RELATIONSHIP BETWEEN BLEEDING RESISTANCE IN CHIP SEALS AND EMULSION RESIDUE RHEOLOGY

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ABSTRACT

Bleeding in chip seals is influenced by many factors including design inputs, materials’ properties, and project specific conditions. For performance related emulsion testing the Multiple Stress Creep and Recovery (MSCR) test is identified as a potential test related to bleeding in the field as it is an existing method for high temperature performance evaluation of binders in PG grading system. To simulate bleeding of chip seals in the laboratory, the Loaded Wheel Test (LWT) was selected as it allows to investigate the effects of loading cycles and stress level on bleeding of chip seals. To simulate climate, a temperature control unit was added to the LWT device to allow for testing at high temperatures range at which potential for bleeding is highest. The objective of this paper is to present the results of investigating the relationship between performance of emulsion residue measured by the ASTM D7405 “MSCR” test, and chip seals bleeding resistance as measured by the modified Loaded Wheel Test (LWT). Results collected with the modified LWT show that emulsion application rate, aggregate gradation, and emulsion properties are significant factors affecting bleeding. MSCR test is found as a promising tool for performance evaluation of emulsion residue, as the test is capable of differentiating between emulsion chemistries and modification in terms of sensitivity to both temperature and stress. In relation to chip seal bleeding resistance both the non-recoverable creep compliance (Jnr) and %Recovery parameters obtained from the MSCR test results were identified as significant properties affecting potential for bleeding.
INTRODUCTION

Chip Seal is placed on a variety of roadways from those with low, medium and high traffic volumes, where low volume is defined as those with average daily traffic (ADT) less than 5000, while high volumes as those with more than 20,000 ADT. Polymer modified asphalt emulsions are recommended for roads with high traffic volumes (1, 2). Also, inverted seals has successfully been used on high traffic volume (30,000 ADT) for Australia pavements (3). Since the majority of traffic is composed of passenger cars and small trucks, it is important to select the appropriate range of stress levels for laboratory evaluation of bleeding.

Bleeding is an important failure since it reduces the surface texture of the pavement, and hence compromises the safety of the traveling public, particularly during wet seasons and at intersections. Bleeding performance of chip seal relies on many factors, including climatic condition, traffic volume and type, aggregate properties, asphalt emulsion properties, emulsion application rate and existing pavement surface. Aggregate properties including size, shape and gradation, toughness influence bleeding performance.

In regards to materials’ properties of both the chip seal aggregate and emulsion, they contribute to bleeding resistance. For example, aggregate size and non-uniform aggregate gradations increase potential for bleeding, however aggregate size can be accounted for by adjusting emulsion application rates so as to provide an equivalent embedment percentage to smaller aggregates (4, 5). To resist bleeding, ideal emulsion residue properties include resistance to softening at increased temperatures and/or stresses. The performance of chip seal is largely dependent on the asphalt emulsion as it is the binding component between the aggregates as well as the existing surface. Soft asphalt emulsion is expected to bring about the bleeding in hot weather. Therefore, stiffening the emulsion by modification could influence the bleeding performance favorably. However, since the cost of modified asphalt is higher than that of unmodified asphalt, the selection of suitable asphalt emulsion for each location should be based on critical factors. Climate is one necessary factor that requires consideration for the bleeding since in hot weather bleeding tend to occur more often due to softening of asphalt binders. This phenomenon ease chips penetrate into the underlying binder, leaving excess asphalt binder on the surface (6). Therefore, asphalt emulsion type need to be selected depending on the climate for each region.

In addition to climate, the condition of existing pavement surface and application rates also must be considered. Prior to selecting the target emulsion application rate, the existing pavement is surveyed and an application rate correction factor is applied to account for the existing pavement surface condition. The application rate must be correct during construction to achieve optimum performance of the chip seal; if the emulsion application is too low, it will not retain chips in place under traffic and cause raveling, while if it is too much bleeding in hot weather and will result in loss of friction. Generally, for high traffic volumes the emulsion application rates are lower to take into account the effect of repeated loading (7). This is because the heavy traffic will continue to embed the aggregates into the underlying surface after the road is opened to traffic.

Chip seal design factors including aggregate gradation, application rate, traffic volume, and traffic stress are taken into account in this study through varying materials and testing conditions. The objective for the research is to present the results of investigating the relationship between performance of emulsion residue measured by the ASTM D7405 “Multiple Stress Creep and Recovery (MSCR)” test, and chip seals bleeding resistance as measured by the modified Loaded Wheel Test (LWT).
MATERIALS AND TESTING PROCEDURE

Materials
Five emulsions and two aggregate types were used in this study. The selected emulsions included cationic and anionic emulsions, in order to account for the effects of emulsion chemistry, and polymer and latex modified emulsions for the effect of modification on resistance to bleeding. The asphalt emulsions (CRS-2, CRS-2L, CRS-2P, HFRS-2 and HFRS-2P) were procured by emulsion suppliers in Wisconsin. All emulsions were combined with both granite and limestone aggregate sources to study the effects of aggregate source properties. The properties of the aggregate used are given in Table 1. These properties meet the specification of AASHTO T96 and ASTM D 5821 for % LA abrasion and % fractured faces accordingly.

<table>
<thead>
<tr>
<th>Aggregate Properties</th>
<th>Specification</th>
<th>Granite</th>
<th>Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>% LA abrasion</td>
<td>Limit 35%</td>
<td>18.1%</td>
<td>23%</td>
</tr>
<tr>
<td>% Fracture Faces</td>
<td>90-100</td>
<td>95%</td>
<td>90%</td>
</tr>
</tbody>
</table>

Aggregate Gradation
Chip seals are generally constructed with uniform gradations. The effects of gradation were evaluated by considering two gradations, namely coarse and fine, based on the maximum aggregate size. The coarse gradation is made up of 50% passing 9.5 mm and 0% passing the 6.5 mm size sieve. The fine gradation had 50% passing 6.5 mm size sieve and 0% passing 4.75 mm size sieve as shown in Figure 1. In addition, all aggregate was washed to remove dust coatings from the larger particles.

Material Application Rates
Material application rates for chip seal samples were determined using the equations of the modified McLeod’s Method (8). In order to account the effects of emulsion application rate, two binder application rates of 35% and 70% air void filled were selected. Table 2 presents material application rates used in this study.
<table>
<thead>
<tr>
<th>% Void Filled</th>
<th>Aggregate Gradation</th>
<th>Emulsion Type</th>
<th>Emulsion Application Rate (l/m²)</th>
<th>Aggregate Application Rate (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CRS-2</td>
<td>CRS-2L</td>
<td>CRS-2P</td>
</tr>
<tr>
<td>35%</td>
<td>Fine</td>
<td>1.02</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
<td>1.51</td>
<td>1.42</td>
<td>1.44</td>
</tr>
<tr>
<td>70%</td>
<td>Fine</td>
<td>2.03</td>
<td>1.91</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
<td>3.02</td>
<td>2.84</td>
<td>2.87</td>
</tr>
</tbody>
</table>

**Emulsion Residue Performance Evaluation**

The overall objective of the testing plan was to investigate the emulsion residue non-recoverable creep compliance (Jnr) value as a potential factor that indicative of bleeding performance. The MSCR test as specified in ASTM D7405 and AASHTO TP70 was used to evaluate if the Jnr values correlate with bleeding resistance at high temperatures.

Test conditions were varied to assess both sensitivity to temperature and stress. AASHTO M 332 provides specification criteria based on the Jnr value for different traffic loading conditions. In the specification the maximum allowable value for standard traffic (S) is equal to 4.5 kPa⁻¹, for subsequent traffic conditions associated with heavy (H), very heavy (V), and extremely heavy (E) the Jnr threshold is reduced to adjust for increasing traffic levels. In this study the range of test temperatures was selected to represent possible service temperatures experienced in Wisconsin and to obtain Jnr values above and below the S-grade threshold. To further assess stress sensitivity, a third stress level of 10 kPa was included in the test procedure. All emulsion residues were recovered using the low temperature evaporative recovery procedure specified in AASHTO PP 72, this recovery method involves drawing the emulsion down to a film thickness of 381 µm on a silicone mat and curing it for 6 hours at 60°C in a forced draft oven.

**Modified Loaded Wheel Test to Assess Chip Seals Bleeding**

Previous research (9) has established that the Multiple Stress Creep Recovery (MSCR) test is capable of discriminating between emulsion type and effect of emulsion modification; however these efforts did not include comparisons to chip seal performance. As a result, a test was needed to validate that the differences observed in emulsion residue Jnr values are related to chip seal performance, and applying this relationship to propose performance limits for bleeding.

In this study, applying the modified Loaded Wheel Test (LWT) test to evaluation of bleeding in chip seals modifications were conducted including the modification of temperature control device, dimensions of the base plate to secure the sample, rubber mat to protect tire wear, neoprene foam to represent existing flexible pavement and clamps to hold the sample during testing (10) as shown in Figure 2.
Samples consisting of the emulsion/aggregate combinations were prepared according to guidance provided in ASTM D7000. After curing, samples were placed on the LWT support and heated to the specified testing temperature. Testing included 2 replicates for each sample by rotating the sample 90° to the wheel path. Once the test was completed, the sample was scanned and a digital image was taken and processed to compare the initial image with the same after trafficking. To conduct this analysis the IPAS\(^2\) software developed by UW-Madison was used to convert the captured image to a binary (black/white) image using well established image threshold techniques \((11)\). An example of the application of image analysis to quantify bleeding is provided in Figure 3.

The extent of bleeding is then calculated using Equation 1:

\[
\text{Bleeding (\%)} = \frac{AA_{\text{initial}} - AA_x}{AA_{\text{initial}}} \times 100
\]  

where,

\[AA_x = \text{Area fraction of Aggregate (white color) after x cycles.}\]
\[ AA_{\text{initial}} = \text{Area fraction of Aggregate (white color) prior to testing.} \]

Since both images are processed using the same filtering threshold, the difference can be assumed to be the effect of bleeding. The smaller the white area (aggregates) after \( x \) cycles, the more is the bleeding Percent).

**Experimental Design**

The objective for the experiment was assessment of the effects of design factors on bleeding resistance and relationship between \( J_{nr} \) and Bleeding resistance. The experimental plan is given in Table 3. This experiment was carried out with granite aggregate, a constant stress level of 299 kPa (43.4 psi), one day curing time and loading cycle kept at 200 cycles. The test procedure used to evaluate residue properties is described in subsequent sections.

In the experimental design, there were 3 emulsion types and one aggregate type for conducting the test to quantify the factors influencing bleeding of chip seals. To verify that the factors identified as significant from the main experimental plan, an additional “null” experiment was conducted to verify that the measured and the estimated bleeding based on model derived from main experiment can correlate well. For the null experiment, different emulsions and aggregate than those used in the main experiment were selected. Specifically, the null experiment used Limestone coarse gradation was used with a stress of 299 kPa (43.4 psi), one day curing time and loading cycles of 200 cycles. The null experiment matrix is shown in Table 4.

**TABLE 3 Experimental Design for Assessing Effects of Design Factors on Bleeding Resistance and Relationship between \( J_{nr} \) and Bleeding Resistance with LWT**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
<th>Description</th>
<th>Parameter Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulsion Type</td>
<td>3</td>
<td>CRS-2, CRS-2P &amp; CRS-2L</td>
<td>% Area with Bleeding (by Imaging)</td>
</tr>
<tr>
<td>Aggregate Gradation</td>
<td>2</td>
<td>Fine &amp; Coarse</td>
<td></td>
</tr>
<tr>
<td>Emulsion Application Rate</td>
<td>2</td>
<td>30 &amp; 70% voids filled</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>3</td>
<td>( J_{nr} ) @ 3.2 kPa - 0.5, 2.0, 5.0 (adjust temperature to keep ( J_{nr} ) constant)</td>
<td></td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total Tests</td>
<td></td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4 Null Experiment Design for Verifying the Best Subsets for Bleeding Resistance with LWT**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
<th>Description</th>
<th>Parameter Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulsions</td>
<td>2</td>
<td>HFRS-2, HFRS-2P</td>
<td>% Area with Bleeding</td>
</tr>
<tr>
<td>Emulsion application rate</td>
<td>2</td>
<td>%void filled= 70%</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>2</td>
<td>( J_{nr} ) @3.2 kPa - 2.0, 5.0</td>
<td></td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total Tests</td>
<td></td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
As shown in Table 3 three levels of \( J_{nr} \) (0.5, 2 and 5 kPa\(^{-1}\)) were selected to represent low, medium and high bleeding potential, respectively. The experiment controlled \( J_{nr} \) by changing temperature rather than controlling temperature because it will isolate the effects of design factors without having the confounding effect of different \( J_{nr} \) values of different emulsion. Testing was carried out on different emulsion residues to determine the test temperature at which the \( J_{nr} \) at the stress level of 3.2kPa was equal to 0.5, 2.0, and 5 kPa\(^{-1}\). The temperatures determined for different emulsion are presented in Table 5.

**TABLE 5 Test Temperatures at which Different Emulsions Meet the Specified \( J_{nr} \) Values for a Stress Level of 3.2kPa.**

<table>
<thead>
<tr>
<th>Emulsion</th>
<th>( J_{nr} ) at 3.2kPa</th>
<th>Temperature (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRS-2</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>CRS-2L</td>
<td>0.5</td>
<td>46</td>
</tr>
<tr>
<td>CRS-2P</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>CRS-2</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>CRS-2L</td>
<td>2.0</td>
<td>53</td>
</tr>
<tr>
<td>CRS-2P</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>CRS-2</td>
<td></td>
<td>59.5</td>
</tr>
<tr>
<td>CRS-2L</td>
<td>5.0</td>
<td>61</td>
</tr>
<tr>
<td>CRS-2P</td>
<td></td>
<td>67</td>
</tr>
</tbody>
</table>

**EXPERIMENTAL RESULTS**

Chip seal samples were prepared and tested with LWT at the test temperatures corresponding to emulsion \( J_{nr} \) values of 0.5, 2, and 5 kPa\(^{-1}\) as listed in Table 5. The results for the emulsion application rate (EAR) of 35% air void filled are presented in Figure 4 for the fine and coarse gradations. The results for both gradations show a positive relationship between \( J_{nr} \) and % bleeding of chip seals. As the \( J_{nr} \) increases, the amount of bleeding observed increased as well for all the three emulsions and both aggregate gradations.

The % bleeding almost doubles when the \( J_{nr} \) increases from 0.5 to 5 kPa\(^{-1}\). This indicates that \( J_{nr} \) at 3.2kPa could be a good indicator of emulsion bleeding potential. The results, however, show minimal sensitivity to emulsion type irrespective of aggregate gradation, except for the \( J_{nr} \) equal 5 kPa\(^{-1}\) for the fine gradation. This implies that under these test conditions, the emulsion residues \( J_{nr} \) value is the most important factor irrespective of emulsion modification. In other words latex and polymer modified emulsions, as well as unmodified emulsions will provide similar resistance to bleeding if they have equal \( J_{nr} \) values at the testing temperature.
The results for the high EAR (70% air voids filled) are shown in Figure 5 for the fine and coarse gradation. Similar to the trend observed for the low EAR, a positive relationship between % bleeding on chip seals and Jnr can be noted. % bleeding also doubled when the Jnr is increased from 0.5 to 5 kPa$^{-1}$, indicating that residue with high Jnr maybe prone to bleeding. The % bleeding ranges for fine gradation between 30-38%, 41-49% and 59-65%, for the Jnr values of 0.5, 2.0, and 5.0 kPa$^{-1}$, respectively, for all 3 emulsion types. Similarly the % bleeding for coarse gradation increases at higher Jnr. Difference of % bleeding between fine and coarse gradation for the high emulsion rate varies depending on the Jnr value. The % bleeding values for coarse gradation are greater than those of fine aggregate by 17%, 24% and 18% for Jnr 0.5, 2.0 and 5 kPa$^{-1}$, respectively.
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The results for the high EAR also show less sensitivity to emulsion modification type (P versus L) than to Jnr values. There is a noticeable difference between modified and unmodified emulsions in terms of % bleeding at all values of Jnr. These results indicate that Jnr is related to % bleeding for both conventional and modified emulsion types and that the effect of modification is marginal when compared at the same Jnr value. Recall that the experiment controlled Jnr value rather than temperature in the LWT comparisons. As a result, modified emulsions achieved a Jnr value of 5.0 kPa-1 at temperatures 1.5C – 6.0C higher than the control.

Furthermore, results show that coarse gradation gives more % bleeding than fine aggregate in all conditions. Since the aggregate shape of coarse aggregates is more angular which cause the non-uniformity of chip spread. This can lead to more stress concentration on contact area. This assumption can be verified by the results shown above.

Figure 6 shows a composite summary of previously presented results. The labels for this figure indicates Emulsion-Gradation (F is fine, C is Coarse)-Jnr at 3.2 kPa. All high emulsion
application rate shows higher % bleeding than low emulsion application rate which chip seals with low emulsion application rate has the % bleeding in range of 21%-70% while chip seals with high emulsion rate has the % bleeding in range of 30%-81%.

**FIGURE 6** Effect of Emulsion Application Rate on Bleeding Resistance.

**Factors That Influence Bleeding Resistance**

The information presented in the previous figures identified many factors that had a potential impact on bleeding resistance including Aggregate Gradation, EAR, and Jr at 3.2kPa. Statistical analysis was used to quantify the significance of these factors and assess their relative contribution to bleeding resistance. Prior to conducting the analysis, factors were added/modified to best represent the materials used. The material property considered for the analysis included those obtained from MSCR testing (%Recovery at 3.2kPa). Moreover aggregate gradation for statistical analysis was quantified by fitting the gradation curve to a cumulative Weibull distribution; parameters κ and λ denote the shape (fineness or coarseness) and the scale (dense or open/gap-graded) of aggregate type, respectively.

The Weibull distribution was fitted to the gradation curves in order to calculate the gradation shape parameters. The parameters calculated were κ and λ which denote the shape (fineness or coarseness) and the scale (dense or open/gap-graded) of aggregate type respectively. These parameters can be determined by the Equation 2. These parameters were used in the statistical analysis to evaluate the effects of gradation.
\[ P(x) = 1 - e^{-\left(\frac{x}{\lambda}\right)^{\kappa}} \]  

(2)

where,

\[ P(x) = \text{Percent finer than sieve } x \]
\[ x = \text{Sieve size in millimeters to the 0.45 power,} \]
\[ \lambda, \kappa = \text{Curve fit parameters shape and scale, respectively.} \]

Analysis of Variance (ANOVA) was conducted at a significant level of 0.05 to screen the significant factors affecting bleeding. For the analysis, the software used is named “R-project” (12). The definitions of each factor include Gradation_\( \lambda \): Weibull distribution parameter which denotes the shape (fineness or coarseness); high \( \lambda \) is more coarseness, EAR: Emulsion Application Rate, Jnr_3.2: \( J_{nr} \) at 3.2kPa, R_3.2: % Recovery at 3.2kPa, Rep: Replicates. The ANOVA result is shown in Table 6.

<table>
<thead>
<tr>
<th>Variables</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradation_( \lambda )</td>
<td>108.43</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>EAR</td>
<td>104.00</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>Jnr_3.2</td>
<td>139.74</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>R_3.2</td>
<td>2.97</td>
<td>0.090</td>
<td>.</td>
</tr>
<tr>
<td>Rep</td>
<td>0.51</td>
<td>0.479</td>
<td></td>
</tr>
</tbody>
</table>

Note: Significance codes—0 '****' 0.001 '***' 0.01 '*' 0.05 ' . 0.1 ' ' 1.

The results presented in Table 6 indicates that Gradation_\( \lambda \), EAR, Jnr_3.2, and R_3.2 are statistically significant factors affecting bleeding resistance. The significant factors can be ordered by perceiving F-value, which the F-value of Jnr_3.2, Gradation_\( \lambda \), and EAR are the ordered significant factors on bleeding resistance. Moreover, the results show that the R-3.2 and replicate were not significant to the bleeding resistance, indicating that the results are reliable and the test method is repeatable.

**Best Subsets Regression**

The measured bleeding is dependent on 5 factors as stated above. However, to design model for the bleeding resistance, only 4 factors were considered to conduct the regression analysis. A best-subsets regression was used to identify factors to include in a prediction model. The independent variables considered in this analysis include Gradation_\( \lambda \), EAR, Jnr_3.2 and R_3.2.

Table 7 shows the results of the analysis by best subsets analysis provided in statistical analysis software called Minitab. The methodology to choose the best subsets is based on a high \( R^2_{adj} \) value and the close value of low Mallow’s Cp and number of variables in chosen subset.
<table>
<thead>
<tr>
<th>Variables</th>
<th>$R^2_{\text{adj}}$</th>
<th>Mallows’ Cp</th>
<th>Gradation_ $\lambda$</th>
<th>EAR</th>
<th>Jnr_3.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.2</td>
<td>272.4</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>68.5</td>
<td>142.3</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>67.7</td>
<td>147.7</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>87.5</td>
<td>17.7</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Using the subset outlined in Table 7, a quantitative prediction model is defined as shown in Equation 3 below.

\[
%\text{Bleeding} = -0.124 + 0.0316 \text{Gradation}_\lambda + 0.410 \text{EAR} + 0.0628 \text{Jnr}_3.2,
\]

\[
R^2_{\text{adj}} = 87.5\%
\]  

where,

- \%Bleeding = Estimated percent coated aggregates by total area
- Gradation_ $\lambda$ = Weibull distribution parameter describes the shape (fineness or coarseness)
- EAR = Emulsion Application Rate
- Jnr_3.2 = Jnr at 3.2kPa

In the best subset the parameters which are included in the regression equation are Gradation_ $\lambda$, EAR and Jnr_3.2. There was no need to include % Recovery since there is a high correlation between Jnr and %recovery. Also, it is very hard to control Jnr and %recovery independently.

The selected model (Equation 3) shows that bleeding is high when Gradation_ $\lambda$ is coarse (high) and EAR and Jnr_3.2 are high. The coefficient for each factors show that the most significant factor to cause bleeding is EAR, followed by Jnr_3.2 and Gradation_ $\lambda$. The best way to use this equation is to input the value of the required EAR and the gradation ($\lambda$) value and select the maximum value of Jnr at the specific climate conditions (pavement temperature) that will lead to the maximum % bleeding allowed. The equation indicates that finer aggregate gradation and lower EAR are also favorable.

As stated earlier, to verify the equation for the bleeding resistance, a new (null) experiment was necessary to be carried out in the LWT test. For the null experiment, the emulsions and aggregate were selected different from the main experiment. The aggregate for this experiment was limestone with 23% LA abrasion and 90% fractured face.

The results shown in Figure 7 indicate that the values from the equation are consistent with the value from the imaging analysis. The label in the plot indicates Emulsion, Jnr at 3.2 kPa, and Emulsion Application Rate. This indicates that all factors in regression analysis significantly affect bleeding resistance.
CONCLUSIONS AND RECOMMENDATIONS

This study evaluated the relationship of emulsion residue Jnr values measured with MSCR standard protocol to bleeding of chip seals measured in the laboratory using a modified LWT device. The following points summarize the findings:

1. The MSCR test is a promising evaluation tool for effect of emulsion residue properties on bleeding performance of chip seals. It is clear that Jnr 3.2 value can differentiating between effects of emulsions in terms of sensitivity to bleeding under different temperatures and cycles. As a result it has potential to be used to identify materials more prone to bleeding due to softening related to temperature.

2. Results presented indicate the emulsion application rate (EAR), aggregate gradation, Jnr at 3.2kPa contribute to the bleeding of chip seals. As expected, the highest impact observed is for EAR when changed from 35 % to 70%, however for each EAR, the Jnr value of the emulsion residue at the test temperature has the second largest effect. Thus laboratory results indicate that for a giver EAR, bleeding performance can be controlled through proper evaluation of emulsions at project climate using MSCR testing.

3. Asphalt emulsions modified with polymers have lower Jnr values and thus have less tendency to allow bleeding at the same temperature.

4. The methodology for laboratory evaluation of bleeding presented in this paper was developed based on the single chip seal. It is understood that many different multi-layer seal treatments are currently used in practice, further research is needed to evaluate if the concepts presented can be applied to other seal systems.

FIGURE 7 Comparison of Measured % Bleeding (Imaging Analysis) and Estimated % Bleeding (Regression Analysis)
ACKNOWLEDGEMENTS
The authors would like to materials suppliers for supporting this project. The support of FHWA and WRI is greatly appreciated.

REFERENCES
14. **Standard Test Method for Sweep Test of Bituminous Emulsion Surface Treatment Samples.**


