Determining Time to Uncontrolled Trafficking After Chip Seal Construction

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Abstract

Predicting the strength of the emulsion residue in a chip seal is directly related to when the chip seal can be opened to traffic after construction. This strength is usually judged subjectively during construction by experienced personnel. Unfortunately, this experience is often gained through the empirical process that often leads to vehicle damage when residues that have not gained sufficient strength release chips under traffic loads. This research was conducted to help eliminate the subjectivity involved in determining when a chip seal can be safely opened to traffic without undue chip loss. The study began with the hypothesis that the moisture content of the emulsion-aggregate system was directly related to residue strength. To test this theory a revised version of ASTM D7000 was developed to measure chip loss for four different aggregate sources and five asphalt emulsions using a full-factorial experiment design. Results indicate the amount of water remaining in the emulsion is directly related to residue strength, as expected. Therefore, by establishing the relationship between water content and chip loss in the revised sweep test the time required in the field before traffic is allowed on the fresh chip seal may be estimated in advance. Other results indicate little correlation between emulsion particle charge and aggregate type at the higher moisture loss level tested, but a possible correlation at the lower moisture loss level tested.

Keywords

Chip seal, sweep test, chip loss, aggregate-emulsion compatibility, windshield damage

Problem Statement

Successful chip seal construction depends on a combination of rational science and qualitative judgment in the field. Success is usually measured by a lack of customer complaints that sometimes occur when loose aggregate chips come in contact with windshields at high speed. Allowing traffic on a fresh chip seal too soon can result in windshield damage if the asphalt binder lacks sufficient strength to resist dislodgement. There-
fore, timing the removal of traffic control is a key element in the success of any chip seal project. A desirable addition to the technology would be a quantitative process that identifies when a chip seal is ready for uncontrolled traffic.

LITERATURE REVIEW

Vehicular damage is a major reason cited by owners for not using chip seals for pavement preservation (Gransberg 2005; Shuler, 1998). This damage is often the result of flying aggregate chips removed by traffic because of inadequate adhesion to the asphalt binder. Sweep tests have been developed for various purposes with respect to chip seal construction (Cornet (1999), Barnet, McCune and Vopat (2001)). The Montana Sweep Test is the most direct method (Lynch, 2007). This procedure sweeps the actual chip seal during construction. When the amount of chips dislodged during the test is less than 10 percent, the chip seal is judged ready for traffic. With practice this procedure probably works well. However, it requires personnel conduct the test in the field during construction. This exposes technicians to traffic and construction hazards. The ASTM D7000 (ASTM 2004) procedure was developed from earlier research (Cornet, 1999), Barnet, McCune and Vopat, 2001) to predict chip loss in emulsion chip seals. This procedure is relatively effective at estimating differences in adhesive abilities of different emulsions when the same aggregate is tested. However, the procedure is not as useful when different aggregates are evaluated with different emulsions. This is because the test utilizes a template to establish the thickness of emulsion application rate. While a single emulsion application rate is suitable for relative comparison between emulsions, when aggregate sizes differ the embedment percentage changes which affects adhesive strength. However, a new laboratory test has been reported (Shuler and Lord, 2009) based on D7000 which eliminates much of the variability associated with the original test and may be a method for predicting early chip strength in the field.

OBJECTIVE

The objective of this research was to develop a means for determining when emulsified asphalt chip seals possess adequate adhesive strength to resist chip loss due to vehicular traffic.

RESEARCH APPROACH

The first step in this research was to develop a repeatable laboratory test that measures the chip loss of emulsified asphalt chip seals after surface abrasion at different ‘system’ moisture contents. The second step was to develop a correlation between the results of this laboratory test and adhesive strength gain for emulsified asphalt chip seals in the field. This correlation could then be utilized to predict, prior to construction, the moisture content required to achieve adequate adhesive strength so the chip seal could be opened to traffic with less potential for vehicular damage.

An existing sweep test described by ASTM D7000 was used as the basis for this research in step one. The test appeared to be a reasonable approach to simulating the forces present in the field which dislodge aggregate chips in chip seals. Therefore, an experiment was designed to measure the ability of the test to discriminate between independent variables believed to affect early chip seal performance. These variables were curing level of the emulsion and moisture content in the aggregate chips. In addition, the effect of aggregate type on emulsion type was desired to determine if the mineralogy of the aggregate affects chip loss as a
function of emulsion chemistry. Therefore, four aggregates and five emulsions were chosen to evaluate early chip seal performance between positively and negatively charged aggregates and commonly used anionic and cationic emulsions. The modified sweep test has been described elsewhere and will not be repeated here (Shuler and Lord 2009).

**EXPERIMENT DESIGN**

**Independent Variables**

Independent variables in this experiment are shown below:

- **Aggregates:** Basalt, Granite, Limestone, Alluvial
- **Emulsions:** RS-2, RS-2P, CRS-2, CRS-2P, HFRS-2P
- **Emulsion Cure:** 40%, 80%
- **Aggregate Moisture:** Dry, Saturated Surface Dry (SSD)

A full-factorial experiment was designed for each emulsion according to the model shown below:

\[ Y_{ijkl} = A_i + W_k + M_l + AW_{ik} + AM_{il} + WM_{kl} + AW_{Mkl} + \epsilon_{ijkl} \]

Where,

- \( Y_{ijkl} \) = Chip Loss, %
- \( A_i \) = effect of aggregate i on mean
- \( W_k \) = effect of water removed k on mean
- \( M_l \) = effect of aggregate moisture l on mean
- \( AW_{ik} \), etc. = effect of interactions on mean
- \( \epsilon_{ijkl} \) = random error for the ith aggregate, jth emulsion, kth water removed, and lth replicate

The experiment was blocked with respect to emulsion so that each emulsion could be utilized at the same time after formulation. This eliminated potential variability that could be associated with differences in emulsion age.

**MATERIALS**

Emulsions were manufactured by SEM Materials in Commerce City, Colorado with properties shown in Table 1. Limestone (LSTN) aggregate was obtained from the Castle Materials quarry in Colorado Springs, CO, granite (GRNT) was obtained from the Lafarge quarry in Pueblo, CO, basalt (BSLT) from the Asphalt Paving Company quarry in Golden, CO and the alluvial (ALLV) from Everist Materials in Silverthorne, CO. The properties of these materials are presented in Table 2.
## Table 1. Emulsion Properties

<table>
<thead>
<tr>
<th>Emulsion Tests</th>
<th>RS-2P</th>
<th>RS-2</th>
<th>CRS-2</th>
<th>CRS-2P</th>
<th>HFRS-2P</th>
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</thead>
<tbody>
<tr>
<td>Viscosity, SFS 122F</td>
<td>108</td>
<td>96</td>
<td>78</td>
<td>119</td>
<td>132</td>
</tr>
<tr>
<td>Storage Stability, 1 day, %</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
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<tr>
<td>Sieve Test, %</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Demulsibility, 35 ml</td>
<td>65</td>
<td>72</td>
<td>76</td>
<td>76</td>
<td>42</td>
</tr>
<tr>
<td>Residue, by evaporation, %</td>
<td>65.1</td>
<td>68.0</td>
<td>67.9</td>
<td>67.7</td>
<td>65.3</td>
</tr>
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</table>

## Table 2. Aggregate Properties

<table>
<thead>
<tr>
<th>Sieve No. (in.)</th>
<th>Sieve Size (mm)</th>
<th>LSTN</th>
<th>GRNT</th>
<th>BSLT</th>
<th>ALLV</th>
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<tbody>
<tr>
<td>3/4&quot;</td>
<td>19.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>1/2&quot;</td>
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<td>100</td>
<td>100</td>
<td>100</td>
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</tr>
<tr>
<td>3/8&quot;</td>
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<td>99</td>
<td>100</td>
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<tr>
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<td>50</td>
<td>79</td>
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<tr>
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<tr>
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<td>1.18</td>
<td>1</td>
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<td>200</td>
<td>0.075</td>
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<td>1</td>
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<table>
<thead>
<tr>
<th>Property</th>
<th>LSTN</th>
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<th>BSLT</th>
<th>ALLV</th>
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<tbody>
<tr>
<td>Bulk specific gravity</td>
<td>2.615</td>
<td>2.612</td>
<td>2.773</td>
<td>2.566</td>
</tr>
<tr>
<td>Loose unit weight, lbs/ft³</td>
<td>78.3</td>
<td>84.0</td>
<td>92.2</td>
<td>86.1</td>
</tr>
<tr>
<td>L.A Loss, %</td>
<td>26.3</td>
<td>27.8</td>
<td>20.1</td>
<td>22.0</td>
</tr>
<tr>
<td>Flakiness Index</td>
<td>33.8</td>
<td>5.8</td>
<td>13.1</td>
<td>10.5</td>
</tr>
</tbody>
</table>

## RESULTS FROM SWEEP TESTING LABORATORY MATERIALS

Results of the laboratory test are shown in Figures 1 through 4. These figures indicate that at 40 percent curing, chip loss is significant and appears to not be related to emulsion type, aggregate or chip moisture content. However, at 80 percent curing, differences begin to appear. There appears to be a significant difference between polymer and non-polymer modified emulsions, the polymer modified emulsions retaining more chips than the non-modified emulsions, with the exception of the RS-2P, which did not perform as well as the other modified binders.
Figure 1 - Sweep Test Results for All Emulsions Under Dry-40% Cured Conditions

Figure 2. Sweep Test Results for All Emulsions Under Dry - 80% Cured Conditions
RESULTS FROM SWEEP TESTING FIELD MATERIALS

The sweep test was conducted for aggregates and emulsions obtained from three test pavements constructed in Arches National Park, UT, CR11 in Frederick, CO in 2008 and on US101 near Forks, Washington in 2009. Aggregates were tested at dry and saturated surface dry moisture contents and a range of cure levels. Data are presented in Table 3 and the relationship between this curing and chip loss data is shown in Figure 5.
Based on these preliminary results it appears there may be little practical difference between the dry and SSD aggregate conditions with respect to chip loss. The regression equation for both moisture conditions is nearly equal, with very similar slopes and intercepts. There also appears to be little effect regarding the locations. However, there appears to be a strong relationship between emulsion cure and chip loss, as was measured for the laboratory materials.

**FULL SCALE PAVEMENT TESTS**

The laboratory sweep test results shown previously indicate the revised ASTM D7000 procedure may have merit for predicting the strength of emulsion residues with respect to dislodgement due to sweeping stresses. However, this laboratory test would be more useful to practitioners if a method could be developed to predict when traffic could be allowed on the fresh chip seal. Therefore, during chip seal construction at Arches, Frederick and Forks the amount of moisture remaining in the chip seal was measured and compared with the relative strength of the residue on a scale of 1 (no strength) to 10 (ready for traffic, judged by pulling three chips out of the fresh seal and qualitatively judging dislodgement potential from experience). Moisture remaining
in the emulsion was determined by placing plywood pads covered with aluminum foil measuring 24 by 24 inches in front of the asphalt distributor prior to spraying with emulsion. The pads were weighed before and after spraying and chipping and the loss in weight was determined periodically during the day until approximately 95 percent of the water had evaporated. The photo in Figure 6 shows the measurement technique.

This practice was done at three locations for each project shown on Figures 7, 8 and 9. The loss in weight was correlated to percent moisture loss in the emulsion so a comparison to the laboratory sweep test tests could be obtained. As moisture evaporated from the chip sealed pavement and test pads, this resulting moisture loss was measured and compared with the strength of the emulsion residue with respect to adhesion to the aggregate chips using the scale of 1 to 10. Results are shown in Figures 10, 11 and 12 for Arches, Frederick, and Forks, respectively.

The results of this experiment indicate that at approximately 75 to 85 percent water loss chip adhesion reaches the point where significant force is required to dislodge the chip. This is the point where sweeping can commence and traffic can be allowed to travel on the new surface.

Chip loss during the laboratory sweep test shown in Figure 5 on the same aggregates and emulsions from Arches and Frederick indicate a similar result. That is, at approximately 85 percent emulsion cure, residue strength has increased to the point where chips cannot be dislodged during the test. This is very interesting and suggests that a close correlation may exist between the laboratory sweep test and actual residue strength in the field. The qualitative chip strength scale from 1 to 10 is the obvious place to do additional research since it is only based on experience of the research team with chip seal construction.
Figure 7. Chip Adhesion Test Locations - Arches National Park, UT

Figure 8. Chip Adhesion Test Locations - CR 11 Frederick, CO
Figure 9. Chip Adhesion Test Locations - Forks, WA

Figure 10. Residue Strength vs. Emulsion Moisture at Arches
Figure 11. Residue Strength vs. Emulsion Moisture at Frederick, CO

Figure 12. Residue Strength vs. Emulsion Moisture at Forks, WA
CONCLUSIONS

1. A modified version of the ASTM D7000 sweep test has been developed which can compare adhesive strength of different aggregates and emulsions under various curing conditions with acceptable precision.

2. Modified sweep test results generated in this research indicate the amount of water remaining in the emulsion-aggregate system has a large effect on chip retention, as expected.

3. Field observations of emulsion adhesive strength at two full scale test roads indicates that excellent bonding occurs at moisture contents consistent with moisture contents in the laboratory for the same emulsions and aggregates.

4. It seems reasonable that a correlation may be possible between field moisture content of emulsified asphalt chip seals and time to uncontrolled trafficking based on these preliminary findings. More field data should be collected to verify the results presented here to determine if such a correlation is generally useful.

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REFERENCES


