Evaluation of Reclaimed Asphalt Pavement Materials from Ultra-Thin Bonded Bituminous Surface

by

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ABSTRACT

Ultra-thin bonded bituminous surface (UBBS), also known as Novachip, is a preventive maintenance or thin surface treatment that consists of a thin, gap-graded hot-mix asphalt (HMA) layer applied over a thick polymer-modified emulsion membrane. The Kansas Department of Transportation (KDOT) has been using UBBS since 2002. However, some of these projects are now being rehabilitated. The objective of this study is to evaluate whether reclaimed asphalt pavement (RAP) materials from existing UBBS layers can be used in chip seal and Superpave mixtures. UBBS millings were studied with two different polymer-modified emulsions to assess their performance as precoated aggregates in chip seal. The ASTM D7000-04 sweep test was used to assess chip retention of UBBS millings. Three different mix designs were developed for both 12.5-mm and 9.5-mm nominal maximum aggregate size (NMAS). Superpave mixtures using a PG 70-22 asphalt binder and three different percentages (0%, 10%, and 20%) of reclaimed UBBS materials. The designed Superpave mixes were then tested for performance in terms of rutting and stripping using the Hamburg wheel tracking device (HWTD) and moisture sensitivity by the modified Lottman tests. Sweep test results showed that UBBS millings did not improve chip retention. Superpave mix design data indicated volumetric properties of Superpave mixes with UBBS millings met all requirements specified by KDOT. HWTD and modified Lottman test results indicated all designed mixes performed better with the addition of UBBS millings as RAP materials.
INTRODUCTION

Preventive maintenance and rehabilitation are important for any pavement preservation program. The pavement preservation techniques of asphalt-surfaced pavements include many treatments. One of these is the ultra-thin bonded bituminous surface (UBBS or Novachip). UBBS consists of a thin, gap-graded hot-mix asphalt (HMA) layer applied over a thick polymer-modified emulsion membrane (1). This surface layer has been found to reduce noise, minimize back spray and increase visibility under wet conditions (2). KDOT has been using UBBS since 2002, and to date more than 450 miles of UBBS have been placed on the state highway system in Kansas. Some of these projects are being rehabilitated now. Since the UBBS layer is gap graded, conventional overlay might result in moisture trapping within the layer causing stripping of the underlying layers. KDOT is currently extending its use from treatment of the existing surface to in conjunction with some sort of surface preparation such as surface recycling. Since UBBS uses very high-quality aggregates and asphalt binder, use of reclaimed millings from UBBS as precoated aggregates in chip seal and as reclaimed asphalt pavement (RAP) materials in Superpave mixtures is expected to be highly beneficial. Thus, there is a need to evaluate performance of reclaimed UBBS millings for these applications.

OBJECTIVE

The main objectives of this study were to:

a) Evaluate the performance of reclaimed UBBS millings as precoated aggregates in chip seal;

b) Develop Superpave mixture designs incorporating UBBS RAP; and

c) Evaluate the effect of UBBS RAP on the performance of Superpave mixtures, especially in terms of rutting and moisture susceptibility.

EXPERIMENTAL DESIGN AND METHODOLOGY

The research was divided into two parts to achieve the objectives of the study. In the first part, reclaimed UBBS millings were used with two different asphalt emulsions, CRS-1HP and CRS-2P, to evaluate the performance of UBBS millings as precoated aggregates in chip seal. The performance test selected was the ASTM sweep test (ASTM D7000-04). In the second part, three different mix designs were developed in the laboratory, each with 12.5-mm and 9.5-mm nominal maximum aggregate size (NMAS), using a PG 70-22 asphalt binder grade and three different percentages (0%, 10%, and 20%) of reclaimed UBBS materials. The designed Superpave mixes were then tested for performance in terms of rutting using the Hamburg wheel tracking device (HWTD) in accordance with Tex-242-F test method of the Texas Department of Transportation and moisture sensitivity by modified Lottman tests (KT-56).
MATERIALS

Reclaimed UBBS materials were obtained from milling the ultra-thin bonded bituminous surface layers on I-70 in Logan and Gove counties in Kansas. Figure 1(a) shows the gradation of reclaimed UBBS millings. The original UBBS project was placed in 2002 by Ritchie Paving Inc. Asphalt binder PG 70-28 with 0.5% Kling Beta 2912 anti-stripping agent was used. The design asphalt content was 5.3%. Aggregates from the millings were extracted by conducting an ignition oven and then tested to determine gradation. Figure 1(b) illustrates the gradation of the recovered aggregates. According to the test results provided by KDOT, the percent asphalt binder content in the reclaimed UBBS millings was 3.4% and the UBBS RAP PG binder grade was equivalent to PG 84-18. For laboratory mix designs, bulk specific gravity (Gsb) of virgin aggregates, known from original construction records of the UBBS layer, was used as the Gsb value of the reclaimed UBBS millings. Figures 1(c) and 1(d) show the gradations of virgin aggregates used in the 12.5-mm and 9.5-mm NMAS mix designs, respectively. Two cationic rapid-setting, polymer-modified emulsions, CRS-1HP and CRS-2P, were used in the ASTM sweep tests. Asphalt emulsions were obtained from Vance Brothers, Inc., Kansas City, Missouri.

Figure 1 Gradations of the aggregates (a) Used in ASTM Sweep Test (b) Extracted from UBBS Millings (c) Used in 12.5-mm NMAS Mixes (d) Used in 9.5-mm NMAS Mixes
Table 1 Typical Aggregate Properties of Reclaimed UBBS Millings

<table>
<thead>
<tr>
<th>Properties</th>
<th>UBBS millings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk specific gravity</td>
<td>2.44</td>
</tr>
<tr>
<td>Absorption, %</td>
<td>1.4</td>
</tr>
<tr>
<td>Loose dry unit weight, kg/m³</td>
<td>1291.3</td>
</tr>
<tr>
<td>Voids in loose aggregate, %</td>
<td>47</td>
</tr>
<tr>
<td>Moisture content, %</td>
<td>0.12</td>
</tr>
<tr>
<td>Materials passing 0.075 mm, %</td>
<td>0.33</td>
</tr>
<tr>
<td>Median particle size, mm</td>
<td>7.2</td>
</tr>
<tr>
<td>Uniformity Coefficient (Cu)</td>
<td>1.41</td>
</tr>
</tbody>
</table>

ASTM SWEEP TEST

In this study, the ASTM sweep test was used to evaluate chip retention characteristics. The sweep test measures performance characteristics of bituminous materials and field aggregates by simulating a surface treatment during brooming operation (3). In this test, aggregates are sieved to obtain a test sample of a certain size that has 100 percent passing a 9.5-mm (3/8-inch) sieve and less than 1 percent passing a 4.75-mm (No.4) sieve. The amount of aggregate used for each specimen was calculated using Equation 1.

\[
AGG_N = \frac{AGG_{9.5-6.3}}{100} \times [202.1 \times SG_b - 14.7] + \frac{AGG_{6.3-4.75}}{100} \times [146.4 \times SG_b - 4.7]
\]  

(1)

where

\[
AGG_N = \text{amount of aggregate needed for the sweep test, g;}
\]
\[
AGG_{9.5-6.3} = \text{percent of aggregate from 9.5 to 6.3 mm;}
\]
\[
AGG_{6.3-4.75} = \text{percent of aggregate from 6.3 to 4.75 mm; and}
\]
\[
SG_b = \text{bulk specific gravity.}
\]

According to this test method, \(83\pm5\) g (0.18±0.01 lb) of asphalt emulsion at 60\(^\circ\)C (140\(^\circ\)F) is needed for each sample. The asphalt emulsion was poured along the top arc of the exposed felt disk and excess emulsion was removed with a strike-off rod. The pre-weighed aggregates were spread immediately and the specimen was cured in a forced-draft oven before testing for an hour at 35\(^\circ\)C (95\(^\circ\)F). At the end of the conditioning period, any loose aggregates were removed by gentle hand brushing and the specimen was weighed and recorded as initial specimen weight. A mixer abraded the surface of the sample using a 127-mm (5-inch) nylon brush. After one minute of abrasion, the test was stopped and any loose aggregate removed. The abraded sample was weighed and recorded as the final specimen weight. Equation 2 represents the total mass loss based on the initial aggregate sample weight. Mass loss as a percentage of the area exposed to the abrading surface was then calculated as:

\[
\%ML = 1.33 \times \left[ \frac{Wi - Wf}{Wi - Wd} \right] \times 100
\]  

(2)

where

\[
\%ML = \text{mass loss as a percentage;}
\]
\[
Wi = \text{initial specimen weight;}
\]
\[
Wf = \text{final specimen weight;}
\]
\[
Wd = \text{aggregate needed for the sweep test.}
\]
Wi= initial specimen weight,  
Wf= final specimen weight, and  
Wd= asphalt sample disk weight.

LABORATORY MIX DESIGNS

In this study, mix designs were developed in the laboratory to meet the requirements of Superpave 12.5-mm and 9.5-mm NMAS mixtures by using two aggregate sources, one asphalt binder (PG 70-22) and three different percentages of reclaimed UBBS millings (0%, 10%, and 20%). Mixtures with no reclaimed UBBS millings, SM 12.5A and SM 9.5A mixtures, were designed first as control mixtures. These control mixtures served as baselines to compare the mixtures developed by incorporating reclaimed UBBS millings. Then each mixture incorporating 10% or 20% reclaimed UBBS millings was designed. The aggregate design structure of the mixtures incorporating UBBS RAP was kept as close as possible to the baseline or control mixture gradation. Chosen percentages of individual aggregates in aggregate blends are shown in Table 2. Figure 2 shows aggregate blend gradations of 12.5-mm and 9.5-mm NMAS mixtures. The 20-year design, equivalent single axle loads (ESALs), in this study was 0.3 to less than 3 million. Superpave mixtures were developed meeting Superpave volumetric requirements in Kansas. Design asphalt content was selected based on KDOT-specified volumetric criteria at 4.0 percent air voids at N_{des} level of 75 gyrations. For mixtures incorporating UBBS RAP, the percentage of asphalt binder in the UBBS RAP was also taken into account to determine the amount of virgin binder to be added. Mixing and compaction temperature ranges for PG 70-22 asphalt binder were 149 to 156 °C (300 to 312 °F) and 128 to 133 °C (262 to 272 °F), respectively. Mixing was done by a mechanical mixer. After mixing, loose mixture was conditioned for two hours in a forced-draft oven maintained at compaction temperature. Test specimens were then compacted at these temperatures with a Superpave gyratory compactor (SGC). Bulk specific gravity (G_{mb}) of compacted test specimens and maximum theoretical specific gravity (G_{mm}) of loose mix was measured. Then, Superpave gyratory compaction data was analyzed, volumetric properties were calculated, and the design asphalt content was determined.
Table 2 Bulk Specific Gravities and Percentages of Individual Aggregates in Combined Blend

<table>
<thead>
<tr>
<th>Mix Size</th>
<th>Aggregate Type</th>
<th>Bulk Specific Gravity</th>
<th>Percent in Combined Gradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5-mm NMAS</td>
<td>UBBS RAP</td>
<td>2.58</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CS-1</td>
<td>2.577</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>CS-1A</td>
<td>2.575</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>MSD-1</td>
<td>2.568</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>CG-5</td>
<td>2.621</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>SSG</td>
<td>2.619</td>
<td>25</td>
</tr>
<tr>
<td>9.5-mm NMAS</td>
<td>UBBS RAP</td>
<td>2.58</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CS-1</td>
<td>2.496</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>CS-1A</td>
<td>2.572</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>MSD-1</td>
<td>2.588</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>CG-5</td>
<td>2.622</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>SSG</td>
<td>2.62</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 2 Gradations for (a) 12.5-mm NMAS Mixtures (b) 9.5-mm NMAS Mixtures

PERFORMANCE TESTS ON LABORATORY MIXES

Performance tests were conducted to evaluate the performance of designed control mixtures and mixtures containing UBBS RAP. The performance of Superpave mixtures in terms of rutting and moisture susceptibility were analyzed and evaluated to determine the effect of UBBS RAP on mixture performance. Specimens fabricated by the Superpave gyratory compactor at target air voids were used to conduct laboratory performance tests. A brief description of the tests is follows.
**Hamburg Wheel Tracking Device Test**

Hamburg wheel tracking device (HWTD) measures combined effects of rutting and moisture susceptibility of hot-mix asphalt mixtures. The Hamburg wheel tracking device, manufactured by PMW, Inc. of Salina, Kansas, was used in this study. This device can test two specimens simultaneously. The device is operated by rolling a pair of steel wheels across surface of specimens submerged in a water bath held at 50°C. The wheels have a diameter of 204 mm (8 inches) and width of 47 mm (1.85 inches). The device operates at approximately 50 wheel passes/min and the load applied by each wheel is approximately 705±22 N (158±5 lbs). Specimens used in this test were compacted to 7±1 percent air voids using a Superpave gyratory compactor. The specimens were 150mm (6 inches) in diameter and 62mm (2.4 inches) in height. Rut depth was measured automatically and continuously at 11 different points along the wheel path of each sample with a linear variable differential transformer (LVDT) with an accuracy of 0.01 mm (0.0004 inch). HWTD automatically ends the test if the preset number of cycles is reached or if the rut depth measured by the LVDTs reaches a value of 20mm (0.8 inch) for an individual specimen. The rut depth versus number of cycles is plotted to obtain a typical curve as shown in Figure 3. The main parameters obtained from the plot are rut depth, average number of wheel passes, creep slope, stripping slope, stripping inflection point, and post-compaction consolidation. Post-compaction consolidation is the deformation (mm) at 1,000 wheel passes. Creep slope is the inverse rate of deformation (wheel passes per 1-mm rut depth) in the linear region of the plot between the post-compaction consolidation and the stripping inflection point. Creep slope is used to measure rutting susceptibility due to mechanisms other than moisture damage. The stripping inflection point and stripping slope are used to measure moisture damage. The stripping inflection point is the number of wheel passes at the intersection of the creep slope and stripping slope. The stripping slope is the inverse rate of deformation (wheel passes per 1-mm rut depth) after the stripping inflection point (4).

![Typical Hamburg Plot Showing Test Output Parameters](image)

**Figure 3 Typical Hamburg Plot Showing Test Output Parameters**
Modified Lottman Test

Kansas Test Method KT-56, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage, commonly known as the modified Lottman test in Kansas, was used to evaluate moisture susceptibility in this study. For this test, specimens should be 150mm (6 inches) in diameter and 95 mm (3.75 inches) in height. Six specimens are compacted to 7±0.5 percent air voids using the Superpave gyratory compactor. After compaction and air void determination, the specimens are subdivided into two subsets of three samples so that average air void content of the two subsets are approximately equivalent. Diameter and thickness of the specimens are measured before further testing. Three specimens are selected as a control set and tested dry (without conditioning). The other subset of three specimens is conditioned by subjecting those to a partial vacuum saturation of 70 to 80% of air voids by placing them in a vacuum container filled with water so that at least 25 mm (1 inch) of water is covering them. A partial vacuum of 250 to 650 mm of Hg is applied to the container for a short time. After the degree of saturation for each specimen has been verified and meets the test protocol, the conditioned samples are individually wrapped with a plastic film, and placed and sealed in a zip-lock bag with 10mL water. Samples are then placed in a freezer for a minimum of 16 hours at -18°C. After freezing, the samples are thawed by placing them in a hot water bath for 24±1 hours at 60°C. The conditioned samples are then removed from the hot water bath and Saturated surface dry (SSD) mass is recorded, and mass under water is also measured. All conditioned and unconditioned (sealed in plastic wrap) specimens are then placed in a water bath for two hours at 25°C. Final diameter and thickness of conditioned samples is measured after removing them from the water bath before testing. The specimens are tested at a loading rate of 51 mm/minute and peak loads are recorded. The tensile strength is computed using equation 3 (5).

\[
S = \frac{2000P}{\Pi t D}
\]  

(3)

where

| S = tensile strength (kPa), |
| P = maximum load (N), |
| t = specimen thickness (mm), and |
| D = specimen diameter (mm). |

Tensile strength ratio (TSR) is used to denote HMA resistance to the detrimental effects of moisture. It is defined as the ratio of average tensile strength retained after freeze-thaw conditioning (average tensile strength of conditioned specimens) to average tensile strength of unconditioned samples. Percent tensile strength ratio is computed using Equation 4.

\[
TSR = \frac{S_2}{S_1} \times 100
\]  

(4)

where

| S_1 = average tensile strength of unconditioned subset, |
| S_2 = average strength of conditioned subset. |
KDOT and Superpave criterion for acceptable minimum tensile strength ratio is 80% (5).

RESULTS AND ANALYSIS

Results of laboratory tests to evaluate UBBS RAP performance in chip seal and Superpave mixtures are discussed in this section. Chip loss of reclaimed UBBS materials was compared with those obtained for the precoated normal-weight aggregates (6). Volumetric properties of all laboratory designed mixtures were also assessed for various UBBS RAP contents. Laboratory-mix performance was evaluated in terms of rutting and moisture susceptibility. Pair-wise comparisons or contrasts were done to determine statistical differences in a) chip loss between UBBS millings and precoated normal-weight aggregates for chip seal data, and b) laboratory performance of various UBBS RAP contents for Superpave mixtures. The hypothesis test was done on the difference of means of two samples, known as the estimate of the contrast. The usual null hypothesis states that contrast has a zero value, which results in a test where the two means are equal. P-value was used to determine whether to accept or reject it. Statistical Analysis Software (SAS), version 9.2 was used to do the pair-wise comparisons at 95% level of significance.

ASTM Sweep Test Results

In this study, seven replicate specimens for the two aggregate-emulsion combinations were studied to evaluate chip retention performance of reclaimed UBBS millings using the ASTM sweep test. Figure 4 shows the percent chip loss of each aggregate for two different emulsions. In general, UBBS millings experienced higher mass loss (nearly 50%) compared to precoated normal-weight aggregates when CRS-2P emulsion was used. UBBS millings had slightly less chip loss compared to the precoated gravel but higher than precoated limestone aggregates when CRS-1HP emulsion was used. The pair-wise comparisons for mass loss of UBBS millings with respect to precoated normal-weight aggregates and two asphalt emulsions are shown in Table 3. Results show that mean mass loss of UBBS millings and precoated gravel are statistically similar when used with CRS-2P and CRS-1HP emulsions. Differences between UBBS millings and precoated limestone are significant except when limestone was 1.5% precoated and used with CRS-1HP emulsion. The contrast for mass loss of UBBS millings with two different asphalt emulsions show that there is a significant difference in mean percent mass loss between both asphalt emulsions, CRS-1HP was better when compared to CRS-2P. This illustrates that chip retention performance of UBBS millings is affected by the emulsion type used. Since UBBS RAP materials had a significant amount of asphalt, it was expected these would be “equivalent” to “precoated” aggregates, and consequently, chip retention would be improved. Although no significant amount of dust was obtained in dry-sieve analysis of the UBBS millings, good bond between aggregate and emulsion residue was not obtained. This could be because of the aged/old asphalt binder that might have slowed the breaking duration of emulsified asphalt, thus leading to more aggregate loss.
Figure 4 ASTM Sweep Test Results

Table 3 Comparisons of Mass Loss of UBBS Millings with Respect to Precoated Normal Weight Aggregates and Two Asphalt Emulsions

<table>
<thead>
<tr>
<th>Emulsion type</th>
<th>Aggregate type</th>
<th>Aggregate type</th>
<th>Precoating condition</th>
<th>Estimate</th>
<th>Pr &gt;</th>
<th>Differences significant at 95% confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRS-2P</td>
<td>UBBS millings</td>
<td>Gravel</td>
<td>1.5% coated</td>
<td>6.6</td>
<td>0.17</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone</td>
<td>coated</td>
<td>12</td>
<td>0.01</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel</td>
<td>2% coated</td>
<td>5.8</td>
<td>0.16</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone</td>
<td></td>
<td>15.1</td>
<td>0.002</td>
<td>Yes</td>
</tr>
<tr>
<td>CRS-1HP</td>
<td>UBBS millings</td>
<td>Gravel</td>
<td>1.5% coated</td>
<td>-4.1</td>
<td>0.24</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone</td>
<td>coated</td>
<td>4.5</td>
<td>0.22</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel</td>
<td>2% coated</td>
<td>-2.1</td>
<td>0.54</td>
<td>No</td>
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<td></td>
<td></td>
<td>Limestone</td>
<td></td>
<td>9.4</td>
<td>0.016</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Aggregate type | Emulsion type | Emulsion type | Estimate | Pr > | Differences significant at 95% confidence level |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UBBS millings</td>
<td>CRS-1HP</td>
<td>CRS-2P</td>
<td>-14.1</td>
<td>0.0008</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Laboratory Mix Designs

Table 4 shows the Superpave mixture volumetric properties and design asphalt content of mix designs developed in the laboratory. Design asphalt content was chosen for each mixture to have percent air voids @ Ndes, as close to 4.0% as possible. Figure 5 illustrates the virgin and UBBS RAP asphalt contents for all mixtures developed in the laboratory. There is a decrease in virgin asphalt content with an increase in UBBS RAP content. This represents an economical benefit since asphalt cement is the expensive part of hot-mix asphalt. The mix design data illustrates that volumetric properties of all mixes incorporating UBBS RAP met the requirements specified by KDOT. It can be observed that results for VMA and VFA did not change significantly with addition of UBBS RAP. The data also shows a slight decrease in percent VMA with increasing UBBS RAP content. This could be due to the extent of blending between old and virgin asphalt binder, since the aggregate design structure is similar for the 12.5-mm NMAS and 9.5-mm NMAS mixes.

**Table 4 Volumetric Properties of Designed Superpave Mixtures**

<table>
<thead>
<tr>
<th>Mix size</th>
<th>% UBBS millings</th>
<th>Total asphalt content %</th>
<th>Virgin asphalt content %</th>
<th>RAP asphalt content %</th>
<th>% Air voids @ Ndes</th>
<th>% VMA</th>
<th>% VFA</th>
<th>Dust to binder ratio</th>
<th>% Gmm @ Nini</th>
<th>% Gmm @ Nf</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5-mm NMAS</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>4.2</td>
<td>14.1</td>
<td>70.4</td>
<td>0.68</td>
<td>89.2</td>
<td>96.7</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.8</td>
<td>4.48</td>
<td>0.32</td>
<td>4.5</td>
<td>14</td>
<td>67.8</td>
<td>0.7</td>
<td>88.9</td>
<td>96.4</td>
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<td>20</td>
<td>4.7</td>
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<td>0.65</td>
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<td>14</td>
<td>69</td>
<td>0.68</td>
<td>88.8</td>
<td>96.6</td>
</tr>
<tr>
<td>KDOT Spec</td>
<td>4</td>
<td>Min 14</td>
<td>65-78</td>
<td>0.6-1.2</td>
<td>≤90.5</td>
<td>&lt;98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5-mm NMAS</td>
<td>0</td>
<td>6.4</td>
<td>6.4</td>
<td>0</td>
<td>3.6</td>
<td>16.6</td>
<td>78</td>
<td>0.66</td>
<td>88.9</td>
<td>97.5</td>
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<td></td>
<td>10</td>
<td>5.9</td>
<td>5.58</td>
<td>0.32</td>
<td>4.6</td>
<td>16.41</td>
<td>71.5</td>
<td>0.78</td>
<td>88</td>
<td>96.4</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>5.6</td>
<td>4.96</td>
<td>0.64</td>
<td>3.7</td>
<td>15.21</td>
<td>75.49</td>
<td>0.78</td>
<td>89</td>
<td>97.3</td>
</tr>
<tr>
<td>KDOT Spec</td>
<td>4</td>
<td>Min 15</td>
<td>65-78</td>
<td>0.6-1.2</td>
<td>≤90.5</td>
<td>&lt;98</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

TRB 2013 Annual Meeting Paper revised from original submittal.
In this study, three replicate specimens for each mix design were tested using the Hamburg wheel tracking device (HWTD) to evaluate rutting and stripping performance. The specimens were compacted to 7±1% air voids and tested at 50°C. The test was continued until a 20-mm rut depth was reached for each specimen. Figure 6 illustrates performance of all laboratory mixes in terms of average number of wheel passes to 20-mm rut depth, creep slope, stripping slope, and stripping inflection point (SIP). In general, the mixes with higher UBBS RAP content performed better when compared to the base mix (no UBBS RAP), illustrating that UBBS RAP content is an important factor in improving rutting performance. Table 5 shows the pair-wise comparisons of HWTD data among various UBBS RAP contents. There is no significant difference in 0% and 10% UBBS RAP content in HWTD results for both 12.5-mm NMAS and 9.5-mm NMAS mix types. This implies that 10% UBBS RAP did not show any change in the average number of wheel passes (HWTD data) statistically, though the effect of UBBS RAP was evident from Figure 6. For 12.5-mm NMAS mix size, UBBS RAP contents of 10% and 20% are not significantly different, while an opposite trend is observed for 9.5-mm NMAS mix size. The pair-wise comparisons or contrasts confirm that the higher the UBBS RAP content, the more significant are differences at the 95% confidence interval. This can be due to the higher amount of aged asphalt binder in the mixtures with higher UBBS RAP content.
Figure 6 Effect of UBBS RAP on HWTD Output Parameters for All Mixes: (a) Average Number of Wheel Passes to 20-mm Rut Depth (b) Creep Slope, (c) Stripping Slope, and (d) Stripping Inflection Point
Table 5 HWTD Data Comparisons for All Mixes with Various UBBS RAP Contents

<table>
<thead>
<tr>
<th>Mix size</th>
<th>Compare</th>
<th>Average no. of wheel passes to 20-mm rut depth</th>
<th>Differences significant at 95% confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%UBBS RAP</td>
<td>%UBBS RAP</td>
<td>Estimate</td>
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<tr>
<td>12.5-mm NMAS</td>
<td>0</td>
<td>10</td>
<td>-8399</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>-13363</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>-4964</td>
<td>0.24</td>
</tr>
<tr>
<td>9.5-mm NMAS</td>
<td>0</td>
<td>10</td>
<td>-3111</td>
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<tr>
<td></td>
<td>20</td>
<td>13363</td>
<td>0.0004</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>-9913</td>
<td>0.0018</td>
</tr>
</tbody>
</table>

Modified Lottman Test Results

The modified Lottman test (KT-56) was done on all laboratory-designed mixtures to assess their sensitivity to moisture damage. For this test, six specimens were compacted at 7±0.5% air voids for each mix design; three of these were conditioned by subjecting them to the freeze-thaw cycle and the other three were unconditioned. Moisture susceptibility is measured as the percentage of average tensile strength ratio of the conditioned specimens to unconditioned specimens. In this study, no liquid anti-stripping agent was used, indicating the asphalt binder effect on adhesion to the aggregates. Figure 7(a) shows the average tensile strength of both conditioned and unconditioned samples for each mix. In general, average tensile strengths increased with an increase in percent UBBS RAP content in the mix. This illustrates that the mixture stiffens with an addition of UBBS RAP, as there is an increase in the amount of aged/old binder which affects the bond to the aggregates, and ultimately the tensile strengths. Figure 7(b) illustrates tensile strength ratios (TSR). There is a decrease in TSR values with the addition of UBBS RAP. All mixes have met the minimum TSR requirements specified by KDOT, illustrating no significant effect on moisture susceptibility of the mixtures for up to 20% UBBS RAP. Pair-wise comparisons for tensile strengths among various UBBS RAP contents are shown in Table 6. It can be observed that differences in conditioned and unconditioned strengths among various UBBS RAP contents are significant at the 95% confidence level except for 0% -10% RAP contents for both 12.5-mm and 9.5-mm NMAS mixes. The estimate value for all comparisons is negative, which indicates an improvement in tensile strength with the addition of UBBS RAP. This was expected as there is aged asphalt binder in these mixtures which increases their stiffness.
Figure 7 (a) Conditioned and Unconditioned Strengths of All Laboratory Mixes (b) Tensile Strength Ratios

Table 6 Tensile Strength Comparisons for All Mixes with Various UBBS RAP Contents

<table>
<thead>
<tr>
<th>Mix size</th>
<th>Compare</th>
<th>Unconditioned Strength</th>
<th>Conditioned Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%UBBS RAP</td>
<td>%UBBS RAP</td>
<td>Estimate</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>12.5-mm NMAS</td>
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<td>12.5-mm NMAS</td>
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<td>20</td>
<td>-263.66</td>
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<td>12.5-mm NMAS</td>
<td>20</td>
<td>10</td>
<td>-162.62</td>
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<tr>
<td>9.5-mm NMAS</td>
<td>0</td>
<td>10</td>
<td>-263.20</td>
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<td>9.5-mm NMAS</td>
<td>10</td>
<td>20</td>
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<tr>
<td>9.5-mm NMAS</td>
<td>20</td>
<td>10</td>
<td>-92.77</td>
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CONCLUSIONS

The following conclusions can be drawn from this study:
- Reclaimed asphalt pavement (RAP) materials from ultra-thin bonded bituminous surface (UBBS) layers when used in chip seal did not show good chip retention in the ASTM sweep tests with emulsified asphalts.
- Statistically, no significant difference in chip loss was found between reclaimed UBBS materials and precoated gravel. Chip loss was significantly higher for reclaimed UBBS materials when compared to that of precoated limestone, regardless of emulsion type used in the ASTM sweep tests.
Three different mixes with 12.5-mm and 9.5-mm NMAS were successfully developed in the laboratory for three different UBBS RAP contents and a PG 70-22 asphalt binder grade. Mix design data indicated volumetric properties of all mixes with UBBS RAP met all requirements of the Kansas Department of Transportation. Asphalt content decreased with increasing UBBS RAP content.

Hamburg wheel tracking device test output parameters indicated that rutting performance of mixes improved with the addition of UBBS RAP.

Modified Lottman test results showed average tensile strengths of mixes increased with an increase in UBBS RAP content, illustrating increased mixture stiffening due to the addition of UBBS RAP.

All designed mixes met minimum tensile strength ratio (TSR) criteria specified by the Kansas Department of Transportation. There was a slight decrease in TSR with an increase in UBBS RAP, illustrating no significant effect on the moisture susceptibility of Superpave mixtures for up to 20% UBBS RAP.

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REFERENCES