EXPLORING SUSTAINABLE PAVEMENT REHABILITATION: COLD-IN-PLACE RECYCLING WITH EXPANDED ASPHALT MIX

Peter Chan, B.ASc, M.ASc Candidate. (Corresponding Author)
Department of Civil and Environmental Engineering, University of Waterloo,
200 University Avenue West, Waterloo, Ontario, Canada, N2L 3G1.
Phone (519)-888-4567 ext 33872,
Fax (519)-888-4300
pcpchan@engmail.uwaterloo.ca

Susan Tighe, PhD, PEng, Canada Research Chair and Professor
Civil and Environmental Engineering Department, University of Waterloo
200 University Ave W., Waterloo, ON, N2L 3G1
Phone: 519 888 4567 ext. 33152
Fax: 519 888 4300
Email: sltighe@civmail.uwaterloo.ca

Susanne Chan, M.ASc, P.Eng, Pavement Design Engineer
Ontario Ministry of Transportation, Pavements and Foundations Section
1201 Wilson Ave., Downsview, ON, M3M 1J8
Phone: 416-235-5311
Fax: 416-235-3919
Susanne.Chan@ontario.ca

July 31, 2009

Word Count
3716 Words
3 Figures = 750 Words
3 Tables = 750 Words
Total = 5213 Words
P. Chan, S. Chan, S. Tighe

ABSTRACT
Pavement rehabilitation is a critical component to maintain pavement serviceability and performance. Riding surface of the pavement deteriorates over time due to environment, load, material and construction related distresses. In a society where funding and natural resources are scarce, sustainable pavement rehabilitations become the emerging trend to maximize pavement performance using the available funds.

Cold In-Place Recycling with Expanded Asphalt Mix (CIREAM) is a very sustainable pavement rehabilitation technique currently available in the industry. CIREAM is an in-place recycling technique that utilizes expanded asphalt (also known as foamed asphalt) without pulverizing the existing pavement. It works similar to cold in-place recycling (CIR) in terms of milling existing pavement when CIR typically uses emulsified asphalt to provide additional adhesion to the recycled aggregates. Foamed asphalt and emulsified asphalt both use water as an additive to cause asphalt cement to foam. The potential benefit of CIREAM includes savings in asphalt cement, in situ recycling of aggregates, significant money and time savings in transportation cost and disposal cost, and low curing time after rehabilitation for traffic.

The paper explores planning, design, construction, quality assurance, and environmental aspect of CIREAM in a qualitative manner. The planning for CIREAM involves identifying potential pavement distresses that can be treated with CIREAM. The CIREAM rehabilitation design considers CIREAM mix design, mill depth design, and overlay design. This paper addresses critical items for construction to ensure a good quality results. Quality assurance tests are also explored to understand the acceptance criteria for CIREAM rehabilitation. Lastly, the environmental evaluation for CIREAM through PaLATE analysis is conducted to demonstrate the environmental impacts of CIREAM compared to conventional mill and overlay. This analysis illustrates the energy use, emissions, and carbon footprint associated with CIREAM rehabilitation.
INTRODUCTION
Pavement rehabilitation is an important element to enable pavement to reach its intended life cycle. The goal of pavement rehabilitation is to eliminate the distresses present in the pavement structure, fix deficiencies, restore smoothness, improve safety, and extend the pavement service life. As the pavement ages, it deteriorates and loses its performance over time. The selection of proper rehabilitation for different highway projects is essentially a routine activity for pavement engineers working for highway agencies. In a society where funding and natural resources are scarce, sustainable pavement rehabilitations become the emerging trend to maximize pavement performance using the available funds.

Cold In-Place Recycling with Expanded Asphalt Mix (CIREAM) is a relatively new rehabilitation technique available for flexible pavement. As the name suggests, this rehabilitation technique combines the conventional Cold In-Place Recycling (CIR) and expanded (foamed) asphalt. Currently, most of the published information on CIREAM rehabilitations are in the form of project reports, research articles, construction specifications and industrial journals. There are several CIREAM projects completed in North America such as Highway 7 Perth in Ontario, and Wood County Road in Ohio for the past five years (1, 2). The Ministry of Transportation Ontario (MTO) has a CIREAM construction specification called Ontario Provincial Standard and Specification (OPSS) 335 (3). This specification dictates the submission requirements for a CIREAM rehabilitation project. However, the planning and design of CIREAM are also crucial elements that dictate the performance of the finished product.

This paper explains the features and benefits of the CIREAM rehabilitation in a qualitative manner. In addition, this paper further discusses various aspects of CIREAM rehabilitation included planning, overlay design, mix design, construction considerations, quality assurance tests, and environmental evaluation of CIREAM rehabilitation using PaLATE software.

CIREAM FEATURES AND BENEFIT
Both CIR and CIREAM are in-place recycling techniques. Both techniques recycle part of the existing asphalt pavement on site by cold milling at designed depth to create a CIR or CIREAM binder courses. A large portion of the existing pavement structure remains untouched for these recycling techniques at the end of the rehabilitation. Thus, they yield high percentage of recycled content. The cost of virgin material and transportation are greatly reduced compare to utilize a conventional mill and overlay rehabilitation. The milled pavement is essentially reclaimed asphalt pavement (RAP). This RAP is stabilized (or strengthen) using emulsified or expanded asphalt prior to apply new hot mix asphalt overlay to create CIR binder course or CIREAM binder course respectively. Technically, CIREAM binder is different than CIR binder in the sense that it uses expanded asphalt to stabilize the in-situ RAP.

Expanded asphalt is essentially injecting a designed amount of cold water into hot asphalt cement inside the pavement-mixing unit (4). Typically, hot asphalt cement would have a temperature higher than the boiling point of water (i.e. over 100°C). As cold water contacts with the asphalt cement, the water is turned into steam immediately and traps in thousands of tiny asphalt bubbles, also known as the foaming process (5). Expanded asphalt has a lower viscosity than normal hot mix asphalt cement due to the addition of water. The lower viscosity eases foamed asphalt to blend in with the in-situ RAP. The amount of water injected to the asphalt is discussed in the mix design section of this paper.
On the other hand, emulsified asphalt also uses water to reduce its viscosity. Emulsified asphalt mixes “asphalt cement and water in which microscopic beads of asphalt cement are suspended in water molecules” (6). Emulsified asphalt is commonly used for applications such as base stabilization, cold mix asphalt, and tack coating (6).

The expanded asphalt causes CIREAM rehabilitation to have three advantages over CIR rehabilitation. The first advantage is the rapid curing time of CIREAM binder. Typically, the curing time prior to open for traffic of CIREAM rehabilitation is 2 days, whereas for a CIR rehabilitation is 14 days (1). The shorter curing time for the pavement is particularly important on busy freeways to save user cost and delay for the agency. The second advantage is that expanded asphalt is less prone to moisture susceptibility than emulsified asphalt (4). The post construction reflective cracking mitigation is another attractive feature by CIREAM rehabilitation (1).

The structural layout of CIREAM rehabilitation involves in-place recycling of existing asphalt concrete pavement surface at partial depth. Although full depth reclamation with expanded asphalt (also known as expanded asphalt stabilization) allows in-place recycling of asphalt at its full depth, this paper would focus on the discussion of CIREAM rehabilitation. Therefore, the bottom portion of existing asphalt concrete remains untouched throughout the CIREAM rehabilitation process. The new asphalt overlay surface is added as the riding surface for vehicles. The existing untouched asphalt concrete and CIREAM binder course become two binder courses for this pavement structure. Figure 1 and 2 show the schematic of CIREAM rehabilitation cross section drawings of pre-rehabilitation and post-rehabilitation respectively.

FIGURE 1 CIREAM Pre-rehabilitation Cross Section

FIGURE 2 CIREAM Post-rehabilitation Cross Section
Figure 2 shows post rehabilitation, an additional CIREAM binder course and new overlay is added on top of the existing pavement. The required thickness of the CIREAM binder course and asphalt overlay will be discussed in the design section of this paper.

PLANNING FOR CIREAM

This section discusses the planning aspect of the CIREAM rehabilitation. CIREAM planning involves potential examinations and evaluations prior to the decision for a CIREAM rehabilitation project. The importance of pavement distress survey, pavement evaluation, and forensic investigation of distresses by destructive and non-destructive techniques must not be underestimated.

According to Transportation Association of Canada Pavement Design and Management Guide (6), CIR rehabilitation is a good candidate to rehabilitate pavement with load associated, environmental associated and material associated distresses (6). Structural evaluation of the pavement should be completed before deciding whether CIREAM rehabilitation is the appropriate candidate because CIREAM rehabilitation does not affect the base layers of the pavement. Therefore, the presence of low structural adequacy, base failure, severe reflection cracking or subgrade contamination in the pavement would cause CIREAM rehabilitation be an inappropriate alternative.

Based on project experience in Ohio, Pennsylvania, and Ontario, CIREAM rehabilitation is suitable for pavement that is plagued with the following distresses (1, 2, 8):

- Poor patching
- Block cracking
- Thermal cracking at centreline
- Fatigue cracking
- Raveling
- Roughness

Nevertheless, alligator cracking and reflection cracking requires special investigation by engineers. Alligator cracking appears when series of cracks connect together and forms an area of severely rough surface. The root cause of alligator cracking could be fatigue, base failure, or even temperature related. A possible way to confirm the cause of failure would involve core drilling of the pavement to check the depth of the cracks and the presence of reflection cracks. As a general rule, it is desirable to have a uniform and sealed surface prior to laying asphalt concrete material to ensure adequate strength and adhesion. If reflection cracks are present, AASHTO 93 section 5.4.3 suggested three treatments that could be used prior to CIREAM rehabilitation (7):

- Apply geotextile on the milled surface after the application of crack seal
- Provide a crack relief layer using open graded coarse aggregate and asphalt cement.
- Increase asphalt overlay thickness to reduce bending stress and shear stress

If severe reflection cracks are present on the pavement to the point CIREAM rehabilitation becomes uneconomical, reconstruction or other rehabilitations such as full depth reclamation or expanded asphalt stabilization should be used to pulverize the existing asphalt surface. Reflection cracks have significant influence on the serviceability of the pavement. Therefore, it must be treated and controlled prior to rehabilitation or reconstruction.
DESIGN FOR CIREAM

A CIREAM rehabilitation primarily has few design criteria that need to be considered: overlay design, mill depth design, and foamed asphalt design. Overlay thickness design and mill depth design are primarily consultant’s responsibility. Milling involves removing the existing pavement to a specific depth. The mill depth is a function of the pavement distresses survey result but are generally limited to a maximum of 150 millimetres. OPSS 335 suggests the mill depth should avoid the bottom 25 millimetres of existing hot mix asphalt for CIREAM rehabilitation (3).

Overlay thickness design of CIREAM rehabilitation is the design of the finishing surface course of the new pavement. There are various overlay design models and computer softwares available in the market today to aid this design. The goal of the overlay design is to decide on an adequate thickness for the required traffic load. The detail discussion of overlay design procedure will not be covered in this paper. Table 1 provides three potential design models for overlay design (6, 7, 9).

TABLE 1 Overlay Design Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Input</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHWA Mechanistically Design</td>
<td>ESAL, rutting, fatigue</td>
<td>Modern Pavement Management</td>
</tr>
<tr>
<td>Asphalt Institute Overlay</td>
<td>Representative rebound</td>
<td>Pavement Design and Management Guide</td>
</tr>
<tr>
<td>Design (MS-17)</td>
<td>deflection, ESAL</td>
<td></td>
</tr>
<tr>
<td>AASHTO 93 Overlay Design</td>
<td>Structural number, existing</td>
<td>AASHTO Guide for Design of Pavement Structure</td>
</tr>
<tr>
<td></td>
<td>pavement layers, subgrade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>resilient modulus</td>
<td></td>
</tr>
</tbody>
</table>

Although there is no unique design tool to dictate the overlay design, the pavement designer could use the concept of granular base equivalency (GBE) as a simple verification tool for overlay design to ensure adequate pavement performance. In the GBE calculation, the CIREAM binder course is considered as an equivalent asphalt binder course. For example, the minimum GBE for Ontario highway pavement design is 750 mm (1). Table 2 shows the GBE coefficients and sample calculation based on Ontario conditions (6). OPSS 335 also suggests that overlay thickness should be within 40 mm to 75 mm. For a more sustainable design, the incorporation of RAP shall be considered as potential aggregate substitute for overlay material.

TABLE 2: GBE Coefficients for Ontario

<table>
<thead>
<tr>
<th>Layer</th>
<th>GBE Equivalent Coefficient</th>
<th>Assumed Typical Thickness (mm)</th>
<th>GBE (mm) = Coefficient x Thickness</th>
<th>Total GBE (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Asphalt</td>
<td>2.0</td>
<td>90</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>CIREAM Binder</td>
<td>1.8</td>
<td>100</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Existing Asphalt</td>
<td>1.8</td>
<td>30</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Granular Base</td>
<td>1.0</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Granular Subbase</td>
<td>0.67</td>
<td>300</td>
<td>200</td>
<td>764</td>
</tr>
</tbody>
</table>
Foamed asphalt design involves the cold water injection rate and percent asphalt added to the CIREAM binder. The foamed asphalt design is contractor’s responsibility to follow OPSS 335 to produce the desired CIREAM binder course. A schematic diagram for the CIREAM creation is shown in Figure 3 (10).

![FIGURE 3 Schematic Diagram of CIREAM Process (10)](image)

Figure 3 is the cross section view of a CIREAM train working longitudinally along the pavement. Figure 3 shows milling, addition of cold water and asphalt cement to the existing pavement simultaneously to create an in-place recycling of RAP. Performance graded asphalt cement (PGAC) are commonly used in foamed asphalt operation. The gradation of PGAC is dependent on two factors: the climate that the pavement is exposed to, and contractor’s experience. OPSS 335 suggested minimum a 1% expanded asphalt by mass in the total CIREAM binder course (3). The amount of cold water and its injection rate is typically 1% minimum by volume (1).

CONSTRUCTION CONSIDERATION FOR CIREAM REHABILITATION
This section discusses the construction aspects of CIREAM rehabilitation. First of all, it is desirable to perform CIREAM rehabilitation under warm and dry weather conditions. The construction scope of CIREAM rehabilitation can be summarized into six steps:

1. Setup road closure and traffic protection
2. Cold milling the existing pavement, creation of CIREAM binder course, followed by compaction
3. Cure CIREAM binder course for minimum two days
4. Sweep and clean the cured surface
5. Provide tack coat to CIREAM binder course to enhance adhesion
6. Provide new asphalt overlay and compaction of final surface

Prior to CIREAM rehabilitation, the contractor must provide safety measures for the road closure. These safety measures include traffic protection plans that clearly separate the work zone from the vehicle traffic, traffic control, detour routes, safety barriers, etc… Safety is important for road users and workers repairing the work zone.

Step 2 is the fundamental step of recycling the existing pavement into CIREAM binder course. The schematic diagram of this step is shown in Figure 3 previously. This step
commences once the desired amount of asphalt cement and cold water are programmed in the
CIREAM train. It mills and recycles the pavement simultaneously to produce the CIREAM
binder course. The resulting CIREAM binder surface may not be uniform at the end of the
operation. Therefore, compaction of CIREAM binder course provides the forces to tighten the
bond between RAP and foamed asphalt. Running pneumatic rollers over the surface generally
completes compaction of the CIREAM binder course.

Step 3 is a curing stage of CIREAM binder course. The goal of the curing process is to
evaporate the solvent in the CIREAM binder course. The evaporation stiffens the CIREAM
binder course and hardens the foamed asphalt. The suggested minimum curing time is two days
(1, 4).

Although the CIREAM surface has been compacted prior to the curing stage, this binder
course surface may not be uniform due to fluffing and debris may be present. As a general rule
for typical overlays projects including CIREAM rehabilitation, any debris on the surface shall be
removed prior to application of tack coat. Tack coat is a thin layer of asphalt cement or asphalt
emulsion that forms a bond between existing surface and new overlay (11). Again, contractor
shall carefully calibrate the amount of tack coat. Excess tack coat will caused bleeding on the
pavement; and inadequate tack coat will not provide sufficient bonding between CIREAM binder
and overlay material.

The last step of the CIREAM rehabilitation is asphalt overlay. As previously mentioned,
the contractor will overlay asphalt concrete as per the design requirement and use the regional
specification for asphalt material.

SUBMISSION REQUIREMENTS AND TESTING FOR CIREAM REHABILITATION

The agency performs tests during and at the end of the CIREAM rehabilitation for quality
assurance purposes. For the discussion on this paper, it is limited to the tests performed by MTO
CIREAM rehabilitations. The rationale of the test and minimum acceptable criteria are also
discussed.

The physical requirement of CIREAM binder involves testing three properties: dry
tensile strength, wet tensile strength, and tensile strength ratio. Generally, the indirect tensile
strength test is performed to the CIREAM binder to obtain these three properties. This indirect
tensile strength test may follow procedure such as ASTM D6931-07 or MTO LS-297 (1, 12).
The tensile strength of the CIREAM binder provides indication for (12):

• Moisture susceptibility
• Rutting potential
• Cracking potential

MTO suggests that 90% of the dry tensile strength should be minimum of 350kPa and
100% of dry tensile strength greater than 300kPa (3). For wet tensile strength 90% should have
the minimum of 175kPa and 100% of wet tensile strength greater than 150kPa (3). The tensile
strength ratio of CIREAM binder, which is the quotient of wet tensile strength divided by dry
tensile strength, should be minimum of 50% (3). On a side note, the tensile strength ratio of a
Superpave asphalt mix would require 80% (13). Possible reasons for the reduction of minimum
tensile strength required for CIREAM binder:

• CIREAM binder does not have the same strength and uniformity compared to virgin
  material used for superpave mix on surface course.
• CIREAM binder is not a surface course, so it does not need a high tensile strength ratio to
  ensure adequate strength on wet conditions.
A high tensile strength requirement may be costly to achieve, hence it defeats the purpose of recycling. If a section of the pavement does not satisfy the tensile strength requirement, it is the contractor’s responsibility to remove the unacceptable material and replace with proper binder course substitute. Severe segregation, stripping, and raveling of CIREAM binder would also deem for replacement for binder course substitute (3).

Bulk specific gravity is also commonly tested on CIREAM binder. Bulk specific gravity is the ratio of weight of unit volume aggregate to the weight in air of equal volume distilled water at same stated temperature (14). Bulk specific gravity is a measure of the density and absorption properties of a material. In pavement mix design such as Marshall or Superpave, the void in mineral aggregate (VMA) calculation requires the bulk specific gravity of the material (15, 16). VMA is a measure of intergranular void space between aggregate after compaction included air and asphalt presented in the form of total volume of a sample (15). It provides an indicator how well the CIREAM binder is blended during the rehabilitation.

Post construction tests are also crucial for quality assurance check by agencies. Common post construction tests include falling weight deflectometer (FWD) test and resilient modulus test. The main advantage of FWD test is a non-destructive mean of structural evaluation to determine the deflection response of the pavement for the given impact load. Resilient modulus is another way to determine the stiffness of the pavement. Both FWD test and resilient modulus test results can be used as input for pavement structural design in the future.

ENVIRONMENTAL EVALUATION OF CIREAM

This section evaluates the environmental impacts of CIREAM rehabilitation. As mentioned previously, CIREAM rehabilitation has environmental benefit such as high recycled content, reduced energy use in cold milling process of existing pavement, and potential to use RAP as overlay material. The amount of energy use and emission released to the environment directly affects our quality of living.

For the purpose of this paper, PaLATE software is used to estimate energy and emission of CIREAM rehabilitation and conventional mill and overlay. Horvath at the University of California at Berkeley originally developed PaLATE as a freeware to estimate economic and environmental cost (17). PaLATE is capable in estimating the energy use and emission of a road construction or rehabilitation projects based on pavement thickness design. For the estimation, Table 3 summarized the two rehabilitation designs used in Highway 7 Perth in Ontario, Canada (1).

### TABLE 3 Design Input for PaLATE

<table>
<thead>
<tr>
<th>Design Layer</th>
<th>CIREAM</th>
<th>Mill and Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>50mm new overlay</td>
<td>130mm new overlay</td>
</tr>
<tr>
<td>Layer 2</td>
<td>100mm CIREAM binder course</td>
<td>100mm new granular base</td>
</tr>
<tr>
<td>Layer 3</td>
<td>150mm existing asphalt binder course</td>
<td></td>
</tr>
<tr>
<td>Layer 4</td>
<td>160mm existing granular base</td>
<td></td>
</tr>
<tr>
<td>Layer 5</td>
<td>450mm existing granular subbase</td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>910mm GBE</td>
<td>840mm</td>
</tr>
<tr>
<td>GBE</td>
<td>812.5mm GBE</td>
<td>705mm GBE</td>
</tr>
</tbody>
</table>

For simplicity of the PaLATE estimation, the pavement section is assumed to have a length of 1 kilometre and total pavement width of 7 metres (2-lane highway with 3.5 metres lane width). Table 4 shows the CO₂ and energy estimation from PaLATE.
TABLE 4 PaLATE Results

<table>
<thead>
<tr>
<th>Design Option</th>
<th>CIREAM</th>
<th>Mill and Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (GWP)</td>
<td>44</td>
<td>107</td>
</tr>
<tr>
<td>Energy (MJ)</td>
<td>845,000</td>
<td>2,000,000</td>
</tr>
</tbody>
</table>

The results in Table 4 clearly show that CIREAM rehabilitation is a more environmental friendly rehabilitation than mill and overlay. Combined with the cost savings from the in-place recycling of existing asphalt, CIREAM rehabilitation is one of the most sustainable pavement rehabilitation available in the market today.

CONCLUSIONS

In conclusion, this paper explores the essential of CIREAM rehabilitation qualitatively in terms of its features, planning, design, construction and environmental evaluation. CIREAM rehabilitation features an in-place recycling of existing pavement that uses of foamed asphalt to stabilize the existing asphalt pavement. The planning of CIREAM investigates the pavement distresses that designers should be aware of prior to decide CIREAM rehabilitation as the most sustainable alternative. The design of CIREAM rehabilitation includes consultant design of overlay thickness and mill depth; the contractor designs the CIREAM binder and overlay mix. Construction aspects of CIREAM rehabilitation are explored to understand how to produce an effective CIREAM rehabilitation. Quality assurance tests are discussed because it demonstrates why agencies perform tests to ensure pavement serviceability. Lastly, the environmental impact of CIREAM construction is evaluated using PaLATE software and shows that it provides emission and energy savings compared to conventional mill and overlay.

With many road infrastructures currently aging in North America, the selection of proper pavement rehabilitation is essential to maximize the level of service for users. CIREAM rehabilitation will continue to grow strong as sustainable pavement rehabilitation available in the market. Nevertheless, the importance of pavement evaluation, distress survey, prediction models, and good understand of different pavement technologies cannot be underestimated in the determination of best pavement rehabilitation available for a given roadway.

ACKNOWLEDGEMENT

Our genuine and sincere thank to:

- Mr. Vince Aurillio, P.Eng., Manager at DBA Engineering Limited,
- Dr. Ludomir Uzarowski, P.Eng., Associate at Golders Associates Limited.

for their assistance in providing their experience with CIREAM practices and pavement design practices in the province of Ontario.

REFERENCES


