RECYCLED ASPHALT PAVEMENT (RAP) USED IN SUPERPAVE MIXES MADE WITH RUBBERIZED ASPHALT

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ABSTRACT: This project evaluated the performance of 9.5 mm Superpave mix designs containing recycled asphalt pavement (RAP). Twelve mix designs meeting South Carolina Department of Transportation (SCDOT) specifications were prepared using two aggregate sources. The RAP used in each mix design contained aggregate from the same source as the virgin aggregate. The 3-Tier concept was used to incorporate RAP into the mixtures in the first (less than 15%) and third (greater than 25%) tiers. Each mix was also made by modifying the respective binder with crumb rubber. In general, the mixtures containing RAP improved the rutting resistance and either increased, or had no significant effect on the indirect tensile strength (ITS). The tensile strength ratio (ITS) was not affected by the addition of RAP. Also, the use of CRM binder increased the rut resistance over the unmodified binder, while not significantly affecting the ITS or moisture susceptibility.

KEY WORDS: Rubber, asphalt, RAP, Superpave, recycling, rutting

1. INTRODUCTION

Recycled asphalt pavement (RAP) has been widely used in the United States since the 1970s and is a major benefit to the asphalt paving industry [1]. The use of RAP allows for a lower mix material cost, elimination of the RAP disposal costs, and removal of a waste product from landfills. There are many additional benefits of using RAP including:

- Recycling material that would otherwise be disposed of at the taxpayer's expense, with a risk of harming the environment if disposed of improperly.
- Maintaining original roadway geometrics.
- Lowering the initial cost of the pavement by utilizing recycled binder and aggregate, which have a lower cost.
- No sacrifice in the mix performance when the RAP is handled and incorporated into the mixture using the proper methods.

Recycling asphalt pavements is currently the largest single recycling practice in the United States. In 2002, 30,000,000 tons of RAP was used in hot mix asphalt (HMA) with a savings of over $300 million, accomplished by lowering material costs for the newly placed asphalt and eliminating the disposal cost of the RAP [2].

With the inception of the Superpave mix design method, there was no mention of the use of RAP in Superpave mixes. The Superpave system did not restrict the use of RAP in the design, but the new system made no address of the use of RAP and there were no guidelines to follow for incorporating RAP. Recently, there has been much research on this issue and guidelines have been set, allowing for the industry to use RAP. Research has led to findings including the Black Rock Study, the use of the 3-Tier Approach, the use of linear blending, and technicians' manuals for the use of RAP in Superpave mixes [1,3,4]. The testing of the recovered RAP binder using the Superpave binder testing equipment is now incorporated in AASHTO TP2.

An additional benefit to the asphalt paving industry is the use of polymer modified binder. There are two forms of polymers, elastomers (rubber) and plastomers (plastics). When asphalt binder is modified with elastomers, the result is usually a pavement that is more flexible and resilient. An example of the use of elastomers is crumb rubber modified (CRM) binder.

The use of CRM binders is a result of the asphalt paving industry's desire for a higher standard of performance and longer lasting pavements. The use of CRM binders began as early as the 1960s and today has been incorporated in several states' Department of Transportation Specifications. In 2001, approximately 281,000,000 scrap tires were generated in the U.S. Of this, 77.6% were consumed by scrap tire markets. For example, approximately 115,000,000 were used as fuel, 40,000,000 were used for civil engineering projects and 34,000,000 were converted into crumb rubber and recycled into products. In addition, 25,000,000 were estimated to be disposed of in landfills or monofills [5].

Crumb rubber can be added to asphalt mixtures through two basic procedures, the wet and dry processes. In the wet process, the crumb rubber serves as part of the asphalt binder in the mix, while in the dry process the rubber is part of the interlocking aggregate structure in the mix. When using the wet process, the crumb rubber is fine ground and reacted with the asphalt binder prior to its addition to the aggregates. This new CRM binder is then added to the aggregate. In the dry process, larger pieces of crumb rubber are used and mixed with the aggregate, and then the asphalt binder is added to the aggregate rubber mixture.

The main objective of this project was to investigate Superpave asphalt mix designs containing both CRM binder and RAP. This objective was accomplished by conducting twelve 9.5 mm Superpave mix designs in accordance with South Carolina Department of Transportation (SCDOT) specifications. The performance of each mixture was evaluated by measuring the indirect tensile strength (ITS), moisture susceptibility, and rut resistance.

2. EXPERIMENTAL METHODS AND MATERIALS

The purpose of this project was to investigate the combined use of RAP and CRM binders in Superpave mixtures. The project used a conventional Superpave HMA mixture as a control mix that was composed entirely of virgin binder and aggregate. The modified asphalt binder contained 10% crumb rubber by weight of the virgin binder. The rubber particles used were ambient shredded, minus 40 mesh crumb rubber (i.e., smaller than 0.425 mm).

The unmodified binder mixes contained 0% RAP, a low percentage of RAP (i.e., 15%), and a high percentage of RAP (i.e., 30 or 38%, depending on the aggregate source). The CRM mixes contained 0% RAP, the same low percentage of RAP, and the same high percentage of RAP as the unmodified set of mixes. Each mix passed SCDOT Superpave Specifications including the indirect tensile strength (ITS) and rut depths by means of the Asphalt Pavement Analyzer (APA). The ITS and APA test results were statistically analyzed by means of the SAS System using the GLM procedure. An illustration of the project design is shown in Figure 1. The materials used in the project were two granite aggregate sources, two RAP sources, one crumb rubber source, one lime source as an anti-strip additive, and one binder source for each RAP percentage tier.

2.1. Materials

The CRM asphalt binder used is this project met the specifications of the Asphalt Rubber Technology Service (ARTS) located in the Clemson, South Carolina. This CRM binder contained 10% crumb rubber by weight of the virgin binder. The crumb rubber was added by the wet process with a reaction time of 30 minutes, reaction temperature of 177°C, and a reaction speed of 700 rpm, by means of a mechanical mixer. The rubber particles used were ambient ground, minus 40 mesh crumb rubber.

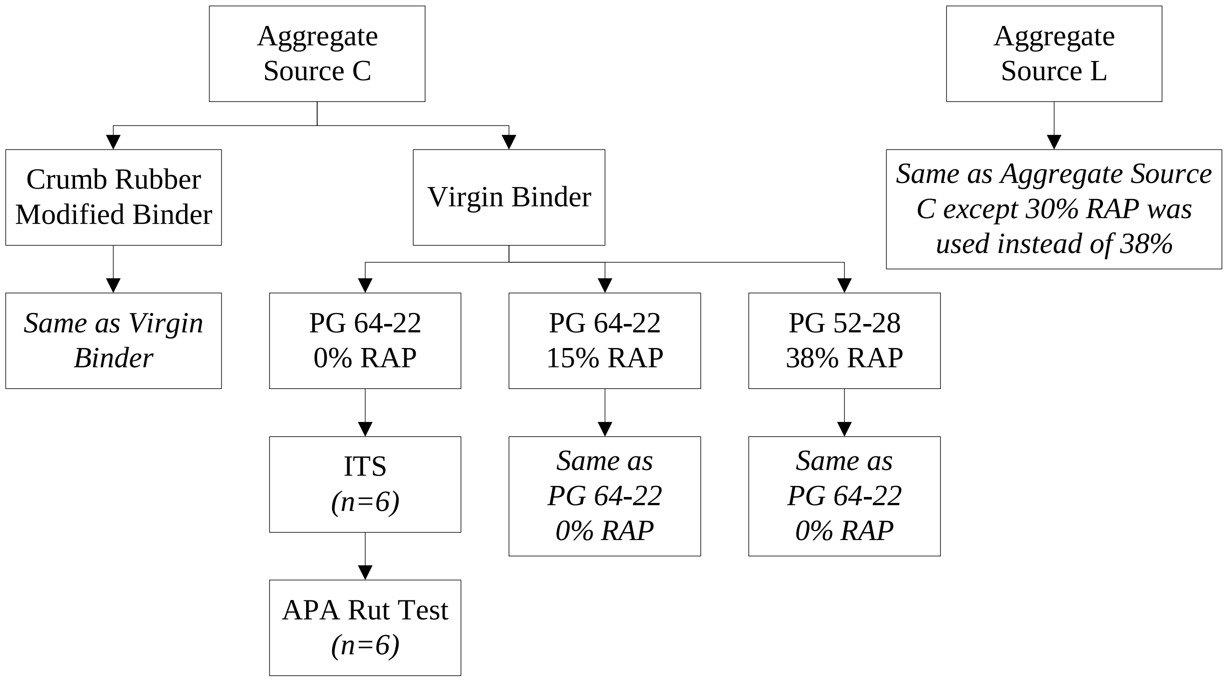

Figure 1. Experimental design

This research incorporated commonly used local aggregate sources and classifications. Two granite aggregate sources were used (Sources C and L.) Three aggregate classifications were used from each source including 789, regular screenings (RS), and washed screenings (WS). Hydrated lime was used as an anti-strip additive and was added at a rate of 1% by dry weight of virgin aggregate.

Two RAP sources (Sources A and B) were used for the mix design. RAP Source A and aggregate Source C are from the same local area and were used in combination for the mix designs. RAP Source B and aggregate Source L are from the same local area and were used in combination for the mix designs. Both RAP sources are approved SCDOT sources and used an original binder equivalent to a PG 64-22. The aged binder was recovered from each RAP source by means of extraction and the Abson recovery system, AASHTO T164 and AASHTO T170, respectively. The recovered RAP binder was tested according to AASHTO TP2. The crumb rubber modified binders were graded according to AASHTO MP1 using a dynamic shear rheometer (DSR), rotational viscometer, and bending beam rheometer (BBR).

A PG 64-22 binder was used for the mixes with 0% RAP and 15% RAP. The recovered RAP binder properties were tested using AASHTO TP2 and it was determined that a new binder grade of PG 52-28 would be used in each recycled mixture using RAP in the percentage range of the 3rd Tier (i.e., greater than 25% RAP). Table 1 shows the mix matrix.

2.2. Mix Design and Testing Procedures

A 9.5 mm Superpave mixture was used for the mix designs in this experiment. This particular mix design is for a primary route surface course mix in South Carolina. SCDOT 9.5 mm Superpave volumetric and compaction specifications, shown in Table 2, were used [6].

Table 1. Mix design matrix

<table>
<tr><th>Aggregate</th><th>Anti-strip</th><th>Binder</th><th>Modifier</th><th>RAP Source</th><th colspan="2">RAP Percentages</th></tr>
<tr><td rowspan="2">Source C</td><td rowspan="8">Lime</td><td rowspan="4">PG 64-22</td><td>None</td><td rowspan="2">Source A</td><td>0%</td><td>15%</td></tr>
<tr><td>CRM</td><td>0%</td><td>15%</td></tr>
<tr><td rowspan="2">Source L</td><td>None</td><td rowspan="2">Source B</td><td>0%</td><td>15%</td></tr>
<tr><td>CRM</td><td>0%</td><td>15%</td></tr>
<tr><td rowspan="2">Source C</td><td rowspan="4">PG 52-28</td><td>None</td><td rowspan="2">Source A</td><td colspan="2">30%</td></tr>
<tr><td>CRM</td><td colspan="2">30%</td></tr>
<tr><td rowspan="2">Source L</td><td>None</td><td rowspan="2">Source B</td><td colspan="2">38%</td></tr>
<tr><td>CRM</td><td colspan="2">38%</td></tr>
</table>

Table 2. SCDOT 9.5 mm Superpave specifications

<table>
<tr><td rowspan="11">Aggregate Gradation</td><th colspan="2">Sieve Designation</th><th colspan="2">% By Weight Passing</th></tr>
<tr><td>37.5 mm</td><td>1 ½ inch</td><td colspan="2">100</td></tr>
<tr><td>25.0 mm</td><td>1 inch</td><td colspan="2">100</td></tr>
<tr><td>19.0 mm</td><td>3/4 inch</td><td colspan="2">100</td></tr>
<tr><td>12.5 mm</td><td>1/2 inch</td><td colspan="2">98.0 – 100.0</td></tr>
<tr><td>9.5 mm</td><td>3/8 inch</td><td colspan="2">90.0 – 100.0</td></tr>
<tr><td>4.75 mm</td><td>No. 4</td><td colspan="2">54.0 – 70.0</td></tr>
<tr><td>2.36 mm</td><td>No. 8</td><td colspan="2">32.0 – 48.0</td></tr>
<tr><td>600 μm</td><td>No. 30</td><td colspan="2">14.0 – 26.0</td></tr>
<tr><td>150 μm</td><td>No. 100</td><td colspan="2">5.0 – 13.0</td></tr>
<tr><td>75 μm</td><td>No. 200</td><td colspan="2">3.0 - 9.0</td></tr>
<tr><td rowspan="5">Volumetric</td><td colspan="2">% Max. Density at N_{des}</td><td colspan="2">96</td></tr>
<tr><td colspan="2">% VMA</td><td colspan="2">15.5 – 17.5</td></tr>
<tr><td colspan="2">%Voids Filled</td><td colspan="2">70 - 80</td></tr>
<tr><td colspan="2">% Max. Density at N_i</td><td colspan="2">$\leq$ 89</td></tr>
<tr><td colspan="2">% Max. Density at N_m</td><td colspan="2">$\leq$ 98</td></tr>
<tr><td colspan="5">Dust to Asphalt Ratio 0.60 - 1.20</td></tr>
<tr><td colspan="2" rowspan="2">Type of Facility</td><th colspan="3">Number of Gyrations</th></tr>
<tr><th>N_{ini}</th><th>N_{des}</th><th>N_{max}</th></tr>
<tr><td colspan="2">Primary Routes</td><td>7</td><td>75</td><td>115</td></tr>
</table>

The rut resistance of each mixture was tested using the Asphalt Pavement Analyzer (APA). Six cylindrical APA samples were prepared for each mix design using the Superpave gyratory compactor. The 150 mm diameter samples were compacted to a height of 75 mm and prepared to reach 4 ± 1% air voids. All samples were conditioned and tested at 64°C. Each set of samples was conditioned at 64°C for 4 hours prior to testing in the APA machine. During testing, the test chamber in the APA was maintained at a temperature of 64°C. The APA settings used were a downward force of 445 N and the rubber hoses were pressurized to 689 kPa.

3. RESULTS AND DISCUSSION

3.1. Binder Testing

The recovered RAP binder properties were tested using AASHTO TP2 and it was determined that a new binder grade of PG 52-28 would be used in each recycled mixture that used RAP in the percentage range of the 3rd Tier, 30 or 38%. Binder testing of the CRM binder using PG 64-22 showed the modified binder to be graded at PG 76-22. In addition, binder testing of the CRM binder using PG 52-28 showed the modified binder to be graded at PG 76-28.

3.2. Mix Design

Each of the aggregates and its corresponding local RAP source were able to be combined in asphalt mixtures containing first and third tier range of RAP percentages and each mix passed the SCDOT 9.5 mm Superpave specifications. A total of 12 mix designs were conducted. A summary of the mix design descriptions with corresponding code is shown in Table 3.

Table 3. Mix design descriptions

Mix Code	Aggregate	Binder Type	Percentage of RAP
LV0	L	Virgin PG 64-22	0%
LM0	L	Modified PG 64-22	0%
LV15	L	Virgin PG 64-22	15%
LM15	L	Modified PG 64-22	15%
LV30	L	Virgin PG 52-28	30%
LM30	L	Modified PG 52-28	30%
CV0	C	Virgin PG 64-22	0%
CM0	C	Modified PG 64-22	0%
CV15	C	Virgin PG 64-22	15%
CM15	C	Modified PG 64-22	15%
CV38*	C	Virgin PG 52-28	38%
CM38*	C	Modified PG 52-28	38%

** In this mixture the RAP source was modified in order to incorporate a 3rd Tier range percentage of RAP into the recycled mixture. Only RAP retained on the No. 8 sieve was used.*

Table Legend:
Three part mix design coding system:
** The first letter represents the aggregate source, either L or C,*
** The second letter represents the Binder Type, M for modified and V for virgin, and*
** The number at the end represents the percentage of RAP used.*

3.3. Indirect Tensile Strength Testing

Results of indirect tensile strength (ITS) testing for the mixtures prepared with aggregate L and C are illustrated in Figures 2 and 3, respectively. The tensile strength ratio (TSR), which is a measure of a mixture's resistance to moisture damage, is also included in these figures. The minimum wet ITS and TSR according to the SCDOT specifications is 448 kPa and 85%, respectively [5].

The ITS results of the mixtures made with aggregate L indicated that each mix exceeded the minimum requirements for ITS and TSR (Figure 2). In all cases, the dry and wet ITS increased with increasing RAP percentages, while the TSR did not vary significantly. In addition, mixtures made with CRM binders resulted in higher dry ITS than the mixtures with the same RAP content made with unmodified binder. The wet ITS values for the CRM binders were lower than the corresponding unmodified mixture, but the TSR still exceeded 85% in all cases.

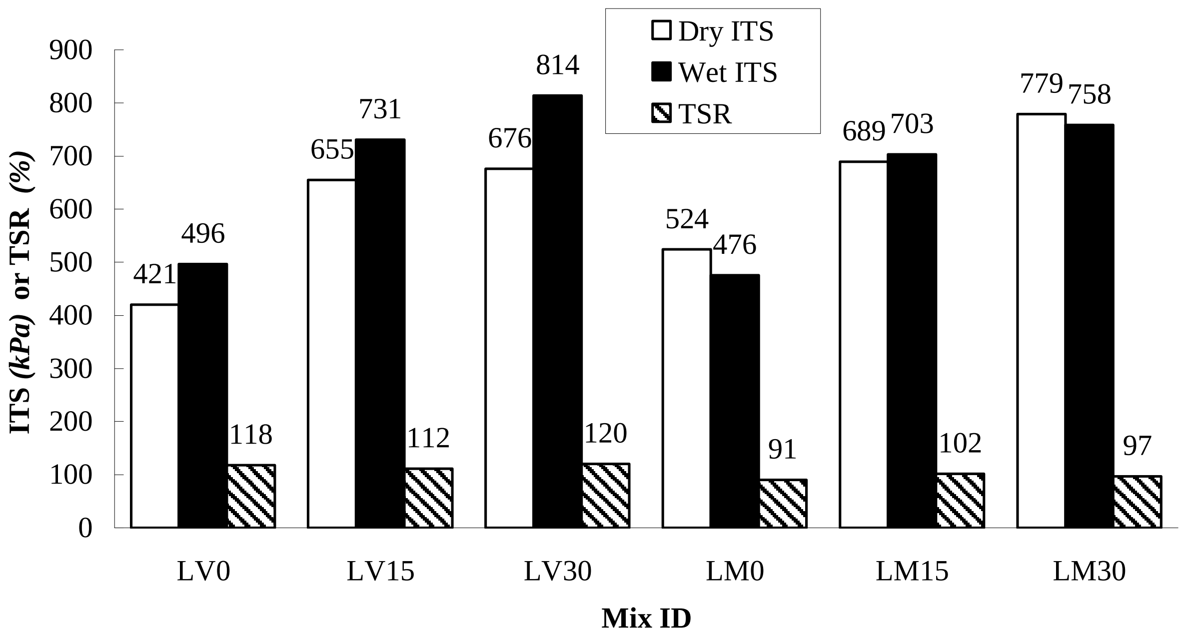

Figure Legend:
Three part mix design coding system:
** The first letter represents the aggregate source, either L or C,*
** The second letter represents the Binder Type, M for modified and V for virgin, and*
** The number at the end represents the percentage of RAP used.*

Figure 2. Indirect tensile strength (ITS) and tensile strength ratio (TSR) results for aggregate Source L

The ITS results for aggregate C are shown in Figure 3 and indicate that all mixtures exceeded the minimum wet ITS and TSR requirements according to the SCDOT specifications. Except for mix CV15, which was lower than the others, there was no significant difference between the dry ITS for any of the mixtures. In addition, both of the mixtures containing 15% RAP showed significantly higher wet ITS when compared to the others. The use of CRM binders did not have as significant an effect as it did with aggregate L.

3.4. Rut Depth Testing

The mean APA rut depth measurements from the six tested samples for each of the twelve mix designs are illustrated in Figure 4. The results indicate that all of the mixtures produced rut depths below the maximum rut depth limit of 5 mm for mixes using PG 76-22 binder or 7 mm for mixes made with PG 64-22 binder as set by the SCDOT. Further analysis of the results show that the mixes made with the CRM binder generally produce smaller rut depths than the mixes containing unmodified binder, as expected. Additionally, mixes containing RAP with the same binder and aggregate generally provided similar or better resistance to rutting than mixes without RAP with the exception of the CV38 mixture.

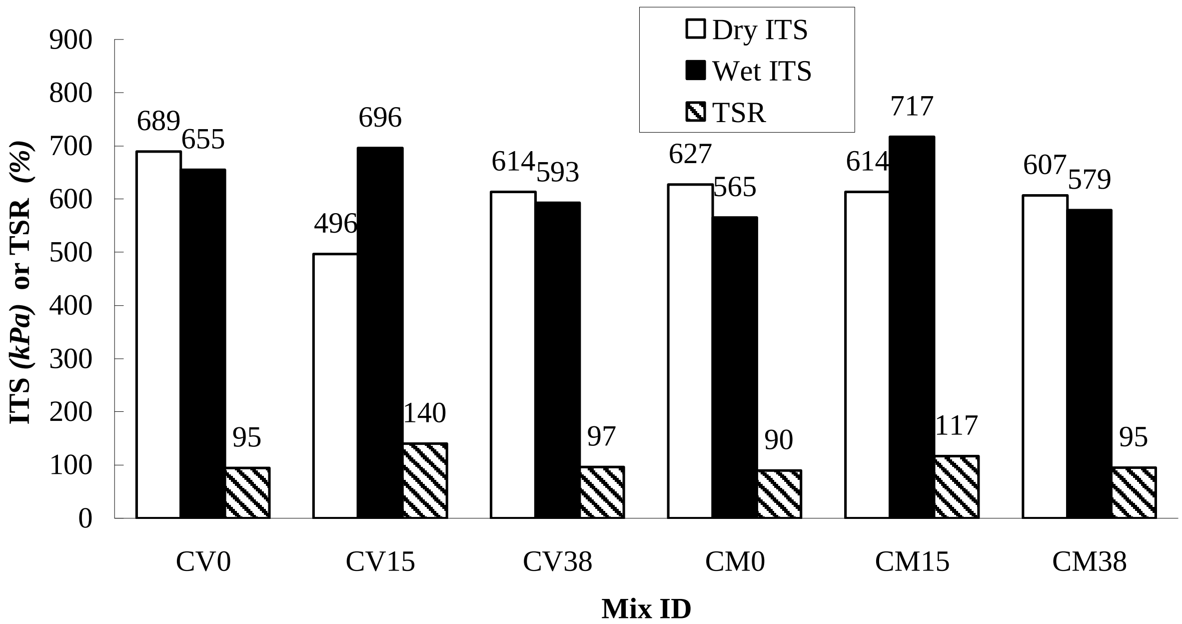

Figure Legend:
Three part mix design coding system:
** The first letter represents the aggregate source, either L or C,*
** The second letter represents the Binder Type, M for modified and V for virgin, and*
** The number at the end represents the percentage of RAP used.*

Figure 3. Indirect tensile strength (ITS) and tensile strength ratio (TSR) results for aggregate Source C

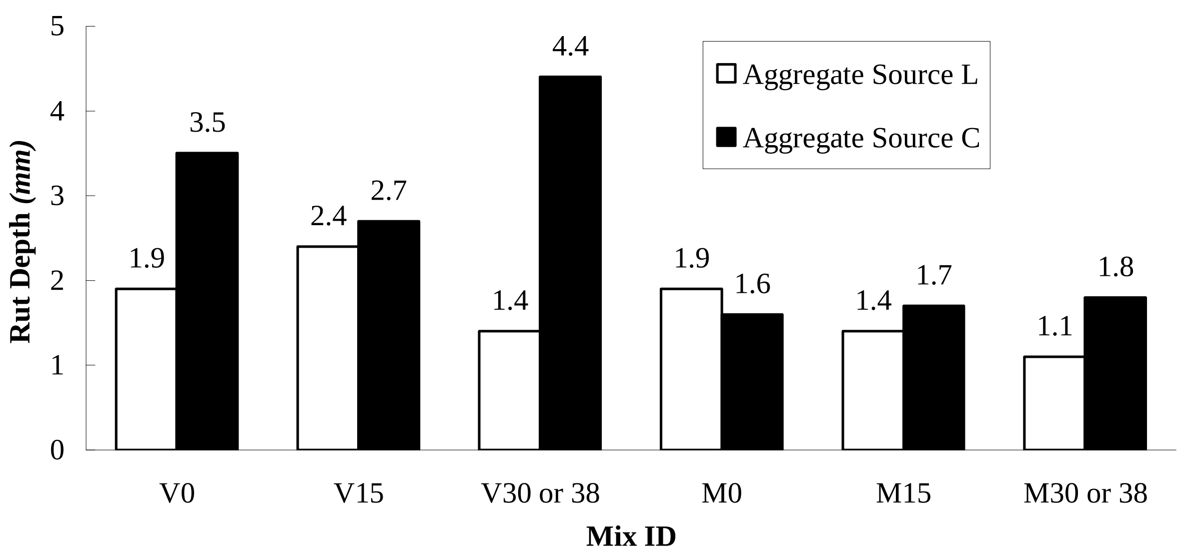

Figure Legend:
Three part mix design coding system:
** The first letter represents the aggregate source, either L or C,*
** The second letter represents the Binder Type, M for modified and V for virgin, and*
** The number at the end represents the percentage of RAP used.*

Figure 4. Rut depth results for mix designs

4. CONCLUSIONS

This research project evaluated the performance of recycled asphalt pavement (RAP) in 9.5 mm Superpave mixtures made with crumb rubber modified (CRM) asphalt binders. RAP was added to the mixtures at percentages of 15 and 30 or 38% by weight of the mixture. These RAP mixes were compared to control mixes made without RAP. Based on the results of this research, the following conclusions can be made:

- RAP can be combined (in both high and low percentages) in Superpave mixes that use CRM binder and pass the SCDOT Superpave specifications.
- Mixes containing both RAP and CRM binder that pass the SCDOT Superpave specifications will meet the performance specifications of a maximum APA rut depth of 7 mm for PG 64-22 and 5 mm for PG 76-22.
- In general, the mixes using CRM binder yielded significantly lower rut depths than the mixes using virgin binder.
- In general, the mixes using virgin binder yielded significantly higher TSR values that the mixes using the CRM binder.
- In general, the variation of RAP percentage used in a mix has no significant effect on the moisture susceptibility of the mixtures.

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