TECHNICAL REPORT
STANDARD TITLE PAGE

1. Report No.	2.Government Accession No.	3. Recipient's Catalog No.
IHRB Report TR-474		

4. Title and Subtitle	5. Report Date
Validation of the New Mix Design Process for Cold In-Place Rehabilitation Using Foamed Asphalt	June 2007
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
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9. Performing Organization Name and Address	10. Work Unit No.
Public Policy Center University of Iowa 227 South Quadrangle Iowa City, IA 52242-1192	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Iowa Highway Research Board Iowa Department of Transportation 800 Lincoln Way Ames, IA 50010	Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Asphalt pavement recycling has grown dramatically over the last few years as a viable technology to rehabilitate existing asphalt pavements. Iowa's current Cold In-place Recycling (CIR) practice utilizes a generic recipe specification to define the characteristics of the CIR mixture. As CIR continues to evolve, the desire to place CIR mixture with specific engineering properties requires the use of a mix design process. A new mix design procedure was developed for Cold In-place Recycling using foamed asphalt (CIR-foam) in consideration of its predicted field performance. The new laboratory mix design process was validated against various Reclaimed Asphalt Pavement (RAP) materials to determine its consistency over a wide range of RAP materials available throughout Iowa. The performance tests, which include dynamic modulus test, dynamic creep test and raveling test, were conducted to evaluate the consistency of a new CIR-foam mix design process to ensure reliable mixture performance over a wide range of traffic and climatic conditions. The "lab designed" CIR will allow the pavement designer to take the properties of the CIR into account when determining the overlay thickness.

17. Key Words	18. Distribution Statement
Cold In-place Recycling (CIR), Reclaimed Asphalt Pavement (RAP), Foamed Asphalt, Mix Design Process, Dynamic Modulus Test, Dynamic Creep Test.	

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	233	N/A

Form DOT F 1700.7 (8-72)

EXECUTIVE SUMMERY

Iowa's current Cold In-place Recycling (CIR) practice utilizes a generic recipe specification to define the characteristics of the CIR mixture. The contractor is given latitude to adjust the proportions of stabilizing agent to achieve a specified level of density. As CIR continues to evolve, the desire to place CIR mixture with specific engineering properties requires the use of a mix design process. The “lab designed” CIR will allow the pavement designer to take the properties of the CIR into account when determining the overlay thickness. A significant drawback to using emulsion as the stabilizing agent is the amount of water associated with the emulsion. High amounts of water limit the ability to increase binder content and extent the time required to cure the CIR layer. Using foamed asphalt as the stabilizing agent could significantly reduce these limitations.

During the phase I study, a new mix design process was developed for evaluating CIR-foam mixtures. Some strengths and weaknesses of the mix design parameters were identified and the laboratory test procedure was modified to improve the consistency of the mix design process of Cold In-place Recycling using foamed asphalt (CIR-foam). Based upon the critical mixture parameters identified, a new mix design procedure using indirect tensile test and vacuum-saturated wet specimens was developed. Phase II study was then launched to validate the developed laboratory mix design process against various Reclaimed Asphalt Pavement (RAP) materials to determine its consistency over a wide range of RAP materials available throughout Iowa.

Collection and Evaluation of RAP Materials

During the summer of 2004, in order to validate the mix design process developed during the phase I study, RAP materials were collected from seven different CIR project sites: three CIR-foam and four CIR-ReFlex sites. CIR project sites were selected across the state of the Iowa, which included Muscatine County, Webster County, Hardin County, Montgomery County, Bremer County, Lee County, and Wapello County.

First, RAP materials were divided into six stockpiles that were retained on the following sieves: 25mm, 19mm, 9.5mm, 4.75mm, 1.18mm, and those passing through the 1.18mm sieve. The sorted RAP materials were then weighed and their relative proportions were computed. All RAP materials were considered from dense to coarse with very small amount of fine aggregates passing through the 0.075mm (No. 200) sieve. All RAP materials passed through the 38.1 mm sieve and less than 1.0% was retained on the 25mm sieve except those at Muscatine (2.6%), Hardin (6.0%), and Wapello Counties (1.3%). Gradation analyses for seven RAP sources were conducted and the RAP materials from Muscatine County were the coarsest followed by Montgomery, Webster and Wapello Counties; and those from Hardin, Bremer and Lee Counties were finer. Overall, gradations of extracted aggregates were relatively fine with a large amount of fine material passing through a 0.075mm sieve.

The flat and elongation ratio test was performed on RAP materials in accordance with ASTM D 4791. All RAP materials exceeded the 10% limit of a 3:1 ratio and RAP materials from Lee County were the most flat and elongated, followed by Wapello County. The least flat and elongated materials were from Hardin, Montgomery and Bremer Counties. Very few RAP materials were flat and elongated at a ratio greater than 5:1. To investigate compaction characteristics of RAP materials, as a reference point, RAP materials were compacted using a gyratory compactor without adding water or foamed asphalt. There was a significant increase in bulk specific gravity by adding foamed asphalt.

The extracted asphalt content ranged from 4.59% for RAP materials collected from Wapello County to 6.06% from Hardin County. The extracted asphalt of RAP material from Montgomery County exhibited the highest penetration of 28 and a small $G^*/\sin\delta$ value of 1.08 at the lowest test temperature of 76°C whereas that of Lee County showed the lowest penetration of 15 and $G^*/\sin\delta$ value of 1.06 at the highest test temperature of 94°C.

Validation of a New Mix Design Process

The indirect tensile strength test of the vacuum-saturated specimens was conducted using seven different RAP materials at five foamed asphalt contents, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0%, given a fixed moisture content of 4.0%. The specimens were compacted by gyratory compactor at 30 gyrations or by Marshall hammer at 75 blows and were cured at 40°C oven for three days or 60°C for two days. The indirect tensile strength of gyratory compacted and vacuum-saturated specimens was more sensitive to foamed asphalt contents than that of Marshall hammer compacted and vacuum-saturated specimens. The indirect tensile strength of CIR-foam specimens cured for two days at 60°C oven was significantly higher than that of CIR-foam specimens cured for three days at 40°C oven.

The optimum foamed asphalt content was determined when the highest indirect tensile strength of vacuum saturated specimens was obtained. Based on the test results, neither air voids nor flat and elongation characteristics of RAP materials affected the indirect tensile strength of the CIR-foam mixtures. The highest indirect tensile strengths were obtained from the RAP materials with a large amount of hard residual asphalt. However, the optimum foamed asphalt content was not affected by the amount of residual asphalt content.

Performance Test Results

The performance tests, which include dynamic modulus test, dynamic creep test and raveling test, were conducted to evaluate the consistency of a new CIR-foam mix design process to ensure reliable mixture performance over a wide range of traffic and climatic conditions.

The dynamic modulus tests were performed on CIR-foam mixtures at six different loading frequencies, 0.1, 0.5, 1, 5, 10 and 25 Hz, and three different test temperatures, 4.4, 21.1 and 37.8°C. Within each source of RAP materials, the dynamic moduli of RAP materials were not affected by loading frequencies but significantly affected by the test temperatures. The dynamic moduli measured at three foamed asphalt contents were significantly different among seven RAP sources. Rankings of RAP materials by the dynamic modulus value changed when the foamed asphalt was increased from 1.0% to 3.0%, which indicates that the dynamic modulus values are affected by a combination of foamed asphalt content and RAP aggregate structure.

At 4.4°C, dynamic modulus of RAP materials from Muscatine County was the highest, Webster County was second and Lee and Hardin Counties were the lowest. At 21.1°C, dynamic modulus of RAP materials from Webster County was the highest followed by Muscatine County whereas Lee and Hardin Counties stayed at the lowest level. At 37.8°C, dynamic modulus of RAP materials from Muscatine became the lowest whereas Webster County was the highest.

It can be postulated that RAP material from Muscatine is sensitive to temperature because they were the coarsest with least amount of residual asphalt content. Therefore, the coarse RAP materials with a small amount of residual asphalt content may be more fatigue resistant at a low temperature but more susceptible to rutting at a high temperature. On the other hand, fine RAP materials with a large amount of hard residual asphalt content like Hardin County may be more resistant to rutting at high temperature but more susceptible to fatigue cracking at low temperature.

A master curve was constructed for a reference temperature of 20˚C for each of seven RAP sources. Master curves are relatively flat compared to HMA mixtures, which supports that foamed asphalt mixtures are not as viscoelastic as HMA. More viscoelastic behavior was observed from the foamed asphalt mixtures with higher foamed asphalt content.

Based on the dynamic creep test, RAP materials from Muscatine County exhibited the lowest flow number at all foamed asphalt contents whereas those from Lee and Webster Counties reached the highest flow number. The lower the foamed asphalt contents, the flow number was higher, which indicates the foamed asphalt content with 1.0% is more resistant to rutting than 2.0% and 3.0%.

RAP materials from seven different sources were ranked by the flow number. Overall, the rankings of RAP materials did not change when the foamed asphalt was increased from 1.0% to 3.0%, which indicates that flow number is affected more dominantly by the RAP aggregate structure than by the foamed asphalt content. The finer RAP materials with a higher amount of the harder binder were more resistant to rutting. This result is consistent with the findings based on dynamic modulus test performed at 37.8˚C.

Based on the laboratory performance test results, it can be postulated that RAP materials from Wapello and Webster Counties would be more resistant to both fatigue and rutting.

RAP materials from Muscatine, Bremer and Montgomery Counties would be more resistant to fatigue cracking but less resistant to rutting. RAP materials from Hardin and Lee Counties would be more resistant to rutting but less resistant to fatigue cracking.

Based on the raveling test results, the foamed asphalt specimens at 2.5% foamed asphalt content showed less raveling loss than those of 1.5% foamed asphalt content. It was found that the raveling test was very sensitive to the curing period and foamed asphalt content of the CIR-foam specimens. To increase cohesive strength quickly, it is necessary to use higher foamed asphalt content of 2.5% instead of 1.5%.

Short Term Performance of CIR Pavements

To evaluate the short-term performance of CIR pavements, the digital images were collected from these CIR project sites using the Automated Image Collection System (AICS) and the images were analyzed to measure the length, extent, and severity of different types of distress. Based upon the condition survey result performed in one year after the construction, all have performed very well without any serious distress observed. Some minor longitudinal and transverse cracks were observed near the interface between rehabilitated and un-rehabilitated pavements in Montgomery, Hardin, and Bremer Counties. Transverse cracks occurred more frequently than longitudinal cracks at most pavement sections, which can be considered as the early distress type.

Conclusions

Asphalt pavement recycling has grown dramatically over the last few years as a viable technology to rehabilitate existing asphalt pavements. Rehabilitation of existing asphalt pavements has employed different techniques; one of them, Cold In-place Recycling with foamed asphalt (CIR-foam), has been effectively applied in Iowa. This research was conducted to develop and validate a new laboratory mix design process for CIR-foam in consideration of its predicted field performance.

Based on the extensive laboratory experiments, the following conclusions are derived:

- Gyratory compactor produces the more consistent CIR-foam laboratory specimen than Marshall hammer.
- Indirect tensile strength of gyratory compacted specimens is higher than that of Marshall hammer compacted specimens.
- Indirect tensile strength of the mixtures cured in the oven at 60˚C for 2 days is significantly higher than that of mixtures cured in the oven at 40˚C for 3 days.
- Dynamic modulus of CIR-foam is affected by a combination of the RAP sources and foamed asphalt contents.
- The coarse RAP materials with a small amount of residual asphalt content may be more resistant to fatigue cracking but less resistant to rutting.
- CIR-foam is not as sensitive to temperature or loading frequency as HMA.

- Based on the dynamic creep tests performed at 40˚C, CIR-foam with 1.0% foamed asphalt is more resistant to rutting than CIR-foam with 2.0% or 3.0%.
- Based on the dynamic creep tests performed at 40˚C, RAP aggregate structure has a predominant impact on its resistant to rutting.
- Based on the dynamic creep test results performed at 40˚C and dynamic modulus test performed at 37.8˚C, the finer RAP materials with the more and harder residual asphalt were more resistant to rutting.
- CIR-foam specimens with 2.5% foamed asphalt content are more resistant to raveling than ones with 1.5%.
- There is a significant variation in distribution of foamed asphalt across the lane during the CIR-foam construction, which could affect its field performance.

Recommendations

Based on the extensive laboratory experiments and the field evaluations, the following recommendations are made:

- 30 gyrations are recommended for producing the equivalent laboratory specimens produced by 75-blow Marshall hammer.
- Laboratory specimens should be cured in the oven at 60°C for 2 days.
- To determine the optimum foamed asphalt content, indirect tensile strength test should be performed on vacuum saturated specimen.
- Gyratory compacted specimens should be placed in 25˚C water for 20 minutes, vacuumed saturated at 20 mm Hg for 30 minutes and left under water for additional 30 minutes without vacuum.
- The optimum foamed asphalt content should be increased from 1.5% to 2.5% if the penetration index of the residual asphalt from RAP materials increases from 28 to 15.
- The proposed mix design procedure should be implemented to assure the optimum performance of CIR-foam pavements in the field.

Future Studies

- CIR-foam pavements should be constructed following the new mix design process and their long-term field performance should be monitored and verified against the laboratory performance test results.
- New mix design and laboratory simple performance tests should be performed on the CIR-foam mixtures using stiffer asphalt binder grade, i.e., PG 58-28 or 64-22.
- Static creep test should be evaluated for a possible addition to the performance test protocol.
- New mix design and laboratory performance tests should be evaluated for CIR-emulsion mixtures.

- To better simulate the field performance as a base, performance tests should be performed on both CIR-foam and CIR-emulsion specimens with a horizontal confined pressure.
- A comprehensive database of mix design, dynamic modulus, flow number and raveling for both CIR-foam and CIR-emulsion should be developed to allow for an input to the Mechanistic-Empirical Pavement Design Guide (MEPDG).