COLD IN-PLACE RECYCLING USING ASPHALT EMULSION
FOR STRENGTHENING FOR SASKATCHEWAN LOW
VOLUME ROADS

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Grain transportation rationalization and value added initiatives within the agriculture and resource sectors are significantly increasing truck traffic on Saskatchewan roads. As a result, there is a need to strengthen many low volume roads. However, budget constraints and aggregate shortages in some areas of the province render conventional road strengthening techniques untenable. Because of this, Saskatchewan Department of Highways and Transportation is investigating cold in-place recycling and alternative strengthening techniques for low volume roads. Several test sections were constructed during the summer of 1999 to evaluate cold in-place recycled and asphalt emulsion strengthened road systems. This study included a sensitivity analysis of two cold in-place recycled mixes from Highway 15 (recycled asphalt mat on subgrade and a recycled granular patch) and a virgin laboratory blend control mix (standard SDHT Type 71 hot mix aggregate blend), mixed with two asphalt emulsions (HF-150S and SS-1C). Compacted specimens were tested for standard Proctor moisture-density and Marshall stability. The laboratory observations were compared with those in the Highway 15 field test sections. This study identified specific issues required for the engineering, construction and quality control-quality assurance of cold in-place recycled and asphalt emulsion stabilized road systems.

Résumé

La rationalisation du transport du grain et les initiatives de la valeur ajoutée dans les secteurs de l'agriculture et des ressources augmentent considérablement la circulation des camions sur les routes de la Saskatchewan. Il en résulte donc un besoin de renforcer plusieurs routes à faible trafic. Cependant, les contraintes budgétaires et la pénurie de granulats dans certaines régions de la province rendent indéfendables les techniques conventionnelles de renforcement des chaussées. À cause de cela, le Ministère de la Voirie et des Transports de la Saskatchewan examine le recyclage à froid en place et les techniques alternatives de renforcement pour les routes à faible trafic. Plusieurs sections d'essais ont été construites durant l'été 1999 pour évaluer les réseaux routiers recyclés à froid en place et renforcés à l'émulsion de bitume. Cette étude inclut une analyse de sensibilité de deux enrobés recyclés à froid en place: un de l'autoroute 15 (couche de revêtement bitumineux recyclé sur une infrastructure et un rapiéçage granulaire recyclé) et un d'un mélange contrôle vierge en laboratoire (enrobé à chaud standard SDHT Type71), malaxés avec deux émulsions de bitume (HF-150S et SS-1C). Sur des échantillons compactés, on a fait les essais Proctor standard de densité - humidité et l'essai de stabilité Marshall. Les données de laboratoire ont été comparées à celles des sections d'essais de l'autoroute 15. Cette étude a identifié des résultats spécifiques requis par l'ingénierie, la construction, le contrôle et l'assurance de la qualité des réseaux routiers recyclés à froid en place et stabilisés à l'émulsion de bitume.
1 INTRODUCTION

Saskatchewan Department of Highways and Transportation (SDHT) is responsible for maintaining approximately 10,000 km of low volume roads, which accounts for more than a one-third of the Provincial Highway system [1]. Many of these low volume roads, such as thin membrane surfaced (TMS) and asphalt mat on subgrade (AMOS) are rapidly deteriorating because of increasing truck traffic resulting from rationalization of the transportation system. As a result, much of the Saskatchewan low volume road system needs to be strengthened. However, budget constraints render conventional strengthening solutions untenable in many applications. Cold in-place recycling and asphalt emulsion strengthening may present an economical interim solution for some failing low volume roads.

1.1 Background

From 1950 to 1970, SDHT constructed approximately 8600 km of TMS and AMOS roads throughout the province. TMS and AMOS roads did not significantly improve structural strength, but provided a cost effective dust, mud, and stone-free rural road system. Figure 1 compares the cross sections of a typical TMS/AMOS road structure and a standard structural pavement [2].

![TMS/AMOS and Standard Structural Pavement Cross-Sections](image)

**Figure 1  TMS/AMOS and Standard Structural Pavement Cross-Sections**

(TMS = thin membrane surfaced; AMOS = asphalt mat on subgrade; HMAC = hot mix asphalt concrete)

Rationalization of transportation in Canada has encouraged the use of larger, more efficient trucks, including eight and nine-axle commercial trucks, on rural roads. The increase in the weights,
dimensions and volumes of the truck traffic on Saskatchewan roads poses a serious problem with regards to the performance of Saskatchewan TMS and AMOS roads [1]. Currently, SDHT employs a number of preservation treatments for TMS and AMOS roads [2].

- Graded aggregate seal: surface treatment for minor fatigue cracking or rutting.
- Cold mix patching: repair of surface breaks in localized areas with intensive cracking.
- Base overlay with a double-seal wearing course: complete rehabilitation of failed low volume roads.
- Reversion to gravel: interim treatment to improve the safety of failing low volume roads under budget constraints.

Because current budgets are unable to maintain an acceptable level of service across the entire road network using conventional preservation treatments, innovative strengthening treatments are being investigated. Recent advancements in cold in-place recycling (CIR) make CIR an attractive treatment alternative for strengthening Saskatchewan low volume roads [3, 4, 5]. An advantage to CIR technology is that it provides the ability to blend stabilizers into the reclaimed material via computer-controlled injection directly into the milling drum.

In 1999, SDHT undertook a number of CIR projects involving asphalt emulsion stabilization. The objective of this study was to evaluate cold in-place recycled mixes stabilized with alternative asphalt emulsions. The scope of this study included:

- Reclaimed material obtained from the rehabilitation of Highway 15-10:

![Figure 2 Stabilization With Cold In-Place Recycling](image)
Recycled asphalt pavement comprising 50 mm of virgin aggregate milled into the existing asphalt mat on a clay-till subgrade.

Recycled asphalt pavement comprising 50 mm of virgin aggregate milled into a double seal-wearing course over a granular patch.

- Standard SDHT Type 71 aggregate obtained from Highway 1-20 construction site.
- Asphalt emulsion stabilizers HF-150s and SS-1c.
- Marshall specimens prepared based on Asphalt Institute MS-19, AASHTO Task Force 38 and Oregon DOT standard methods [6, 7, 8, 9].
- Asphalt emulsion contents based on surface and base course mix design as per Asphalt Institute MS-19.
- Mix evaluation including Proctor moisture-density and Marshall stability of the alternative cold in-place recycling mixes.

2 HIGHWAY 15 PRELIMINARY SITE INVESTIGATION

Figures 3 and 4 show common distresses found throughout the Highway 15-10 test site prior to reclamation. Common distresses found on Highway 15-10 included low to moderate fatigue cracking, moderate shoving, potholes, severe rutting, transverse cracking, and numerous surface breaks on the outer and inner wheel path. The as-built records of Highway 15-10 show 150 mm of hot mix asphalt constructed over a prepared subgrade. However, years of traffic and preservation treatments have resulted in variability of the asphalt concrete mat. Figure 5 illustrates the ground penetrating radar (GPR) thickness-profile for one of the Highway 15-10 test sections. As seen in Figure 5, the surface layer was found to range from 25 mm to 225 mm with several granular deep patches.
Figure 4  Typical Surface Distresses on Highway 15-10

Figure 5  Ground Penetrating Radar Thickness Plot of Highway 15-10
3 HIGHWAY 15-10 CONSTRUCTION RESULTS

Figure 6 illustrates an area of the test section that contained a granular patch prior to rotomixing. The steel drum rollers caused a checking failure in the surrounding area, except for the area that contained the granular patch. Not only did this section compact better, it withstood the short-term impact of the traffic unlike the rest of the test sections, which can be seen in Figure 7. Soon after Highway No. 15-10 was open to traffic, numerous soft spots began to develop at various locations throughout the test sites.
4 LABORATORY CHARACTERIZATION OF ROTOMIXED AGGREGATE MATERIALS

Ground Penetrating Radar was used to identify specific areas from which samples were retrieved from Highway 15-10, including areas where 50 mm of granular base had been rotomixed into the asphalt mat, and where 50 mm of granular base had been rotomixed into a granular patch. In addition to the recycled material, a laboratory control blend was prepared using a standard SDHT Type 71 Marshall dense graded hot mix aggregate gradation. (Is there some simple way of characterizing “SDHT Type 71” aggregate, for the benefit of those readers not familiar with “SHDT Type 71”?). Figure 8 illustrates the grain size analysis results obtained from the four aggregate types considered in this study. The SDHT Type 71 hot mix aggregate blend was prepared in the laboratory using the gradation specified for Highway 1-20 paving project and the rotomixed aggregate from Highway 15-10 was taken directly from the roadbed after the first pass with the cold in-place recycler.
At first glance, the grain size distribution of the rotomixed material retrieved from the Highway 15-10 roadbed showed little difference between the rotomixed AMOS and granular patch. However, further investigation determined that the CIR mixtures contained significant clay lumps as shown in Figure 9. To quantify the portion of clay lumps contained within the Highway 15-10 rotomixed material, the recycled materials were soaked in water for 24 hours and periodically agitated by hand to disintegrate the clay lumps. The soaked recycled materials were then subjected to a washed grain size analysis, as illustrated in Figure 10.

The proportion of residual asphalt cement in the recycled mix was determined by placing the CIR material in an ignition oven to burn off all the asphalt cement particles. The resulting extracted gradation, which excludes the clay lumps and asphalt cement in the CIR material is also shown in Figure 10.
Sand equivalency testing was also performed to quantify the amount of fines in the material. The sand equivalency value is computed as the ratio of the sand to clay fractions as determined by settlement in a standing hydrometer and is expressed as a percentage. As seen in Figure 11, the CIR granular patch and SDHT Type 71 had sand equivalency values of 61 and 51, respectively. Both of these materials meet the specifications for a SuperPave™ Level 1 hot mix. However, the CIR AMOS material did not meet the minimum SuperPave™ criterion for sand equivalency of 36.

Figure 10 shows the fine and sand sized particles of each material gradation. It can be seen that the percent fines (defined as percent passing the No. 200 or 0.071 mm sieve) in the Highway 15-10 rotomixed material increases substantially once the clay lumps are broken down. The granular patch contained approximately ten percent passing the No. 200 sieve while the rest of the AMOS showed approximately 17 percent passing the No. 200 sieve. This indicates that the subgrade was probably milled into the reclaimed material during reclamation of the AMOS.
Figure 10  Grain Size Distribution of Highway 15-10 Cold in-Place Recycled (CIR) Materials
(AMOS = asphalt mat on subgrade)

Figure 11  Sand Equivalency of Highway 15-10 Cold in-Place Recycled Materials (CIR) and Saskatchewan Department of Highways and Transportation (SDHT) Type 71 Hot Mix Aggregate
(AMOS = asphalt mat on subgrade)
5 LABORATORY ANALYSIS OF ASPHALT EMULSION

The characteristics of each asphalt emulsion used in this study are summarized in Table 1.

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>HF-150S*</th>
<th>SS-1C**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity @ 50 deg C, S.F.S. (ASTM D 244)</td>
<td>65</td>
<td>--------</td>
</tr>
<tr>
<td>Viscosity @ 25 deg C, S.F.S. (ASTM D 244)</td>
<td>--------</td>
<td>23</td>
</tr>
<tr>
<td>Penetration of residue@ 25 deg C (100gm, 5 sec), dmm (ASTM D 5)</td>
<td>182</td>
<td>200</td>
</tr>
<tr>
<td>Residue by distillation, % by weight (ASTM D 244)</td>
<td>61.1</td>
<td>59.4</td>
</tr>
<tr>
<td>Total distillate, % by weight (ASTM D 244)</td>
<td>38.7</td>
<td>40.5</td>
</tr>
<tr>
<td>Oil portion of distillate, % by weight, (ASTM D 244)</td>
<td>1.7</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* HF-150s is a high float medium setting asphalt emulsion designed for seal coating
** SS-1c is a slow setting cationic asphalt emulsion.

As can be seen in Table 1, the properties of HF-150s and SS-1c are similar. The primary difference between HF-150s and SS-1c is that HF-150s is a medium set emulsion where as SS-1c is a slow setting emulsion. The Asphalt Institute’s Manual Series -19 (MS-19) [7] states that a medium set emulsion is normally used with aggregates that do not have an excessive amount of fines. Conversely, slow setting emulsions are normally used with aggregates that have a significant amount of fines [7]. HF-150s emulsifier also imparts a gel structure to the asphalt residue. This gel structure and chemical charge results in increased film thickness, which prevents the asphalt cement from bleeding and draining down off the aggregates. SS-1 is slow setting because of the higher amount of emulsifier present in the emulsion, which prevents it from breaking as soon as it becomes in contact with the aggregate.

6 LABORATORY MIX ANALYSIS

The Asphalt Institute MS-19 [7] mix analysis procedure was used to determine the target design asphalt emulsion contents for each mix. MS-19 contained two formulas based on the percentage of aggregate passing the 4.75 mm (No. 4) sieve.

$$\text{Base Mix Percent Emulsion} = \frac{\left[(0.06 \times B) + (0.01 \times C)\right] \times 100}{A} \tag{1}$$

$$\text{Surface Mix Percent Emulsion} = \frac{\left[(0.07 \times B) + (0.03 \times C)\right] \times 100}{A} \tag{2}$$

Where:
- Percent Emulsion = estimated initial percent asphalt emulsion by dry weight of aggregate
- A = percent residue of emulsion by distillation
- B = Percent of dry aggregate passing 4.75mm (No. 4) sieve
- C = Percent of dry aggregate retained on 4.75mm (No. 4) sieve
Table 2 summarizes the emulsion contents required for the CIR AMOS, CIR Granular Patch and SDHT Type 71 as specified by MS-19 for surface and base mix.

Table 2  Target Design Percent Asphalt Emulsion Content for Various Aggregate Types

<table>
<thead>
<tr>
<th>AGGREGATE TYPE</th>
<th>MIXTURE TYPE</th>
<th>TARGET DESIGN ASPHALT EMULSION, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR AMOS</td>
<td>Base</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>8.0</td>
</tr>
<tr>
<td>CIR Granular Patch</td>
<td>Base</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>9.0</td>
</tr>
<tr>
<td>SDHT Type 71</td>
<td>Base</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>8.0</td>
</tr>
</tbody>
</table>

CIR = cold in place recycled; AMOS = asphalt mat on subgrade; SDHT = Saskatchewan Department of Highways and Transportation

6.1 Standard Proctor Moisture Density Evaluation

Previous works recommend compacting asphalt emulsion mixes at total liquids content equal to optimal standard Proctor moisture content [7, 8, 9]. Standard Proctor moisture-density properties of each aggregate type at each design asphalt emulsion content were therefore determined for the three mix aggregates and two asphalt emulsion types. As seen in Figures 11 through 16, the optimum total liquids content with asphalt emulsion added was always higher than without asphalt emulsion whereas the maximum dry density with asphalt emulsion was always lower than without asphalt emulsions added to the mix. It is also interesting to note that materials compacted with SS-1c had a higher dry density than when compacted with HF-150s.

It was found during lab characterization that the total liquids content significantly affects mixing and coating of aggregate particles. It was found that SS-1c coated the aggregate particles reasonably well at standard optimum moisture content, whereas HF-150s was observed to have poor coating at all moisture contents. Similarly, the SDHT Type 71 standard Marshall dense graded hot mix aggregate blend showed that the HF-150s broke once the emulsion came into contact with the sands and fines, making it difficult to achieve reasonable coating at any water content. Conversely, SS-1c asphalt emulsion coated the SDHT Type 71 virgin aggregate blend well at optimal moisture content.
Figure 11  Standard Proctor Moisture Density Relationship of Cold In-place Recycled Asphalt Mat On Subgrade With and Without the Slow Setting Cationic Asphalt Emulsion SS-1c

Figure 12  Standard Proctor Moisture Density of Cold In-Place Recycled Asphalt Mat on Subgrade With and Without the High Float Asphalt Emulsion HF-150s
Figure 13  Standard Proctor Moisture Density Relationship of Cold In-place Recycled Granular Patch With and Without Slow Setting Cationic Asphalt Emulsion SS-1c

Figure 14  Standard Proctor Moisture Density Relationship of Cold In-place Recycled Granular Patch (GP) With and Without High Float Asphalt Emulsion HF-150s
Figure 15 Standard Proctor Moisture Density Relationship of Saskatchewan Department of Highways and Transportation (SDHT) Type 71 Aggregate With and Without Slow Setting Cationic Asphalt Emulsion SS-1c

Figure 16 Standard Proctor Density of Saskatchewan Department of Highways and Transportation (SDHT) Type 71 Aggregate With and Without High Float Asphalt Emulsion HF-150s
6.2 Marshall Stability-Flow Analysis

Marshall specimens were prepared as specified in Asphalt Institute MS-19 mix design method for asphalt emulsion stabilized dense-graded aggregate mixes. Marshall specimens were prepared for the different aggregate gradations, asphalt emulsions, and asphalt emulsion contents as shown in Figure 17.

Each aggregate type was tested with two different amounts of SS-1c and HF-150s asphalt emulsion in accordance with the base and surface mixture calculations of MS-19. Each specimen was compacted at optimum total-liquids content determined by the Proctor moisture-density relationships.

![Figure 17 Marshall Specimens Across Aggregate Types and Asphalt Emulsion](image)

Figure 17 illustrates Marshall stability with respect to percent residual asphalt cement content across the aggregate types and asphalt emulsions considered in this study. As seen in Figure 18, the SDHT Type 71 hot mix aggregate produced a higher stability relative to the CIR materials and the stability of the SS-1c stabilized Marshall specimens was found to be higher than that of the HF-150s Marshall specimens. Although all Marshall stability results were found to exceed the minimum required Marshall stability as specified by MS-19, the Marshall stability was found to decrease with increased residual asphalt emulsion. The decreasing trend in Marshall stability does not coincide with conventional reasoning of adding a stabilization material that induces tensile strength and stiffness into the material system. Therefore, it was hypothesized that some additional phenomenon may be affecting the Marshall stability results.

During specimen preparation and evaluation, a number of possible sources for the observed decreasing trends in Marshall stability were hypothesized. Firstly, the clay lumps that were pulled into the AMOS mix during the construction process may have acted as weak aggregate and may have affected the mix stability results. Secondly, after laboratory curing as specified by MS-19, the center of the specimens were noticeably darker than the outer faces as shown in Figure 19. This may indicate that specimen curing was not complete at time of testing.
Figure 18  Effect of Residual Asphalt Content on Marshall Stability of Several Aggregate Mixtures

(SS-1c = slow-setting cationic asphalt emulsion; AMOS = asphalt mat on subgrade; SDHT = Saskatchewan Department of Highways and Transportation)
During the Marshall stability testing of the specimens, significant bulging of the sample perpendicular to the Marshall platens was also observed. Samples were split in half and were found to be relatively moist. This observation further supports suspicion that the samples were not fully cured at the time of testing.

The observed curing variability led to further testing to quantify the effect of total liquid content at constant emulsion content. The CIR Granular Patch with seven percent SS-1c was arbitrarily selected for the moisture content sensitivity analysis. The total liquid content was varied in one percent increments from nine percent to thirteen percent (optimal total liquids content of eleven percent ± two percent).

Figure 20 shows that the mixes with higher total liquid contents at time of compaction produced lower Marshall stabilities. Figure 21 illustrates that increased water content at the time of compaction resulted in more water being retained in the sample after the same period of curing. The resulting trend of decreasing Marshall stability confirms that the degree of curing can vary with respect to moisture content. It is interesting to note that the Marshall samples tested at eleven percent total liquids content did not cure at the same rate as the other samples due to experimental error.
Figure 20  Effect of Total Liquids Content on Marshall Stability for Cold In-place Recycled Granular Patch Materials containing Seven Percent Slow Setting Cationic Asphalt Emulsion SS-1c
7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Recent rationalization of the transportation in Canada has significantly increased the amount of truck traffic on the Saskatchewan low volume road system. As a result, the thin membrane surfaced (TMS) and asphalt mat on subgrade (AMOS) roads are experiencing commercial truck loads which they were never designed to carry. Consequently, many of these low volume roads are rapidly deteriorating, and SDHT is investigating cold in-place recycling as an alternative to strengthen Saskatchewan low volume roads.

The objective of this study was to evaluate cold in-place recycled and asphalt emulsion stabilized mixes from Highway 15. This study revealed that moisture content, asphalt emulsion, cure rate, and recycled material variability could have a significant impact on the behaviour of cold in-place recycled asphalt emulsion systems. Current asphalt emulsion mix design methods were found to be diverse, and rely a great deal on empiricism and experience. As a result, conventional mix analysis methods may not provide the degree of control required to quantify performance related properties.

The optimum total liquids content for compaction of asphalt emulsion stabilized mixes is often assumed to be equal to the optimum water content for compaction of unmodified soil, as per the standard Proctor moisture-density relationship. However, this assumes that all asphalt emulsions exhibit viscosities and compaction properties similar to that of water. This study showed that different asphalt
emulsions significantly influence the Proctor moisture-density relationship of asphalt emulsion stabilized mixes.

Gravimetric water content retained in the sample after curing appears to affect Marshall stability. This study found that curing protocols in mix design procedures should not be based on specific times and temperatures, but rather be based on maximum retained moisture content which will account for variability in time, temperature and humidity during curing.

The percent fines in the mix was also found to affect the behavior of the asphalt emulsion mix properties as seen in the laboratory and in the field. As seen on Highway 15-10, the fines incorporated in the subgrade during the cold in-place recycling process adversely affected the performance of the recycled mix. In the mixing applications, aggregate must have a very low percentage of sand and fines to mix well with medium set emulsions like HF-150s. In addition, clay was present in the rotomixed material as conglomerated lumps. During the injection of the asphalt emulsion, clay lumps were coated with emulsion, but were not penetrated. It is currently unclear what amount of fines warrants the use of a slow set emulsion, such as SS-1c, as compared to a medium set emulsion, such as HF-150s.

This study identified the need for improved site investigation, laboratory testing and specifications. Quality control and quality assurance criterion specifically intended for cold in-place recycling and asphalt emulsion stabilization are required. The following recommendations are suggested for future research involving cold in-place recycling and asphalt emulsion stabilization:

a) Specimens used in the mix design process should be tested at constant gravimetric water content, rather than curing specimens for a set time and temperature.
b) Quantify in-situ road structure materials accurately to ensure more compatible matching of emulsion and aggregate.
c) Define the selection envelope for standard asphalt emulsions and cold in-place recycled materials on the basis of fines and sand sized particle content.
d) Maintain tight controls on the depth of reclamation to ensure only the materials specified in the design are considered in the field.
e) Performance-based structural equivalences should be based on the structural benefits obtained from cold in-place recycled and stabilized road systems.
8 REFERENCES