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# EFFECT OF GROUND TIRE RUBBER PARTICLES ON OPEN-GRADED MIXTURE PERFORMANCE

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December 2013

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## DISCLAIMER

**TABLE OF CONTENTS**

# 1 INTRODUCTION

Approximately 270 million waste tires are generated annually in the United States. In addition to the continued waste, the United States has an estimated 800 million stockpiled waste tires (*1*). In the year 2000, 45 percent of the waste tires generated annually were disposed of in landfills or illegally stockpiled (*2*). This number of stockpiled tires creates danger to the environment by providing a breeding ground for vermin and mosquitos while also creating a fuel source for unexpected fires (*2*). To magnify the problem of the stockpiled tires, limited tire disposal options are available.

Due to these concerns, landfilling waste tires is not the practical long-term solution for the disposing of scrap tires. These issues have led many researchers and industries to evaluate the use of the waste tires as recyclable material and even fuel sources. As of 2001, the largest market for scrap tires was the cement industry that used the tires as fuel to heat kilns (*3*). Approximately 125 million tires are used annually for tire-derived fuel (*4*). Other practical solutions for repurposing the waste material include civil engineering applications, producing carbon black, creating recycled rubber products, and as modifiers for plastic goods.

A 1989 Transportation Research Board synthesis on potential civil engineering applications for scrap tires showed modifiers for asphalt binder, lightweight embankments, retaining walls, safety hardware, and pavement sub base as potential recycling uses (*5*). Using scrap tires as a modifier for asphalt materials was found to be the most practical solution for repurposing the waste material, which could successfully incorporate two to six tires per metric ton of modified asphalt binder. The use of scrap tires as a modifier for asphalt binder requires that the waste material be ground to a fine crumb-like size, which is commonly referred to as ground tire rubber (GTR) modifier.

The most important aspect of using crumb rubber is the performance evaluation of rubber modified asphalt pavements. The findings from the modified binder testing show that crumb rubber changes the rheological properties of the binder. This would suggest that the performance properties of the mixture could be enhanced by the rubber modification of the binder. Studies have shown that rubber modification of asphalt pavement could enhance the performance of low temperature flexibility, provide a higher strength when wet, and offer more resistance to oxidative hardening (*6*). Other reports show the addition of rubber can modify thermal cracking, rutting, reflective cracking, and aging (*7*). While the logic that increased binder performance leads to increased pavement performance seems reasonable, many organizations like NCAT and FHWA indicate that laboratory material performance has not always correlated well with measured field performances. Because of the differences with laboratory and field performances, the need for field experiments is paramount.

It is well understood that GTR mixtures are different than conventional asphalt mixtures. GTR mixtures require more binder to be added to mixtures. The increase in binder along with the increase in viscosity of the binder due to the addition of rubber results in a thicker film of binder to coat the aggregate particles (*5*). Laboratory testing has shown the additional binder due to rubber content can cause the modified materials to absorb elastic stress better than conventional mixtures. While increased elastic properties are desirable, a common problem with the increased binder content is flushing and reduced air voids. With the increase of binder, existing mix designs may not provide enough void space to account for an increased volume of rubber modified binder. The necessary modifications to the aggregate structure could allow for the proper voids while limiting flushing. As states are becoming more open to the idea of incorporating GTR in their asphalt mixtures, evidence of their performance in both the field and laboratory needs to be assessed for various mixture types of asphalt concrete.

### 1.1 Objective and Scope

The objective of this research was to assess how GTR affected the design and performance of open-graded friction course (OGFC) mixtures. This was completed by comparing six different GTR modified asphalts and designing similar OGFC mixtures with the modified binders. The mixtures were then subjected to performance tests to compare their performance to a control OGFC which used a polymer-modified asphalt binder.

## 2 TESTING PLAN AND RESULTS

Laboratory testing of hot mix asphalt is critical in evaluating the feasibility of any mixture design. For this study, six crumb rubber products were used as asphalt binder modifiers in open-graded mixtures. Performance testing was conducted to determine if GTR modified binders could be used successfully in OFGC mixtures. Previous studies (*8-10*) have shown that producing hot mix asphalt with rubber modified binders yields a final material with high durability. These reports indicated that the rubber modified materials exhibited high resistance to rutting and cracking, but the majority of past studies focused on dense or gap-graded mixtures. The six GTR binders used three ambient ground materials and three cryogenic ground materials for binder modification. The ambient materials were the -20 mesh, -30 Crackermill (type of grinder), and the MD-400-AM materials. The cryogenic ground materials were the Cryohammer, MD-105-TR, and MD-400-TR materials.

The six rubber products modified a standard PG 67-22 binder. More details of this procedure and results are provided elsewhere (*11*); however, it should be noted that all of the GTR-modified asphalt binders were able to achieve a high temperature performance grade of at least 76°C (*11*). Once the modified binder had been created and mix designs completed, OGFC specimens were fabricated for performance testing. The specimens were subjected to Hamburg testing (AASHTO T 324), Asphalt Pavement Analyzer testing (GDT115), Cantabro testing (ASTM D7064M-08), and permeability testing (Florida Method 5-565). The results from these performance tests were then used to evaluate any potential influence of the rubber-modified binders on the mixture durability, rutting resistance, and permeability.

### 2.1 Mix Designs

A 12.5 mm nominal maximum aggregate size (NMAS) open-graded mix design was utilized to create seven different mixtures to be tested for performance characteristics. The seven mixtures included a control material (SBS with fibers) and specimens modified with the six afore mentioned rubber products. A singular aggregate skeleton was developed for all seven of the mixtures. The aggregate design consisted of granite 78's, baghouse fines, hydrated lime, and coarse fractionated reclaimed asphalt pavement (RAP) material. The target air voids for this design was 16 percent or greater. The control open-graded material was fabricated with a PG 76-22 SBS (2.5 percent concentration) modified binder and fibers. This material was created as a comparison for the six rubber modified mixes. The target binder content for the control design was 5.75 percent. Cellulose fibers necessary for the control design were added at a rate of 0.3 percent by weight of the mix.

The binder content of the control design was augmented to create rubber modified specimens. The binder content of the original design was increased from 5.75 to 6.33 percent for all of the rubber mixtures that included 10 percent rubber by weight of binder. This has been recommended in past research (*5*). For the singular mixture that used 15 percent loading, this increased the binder content from 5.75 to 6.61 percent. The increases established a more consistent effective binder content between the seven mixtures by accounting for the percentage of rubber modification.

## 2.2 Aggregate Batching

The percentages for each of the previously described materials by weight of aggregate in the blend are presented in Table 1.

**Table 1. Percentage of Weight in Aggregates Blend**

| Aggregate Material | Percentage of Weight |
|---|---|
| Granite 78's | 83 % |
| Coarse RAP | 15 % |
| Baghouse Fines | 1 % |
| Dry Hydrated Lime | 1 % |

The two major components of the mix, granite 78's and coarse RAP, were batched separately. The separate batching was performed to ensure that the RAP material did not receive excess aging while being heated in preparation for the mixing process. The baghouse fines were batched and prepared for the mixing process with the granite 78's material. The hydrated lime was not subjected to any direct heating and was batched just before the mixing process to ensure that the dry hydrated lime remained effective as an antistripping agent. Table 2 shows the individual aggregate gradations and the gradation of the blend.

**Table 2. Percent Passing Gradation of the Aggregate and the Blend**

| Sieve Size, mm | Granite 78’s | Coarse RAP | Bag House Fines | Hydrated Lime | Blend |
|---|---|---|---|---|---|
| 50 | 100 | 100 | 100 | 100 | 100 |
| 37.5 | 100 | 100 | 100 | 100 | 100 |
| 25 | 100 | 100 | 100 | 100 | 100 |
| 19 | 100 | 100 | 100 | 100 | 100 |
| 12.5 | 94 | 99 | 100 | 100 | 95 |
| 9.5 | 61 | 87 | 100 | 100 | 66 |
| 4.75 | 12 | 46 | 100 | 100 | 19 |
| 2.36 | 2 | 38 | 100 | 100 | 10 |
| 1.18 | 1 | 33 | 100 | 100 | 8 |
| 0.6 | 1 | 25 | 100 | 100 | 7 |
| 0.3 | 1 | 16 | 100 | 100 | 5 |
| 0.15 | 1 | 10 | 100 | 100 | 4 |
| 0.075 | 0.6 | 7.3 | 100 | 100 | 4 |
| Pan | - | - | - | - | - |

For the control specimens with no crumb rubber, the cellulose fibers were batched just before the mixing process and were integrated into the design prior to the mix process. The fibers were not exposed to the heating required to prepare the aggregate and RAP for the mix process. The weights of the aggregates batched were controlled to the nearest 0.3 grams. The weight of the baghouse fines, hydrated lime, and fibers were controlled to the nearest 0.1 grams. The mix design and volumetric properties of the 12.5mm NMAS control mix with an optimum binder content of 5.75% are shown in Table 3.

**Table 3. Mixture Properties for Control Design with Optimum Binder Content**

| Mixture Property | Value |
|---|---|
| Optimum AC, % | 5.75 |
| AC from Virgin Binder, % | 5.19 |
| AC from RAP, % | 0.56 |
| Va, % | 15.0 |
| VMA, % | 25 |
| VFA, % | 35.1 |
| Effective AC, % | 4.91 |
| Dust/Asphalt | 0..73 |
| Draindown | 0.00 |
| Gmm | 2.448 |
| Gmb | 2.08 |
| Absorption, % | 0.650 |
| Pba, % | 0.89 |

## 2.3 Specimen Mixing

The batches of granite 78's with baghouse fines and the coarse RAP material were heated in preparation for mixing with two separate procedures. The granite 78's with baghouse fines were placed in a 375° F batch oven and were stored overnight. The material remained in the oven until the mixing procedure started. The coarse RAP was heated for 3 hours at 325° F prior to the start of mixing. This was controlled through the use of a pretimed oven. All heated materials were removed from the oven at the same time to begin the mixing process.

To simplify the process of preparing the hot mix asphalt specimens, all crumb rubber modified binders were prepared before the day of the mixing procedures (*11*). Once blended, the materials were covered and stored at room temperature. When mixing was scheduled, pre-blended material was placed in a timed oven. The oven settings were configured to heat the material at 300° F for four hours prior to the scheduled mixing time. Uniform binders were ensured by re-blending the materials using a procedure documented elsewhere (*11*). After re-blending, the materials were placed in a 300° F oven to await immediate use. Cans of blended binder were stirred with a glass rod between specimen fabrication to ensure a uniform material during heated storage.

The mixing process began by removing the heated bowl and whisk from the batching oven. The bowl was placed on a scale in order for the added materials to be checked for accurate weights. The two heated aggregate batches were then removed from the oven and added to the bowl. A spoon was then used to stir the granite 78's, RAP, and baghouse fines. Once the material was homogenous, the hydrated lime was added to the mixtures followed by the cellulose fibers in the control mixture. The heated aggregate and dry additives were then stirred again to achieve homogeneity.

A small depression was formed in the center of the heated material and binder was poured into the aggregate mixture. The weight of the binder added was controlled to the nearest 0.5 grams. Once the desired amount of binder was added to the mix, the bowl and whisk were attached to the mixer. Mixing was started and a temperature gauge was used to check the mixing temperature. A mixing temperature range of 320° F to 330° F was targeted for 90 seconds. The mixture was blended on the lowest speed setting of the mixer until the majority of the aggregate was coated with binder. The mixer was then stopped and the sides of the mixing bowl were scraped to redistribute any binder-rich or binder-poor areas. The mixer was then restarted and the components were mixed until a desirable binder coating on the aggregate was achieved. After the mixing was completed, the material was removed from the bowl and placed in a pan and aged according to AASHTO R30-10.

## 2.4 Specimen Compaction

For volumetric purposes, the materials were placed in a 325° F oven for two hour short-term aging. The material was monitored to ensure the aging temperature did not induce excessive smoking. If the material was found to smoke at 325° F the temperature was reduced in increments of 5°F until smoking was significantly reduced. This process ensured that the aging temperature of the material remained in a range of 315° F to 325° F . While the material was being aged, molds for a Superpave Gyratory Compactor were placed in a 325° F oven to heat for 30 minutes before the start of compaction.

Compaction began by removing a heated mold and aged material from the ovens. The open-graded mixture was then transferred from its aging pan to a lightly lubricated funnel. The funnel was placed onto a scale so that the weight of aged material for sample fabrication could be controlled. The material was then transferred from the funnel to the heated mold. A temperature gauge was used to determine that the material was in the proper compaction temperature range of 300° F to 315° F. The weight of the first compacted specimen for each of the seven materials studied in this analysis was controlled to 4000 grams. The hot material was compacted to 50 gyrations with a Superpave Gyratory Compactor. Once compacted, the materials were allowed to rest in the compactor for three to five minutes. The specimen was then extruded from the compactor and a collar was placed around the specimen to ensure stability during the cooling process. An iterative process was then utilized to determine a target weight for each of the materials that would result in a sample height between 110 to 120 millimeters. Twenty specimens for each material type were fabricated for performance testing.

### 2.5 Volumetric Characterization

The specimen heights were recorded with calipers after compaction. Three height measurements were taken and the average value was used to characterize each specimen. The densities of the specimens were determined through the methodology described in AASHTO T 275. A Corelok device was used to create a sealed specimen for bulk specific gravity determination. The height of the specimens along with the texture of the open-graded materials required that a double bag method be used to seal the materials. A correction factor was calculated for each specimen to account for the effect of the bag on the bulk specific gravity data. The maximum specific gravity of each material was determined during the mix design process. AASHTO T 209 methodology was followed to conduct the maximum specific gravity determinations. These values were used to determine the air voids of each specimen. Table 4 shows the maximum specific gravities determined during the mix design process. Specimens demonstrating irregular air voids were not utilized in performance testing.

**Table 4. Maximum Specific Gravity of Laboratory Produced OGFC Materials**

| Material | Gmm |
|---|---|
| SBS 76-22 w/ Fibers | 2.488 |
| -20 Liberty @ 15% | 2.441 |
| -30 Cryohammer | 2.444 |
| Crackermill | 2.443 |
| MD-400-TR | 2.432 |
| MD-400-AM | 2.440 |
| MD-105-TR | 2.441 |

Draindown testing was also conducted to characterize the feasibility of the seven designs in preventing binder draindown. This testing was performed according to the methodology provided in AASHTO T 305-09. The purpose of this test is to determine the amount of binder coating that drains from hot mix asphalt at elevated temperatures. The elevated temperatures are intended to simulate production, transport and storage temperatures of the mixture.

Draindown values less than 0.3 percent by weight of the test material is considered acceptable. The production temperature for the open-graded mix was determined to be 305° F. The second temperature for the testing was 27° F warmer at 332° F. Each specimen for draindown testing had a target weight of 1200 grams. Table 5 shows the results of the draindown testing. The Liberty Crackermill material demonstrated the least amount of draindown. The only material that failed the draindown criteria was the MD-400-TR specimens. The results show that the average draindown values for the elevated testing temperature are greater than the 0.3 percent draindown criteria; however, the variability of these test data was unusual. The test was repeated on two new samples and similar variability was witnessed. Overall, however, GTR was used effectively to negate the need for fibers in OGFC mixtures to pass the draindown test.

**Table 5. Draindown of Laboratory Produced OGFC Materials**

| Temp, ° F | Specimen | Control | Liberty - 20 @15% | Liberty Cryohammer - 30 | Liberty Crackermill | Lehigh MD-400-TR | MD-400-AM | MD-105-TR |
|---|---|---|---|---|---|---|---|---|
| 305 | 1 | 0.06 | 0.17 | 0.16 | 0.11 | 0.28 | 0.23 | 0.06 |
| 305 | 2 | 0.45 | 0.20 | 0.18 | 0.07 | 0.30 | 0.28 | 0.09 |
| 332 | 1 | 0.03 | 0.05 | 0.29 | 0.12 | 0.13 | 0.11 | 0.13 |
| 332 | 2 | 0.05 | 0.09 | 0.09 | 0.07 | 0.63 | 0.16 | 0.06 |

## 2.6 Performance Testing

Specimens demonstrating irregular air voids were not selected for performance testing. Irregular air voids were determined to be extremely low or high values using the outlier procedure after the Corelok procedure. Table 6 shows the average air voids of the specimens that were utilized for performance testing. The average air voids represent the void structure of 16 specimens for each material type. The 16 specimens were utilized to characterize the performance of the modified hot mixtures with the Asphalt Pavement Analyzer, Cantabro testing, Hamburg testing, and Permeability testing. As shown in Table 6, each material had an average void structure near the desired 16 percent as outlined in the mix design.

**Table 6. Average Air Voids of Performance Tested Specimens**

| Material | Average Air Voids, % | Standard Deviation % Air Voids |
|---|---|---|
| SBS 76-22 w/ Fibers | 18.07 | 3.17 |
| -20 Liberty @ 15% | 15.35 | 0.75 |
| -30 Cryohammer | 16.79 | 1.21 |
| Crackermill | 15.15 | 3.13 |
| MD-400-TR | 16.03 | 1.77 |
| MD-400-AM | 17.42 | 0.75 |
| MD-105-TR | 17.27 | 1.11 |

The first six specimens selected for testing were confined to height requirements. The specimens with an average height closest to 115 millimeters were selected for APA testing to ensure the heights did not interfere with the APA apparatus. Another three specimens were selected and subjected to permeability testing. The selection of the three specimens required that the surface characteristics be evaluated to ensure that irregularities did not cause poor testing surfaces. Hamburg and Cantabo specimens were selected from the remaining materials.

### 2.7 Asphalt Pavement Analyzer

The rutting susceptibility of each material was evaluated through the use of the APA performance test. The Georgia Department of Transportation GDT115 methodology was followed to prepare the specimens. The specification required that the test specimen be heated at the 64° C testing temperature for a minimum of four hours. The heights of the specimens were recorded from a fixed relative point. The depth to the top of the specimen from the fixed point was taken before seating loads were applied, after seating loadings were applied, and after the completion of the testing. Table 7 shows the average depths that were taken for this testing. The results from the APA testing indicate that the MD-105-TR material exhibited the most rutting susceptibility. The standard deviations of the rutting depths were determined as indicated by the GDOT specification. No material was found to have a standard deviation greater than 2 mm maximum set by the GDOT method, and while one mixture had the most rutting, none of the mixtures exhibited rut depths, which would fail the current GDOT specification. This caused no outliers or discarded values. Figure 1 illustrates the average rutting depths with error bars indicating plus or minus one standard deviation in rutting potential of the materials.

**Table 7. Average APA Performance**

| Material | Rutting from Zero, mm | Standard Deviation for Rutting, mm |
|---|---|---|
| Control | 1.71 | 0.72 |
| 20Mesh | 2.14 | 0.94 |
| Crackermill | 2.20 | 0.41 |
| Cryohammer | 2.15 | 1.00 |
| MD-400-TR | 2.07 | 0.65 |
| MD-400-AM | 1.88 | 0.71 |
| MD-105-TR | 3.23 | 1.01 |

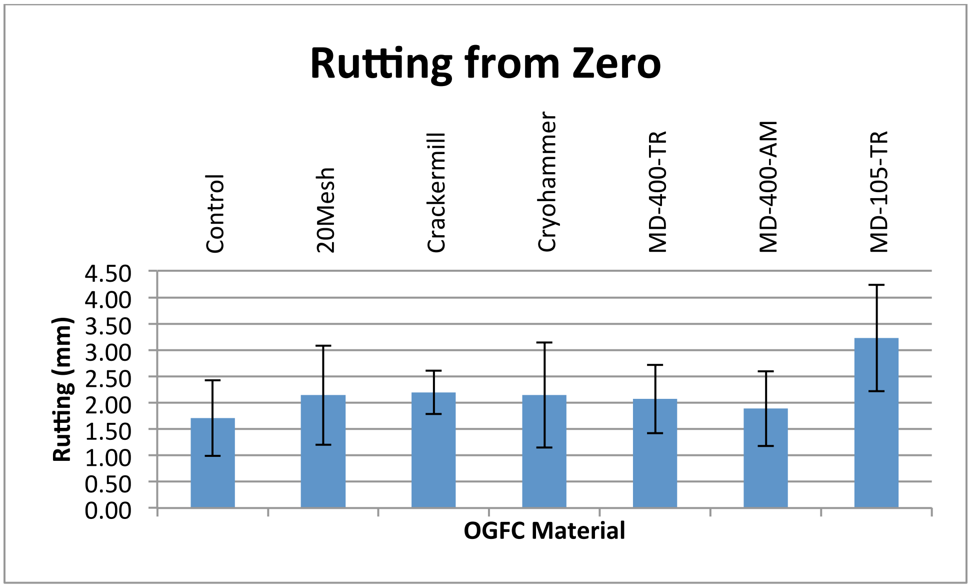

**Figure 1. Average Rut Depth from APA Testing**

While the APA is commonly used as a "Go/No Go" test, the results from the APA testing were statistically analyzed to determine if any material types could be separated into groups of statistically similar means. Minitab 16 was used to conduct an unstacked one-way Tukey-Kramer comparison with $\alpha$=0.05 to analyze the mean values for the rutting depths from the zero point for the APA testing. The 12 rutting depth locations for each material type were used to create a 95 percent confidence interval for the mean rutting value. The confidence intervals were then compared to determine whether any of the materials could be grouped similarly. The analysis showed some statistical differences with the mean confidence intervals of the APA rutting depths.

The Tukey-Kramer analysis reported two statistically different groups with the first group represented by the letter (A) and the second group represented by the letter (B). Table 8 shows the grouping of the materials based on the statistical differences in the mean rutting depths. The analysis shows that the MD-105-TR average APA rutting depth is statistically different from the other materials. The grouping of the data also shows that the Crackermill modified specimens exhibit an average rutting depth with a confidence interval that is statistically similar to both groups. The results indicate that five of the six rubber modified materials illustrate statistically similar APA rutting values to the conventional SBS mix.

**Table 8. Tukey-Kramer Grouping for Average APA Rutting Depths**

| Material | Group | Mean |
|---|---|---|
| SBS with Fibers | B | 1.71 |
| 20 Mesh @ 15% | B | 2.14 |
| Crackermill | A, B | 2.20 |
| Cryohammer | B | 2.15 |
| MD-400-TR | B | 2.07 |
| MD-400-AM | B | 1.89 |
| MD-105-TR | A | 3.23 |

## 2.8 Cantabro Testing

Cantabro Abrasion testing was conducted to evaluate the cohesion, bonding, and effects of abrasion on the open-graded materials. ASTM D7064M-08 was followed to conduct the testing of the materials. The specification required a specimen height of 63.5 mm and 100 mm in diameter which is the same as for the Marshall procedure used when the test was developed. However, every specimen of this study was fabricated to 115 mm high and 150 mm in diameter to ensure that typical Superpave specimens with adequate height and air voids could be used for APA testing. Previous research indicated there was no significant difference in results due to sample size between 100 mm and 150 mm diameter samples (*12*). The materials were tested at room temperature in a L.A. Abrasion machine. No steel charges were used in the testing and the specimens were subjected to abrasion for 300 revolutions at a rate of 30 to 33 revolutions per minute. The material loss from each specimen was recorded. The average material loss of the four specimens tested for each mix is shown in Table 9. The results show that each material type had less than 20 percent material loss as required by the specification. Figure 2 shows the average percentage of material lost as well as error bars indicating the standard deviation of each material.

**Table 9. Average Percent Material Loss for Cantabro Testing**

| Material | Average Loss, % | Standard Deviation of % Loss |
|---|---|---|
| Control | 7.61 | 1.74 |
| 20 Mesh | 15.14 | 1.26 |
| Crackermill | 15.54 | 4.13 |
| Cryohammer | 12.46 | 1.57 |
| MD-105-TR | 5.87 | 2.23 |
| MD-400-TR | 15.64 | 4.47 |
| MD-400-AM | 13.18 | 2.59 |

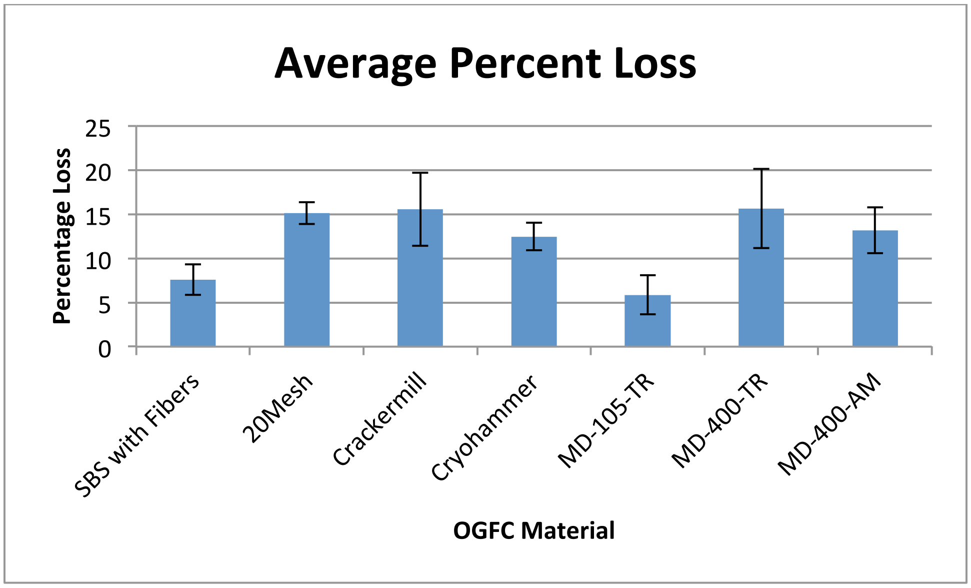

**Figure 2. Average Percentage of Material Loss from Cantabro Testing**

The results from the Cantabro testing were also subjected to Tukey-Kramer analysis with an $\alpha$=0.05 to group statistically similar average percent losses of the open-graded materials. The analysis showed that two statically different groups could be made to separate the Cantabro results. The SBS control and MD-105-TR mixtures were found to have statistically similar average material loss. The MD-400-TR, Crackermill material, and 20 Mesh material were found to have statistically similar material loss. The MD-400-AM modified materials and the Cryohammer modified materials were found to be statistically similar to both groups. Table 10 shows the grouping of the analysis with the Cryohammer and MD-400-AM material receiving both group designations. While there were statistical differences in performance, it is again important to understand the Cantabro test is commonly used as a “Go/No Go” test, and all of these mixtures had average test results less than the maximum loss criterion.

**Table 10. Tukey-Kramer Grouping for Average Cantabro Material Loss**

| Material | Group | Mean |
|---|---|---|
| SBS with Fibers | B | 7.58 |
| 20 Mesh @ 15% | A | 15.15 |
| Crackermill | A | 15.50 |
| Cryohammer | A,B | 12.45 |
| MD-400-TR | A | 15.65 |
| MD-400-AM | A,B | 13.18 |
| MD-105-TR | B | 5.85 |

## 2.9 Hamburg Testing

The rutting performance of each material was evaluated through Hamburg Wheel-Track testing. The methodology for this test procedure was AASHTO T 324-04. The testing apparatus consists of a water bath and weighted testing wheel to induce rutting and moisture susceptibility. The AASHTO specification establishes the maximum acceptable rutting criteria of a material at 0.5 inches. The results from the testing are also subjected to stripping analyses that utilize the change rate of permanent deformation to indicate moisture and load-induced stripping.

Specimens fabricated for this test were compacted to 115 mm high and 150 mm in diameter. Each specimen was then cut so that two testing surfaces could be created from one specimen. The target height of each half from the original specimen was 42.5 mm. The cut materials were then dried in preparation for the testing. Once dry, the materials were mounted into the testing trays. Plaster-of-Paris was used to fill any gap between the two halves in the testing trays. The plaster was allowed to set for 16 hours prior to testing. Test specimens were then conditioned to 50° C in the water bath for 30 minutes prior to the initiation of the testing. Each test was run to 20,000 passes of the tracking wheel to assess the total rut depth and moisture susceptibility. Table 11 shows the average impression or rut depth for each material type. The average values represent three separate tests that were conducted for each material type. The testing shows that the MD-105-TR specimens were the only material that barely failed the average 0.500 inch maximum rutting tolerance specified by the testing conditions. This mixture also had the largest standard deviation of the three test results. Figure 3 shows the average Hamburg impression values and error bars indicating the standard deviation in the averages.

**Table 11. Average Rut Depth from Hamburg Testing**

| Material | Average Impression, in. | Standard Deviation of Impression, in. |
|---|---|---|
| Control | 0.313 | 0.096 |
| 20 Mesh | 0.249 | 0.088 |
| 30 Mesh | 0.252 | 0.043 |
| Cryohammer | 0.350 | 0.049 |
| MD-105-TR | 0.513 | 0.121 |
| MD-400-TR | 0.353 | 0.116 |
| MD-400-AM | 0.331 | 0.060 |

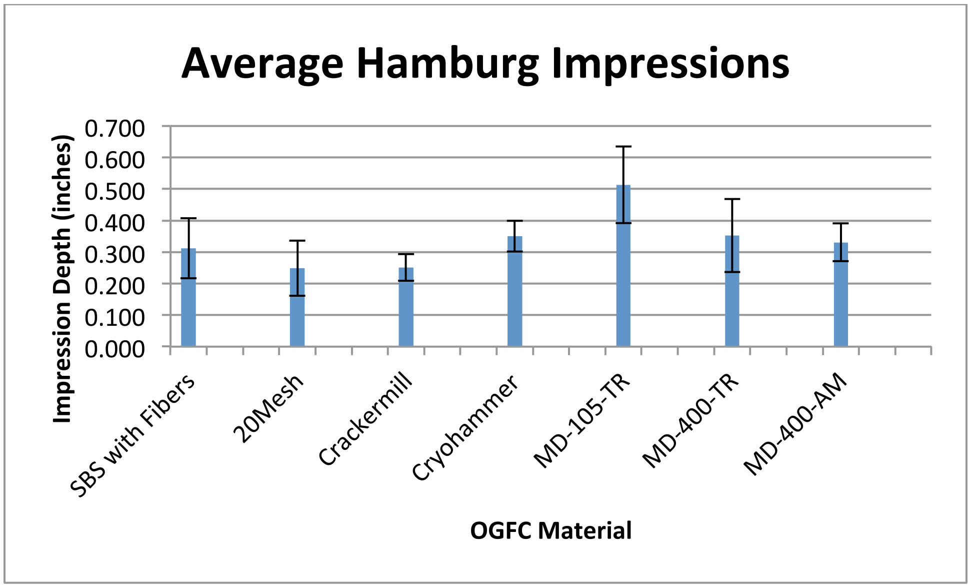

**Figure 3. Average Hamburg Impression Depths**

The impression or rutting values from the 21 Hamburg performance tests were analyzed to determine if any material types had similar confidence intervals that characterized the average Hamburg rutting values. An ANOVA run on the test results of the seven mixtures (α = 0.05) showed that despite one mix failing the maximum rutting threshold, all seven mixtures exhibited statistically similar behavior.

### 2.10 Permeability

Laboratory permeability testing of the seven material types was conducted to determine if the crumb rubber modification had a measureable effect on the inter-connectivity of the voids of the compacted specimens. The Florida Method of Test for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures designated as FM-565 was followed to conduct the testing. A laboratory permeameter similar to the AP-16 sold by Gilson Company Incorporated was used as the testing apparatus. Specimens for permeability testing were saturated by soaking the specimens in water for one hour and then mounted into the permeability device. Water was run through the specimen for approximately five minutes prior to testing. This ensured that the material was completely saturated. Each specimen underwent a minimum of three permeability tests to ensure accurate characterization of the material. The coefficients of permeability for this analysis were determined through the use of a falling head equation for permeability. Equation 1 shows the equation used to determine the values of permeability for each test.

$$k = \frac{a*L}{A*t} * \ln\left(\frac{h_1}{h_2}\right) * t_c \quad (1)$$

where

$k$ = coefficient of permeability,
$a$ = area of the testing pipe,
$L$ = length of the specimen,
$A$ = testing area of the specimen,
$t$ = testing duration,
$h_1$ = initial height of water,
$h_2$ = final height of water, and
$t_c$ = temperature correction for the water.

The testing pipe used in this study had a fixed area of 38.32 square centimeters. The area of the testing specimens was assumed to be constant at 182.41 square centimeters. The testing temperature was determined to be 21.5° C and a correction factor of 0.96 provided in the FM 5-565 procedure was used to correct the permeability data. Table 12 shows the average permeability values of each material. The testing shows the control material to be the most permeable specimens while the -20 mesh material at a 15 percent loading rate was shown to be the least permeable material. It should also be understood that the control had the largest standard deviation of the mixtures. The results are logical in that the control mixture had less asphalt and the highest level of air voids, and therefore a larger void system in place to move the water through the mixture. On the other hand, the 15% 20 mesh mixture had the most binder in the mix to compensate for a larger rubber content

**Table 12. Average Permeability of Laboratory Compacted OGFC Materials**

| Material | Average Permeability ($10^{-5}$ cm/s) | Standard Deviation of Permeability ($10^{-5}$ cm/s) |
|---|---|---|
| Control | 21,346 | 8,438 |
| 20 Mesh | 9,000 | 1,441 |
| Crackermill | 12,795 | 6,826 |
| Cryohammer | 15,876 | 817 |
| MD-105-TR | 15,985 | 5,913 |
| MD-400-TR | 18,676 | 5,846 |
| MD-400-AM | 17,008 | 5,904 |

The results from the permeability testing were also analyzed statistically. An ANOVA analysis was conducted in an attempt to group the similarly performing materials. The analysis utilized the average permeability values from each specimen analyzed. The performance testing yielded 21 permeability values to describe the seven materials. The analysis showed that the 95 percent confidence intervals describing the average permeability values were statistically similar. The analysis did not warrant any material to be grouped separately for permeability performances.

## 3 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the previously described work plan and the results that were obtained from its completion.

- For standard particle size GTR (20 to 40 mesh) there is no significant difference between ambient or cryogenic GTR in any of the three durability tests performed in this study: Hamburg, APA, or Cantabro.
- GTR-modified OGFC mixtures can commonly be used to alleviate the need for fibers to prevent asphalt binder draindown. Only one of the six GTR mixtures failed this test.
- Both the APA and Hamburg Wheel Tracking test showed that GTR-modified OGFC mixtures can be resistant to rutting. Only one GTR-modified mixture failed the Hamburg criterion; however, this mixture had a high standard deviation in its test results and passed the APA. When designed properly, a GTR-modified OGFC mixture should perform well in terms of durability, as all seven mixtures in the study passed the current Cantabro criterion.
- The laboratory permeability of the OGFC is directly related to the air voids. Adding more binder in the asphalt mixture to compensate for the presence of GTR will reduce the overall voids in the mix. This could reduce the permeability of the asphalt mixture.
- Performance results for MD-105-TR show that this micronized rubber powder (MRP) has different performance aspects relative to the other GTRs. Since the MRP was finer than other rubbers, it may have had additional digestion of the rubber itself. Results for this material suggest that lower binder content may be required. However, past studies have shown that this rubber has separation properties which are more desirable than other GTR particles.

Based on these conclusions, the following recommendations can be made.

- GTR (including MPR) can be used as an appropriate substitution for SBS in OGFC mixtures. However, one must assess the permeability, rutting susceptibility, and drain down of the mixture to ensure proper field performance. GTR has been shown to be an adequate replacement for the combination of SBS and fibers to prevent drain down; however, if a GTR OGFC mixture is designed which does not meet the minimum requirement, fibers should be added to the mixture to prevent asphalt loss. Finally, as with all mixtures, rutting should be assessed on an individual mixture basis using the test most commonly required by the individual state to ensure confidence that the mixture will resist rutting in the field.
- The field performance monitoring of GTR-modified OGFC mixtures needs to continue. Until these mixtures are placed on roadways, subjected to environmental conditions, and perform well under live traffic, some states will still be hesitant to fully accept the performance of these mixtures based solely on laboratory data.

## 4 REFERENCES

1. Amirkhanian, S. N. (2001). *Utilization of Crumb Rubber in Asphaltic Concrete Mixtures-South Carolina Experience.* Clemson, SC: Clemson University.
2. Rafat Siddique, T. R. (2004). *Properties of Concrete Containing Scrap Tire Rubber-An Overview.* Waste Management.
3. Nongnard Sunthonpafasit, M. R. (April 2003). *Scrap Tires to Crumb Rubber: Feasibility Analysis for Processing Markets.* Resources Conservation and Recycling.
4. Rafat Siddique, T. R. (2004). *Properties of Concrete Containing Scrap Tire Rubber-An Overview.* Waste Management.
5. Heitzman, M. (1992). *Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier TRR 1339.* Washington, DC: Federal Highway Administration.
6. Marvin Myhre, D. A. (2002). *Rubber Recycling.* Rubber Chemistry and Technology.
7. Amirkhanian, B. J. (2006). *Crumb Rubber Modification of Binders: Interaction and Particle Effects.* Clemson, South Carolina: Clemson University.
8. Lutfi Raad, S. S. (n.d.). *Field Aging Effects on Fatigue of Asphalt Concrete and Asphalt-Rubber Concrete.* Transporation Research Record.
9. Freddy L. Roberts, P. K. (1989). *Investigation and Evaluation of Ground Tire Rubber in Hot Mix Asphalt.* Auburn, AL: National Center for Asphalt Technology.
10. West, R. (1998). *Effect of Tire Rubber Grinding Method on Asphalt-Rubber Binder Characteristics.* Transporation Research Board.
11. Willis, J.R., C. Plemons, P. Turner, C. Rodezno, and T. Mitchell. (2012). *Effect of Ground Tire Rubber Particle Size and Grinding Method on Asphalt Binder Properties.* NCAT Report 12-09, National Center for Asphalt Technology.
12. Watson, D. E., L. A. Cooley, Jr., K. A. Moore, and K. Williams. (2004). *Laboratory Performance Testing of Open-Graded Friction Course Mixtures*. Transportation Research Record 1891, Washington D.C.