Cold In-Place Recycling Forensic Study on U.S. Highway 34 Union County, Iowa

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ABSTRACT

Forensic studies of pavement failures require a clear understanding of the distress observed, a logical approach to examining potential assignable causes, a reasonable connection between the distress and assignable causes, and recommendations to minimize the potential for future failures. The recommendations must be careful to address the cause and to not unduly restrict technology that has a proven record of success. This case study on cold in-place recycling demonstrates this process.

Cold in-place recycling is a successful rehabilitation strategy. As we learn more about this technology, we also learn about its limitations. The dramatic failure of the cold in-place recycled layer under traffic on the U.S. Highway 34 project was investigated. Eleven separate factors were analyzed as possible assignable causes. It was concluded that the level of truck traffic was the primary cause of the failure. The application of cold in-place recycling technology is currently restricted to less than 400 trucks per day until changes are made to the mix design to address higher truck traffic levels.

Key words: cold in-place recycling—rutting
INTRODUCTION

Cold In-place Recycling (CIR) is one of several rehabilitation strategies for hot mix asphalt (HMA) pavements. The criterion for applying CIR includes having a thick HMA pavement that is structurally sound. The primary benefit of CIR is the ability of the recycled layer to delay reflective cracking in the HMA overlay placed over the CIR. The CIR process involves milling the top three to four inches of the HMA pavement, crushing the milled material to a specified size, adding asphalt stabilizing agent to the processed reclaimed asphalt pavement (RAP), placing the CIR mix back onto the pavement, and compacting the CIR layer. Once the layer is compacted and allowed to gain strength, a HMA overlay is placed as a new wearing surface.

On Iowa Department of Transportation (Iowa DOT) projects (and in many states), the CIR layer is used as the driving surface during the period of time between the CIR rehabilitation and the HMA overlay. This part of the paving project process provides two benefits. First, the level of traffic on many Iowa DOT routes would not permit lengthy detours for periods of a week or more. Second, past experience with CIR has demonstrated that opening the CIR layer to traffic generally improves the compaction, particularly in the wheel paths. As the Iowa DOT gains more experience with the proper application of CIR, this rehabilitation strategy is considered to be a viable option on more HMA projects.

On occasion, a phase of a construction project fails. Projects that use CIR are no exception to this rule. The surface of the CIR layer on early projects sometimes ravel under traffic. This has been attributed to a lack of sufficient asphalt stabilizing agent in the CIR to bind the particles together. Other projects have shown distress when the HMA overlay was placed too soon. The CIR layer was not able to support the heavy construction traffic. With each failure, we better understand the key components of the CIR rehabilitation process. The application of CIR on the U.S. Highway 34 (US-34) Union County project added another key component to our understanding of this rehabilitation strategy.

PROJECT DESCRIPTION

The design for the US-34 project included CIR for the existing HMA surface of the composite pavement (HMA over concrete) and placement of a three-inch HMA overlay. There were no unique project features. The project called for 14 lane miles of CIR. As part of the CIR specification, existing HMA was removed by the contractor and sent to the Iowa DOT Central Laboratory for development of the CIR mix design. The mix design process showed that 2.0% foamed asphalt should be added as part of the CIR mixture. This amount was adjusted down to 1.8% as the CIR process started. The mix design decision on the amount of asphalt stabilization is primarily based on the measured wet strength of the mixtures prepared and cured in the lab.

The construction staging for the CIR and HMA overlay was very typical for Iowa DOT rehabilitation projects. Both the CIR and HMA overlay are constructed under traffic. The two-lane section is closed in one direction for an allowable length (generally up to two miles per day), and both directions of traffic are controlled by a pilot car operation. All lanes are open to traffic at night. The CIR subcontractor processes one direction, reaches the end of the CIR limit, then processes the other direction. In this case, the CIR subcontractor started two miles from the west end of the project, proceeded east to the end of the project, turned and continued processing west to the end of the project, and turned east again to finish the project. Due to the curing criteria for CIR, the HMA paving contractor does not bring the HMA plant in until the CIR subcontractor completes his/her rehabilitation of the existing HMA surface.
The CIR process started on May 16 and took 19 calendar days to complete. After each day of CIR, the lanes were opened to traffic. No problems were noted by the construction inspection staff regarding the stability of the CIR layer under traffic.

In a typical CIR process, the curing period requires four to seven days of moderately hot temperatures and no rain events. It is common for the HMA contractor to schedule the HMA overlay two weeks after the CIR is placed. For the US-34 project, the HMA paving crew began placing an HMA shoulder widening unit about one week after the CIR was completed.

FORENSIC STUDY

As early as four days after completing a two-mile length of CIR, severe loss of stability began occurring in isolated 100- to 200-foot sections of the CIR layer under traffic. As the problem increased across the project, an investigation was initiated to determine the cause of the problem. The loss of stability was a serious problem that impacted the progress of the project and, more importantly, the safety of the traffic.

The field inspection staff described the problem as a dramatic loss of strength over a two-hour period that resulted in deep wheel path rutting and shoving of the CIR material. To maintain a safe driving surface, motorgraders were used to blade the rutted and heaved CIR material onto the shoulder.

The balance of this paper discusses the field investigation actions applied to examine the CIR failure and determine the cause of the acute rutting and shoving. The first phase of an investigation is to obtain a clear understanding of the condition observed. Once the material distress is properly defined, the investigation looks for assignable causes. Finally, the investigation must determine the changes needed to eliminate or reduce the causes. For example, HMA rutting is an observed distress condition. Rutting can be caused by poor compaction of the mixture. The compaction process (rolling pattern) may be one of the activities that should be changed to achieve higher density. In this example, the observed distress (rutting) may have several assignable causes. If there is no clear connection between the cause and the distress, other causes must be explored.

On the US-34 project, the observed problem was severe rutting and shoving of the CIR layer under traffic. Pictures of the CIR surface and interviews with the field inspection staff confirmed that the observed problem was rutting and shoving. The difficulty with the investigation was that the rutting and shoving was not consistently observed over the project length. With this background, the investigation needed to determine what cause or combination of causes led to the sporadic problem.

A number of causes are associated with CIR layer loss of stability. Since CIR mixture is similar to HMA, the causes of HMA rutting became the baseline for the investigation. Each of the potential causes was listed, and the design and construction details associated with each cause were examined. The list of potential causes for CIR layer loss of stability is as follows, each of which are explained below:

- Moisture
- Compaction
- Temperature
- Changes in CIR aggregate (RAP age)
- Changes in CIR process (RAP sizing)
- Asphalt stabilizer content
- Asphalt stabilizer type
- Traffic (wheel load)
- Wheel load due to steep grade
- Construction staging (traffic queue)
- Air voids

**Moisture**

Free moisture is a known problem for CIR layers. The adhesive bonds from the CIR process are susceptible to high pore pressures. CIR mix design focuses on the indirect tensile strength of wet-conditioned specimens. During construction, the cured condition of the CIR layer is *loosely* measured as the moisture content in the layer. CIR layers have failed under traffic combined with heavy rains. However, the failures in the field are typically associated with surface raveling. On the US-34 project, there were no significant rain events during the CIR process or during the subsequent traffic.

**Compaction**

Insufficient compaction of the CIR layer reduces the strength of the layer. Traffic placed on the layer will knead and compact the layer further. This additional compaction can create rutting. However, the compaction created by the traffic normally strengthens the CIR material. On the US-34 project, the field compaction complied with the density specification. Even when the sections of CIR with the lowest density are isolated, these sections do not correspond with the sections that experienced rutting.

**Temperature**

High summer temperatures are the most common cause of rutting in HMA. For CIR layers, high temperatures are desirable to rapidly cure the mixture (reduce the moisture content). On the US-34 project, there appeared to be some correlation between high temperature and the occurrence of the CIR rutting and shoving. However, if high temperature was the primary cause, we would expect to find continuous rutting. The observed rutting is sporadic along the project length.

**Age of the CIR**

The CIR process mills, sizes, mixes, places, and compacts the existing HMA surface as a continuous in-place recycling operation. The processed RAP is not removed from the project to a central stockpile to be uniformly blended. It is possible that isolated maintenance overlays were placed in recent years to strengthen the pavement and maintain a smooth ride. If new HMA was processed as part of the CIR, then the use of a soft asphalt stabilizing agent could soften the mixture and create instability in high summer temperatures. Normally, the existing HMA surface material is more than 15 years old and the asphalt binder is aged. On the US-34 project, there was no record or knowledge of recent thin maintenance overlays along the length of the project.

**Size of the CIR**

Speed of the CIR recycling train is controlled by the speed of the milling unit that tows the remainder of the equipment units. The speed of milling can impact the size of the RAP. Previous CIR studies have not identified major changes in the RAP gradation, but a significant change in the gradation could affect the stability of the CIR layer. Very fine-graded RAP may not have sufficient coarse aggregate to maintain stability under traffic. On the US-34 project, there was no observed changed in the speed of the CIR process.
Asphalt Stabilizer Content

The amount of asphalt in HMA and CIR has similar impacts on each mixture. Dry (low asphalt content) mixes are generally stiff and provide good rutting resistance. Wet (high asphalt content) mixes are softer and more prone to rutting. The CIR process uses material weigh belts to proportion the foamed asphalt and RAP. If there are fluctuations in the operation of the proportioning system, the rutting resistance of the CIR layer will vary. On the US-34 project, cores were taken along the project length to obtain samples of CIR mixture with good and poor performance. The results from laboratory ignition oven extraction testing did not indicate any significant variation in total binder content, and there was no trend between the binder content of sections with good and poor performance. The lab results agreed with the quality control foamed asphalt yield checks computed during the CIR process.

Asphalt Stabilizer Type

The asphalt binder used for CIR is a PG 52 -34. This soft binder is specified for CIR to rejuvenate the aged binder in the existing HMA surface. The larger fraction of light oils in the soft binder will be absorbed by the aged binder. On the US-34 project, a unique situation occurred. About the last 25% of the CIR process was performed with a stiffer PG 58 -28 binder for the foamed asphalt. Although the change in binder does not account for the sporadic occurrence of the rutting, it would provide a clue if there are no distressed locations in the sections processed with the stiffer asphalt binder. Some locations of rutting were observed in the CIR section with PG 58 -28 foamed asphalt binder, so the grade of the asphalt stabilization agent is not a cause of the distress.

Traffic

Typical asphalt pavement rehabilitation projects extend over five to ten miles. Along that project length, it is possible to have changes in traffic frequency and load. Traffic load is a factor in any rutting distress. Significant changes in traffic load can cause one part of a project to perform differently from another. On the US-34 project, the overall traffic frequency and load are heavier than the traffic for a typical CIR project. However, there were no identifiable point sources of load that matched the rutted locations.

Steep Grades

Like traffic frequency and traffic loading, pavement on a steep grade experiences higher stress from the traffic. It is common to observe differences in pavement performance between the incline lanes and the decline lanes. On the US-34 project, the terrain across the project length is moderately rolling. However, the locations of rutting and shoving did not always correspond with incline grades.

Construction Staging

Looking at one more aspect of the load applied on the CIR layer, construction staging is sometimes a factor in early pavement distress. The actual load applied on the pavement surface is a combination of the size of the load and the speed at which it passes. The stress on a pavement surface is greater at slow or stopped conditions, like on the approach to intersections. During the CIR process, the traffic is queued at both ends of the construction length and a pilot car directs the queue of traffic across the open lane. At the point of the queue, the traffic is stopped, which applies a high stress on the pavement. On the US-34 project, the inspector’s field log identifies the start and end locations for each day of the CIR process. However, the locations of the rutting did not coincide with the locations of the traffic queues.
Air Voids

Since many of the common causes for CIR rutting distress did not provide a strong explanation for the rutting, the amount of air voids was examined. This potential cause is the opposite of the compaction factor. The compaction factor examined low density mixtures (with high air voids). This factor is related to low air voids (high density mixtures). Measuring the air voids in the CIR layer is an approximation at best. Unlike with HMA, it is difficult to measure the specific gravity of the CIR material because the particles are not completely coated with asphalt. Air voids play a role in some instances of HMA rutting and shoving, particularly on the approaches to intersections. As the traffic slows and the stress increases, the HMA further compacts. The traffic compaction lowers the air void content of the mixture. At very low air void contents, the asphalt binder in the mix begins to fill all the available void space. When this occurs, the surface of the mix begins to flush and the mix stability decreases. On the US-34 project, there were observations of flushing in the wheel paths on short sections of the CIR surface. The description of the severe failures noted rapid displacement rutting and shoving. This would agree with a low air void condition. However, there is no explanation for the sporadic location and timing of the distress.

CONCLUSION

Eleven separate factors were examined to determine the cause of the CIR layer distress. No single, specific factor clearly established a cause for the rutting and shoving. The next step in the investigation looked at the potential impact of a combination of the factors. Of the eleven factors, seven were eliminated from further consideration based on the previous analysis (moisture, changes in CIR age and size, asphalt stabilizer content and size, steep grade, and construction staging). The remaining factors were plotted against the location of the distress. From this analysis, a relative correlation between the individual density measurements and the location of the patches was seen, as shown in Figure 1. The apparent tie to the distress is a function of high CIR construction compaction. Generally, high density due to CIR compaction is not a problem and is encouraged. On this project, however, the high CIR density combined with the heavy truck traffic and higher temperatures pushed the mixture into a low air void condition and created the unstable CIR layer in those sections. Other sections with less CIR compaction density (i.e., higher air voids) were also being further compacted by the heavy truck traffic, but these had not reached the point of low air voids.

Based on this conclusion, the Iowa DOT Office of Materials issued a restriction on the use of CIR. Because there is good performance on many CIR projects, the restriction does not avoid all application of the CIR rehabilitation strategy. The restriction focuses on the key factor on the US-34 project that was unique: heavy truck traffic. The truck traffic on the US-34 project was approximately 600 trucks per day. Previous successful CIR projects with traffic on the CIR layer carried up to 400 trucks per day. The restriction does not recommend the use of CIR on projects that would open the CIR layer to more than 400 trucks per day.

Can CIR rehabilitation technology apply to heavier truck routes in Iowa? A number of states apply CIR technology on heavy truck routes, but their intended CIR mix design and performance criteria are different than Iowa’s. To increase the stability of the CIR mix, the process will require a dry stabilizing agent like cement or fly ash. However, making the CIR mixture stiffer will also reduce the value of the mix to retard reflective cracking. Another option may be the use of a polymer modified asphalt emulsion instead of foamed asphalt. Laboratory testing to compare various mix alternatives using a repeated load axial–permanent deformation performance test should be used. Initial test results with this test protocol showed differences between mixtures.
Figure 1. Actual density and location/date of patching
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