and 50 blow Marshall procedure have been demonstrated to be effective, timely tools to provide feedback to the CIR process. The FOPs should be implemented and the thresholds adopted. Personnel trained to observe the CIR process and given the authority to make adjustments under the specification are needed on each project. Competent Feedback which is more rapid than these tests is needed to obtain optimal processing.

Next Steps:

- 1. Institute improvements in the specification dealing with:
 - a. Pick Up machine power and process.
 - b. Paver Condition
 - c. Lateral segregation and density.
 - d. Longitudinal Joint processing
 - e. Integrate three processing feedback tests along with their FOPs
 - f. Tighter control over the contractor discretion on emulsion adjustment.
- 2. Develop optimum fluid relationships based on temperature as well as gradation
- 3. Develop a time to PEB at cold temperatures and a time to traffic bearing viscosity. This is to be used in emulsion specification. It may be a mix test or a pure emulsion test.
- 4. Develop a way to determine optimum compaction viscosity/break time/temperature.
- 5. Develop a Performance Grading residuum specification for the emulsion.
- 6. Investigate the optimum fluid content as it relates to lime.
- 7. Investigate the optimum fluid content as it relates to rutting vs. durability.

APPENDIX A

DRAFT PROTOCOL FOR FLOW EVALUATION

Field Protocol for Flow of CIR Asphalt

Use this procedure for quick evaluation of flow characteristics of CIR mat in determining appropriate hold time for CIR mixes prior to finish compactive efforts.

Field Procedure

- 1. Perform test in the field on a previously compacted mat.
- 2. Use a standard Marshall hammer which has been removed from its frame.
- 3. Place the Marshall hammer with its head flat on the mat in the place of interest. Do not rock the head or move from the initial placement.
- 4. Pick up the weight until it reaches the upper stop. Drop the weight. Repeat 50 times.

Observation and Documentation

- 1. Observe the depression made by the Marshall Hammer head. Determine whether any lateral deformation has occurred. Lateral deformation will be evidenced by an upward bulge surrounding the hammer head.
- 2. Observe the moisture condition of the mat. Is water bleeding from the mat or is it dry.
- 3. Measure the depth of the depression from the mat surface.
- 4. Record test location, mat temperature, lateral deformation and depth of depression and moisture condition.

Determination of CIR Sample Cure Time

1. If the depression is greater than 10 mm or if the lateral deformation creates a bulge greater than 5mm in height or if the mat is bleeding water, the mat is not ready for final rolling. Release to traffic should be delayed.