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Long-Term Performance of SMA Mixtures Added with Crumb Rubbers in Dry Process

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ABSTRACT

Crumb rubber, made from scrap tires, has been introduced into the production of different types of Hot Mix Asphalt (HMA) in either wet or dry process. In the wet process, the crumb rubber and binder are completely mixed to form Asphalt Rubber (AR), which is then mixed with aggregates in a drum. In the dry process, the crumb rubber is mixed directly with aggregates in the drum to produce an HMA called Rubberized Asphalt Mix. In this paper, the long-term performance of 3-year in service testing pavement of Stone Matrix Asphalt (SMA) pavements with crumb rubber added in dry process was examined through a visual inspection and laboratory testing on cored samples. The results indicated that the distresses of cracking, rutting, raveling, bleeding, pushing, and potholes were not found in the rubberized PEM wearing layer under which rubberized SMA and polymer modified asphalt cement (PMAC) SMA was used, i.e., the rubberized and control PMAC SMA underlayers had similar effect on the performance of the surface PEM. The rubberized SMA core samples taken from the field had slightly higher stability and lower flow than control SMA ones.

INTRODUCTION

Crumb rubber, made from scrap tires, has been introduced into the production of different types of Hot Mix Asphalt (HMA) because it improves resistance to rutting (1, 2, 3, and 4). In the wet process, the crumb rubber and binder are completely mixed to form Asphalt Rubber (AR), which is then mixed with aggregates in a drum at a mix plant. In the dry process, the crumb rubber is mixed directly with aggregates in the drum to produce an HMA called rubberized asphalt mix.

Crumb rubber is added as a substitute for the Polymer-Modified Asphalt Cement (PMAC) normally required to produce a PG 76-22 in three types of HMA: Porous European Mix (PEM), Stone Matrix Asphalt (SMA), and polymer-modified 12.5 mm Superpave mixtures in Georgia. Many studies have addressed the wet process. Some states, like Arizona, California, Florida, and Louisiana, have well established specifications/recommendations on the design and production of AR, HMAs containing AR, and construction methods, based on both laboratory and field tests (5, 6, and 7).

In the typical dry process, crumb rubber is directly added with the aggregates in the drum as a substitute for about 5% or more of the fine aggregate. In some cases, a certain amount of crumb rubber is added to produce HMA without changing the mix design, which is the case in the study. Nevertheless,
during blending, the asphalt binder is expected to coat the aggregates and crumb rubber, and the crumb rubber is expected to react, to some extent, with the hot asphalt as in the wet process to produce an asphalt binder that is more viscous than base binder and as viscous as PMAC.

Previous studies evaluated the properties of the mixtures with crumb rubber in dry process by laboratory experimentation. Cao (8) reported that the addition of recycled tire rubber in asphalt mixtures using dry process could improve engineering properties of asphalt mixtures, and the rubber content had a significant effect on the performance of resistance to permanent deformation at high temperature and cracking at low temperature. Hernández-Olivaresa et al (9) reported the rubber-modified hot-mix asphalt pavement by dry process which was placed and compacted after a controlled time of maturation (ageing) of the warm rubber-modified hot-mix asphalt, which promotes a close interaction between the rubber particles and the binder. Jorge Henrique Magalhães Pinheiro et al (10) reported that small size rubber particles and the interaction time were observed to positively affect the rubberized asphalt mixture (dry process) properties. Rahman et al (11) found rubberized asphalt mixes to be more susceptible to moisture with the degree of susceptibility primarily depending on the amount of rubber in the mixture, rather than the difference in compaction. Pasetto and Baldo (12) investigated the laboratory characterization of rubberized asphalt mix. Results indicated that the rubberized asphalt mixes have a longer fatigue life, a better stiffness behavior at lower temperatures and a bigger permanent deformation resistance at high temperatures than conventional mixtures. Most of present researches about rubberized asphalt mix focus mainly on the laboratory characterization of mix, while the evaluation of field performance of rubberized asphalt mix is minimal.

The rubberized SMA sections and control PMAC SMA sections were paved under a rubberized asphalt PEM wearing course on I-20 Augusta in 2009 using the dry process to modify the asphalt cement with crumb rubber in Georgia. So far, neither a formal evaluation has been performed nor has research on these rubberized pavements generally been documented. Collecting data to evaluate their long-term performance is urgently needed for GDOT to decide whether dry-process technology can be adopted for widespread use in Georgia. Comprehensive evaluation of rubberized asphalt methods and pavement performance is necessary before it can be further applied in Georgia.

OBJECTIVE

The objective of this study is to evaluate the long-term performance of rubberized surface PEM layer and rubberized SMA underlayer with service times of 3 years to evaluate the performance of rubberized PEM surface layer and determine if rubberized SMA underlayer performs as well as PMAC SMA underlayer. This evaluation is to be conducted through a visual inspection and laboratory testing.

TEST SECTIONS
The rubberized PEM test section was constructed in both eastbound and westbound lanes in 2009. The length of the test sections of either eastbound or westbound is 2.15 miles. The rubberized surface PEM mix consisted of mesh-30 crumb rubber at 10% of the weight of the asphalt cement; transpolyoctenamer (TOR) polymer at 4.5% of the weight of the crumb rubber; an asphalt binder with PG 67-22; and crushed granite aggregates. The optimum asphalt binder content (OAC) of the job mix formula for rubberized PEM mix was 6.0%. Table 1 presents the granite aggregate gradation of the rubberized PEM mix (13).

In addition, rubberized and control PMAC SMA pavements were paved under the rubberized PEM surface layer in the eastbound and westbound lanes, respectively. The rubberized SMA mix consisted of mesh-30 crumb rubber at 11.4% of the weight of the asphalt cement; TOR polymer at 4.5% of the weight of the crumb rubber; an asphalt binder with PG 67-22; and crushed granite aggregates. The nominal maximum size of the granite aggregates for both SMA mixes was 12.5 mm. The OAC for both rubberized and control SMA mixes was 6.0%. Table 2 presents the granite aggregate gradation of SMA mix (13).

| Table 1 Aggregate Gradation of PEM |
|-----------------------------------|
| Sieve (mm)           | 19 | 12.5 | 9.5 | 4.75 | 2.36 | 0.075 |
| Percentage Passing (%) | 100 | 90 | 50 | 14 | 8.0 | 3.0 |

| Table 2 Aggregate Gradation of SMA |
|-----------------------------------|
| Sieve (mm)           | 19 | 12.5 | 9.5 | 4.75 | 2.36 | 0.3 | 0.075 |
| Percentage Passing (%) | 100 | 87 | 59 | 26 | 21 | 12 | 9 |

TEST METHODS

The long-term performance of rubberized PEM test sections was evaluated by the visual field inspection and laboratory investigation of core samples taken from the field. The visual field inspection included a series of distress measurements in accordance with the PACES manual, such as cracking, rut depth, raveling, bleeding, pushing, and potholes. Laboratory investigations included density, permeability, Stability and flow. Only laboratory test was conducted on both rubberized and control PMAC SMA core samples.

**Rut Depth**
Rut depth was measured in both wheel paths in the sample area and recorded in millimeters (mm).

**Cracking**
The length of the cracking was measured and the level of the distresses severity was recorded.

**Raveling, Bleeding, and Pushing**
The length of the distresses was measured and the level of the distresses severity was recorded.
Pothole
The total number of potholes was counted for the entire rated segment (normally a mile).

Bulk specific gravity
The bulk specific gravity of the PEM and SMA core samples were measured using the Corelok method following AASHTO T 331 and AASHTO T 166, respectively.

Maximum specific gravity
Maximum specific gravity of the core samples was conducted according to ASTM D6857-03 Standard Test Method.

Permeability
Permeability was measured using the Karol-Warner Flexible Wall Permeameter. The apparatus and testing procedures are detailed in ASTM PS 129-01.

Stability and flow
Stability and flow test of SMA core samples were conducted according to AASHTO T 245.

RESULTS AND DISCUSSION

Inspection of Field Performance

| Item                  | Westbound | Eastbound |
|-----------------------|-----------|-----------|
| Rut Depth (mm)        |           |           |
| section 1             | 0         | 0         |
| section 2             | 0         | 0         |
| section 3             | 0         | 0         |
| section 4             | 0         | 0         |
| Cracking (%)          | 0         | 0         |
| Raveling (%)          | 0         | 0         |
| Bleeding (%)          | 0         | 0         |
| Pushing (%)           | 0         | 0         |

Table 3 presents I-20 Augusta field pavement performance as measured by cracking, rut depth, raveling, bleeding, pushing, and potholes. As mentioned, rubberized PEM pavement was placed in both east- and westbound lanes, while a rubberized SMA was used under the eastbound lane and SMA modified with styrene butadiene styrene (SBS) under the westbound lane. Neither test section showed distress (Figs. 1, 2).
Laboratory Performance of Core Samples

Because sampling on a busy interstate highway requires traffic control such as closing lanes, the number of samples taken was restricted. A total of 12 core samples, 6 from the rubberized PEM with rubberized SMA underlayer and 6 from that with PMAC SMA underlayer were obtained. To measure their properties, the PEM and SMA parts were cut from the core samples.

1) Rubberized PEM Surface Layer Test Results

The surface of the I-20 Augusta testing section is rubberized PEM in both directions, so we could observe how it performs with two different underlayers of rubberized and control PEM. Tables 4 and 5 and Figures 3-5 show that the rubberized PEM with a rubberized SMA underlayer has slightly less density and more air voids and permeability than one with a control SMA underlayer. Hence, the effect of rubberized and control SMA underlayers on the PEM surface layer have no significant difference.
Table 4 Laboratory Test Results of Rubberized PEM Samples

| Sample ID | Thickness of Samples (inch) | Bulk Specific Gravity | Air Voids (%) | Permeability (cm/s) |
|-----------|-----------------------------|-----------------------|---------------|-------------------|
| East Bound |                             |                       |               |                   |
| 1-A*      | 1.4                         | 2.01                  | 16.6          | 0.118             |
| 2-B*      | 1.6                         | 2.04                  | 15.4          | 0.040             |
| 3-A*      | 1.5                         | 2.04                  | 15.4          | 0.075             |
| 4-B*      | 1.6                         | 2.03                  | 15.8          | 0.067             |
| 5-A*      | 1.4                         | 2.03                  | 15.8          | 0.112             |
| 6-B*      | 1.5                         | 1.96                  | 18.7          | 0.123             |
| West Bound |                             |                       |               |                   |
| 7-A*      | 1.3                         | 2.08                  | 13.7          | 0.051             |
| 8-B*      | 1.5                         | 2.01                  | 16.6          | 0.056             |
| 9-A*      | 1.1                         | 2.01                  | 16.6          | 0.086             |
| 10-B*     | Broken                      | ---                   | ---           | ---               |
| 11-A*     | 1.0                         | 2.03                  | 15.8          | 0.048             |
| 12-B*     | Broken                      | ---                   | ---           | ---               |

*A and B of sample ID represent the core samples are from the path wheel and the center of the lane respectively.

Table 5 Average of Test Results of Rubberized PEM Samples

| Item                              | East Bound | West Bound |
|-----------------------------------|------------|------------|
| Bulk Specific Gravity, Average    | 2.018      | 2.031      |
| Air Voids (%), Average            | 16.3       | 15.7       |
| Permeability (cm/s), Average      | 0.089      | 0.060      |

Figure 3 Bulk Specific Gravity of Rubberized PEM Samples
2) SMA Under-layer Test Results

One of the objectives of the I-20 Augusta testing was to compare the performance of rubberized SMA with control PMAC SMA as an under-layer. Tables 6 and 7 show the laboratory test results for SMA core samples. Because the thickness of the core specimens varies from the 2.5 inch depth, correction factors are applied to the maximum load. To determine stability, the following formula is used:

\[ \text{Stability} = \text{Maximum Load} \times \text{Correction Factor} \]

Flow of the mixtures is associated with the thickness of the samples regardless of the type of the mixtures, see Figure 6. There is no thickness correction factor.
available from references or recommendations to modify the flow. For the purpose of comparison, a flow with the thickness being 2.5 inch was calibrated, a standard thickness of a Marshall sample, through interpolation.

Table 6 Properties of the SMA Core Samples

| Item                  | Location                      | Rubberized SMA | Control PMAC SMA | Difference between Rubberized and Control SMA (%) |
|-----------------------|-------------------------------|----------------|------------------|-----------------------------------------------|
| Bulk Specific Gravity | Between Wheel Paths, Average  | 2.274          | 2.262            | 0.5                                           |
|                       | Wheel Path, Average           | 2.301          | 2.280            | 0.9                                           |
|                       | Average of All                | 2.288          | 2.271            | 0.7                                           |
| Maximum Specific Gravity | Between Wheel Paths, Average  | 2.398          | 2.409            | -0.5                                          |
|                       | Wheel Path, Average           | 2.398          | 2.409            | -0.5                                          |
| Air Voids (%)         | Between Wheel Paths, Average  | 5.2            | 6.1              | -14.8                                         |
|                       | Wheel Path, Average           | 4.0            | 5.4              | -25.9                                         |
|                       | Average of All                | 4.6            | 5.8              | -20.4                                         |

Table 7 Stability and Flow of SMA Core Samples

| Item                  | Location                      | Rubberized SMA | Control PMAC SMA | Difference between Rubberized and Control PEM (%) |
|-----------------------|-------------------------------|----------------|------------------|-----------------------------------------------|
| Thickness (inch)      | Between Wheel Paths, Average  | 1.6            | 2                | -20                                           |
|                       | Wheel Path, Average           | 1.7            | 1.9              | -10.5                                         |
|                       | Average of All                | 1.7            | 2.0              | -15.3                                         |
| Maximum Load (LBF)    | Between Wheel Paths, Average  | 1147           | 1596             | -28.1                                         |
|                       | Wheel Path, Average           | 1572           | 1837             | -14.4                                         |
|                       | Average of All                | 1360           | 1717             | -21                                           |
| Correction Factor     | Between Wheel Paths, Average  | 2.39           | 2.39             | 2.39                                          |
|                       | Wheel Path, Average           | 1.99           | 1.99             | 1.99                                          |
|                       | Average of All                | 2.19           | 2.19             | 2.19                                          |
| Corrected Stability (LBF) | Between Wheel Paths, Average  | 2699           | 2407             | 12.1                                          |
|                       | Wheel Path, Average           | 3085           | 2820             | 9.4                                           |
|                       | Average of All                | 2892           | 2614             | 10.8                                          |
| Flow* (0.01inch)      | Between Wheel Paths, Average  | 17             | 26               | -34.6                                         |
|                       | Wheel Path, Average           | 22             | 31               | -29                                           |
|                       | Average of All                | 20             | 29               | -31.8                                         |
| Calibrated Flow** (0.01inch) | Average                        | 34             | 46               | 16.2                                          |

*Flow values not corrected. **Flow values calibrated with a thickness of 2.5 inch
Table 6 shows that the average air voids in rubberized samples from the wheel path and the center of the lane are 4.0% and 5.2%, respectively, and in control SMA samples, 5.4% and 6.1%, respectively. The rubberized SMA had 0.7 % higher bulk specific gravity, and 20.4 % lower air voids than the control SMA, indicating that the rubberized SMA pavement was compacted better during construction. In addition, the core samples from the wheel path have slightly fewer air voids than those from the center of the lane, which may be attributed to higher traffic loading.

It is noted in Table 7 that the rubberized SMA had 10.8 % higher stability, and 16.2 % lower flow (calibrated to 2.5 inch) than the control SMA. These results illustrate that the rubberized SMA mixes have similar or better resistance to permanent deformation than the control SMA. It might be attributed to the lower air voids of rubberized SMA, or the better properties of rubberized SMA.

The average stability of core samples from the wheel path and the center of the lane in the rubberized pavement were 3,085 and 2,699 LBF, respectively, and in the control SMA pavement, 2,820 and 2,407 LBF, respectively. Hence, core samples from the wheel path were slightly more stable than those from the center of the lane possibly because they had been subjected traffic loadings.

Overall, rubberized SMA had fewer air voids, higher stability, and lower flow compared to control SMA. Fewer air voids may explain the higher stability and lower flow.

**SUMMARY AND CONCLUSIONS**

This paper presents an evaluation of the long-term performance of rubberized PEM and SMA pavements using the visual field inspection and laboratory investigation on I-20, August, Ga, which was built in 2009. The following conclusions can be obtained from the presented research:
• After three years in service, the rubberized PEM surface layer indicates, from the visual inspection, that the distresses of cracking, rutting, raveling, bleeding, pushing, and potholes were not found, i.e., in a good performance.

• After three years’ service, the field performance of the rubberized PEM with under-layer of rubberized SMA was similar to that with under-layer of PMAC SMA, indicating the rubberized and control PMAC SMA under-layer from I-20 Augusta had similar resistance to rutting and cracking.

• The rubberized PEM with a rubberized SMA underlayer has slightly less density and more air voids and permeability than one with a control SMA underlayer, indicating that the effect of rubberized and control SMA underlayers on the PEM wearing layer have no significant difference.

• The rubberized SMA had 0.7 % higher bulk specific gravity, and 20.4 % lower air voids than the control SMA, indicating that the rubberized SMA pavement was compacted better during construction.

• The rubberized SMA pavement had slightly higher stability and lower flow than the control, indicating that SMAs with crumb rubber added in the dry process have similar or better resistance to permanent deformation than the controls.

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