GEORGIA DOT RESEARCH PROJECT 11-19
FINAL REPORT

COMPREHENSIVE EVALUATION OF THE LONG-TERM PERFORMANCE OF RUBBERIZED PAVEMENT

PHASE I: LABORATORY STUDY OF RUBBERIZED ASPHALT MIX PERFORMANCE

Georgia Department of Transportation

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Comprehensive Evaluation of the Long-Term Performance of Rubberized Pavement

Phase I: Laboratory Study of Rubberized Asphalt Mix Performance

Final Report

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16. Abstract
Crumb rubber, made from scrap tires, has been introduced into the production of different types of hot mix asphalt (HMA) in either a 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. This paper examines the long-term performance of porous European mix (PEM) and stone matrix asphalt (SMA) pavements to which crumb rubber was added in the dry process. Test sections were visually inspected for surface distress, following the guidelines in the Georgia Department of Transportation (GDOT) Pavement Condition Evaluation System (PACES) manual. Core samples were evaluated in the laboratory on selected physical and durability properties, including the void ratio, permeability, density, Cantabro loss, and Marshall stability Visual inspection results show that the performance of rubberized pavement almost equals that of polymer-modified PEM with no rutting, raveling, or cracking, while the Cantabro test showed a higher mass loss after 3 years' service. After 5 years' service, the rubberized pavement performed slightly better to rutting depth, while other visual indicators remained the same. The rubberized SMA pavement had slightly higher Marshall stability and lower flow than the control SMA pavement, with similar effects on the polymer-modified PEM's surface performance.

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EXECUTIVE SUMMARY

Background

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 (1-4). In the wet process, crumb rubber and binder are completely mixed to form asphalt rubber (AR), which is then mixed with aggregates in a mixing drum at an asphalt plant. Many studies have addressed the wet process, and states like Arizona, California, Florida, and Louisiana have well-established specifications or recommendations for the design and production of AR, HMAs containing AR, and construction methods, based on both laboratory and field tests (5-7).

In the typical dry process, which is considered easier and more economical than the wet, the crumb rubber is mixed directly in the drum as a substitute for 5% or more of the fine aggregate to produce an HMA called *rubberized asphalt mix*. In some cases, a certain amount of crumb rubber is added without changing the mix design. The crumb rubber used in the mixture design for the projects in the study does not replace the aggregate; that is, it is added on top of the mix design based on AC content. It is expected to react with the hot asphalt cement as in the wet process to produce an asphalt binder that is more viscous than base asphalt cement and as viscous as polymer-modified asphalt cement (PMAC).

Previous studies evaluated the properties of the mixtures added with the crumb rubber in the dry process. Rahman et al. (8) found that, compared to conventional mixtures, dry process crumb rubber-modified (CRM) asphalt mixtures are more susceptible to moisture to a degree that depends primarily on the amount of rubber rather than any difference in compaction. In laboratory tests, Pasetto and Baldo (9) found that rubberized asphalt mixes have a longer fatigue life, better stiffness behavior at lower temperatures, and greater permanent deformation resistance at high temperatures than conventional mixtures. Solaimanian et al. (10) found that combining 5% mesh-14 ground tire rubber (GTR) and VESTENAMER®, a cross-linking rubber polymer that hardens asphalt binder, increased the high-temperature binder one grade; the failure strain at low temperature increased; and repeated shear tests at constant specimen height demonstrated improved resistance to rutting.

In Georgia, crumb rubber has been used to modify asphalt cement as a substitute for the 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. Test sections of rubberized and control PMAC PEM and rubberized and control PMAC SMA were paved on I-75 Valdosta (2009), I-20 Augusta (2009), and I-75 Perry (2007) using the dry process. Data evaluating their long-term performance will allow the Georgia Department of Transportation (GDOT) to decide whether to adopt dry-process technology for widespread use.

Objectives

This study evaluated the performance of rubberized PEM after 3 and 5 years of service and SMA pavements at 3 years of service to determine if they perform as well as PMAC, PEM, and SMA pavements. We inspected the test pavements visually for such distresses as rutting, cracking, raveling, and potholes and conducted laboratory tests to determine the physical properties and durability of core samples.

Major Findings

Field Inspection

1）After three years' service, visual inspection indicated that the field performance of the rubberized PEM pavement was similar to that of control PMAC pavement. No cracking, raveling, bleeding, pushing, potholes, or excessive rutting were found in the I-75 Valdosta and I-20 Augusta rubberized test sections. Only two profiles of PMAC PEM pavement near I-75 Valdosta, milepost 10, showed minor rutting of 1/16 inch, measured using a specially designed rutting ruler. The skid resistance of the rubberized PEM test section was slightly better than that of the control PMAC PEM pavement from I-75 Valdosta.

2) After five years' service, visual inspection showed that the field performance of the rubberized PEM pavement from I-75 Perry was similar to that of control pavement. Neither bleeding nor pushing was found in either, while rut depth was less in the rubberized PEM pavement than the control PEM pavement. Both I-75 Perry test sections of PEM pavement showed similar reflection cracking, which has nothing to do with the materials. Raveling was found only in the first 24 feet of the rubberized PEM test section.

3）Visual inspection of the I-20 Augusta PEM test sections showed that rubberized and control PMAC SMA underlayers performed similarly in terms of resistance to rutting and cracking.

Lab Evaluation of Core Samples

1）Laboratory performance test results indicated that the rubberized PEM mixture had lower bulk specific gravity, better permeability, and higher Cantabro loss than the 3-year I-75 Valdosta control pavement and the 5-year I-75 Perry control pavement.

2) Rubberized SMA specimens had slightly greater Marshall stability and less flow than the control SMA. SMA mixed with crumb rubbers in the dry process had similar or better resistance to permanent deformation than the control SMA.

3) The value of Cantabro loss increased with service life for both rubberized and control PEM specimens. The deviation of the Cantabro test results was large due to the difficulty of measuring the nonstandard size of the aged samples.

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Chapter 1 Introduction

1.1 Background and Objectives

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. 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.

In Georgia, crumb rubber has been used to modify asphalt cement 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. Many studies have addressed the wet process, and states like Arizona and California have well-established specifications/recommendations on the design and production of AR, HMA containing AR, and construction methods based on both laboratory and field tests. Three years ago, test sections on I-75 and I-20 in Georgia were paved with PEM and SMA using the dry process to modify the asphalt cement with crumb rubber, but their performance was not formally evaluated, nor had research on these rubberized pavements generally been documented. The Georgia Department of Transportation (GDOT) urgently needed data on their long-term performance to decide whether to adopt dry-process technology for widespread use.

In the typical dry process, crumb rubber is added directly in the drum as a substitute for 5% or more of the fine aggregate. In some cases, a certain amount is added without changing the mix design. The crumb rubber used in the mixture design for the study projects did not replace the aggregate; that is, it was added on top of the mix based on AC content. During blending, the asphalt binder is expected to coat the aggregates and crumb rubber, which 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. For rubberized HMA pavement to be a competitive substitute, research must prove that it performs as well as HMA pavement containing PMAC for either PEM or SMA.

Phase 1 tasks were as follows:

Task 1 Literature review: We reviewed the documents on crumb rubber-modified mixtures and pavements and polymer-modified asphalt (PMA) mixtures and pavements, including PEM and SMA, and identified the laboratory evaluation index and criteria.

Task 2 Visual inspections: Visual inspection of the rubberized and control PEM test sections included pavement distresses, such as rutting, cracking, raveling and potholes.

Task 3 Laboratory investigations. Equal numbers of cores were obtained from wheel paths and lane centers for each section of testing pavement. For rubberized and control PMAC PEM core samples, we tested density, permeability, and Cantabro loss; for rubberized and control PMAC SMA core samples, we tested density, flow, and stability.

1.2 Report Organization

This report is divided into 6 chapters. Chapter 1 presents a general introduction to rubberized pavement and the study's objectives and scope of work. Chapter 2 presents the literature review. Chapter 3 describes construction of the test sections; chapter 4 summarizes field inspection of performance. Chapter 5 summarizes the laboratory evaluation of core samples, and Chapter 6 presents our conclusions and recommendations.

Chapter 2 Literature Review

2.1 Wet Process and Dry Process

Crumb rubber-modified (CRM) asphalt paving materials have been successfully used for crack-filling, chip-sealing, stress-absorbing membrane interlayers (SAMI), friction courses, and overlays. CRM is generally introduced using either a dry or wet process.

Most CRM-modified asphalt projects conducted in the United States use the wet process. CRM and a binder are first completely mixed to form AR, which is then mixed with aggregates in a drum at a mix plant to produce CRM HMA. The American Society of Testing and Materials (ASTM) has defined the AR produced by the wet process as "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in hot asphalt cement sufficiently to cause swelling of the rubber particles."

In the dry process, CRM is normally used as a substitute for a small portion of the fine aggregate. Particles are blended with the aggregates prior to addition of the asphalt cement. Common methods include the PlusRide and generic dry. The PlusRide technology is a patented process in which CRM particles ranging in size from 4.2 mm to 2.0 mm are added to comprise 1-3% of the total paving mix by weight. The target content of air voids in the asphalt mix is 4%, which is usually attained at asphalt binder content between 7.5 and 9% (11). Generic dry technology uses an equivalent or slightly lower percentage of finer CRM than PlusRide. The CRM is ambient granulated or ground from whole tires.

2.2 Findings on Road Test Sections

In 1994, the Louisiana Department of Transportation and Development (LADOTD) initiated research to compare the long-term performance of pavements with CRM HMA to that of control sections with conventional HMA. Although in laboratory tests the conventional mixtures exhibited greater strength than the CRM mixtures, sections paved with CRM asphalt mixtures showed better overall field performance than corresponding control sections. Both wet and dry CRM-modified HMA performed as well, if not better, than the conventional mix types evaluated (3).

Texas has used asphalt rubber in pavement construction and rehabilitation for a long time, and all of the asphalt rubber porous friction course (PFC) projects evaluated exhibit excellent performance. Resistance to cracking and raveling is particularly impressive. From a costs-and-benefits standpoint, PFC represents the best application for asphalt rubber (12).

The Arizona Department of Transportation has rich experience in AR applications using the wet process. It constructed many large-scale AR overlay projects under both light and heavy traffic conditions and climates ranging from cold and wet to hot and dry. Results indicate that the AR mixtures have performed remarkably well for the last decade, and their long-term crack resistance and corresponding low maintenance costs appear unique (13).

The South Carolina DOT has conducted field research on asphalt mixtures using crumb tires since 1991. According to its findings, Pelham Road (dry process) has somewhat deteriorated in its 8 years of service. The other asphalt rubber projects appear to be in satisfactory condition (14).

In Georgia, Reeves Construction Company paved a one-mile test section with dry process CRM/transpolyoctenamer (TOR)-modified PEM on I-75 near Perry in 2007. This project used 30-mesh-size CRM at 10% the weight of the asphalt cement and 4.5% TOR based on the weight of the CRM. During placement, no difference was observed between this material and conventional PEM, except for reduced smoke (15). Cantabro test results showed no significant difference between the PG 76-22 PEM (conventional asphalt mix) and CRM/TOR-modified PEM (15).

Chapter 3 Test Section Construction Information

3.1 Sites

Two rubberized asphalt PEM sections and a control PMAC PEM section were paved on I-75 Valdosta in 2009 and I-75 Perry in 2007. The rubberized asphalt SMA sections and control PMAC SMA section were paved under a rubberized asphalt PEM wearing course on I-20 Augusta in 2009 (Fig. 3-1). Table 3-1 presents information on each test section.

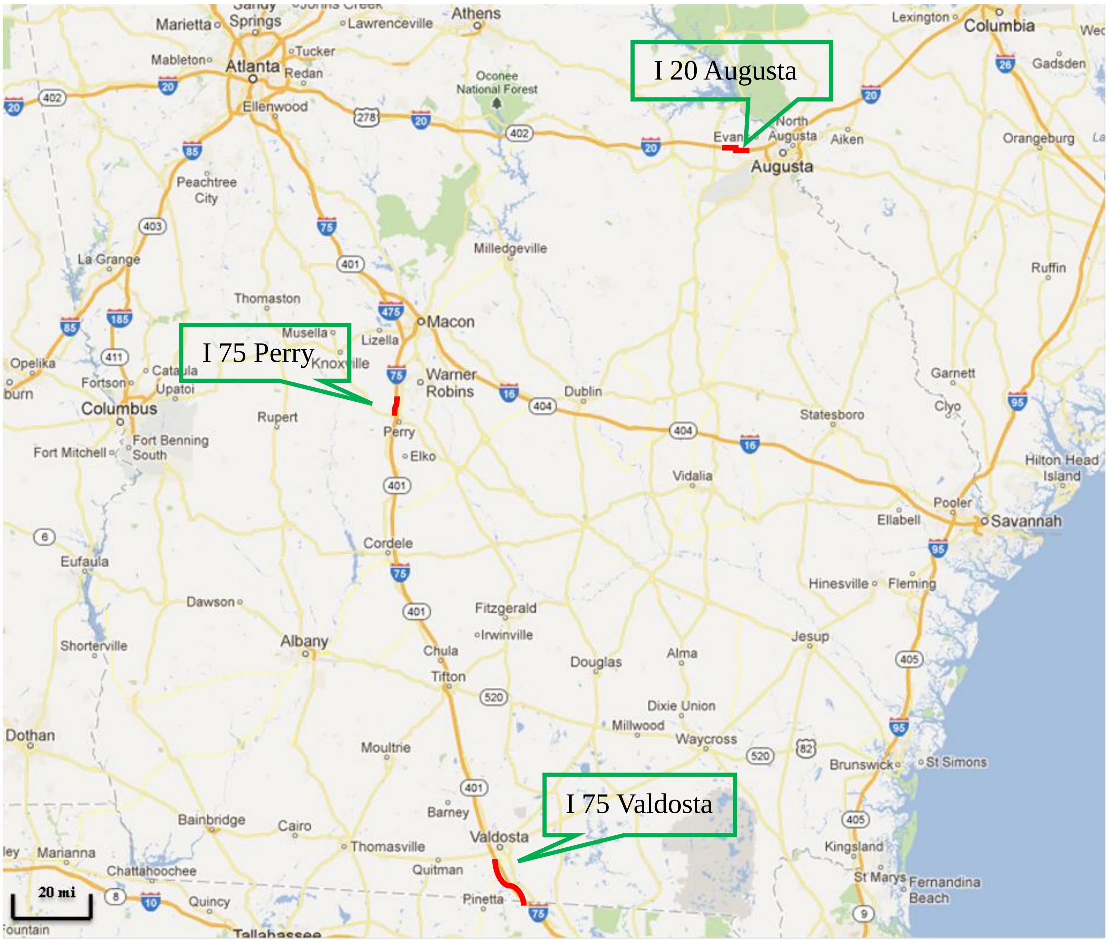

Figure 3-1 Three Test Section Site

Table 3-1 Construction Dates and Locations of Test Sections

Test Section			Thickness (Inch)	Date (Year)	Length (Mile)	Orientation
I-75 Valdosta	Rubberized PEM	Surface	1.25	2009	17	Southbound
	Control PEM	Surface	1.25	2009	17	Northbound
I-20 Augusta	Rubberized PEM	Surface	1.25	2009	2.15	East- and Westbound
	Rubberized SMA	Underlayer	2.0	2009	2.15	Eastbound
	Control SMA	Underlayer	2.0	2009	2.15	Westbound
I-75 Perry	Rubberized PEM	Surface	1.25	2007	1	Northbound
	Control PEM	Surface	1.25	2007	1	Northbound

3.2 PEM Materials and Design

I-75 Valdosta. The southbound section is paved with rubberized PEM, and the northbound section is the control. Both are 17 miles long. The mix consisted of 30-mesh crumb rubber at 10% of the weight of the asphalt cement; transpolyoctenamer (TOR) polymer at 4.5% of the weight of the crumb rubber; and an asphalt binder with PG 67-22. PG test results showed that laboratory blended CRM binder met PG 76-22 of AASHTO M 320 specification requirements but not GDOT's phase-angle requirement (maximum 75-degree). The optimum asphalt binder content (OAC) of the job mix formula for crumb rubber/TOR-modified PEM and PG 76-22 PEM mixes is 6.0 % for this project. Table 3-2 presents the granite aggregate gradation of the job mix formula for both PEM mixes (14).

Table 3-2 PEM Aggregate Gradation of Job Mix Formula

Sieve	3/4"	1/2"	3/8"	N0. 4	N0. 8	N0. 200
Percentage Passing (%)	100	90	50	14	8.0	3.0

The Cantabro test was used to evaluate PEM resistance to raveling. Average-%-loss results obtained from a plant-produced mix for PG 76-22 PEM and crumb rubber/TOR-modified PEM were 18.6% and 19.1%, respectively, or no significant difference, and met GDOT's expected performance rate of less than 20%

I-20 Augusta. The rubberized 2.15 mile PEM test sections were constructed in both east- and westbound lanes in 2009. The rubberized surface PEM mix was consistent with that on I-75 Valdosta and consisted of 30-mesh crumb rubber at 10% of the weight of the asphalt cement; transpolyoctenamer (TOR) polymer at 4.5% of the weight of the crumb rubber; and the OAC of the crumb rubber/TOR-modified PEM and PG 76-22 PEM mixes was 6.0%. Rubberized and control SMA sections were paved under the PEM layer in the east- and westbound lanes, respectively. The nominal maximal size of the granite aggregates for both SMA mixes was 12.5 mm. The OAC for both SMA mixes was 6.0%.

I-75 Perry. This 1-mile testing section was constructed in August 2007. The northbound outside lane is rubberized PEM, and the others are modified SBS. The rubberized and control PEM mixes were consistent with those on I-75 Valdosta.

3.3 SMA Materials and Design

The rubberized and control SMA pavements were constructed under the PEM surface layer on I-20 Augusta in 2009. All eastbound lanes are rubberized SMA, while all westbound lanes are a control SMA pavement to which 11.4% crumb rubber modifier was added. The OAC of the SMA mixes is 6.0%. Table 3-3 presents the granite aggregate gradation of the job mix formula for both SMA mixes.

Table 3-3 SMA Aggregate Gradation of Job Mix Formula

Sieve	3/4"	1/2"	3/8"	NO. 4	NO. 8	NO. 50	NO. 200
Percentage Passing (%)	100	87	59	26	21	12	9

3.4 Dry Process

In the dry process, crumb rubber is mixed directly with aggregates in the drum to produce the PEM and SMA. A volumetric feed system was set up at the asphalt plant to incorporate the blended crumb rubber/TOR material into the RAP collar at the drum (Figs. 3-2, 3-3).

Figure 3-2 Blended Crumb Rubber/TOR Feeder Container (15)

Figure 3-3 Blended Crumb Rubber/TOR Added Type (15)

Chapter 4 Field Inspection of Pavement Performance

4.1 Field Inspection Plan

To obtain representative pavement sections, a preliminary inspection was conducted. The team stood on the shoulder and recorded distresses with the help of traffic control (Figs. 4-1, 4-2). Eight representative sections were selected for further inspection.

Figure 4-1 Traffic Control for a Preliminary Inspection

Figure 4-2 Preliminary Inspection

During lane inspection, traffic control closed the lane according to the requirement of the FHWA's *Manual on Uniform Traffic Control Devices* (MUTCD) (Fig. 4-3). The inspectors walked in the lanes and inspected in detail the amount and severity of the distresses (Fig. 4-4).

Figure 4-3 Traffic Control for Lane Inspection

Figure 4-4 Lane Inspection

4.2 Methods

The long-term performance of the rubberized PEM and control PEM test sections was evaluated by visual field inspection and laboratory investigations of cored samples. The visual inspection followed the GDOT PACES manual (16), which indicates the types of, and measurements for, such roadway surface distress as rutting, cracking, raveling, bleeding, pushing, and potholes.

Rut depth was measured in both sample area wheelpaths and recorded in units of 1/16 inch. Rutting measurements were taken by "blocking" up the stringline using a block of hollow steel pipe (Fig. 4-5).

Figure 4-5 Rut Measurement

Cracking, including load cracking, block/transverse cracking, and the combination, was measured lengthwise, and severity recorded.

Raveling, Bleeding, and Pushing were measured lengthwise, and the level of severity was recorded.

Potholes were counted for the entire rated segment, normally a mile.

4.3 I-75 Valdosta

Table 4-1 summarizes I-75 Valdosta pavement performance as measured by rut depth, cracking, raveling, bleeding, pushing, and potholes. After three years' service, the field performance of the rubberized PEM pavement is obviously similar to that of the control PEM pavement. Cracking, raveling, bleeding, pushing, and potholes were not found in either (Figs. 4-6, 4-7), and only two profiles of the control PEM pavement near milepost 10 showed minor rutting at a depth of 1/16 inch.

Table 4-1 Field Inspection Test Results, I-75 Valdosta

Item		Control PEM	Rubberized PEM
Rut Depth (1/16 inch)	section 1	0	0
	section 2	0	0
	section 3	0	0
	section 4	0	0
	section 5	0	0
	section 6	0	0
	section 7	1	0
	section 8	1	0
Cracking (%)		0	0
Raveling (%)		0	0
Bleeding (%)		0	0
Pushing (%)		0	0

Figure 4-6 Typical Rubberized PEM Surface, I-75 Valdosta

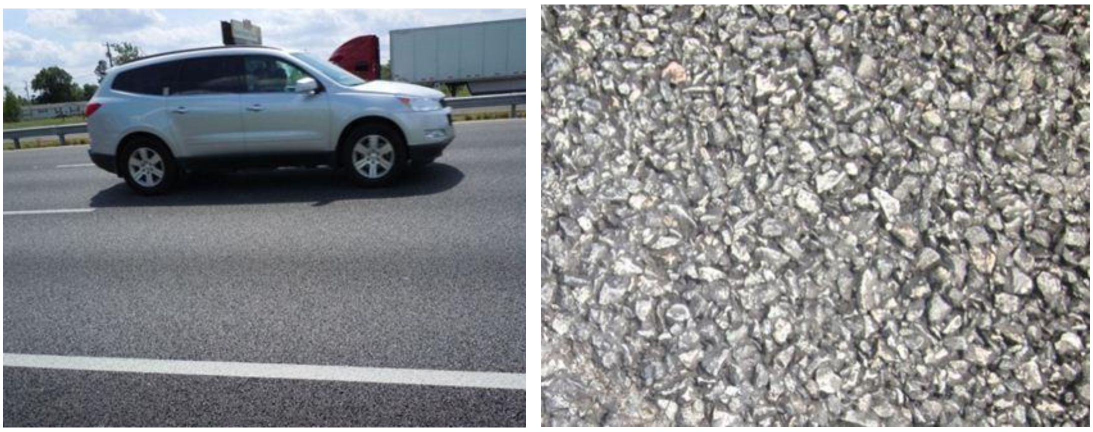

Figure 4-7 Typical Control PEM Surface, I-75 Valdosta

4.4 I-20 Augusta

Table 4-2 Field Inspection Test Results, I-20 Augusta

Item		Westbound	Eastbound
Rut Depth (1/16 inch)	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 4-2 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 placed in the eastbound lane, and SMA modified with Styrene Butadiene Styrene (SBS) was placed in the westbound lane. Neither test section showed distress (Figs. 4-8, 4-9).

Figure 4-8 Typical Rubberized PEM Surface with Rubberized SMA Underlayer, I-20 Augusta

Figure 4-9 Typical Rubberized PEM Surface with Control SMA Underlayer, I-20 Augusta

4.5 I-75 Perry

Table 4-3 Field Inspection Test Results, I-75 Perry

Item		Control PEM	Rubberized PEM
Rut Depth (1/16 inch)	section 1	2	1
	section 2	2	1
	section 3	3	1
	section 4	2	2
	section 5	3	1
	section 6	2	2
	section 7	2	1
	section 8	2	1
Raveling (%)		0	Length of 24’ at the beginning
Bleeding (%)		0	0
Pushing (%)		0	0
Reflection Cracking		Interval: 30´3´´, Length: 12´, Width: 0.5´´-2´´	

Table 4-3 presents I-75 Perry pavement field performance as measured by cracking, rut depth, raveling, bleeding, pushing, and potholes. Again, the rubberized and control PEM pavements performed similarly after five years in service, except for the raveling occurring 24 feet at the beginning of the rubberized PEM test section where it meets the PMAC. Neither bleeding nor pushing was found in either section (Figs. 4-10, 4-11). Average rut depths for the rubberized and control PEM test sections were 1.2/16 and 2.3/16 inch, respectively, which are still very low. This finding illustrates that the rubberized PEM has slightly better rutting resistance than the control section on I-75 Perry.

Figure 4-10 Typical Rubberized PEM Surface, I-75 Perry

Figure 4-11 Typical Control PEM Surface, I-75 Perry

Reflection cracking was observed in both rubberized and control PEM test sections (Fig. 4-12), and the length and severity of reflection cracking were similar. Most cracking crossed over the lane at 30´3´´ intervals. Widths varied from 0.5´´ to 2´´.

Figure 4-12 Reflection Cracking of Rubberized PEM

Where the rubberized PEM test section meets the PMAC, about 24 feet of raveling was evident (Fig. 4-13).

Figure 4-13 Raveling in Rubberized PEM

4.6 Skid Resistance Test

Skid resistance in the wheel paths of PEM pavements was measured by a portable skid resistance tester according to AASHTO T 278-90 (2012) (Fig. 4-14).

Figure 4-14 Skid Resistance Measurement

Table 4-4 Skid Resistance Test Results

Pavement		Skid Resistance (BPN)	
		between Wheel Paths	Wheel Path
I-75 Valdosta	Control PEM	64	57
	Rubberized PEM	64	61
I-20 Augusta	Rubberized PEM	53	54
	Rubberized PEM	62	58
I-75 Perry	Control PEM	56.4	49.1
	Rubberized PEM	50.7	49.8

Table 4-4 presents the results. For the I-75 Valdosta wheel path, the rubberized PEM pavement test section was slightly more skid resistant than the control PEM pavement, and performance was similar in both I-20 Augusta east- and westbound lanes and the I-75 Perry wheel path.

4.7 Conclusions

Visual inspection supports the following conclusions:

(1) After three years' service, the field performance of the rubberized PEM pavement was similar to that of the control pavement. The distresses of cracking, rutting, raveling, bleeding, pushing, and potholes were not found in the I-75 Valdosta or I-20 Augusta rubberized PEM pavement. Only two profiles of the

PMAC PEM pavement near milepost 10 of I-75 Valdosta showed minor rutting of 1/16 inch. Skid resistance of the I-75 Valdosta rubberized PEM test section was slightly better than that of the control PMAC PEM based on the results of the portable skid test.

(2) After five years' service, the I-75 Perry rubberized PEM and control PEM pavements performed similarly. Neither showed bleeding nor pushing. While all profiles of both had rutting, ruts in the rubberized PEM pavement were shallower than those in the control PEM pavement. Both I-75 Perry PEM pavement test sections showed similar reflection cracking, which had nothing to do with the materials. The 24-foot raveling was found only at the beginning of the rubberized PEM test section.

(3) After three years' service, the field performance of the rubberized PEM with an underlayer of rubberized SMA was similar to that with an underlayer of PMAC SMA. The rubberized and control SMA underlayer from I-20 Augusta had similar resistance to rutting and cracking.

Chapter 5 Laboratory Evaluation of Core Samples

5.1 Core Sampling Plan

Since wheel paths are subject to repeated traffic loading, their core samples should be different from core samples taken between them. To determine the influence of traffic loading on pavement physical properties and durability, the same numbers of cores were obtained from wheel paths and lane centers in each test section (Figs. 5-1, 5-2).

Figure 5-1 Core Sample Drilling Location

Figure 5-2 Core Sample Drilling

Because sampling on a busy interstate highway requires closing lanes and controlling traffic, the number of cores taken was restricted. A total of 24 samples from I-75 Valdosta, 12 each from the rubberized and control sections, were taken (Fig. 5-3). A total of 12 samples from I-75 Perry, 6 each from sections with rubberized and control SMA underlayers, were taken (Fig. 5-4). For I-20 Augusta, a total of 12 cored samples, 6 from the rubberized PEM underlaid with rubberized SMA and 6 from that underlaid with PMAC SMA were taken (Fig. 5-5). To measure their properties, the PEM and SMA parts were cut from the core samples.

Figure 5-3 24 Cores from I-75 Valdosta

Figure 5-4 12 Cores from I-20 Augusta

Figure 5-5 12 Cores from I-75 Perry

5.2 Test Methods

To investigate the properties of the rubberized PEM and SMA core samples, a series of laboratory tests, including the bulk specific gravity, Marshall stability, permeability, and Cantabro tests, were conducted.

Bulk Specific Gravity Test

(1) Saturated Surface Dry (SSD) Method for SMA Core Samples. The water displacement method, or saturated surface dry (SSD) method (AASHTO T166 or GDT 39), is most commonly used to determine bulk specific gravity of compacted HMA. A dry sample is first weighed in air and then submerged in a water bath for a specific time. Upon removal, the sample is patted dry with a damp towel, and the SSD mass determined. Based on Archimedes's principle, the SSD method approximates the volume of a compacted asphalt specimen as the volume of water displaced when it is submerged.

(2) CoreLok Method for PEM Core Samples. While the bulk specific gravity (G_{mb}) of compacted HMA samples has been measured by the water-displacement approach outlined in AASHTO T166 or ASTM D2726, this method is inaccurate for open graded (OGFC) and absorptive mixtures. Water infiltration in and out of the sample produces a lower reading of the actual volume and air voids and a higher density estimate.

The CoreLok system automatically seals the samples in specially designed, puncture-resistant polymer bags that allow accurate measurement in the water displacement test (Fig. 5-6). The system consists of a vacuum chamber and bags for sealing both beam samples and 4-6-inch diameter laboratory and field samples. The density of the bag is determined at the factory. Densities measured with the CoreLok system are highly reproducible. The method is ASTM D6752/D6752M-11.

Figure 5-6 Corelok Apparatus

Marshall Stability Test. The Marshall stability test measures the maximal load the test specimen can support at a loading rate of 50.8 mm/minute (2 inches/minute). Basically, the load is increased until it begins to decrease; the procedure is stopped, and the load recorded. At the same time, an attached gauge measures the specimen's plastic flow (Fig. 5-7) in 0.25 mm (0.01 inch) increments. One standard Marshall stability and flow test is AASHTO T 245.

Figure 5-7 Marshall Apparatus

Permeability Tests. Permeability can be defined as the extent to which fluid flows through a porous medium, typically expressed as the coefficient of hydraulic conductivity. A falling head permeability test apparatus is used to determine the rate of flow of water through the specimen. In a graduated cylinder, water is allowed to flow through a saturated asphalt sample, and the time it takes to reach a known change in head is recorded. The permeability coefficient of the asphalt sample is then determined based on Darcy's law. The laboratory permeability of the cores is determined in accordance with the ASTM falling head procedure (ASTM PS 129-01).

Permeability was measured using the Karol-Warner Flexible Wall Permeameter (Fig. 5-8). The apparatus and testing procedure are detailed in ASTM PS 129-01. In this test, the coefficient of water permeability through the specimen is calculated according to Equation 1.

$$\mathrm{k} = \frac{a \times l \times \ln\frac{h_1}{h_2}}{A \times t}$$

where: k = coefficient of water permeability, cm/s;

a = inside cross-sectional area of inlet standpipe, $cm^{2;}$

l = thickness of test specimen, cm;

A = cross-sectional area of test specimen, cm^2;

t = average elapsed time of water flow between timing marks, s;

h_1= hydraulic head on specimen at time t_1, cm; and

h_2= hydraulic head on specimen at time t_2, cm.

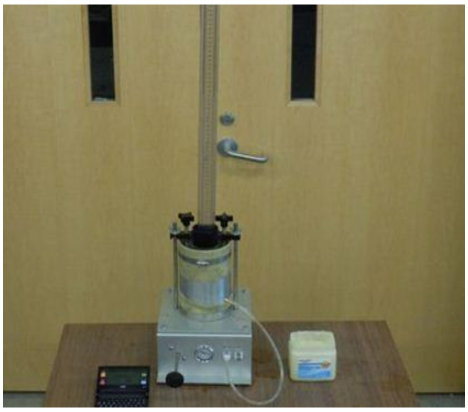

Figure 5-8 Permeability Apparatus

Cantabro Test. The core sample's potential to ravel was evaluated using the Cantabro test. Normally, the core samples are weighed and placed in a Los Angeles abrasion test machine without steel balls (Fig. 5-9), and the drum turned.

Figure 5-9 Cantabro Apparatus

The percentage of mass lost is used to evaluate the core sample's resistance to raveling. Cantabro loss was calculated using the following formula:

$$CL = (A-B)/A \times 100$$

where: CL = Cantabro Loss, %

A = Initial weight of test specimen

B = Final weight of test specimen.

The standard number of revolutions (300) for this study was not adopted because the core samples were much thinner than the standard 2.5±0.05" thickness. In addition, the test was developed for virgin mixtures; thin and aged samples experience breaking rather than abrasion at high rotations. Figures 5-10 and 5-11 indicate two states of breaking and abrasion at revolutions of 40 and 60, respectively, for both rubberized and control samples. To determine the appropriate number of revolutions for the core samples, we conducted several trials at revolutions ranging from 10 to 60 and used the number at which the samples started to break. It was determined that 40, 10, and 40 were the best parameters for the core samples taken from I-75 Valdosta, I-75 Perry, and I-20 Augusta, respectively.

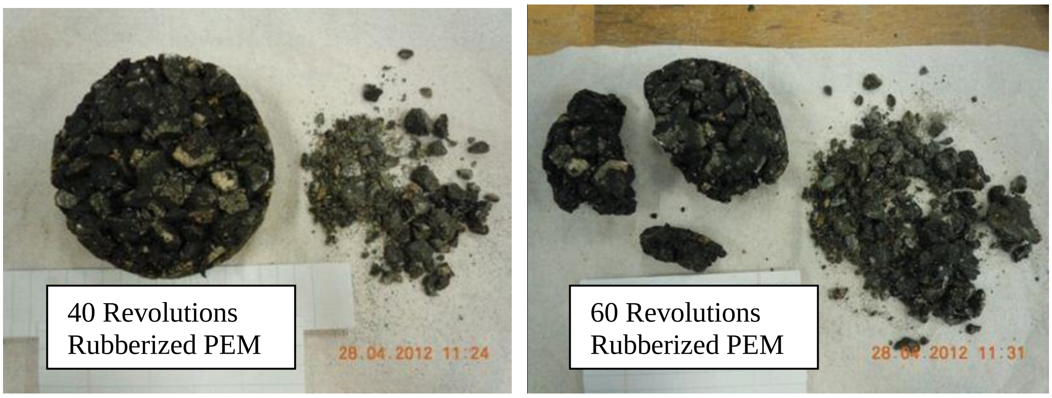

Figure 5-10 Cantabro Loss at Different Revolutions of Rubberized PEM

Figure 5-11 Cantabro Loss at Different Revolutions of Control PEM

Core sample thickness influenced Cantabro loss. Figure 5-12 shows the typical relationship for the I-75 Valdosta samples, and it is similar to that for the I-75 Perry and I-20 Augusta samples: the thicker the sample, the less Cantabro loss.

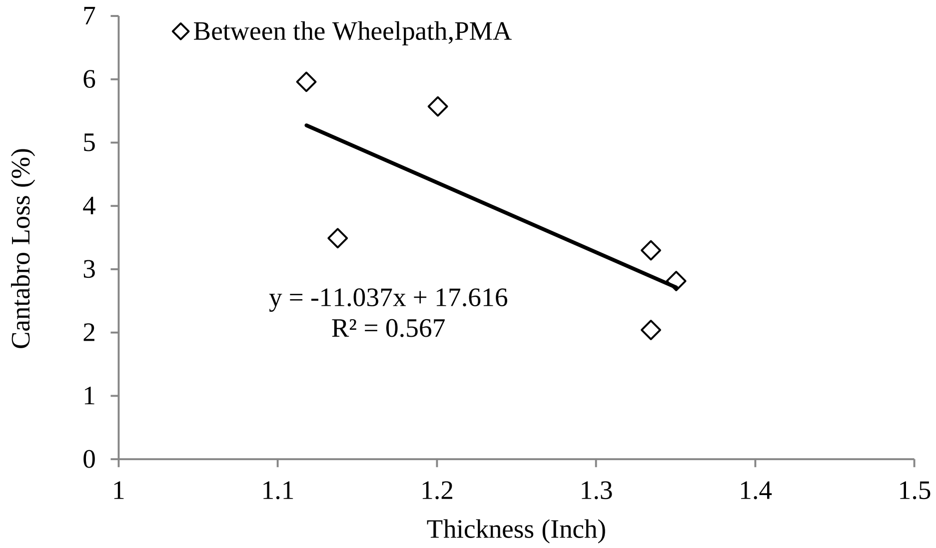

Figure 5-12 Relationship between Thickness and Cantabro Loss after 40 Revolutions in Core Samples, I-75 Valdosta

A master curve, indicating the relationship between the number of rotations and the thickness of the cores with the same mass loss, might allow us to determine the number of rotations needed for a certain thickness. However, the curve developed for the mixtures aged under laboratory by following AASHTO R-30 did not apply to the aged core samples in our project since the revolutions needed for those thin core samples were found to be at least 60. After the same number of rotations, our 3-year core samples were almost intact, while the 5-year samples broke into little pieces and particles (Figs. 5-13, 5-14). Defining Cantabro loss when samples break into little pieces rather than simply abrade is inappropriate. The curve established in the research was not used in the research.

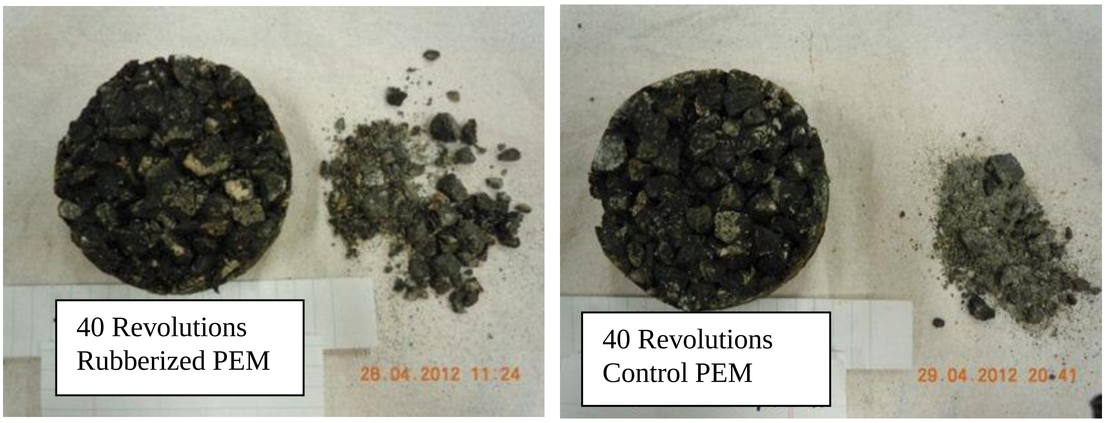

Figure 5-13 Condition of 3-Year Service Cores after 40 Revolutions

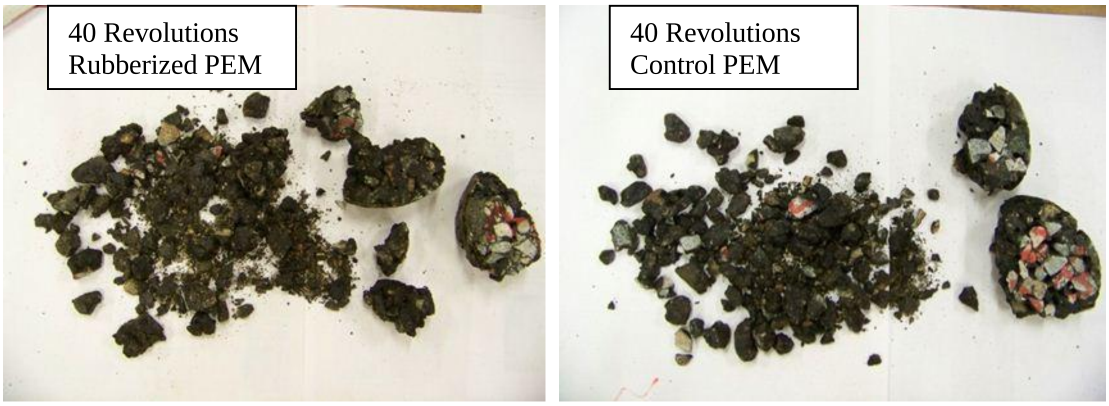

Figure 5-14 Condition of 5-Year Service Cores after 40 Revolutions

5.3 I-75 Valdosta

Tables 5-1 and 5-2 present all laboratory test results, which are also illustrated in Figures 5-15 to 5-18. Note that the rubberized PEM had 0.05-0.08 lower bulk specific gravity values than the control PEM for both the wheel paths and the pavement between them (Fig. 5-15). The rubberized PEM air voids in and between wheel paths are 2.5, 1.3% higher than those of the control PEM (Fig. 5-16). The rubberized PEM had 0.045-0.049 cm/s higher permeability values than the control pavement (Fig. 5-17), which could be attributed to its higher percentage of air voids (Fig. 5-19) and possibly more interconnected void ratio. The lower bulk specific gravity of rubberized PEM may also be due to its higher percentage of air voids.

Table 5-1 Laboratory Test Results of PEM Core Samples, I-75 Valdosta

Sample ID		Thickness of Samples (inch)	Bulk Specific Gravity	Air Voids (%)	Permeability (cm/s)	Cantabro Loss** (%)
Rubberized	1-A*	1.3	2.02	18.5	0.129	10.9
	2-A*	1.3	1.96	21.0	0.214	Broken
	3-A*	1.3	2.03	18.1	0.120	6.3
	4-A*	1.2	2.02	18.5	0.115	31.2
	5-A*	1.1	2.07	16.5	0.085	19.0
	6-A*	1.1	2.02	18.5	0.107	8.6
	7-B*	1.5	2.00	19.4	0.106	20.4
	8-B*	1.5	2.00	19.4	0.075	5.9
	9-B*	1.4	2.03	18.1	0.148	6.6
	10-B*	1.2	2.02	18.5	0.174	8.1
	11-B*	1.2	2.00	19.4	0.129	23.5
	12-B*	1.2	2.02	18.5	0.161	19.3
Control	1-A*	1.3	2.06	17.6	0.140	3.3
	2-A*	1.3	2.08	16.8	0.046	2.0
	3-A*	1.3	2.06	17.6	0.038	2.8
	4-A*	1.2	2.05	18.0	0.125	5.6
	5-A*	1.1	2.05	18.0	0.096	6.0
	6-A*	1.1	2.12	15.2	0.027	3.5
	7-B*	1.5	2.08	16.8	0.094	2.7
	8-B*	1.5	2.08	16.8	0.100	4.8
	9-B*	1.3	2.07	17.2	0.117	2.8
	10-B*	1.3	2.11	15.6	0.090	4.1
	11-B*	1.2	2.09	16.4	0.069	3.1
	12-B*	1.3	2.11	15.6	0.051	5.4

*A and B represent the core samples from the wheel path and center lane, respectively.
** Cantabro loss is not corrected.

Table 5-2 Average of Test Results of PEM Core Samples, I-75 Valdosta

Item	Location	Rubberized PEM, Average	Control PEM, Average	Difference between Rubberized and Control PEM
Bulk Specific Gravity	Between Wheel Paths	2.02	2.07	-0.05
	Wheel Path	2.01	2.09	-0.08
Air Voids (%)	Between Wheel Paths	18.5	17.2	1.3
	Wheel Path	18.9	16.4	2.5
Permeability (cm/s)	Between Wheel Paths	0.128	0.079	0.049
	Wheel Path	0.132	0.087	0.045
Cantabro Loss* (%)	Between Wheel Paths	9.8	3.8	6
	Wheel Path	16.0	4.5	11.5

*Cantabro loss calibrated for 1.3-inch core samples.

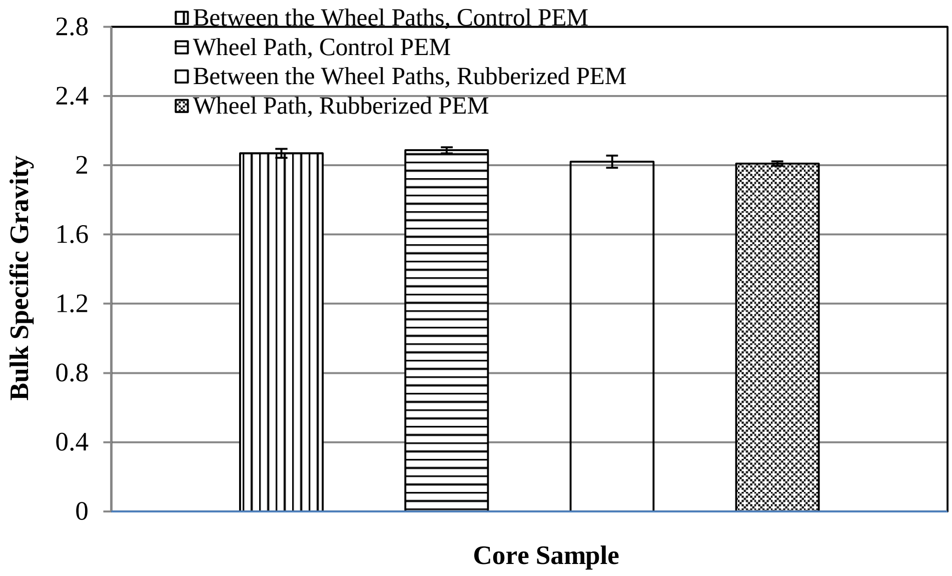

Figure 5-15 Bulk Specific Gravity

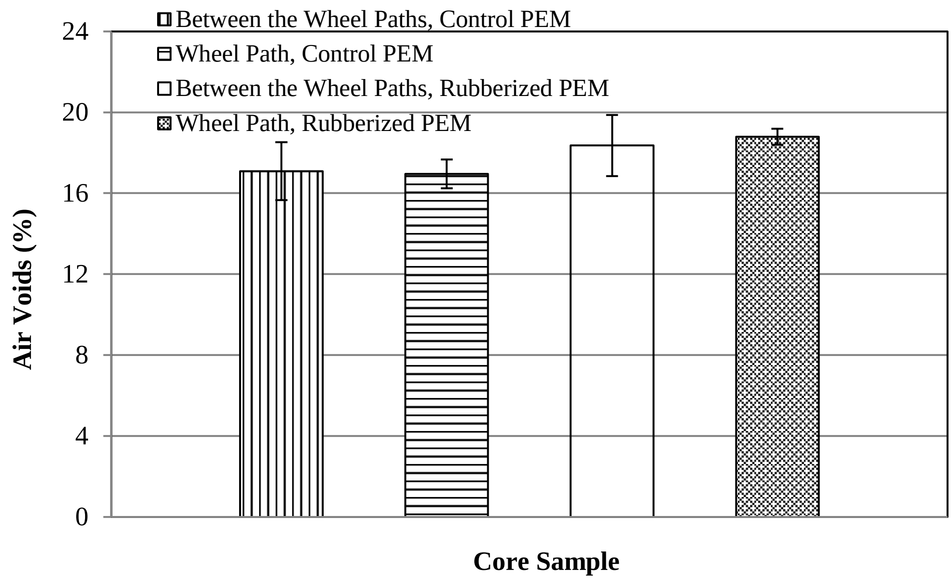

Figure 5-16 Air Voids

Cantabro loss in the rubberized PEM is higher than that of the control PEM for the wheel path and the center lane. For both rubberized and control PEM mix, the Cantabro loss on the wheel path is higher, probably due to traffic loading. The deviation of results for the rubberized PEM is very high. It may be caused by the properties of the aged rubberized mixture samples and their thinness.

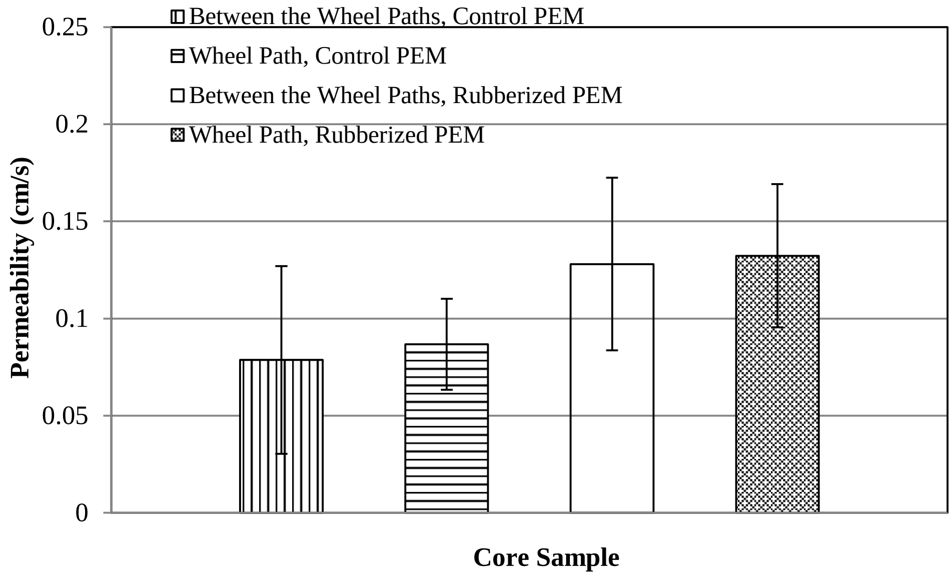

Figure 5-17 Permeability

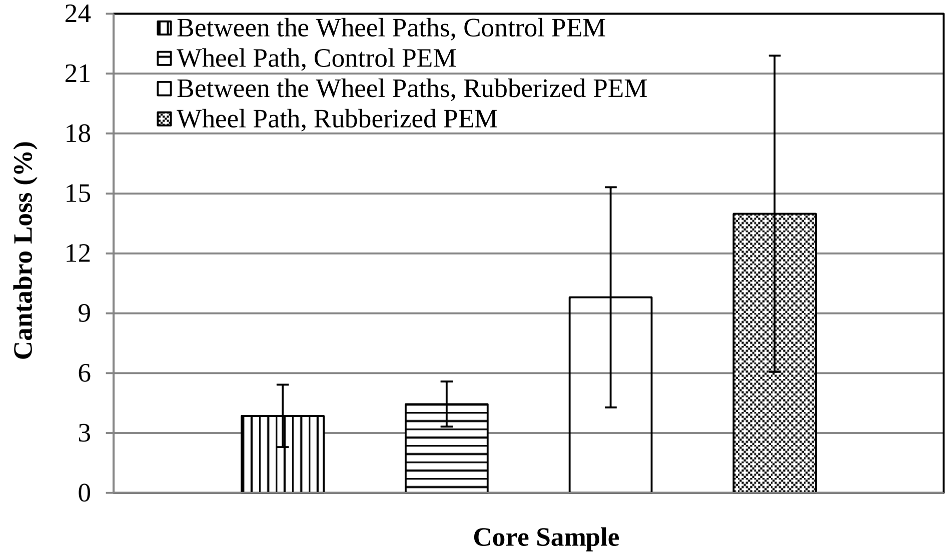

Figure 5-18 Cantabro Loss

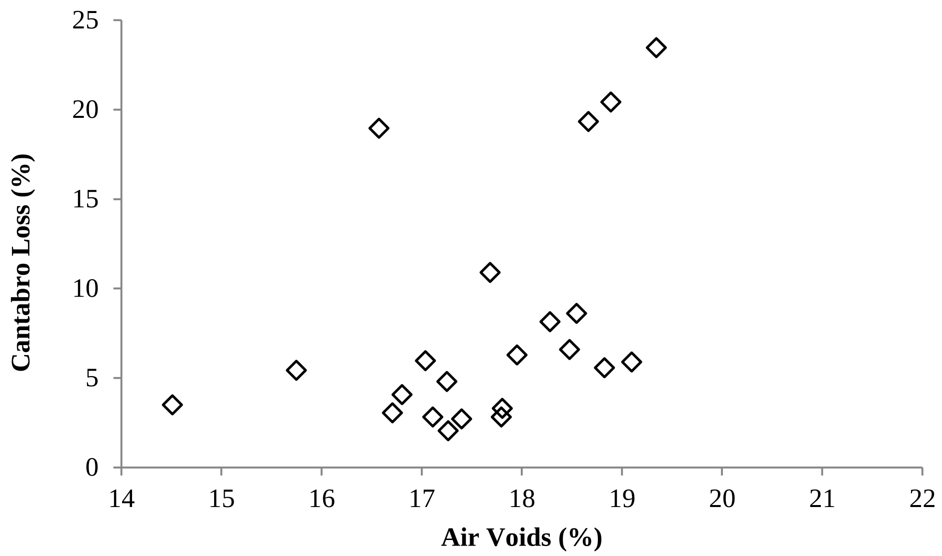

Figure 5-19 Relationship between Air Voids and Cantabro Loss

5.4 I-20 Augusta

5.4.1 Rubberized SMA Underlayer Test Results

One of the objectives of I-20 Augusta testing was comparing the performance of rubberized SMA with control PMAC SMA as an underlayer. Tables 5-3 to 5-5 show laboratory test results for SMA core samples. Because their thickness varied from the 2.5" depth, correction factors were applied to the maximal load. To determine stability, we used the following formula:

Stability = Maximal Load x Correction Factor

Table 5-3 Gravity and Air Voids in SMA Core Samples

Item	Location	Rubberized SMA	Control SMA	Difference between Rubberized and Control
Bulk Specific Gravity	Between Wheel Paths, Average	2.274	2.262	0.012
	Wheel Path, Average	2.301	2.280	0.021
	Average of All	**2.288**	**2.271**	**0.017**
Maximum Specific Gravity	Between Wheel Paths, Average	2.398	2.409	-0.011
	Wheel Path, Average	2.398	2.409	-0.011
Air Voids (%)	Between Wheel Paths, Average	5.2	6.1	-0.9
	Wheel Path, Average	4.0	5.4	-1.4
	Average of All	**4.6**	**5.8**	**-1.2**

Table 5-4 Stability and Flow of SMA Core Samples

Sample ID		Thickness of Sample (inch)	Maximum Load (LBF)	Flow** (0.01inch)
Rubberized SMA	1-A*	1.9	1861	20
	2-B*	1.7	1404	23
	3-A*	1.6	1488	21
	4-B*	1.6	1151	15
	5-A*	1.7	1367	25
	6-B*	1.5	886	13
Control SMA	1-A*	1.8	1620	24
	2-B*	1.8	1151	16
	3-A*	1.7	1103	28
	4-B*	1.9	1259	33
	5-A*	2.3	2788	41
	6-B*	2.2	2379	29

*A and B represent core samples from the wheel path and center lane, respectively.
**Flow values not corrected.

Table 5-5 Average of Stability and Flow

Item	Location	Rubberized SMA	Control SMA	Difference between Rubberized and Control SMA
Thickness (inch)	Between Wheel Paths, Average	1.6	2	-0.4
	Wheel Path, Average	1.7	1.9	-0.2
	Average of All	**1.7**	**2.0**	**-0.3**
Maximum Load (LBF)	Between Wheel Paths, Average	1147	1596	-449
	Wheel Path, Average	1572	1837	-265
	Average of All	**1360**	**1717**	**-357**
Correction Factor	Between Wheel Paths, Average	2.39	2.39	0
	Wheel Path, Average	1.99	1.99	0
	Average of All	**2.19**	**2.19**	**0**
Corrected Stability (LBF)	Between Wheel Paths, Average	2699	2407	292
	Wheel Path, Average	3085	2820	265
	Average of All	**2892**	**2614**	**278**
Flow* (0.01inch)	Between Wheel Paths, Average	17	26	-9
	Wheel Path, Average	22	31	-9
	Average of All	**20**	**29**	**-9**

*Flow values not corrected.

Note that the rubberized SMA had 1.2% fewer air voids, 278LBF higher stability, and 0.09 inch lower flow (not corrected) than the control SMA. These results illustrate that the rubberized SMA mixes have similar or better resistance to permanent deformation than the control SMA. Table 5-3 shows that the average air voids in rubberized samples from the wheel path and center lane are 4.0% and 5.2%, respectively, and in control SMA samples, 5.4% and 6.1%, respectively. Hence, 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. Table 5-4 shows that the average stability of core samples from the wheel path and center 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 lane, possibly because they were subjected to traffic loading.

5.4.2 Rubberized PEM Surface Layer Test Results of

Table 5-6 Laboratory Test Results

Sample ID		Thickness of Samples (inch)	Bulk Specific Gravity	Air Voids (%)	Permeability (cm/s)	Cantabro Loss** (%)
East Bound	1-A*	1.4	2.01	16.6	0.118	8.2
	2-B*	1.6	2.04	15.4	0.040	5.1
	3-A*	1.5	2.04	15.4	0.075	9.3
	4-B*	1.6	2.03	15.8	0.067	4.7
	5-A*	1.4	2.03	15.8	0.112	3.2
	6-B*	1.5	1.96	18.7	0.123	6.5
West Bound	7-A*	1.3	2.08	13.7	0.051	4.9
	8-B*	1.5	2.01	16.6	0.056	4.0
	9-A*	1.1	2.01	16.6	0.086	7.4
	10-B*	Broken	---	---	---	---
	11-A*	1.0	2.03	15.8	0.048	8.2
	12-B*	Broken	---	---	---	---

*A and B represent core samples from the wheel path and center lane, respectively.
** Cantabro loss is not corrected.

Table 5-7 Average of Test Results

Item	East Bound	West Bound
	Rubberized PEM with Rubberized SMA Underlayer	Rubberized PEM with Control SMA Underlayer
Bulk Specific Gravity, Average	2.018	2.031
Air Voids (%), Average	16.3	15.7
Permeability (cm/s), Average	0.089	0.060
Cantabro Loss* (%), Average	6.16	6.11

*Cantabro loss is calibrated for a 1.3-inch thick core sample.

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 5-6 and 5-7 and Figures 5-20-5-22 show that the rubberized PEM with a rubberized SMA underlayer was slightly less dense, with more air voids and permeability, than the section with a control SMA underlayer. Table 5-7 and Figure 5-23 show that the two conditions have similar Cantabro loss values. Hence, rubberized and control SMA underlayers have no significant effect on surface PEM.

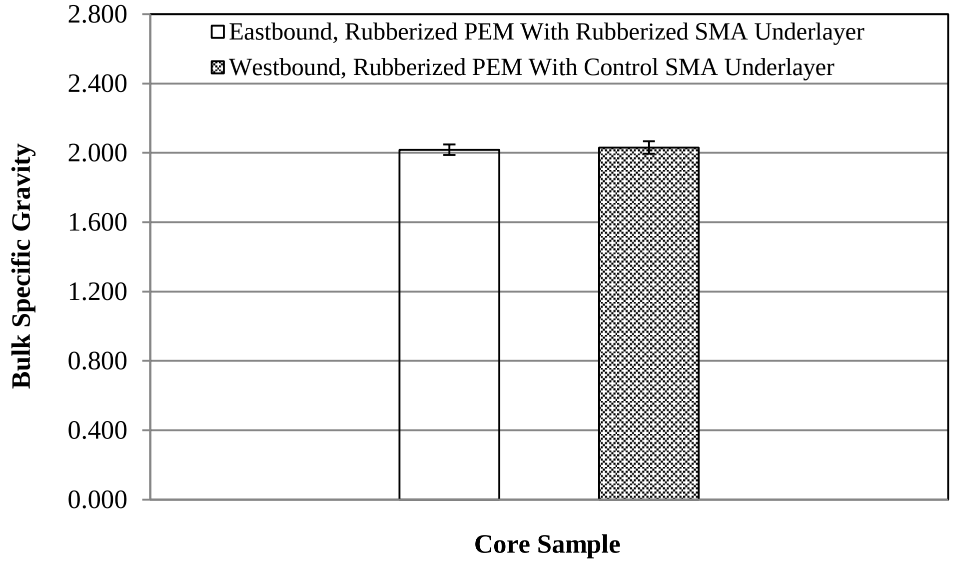

Figure 5-20 Bulk Specific Gravity

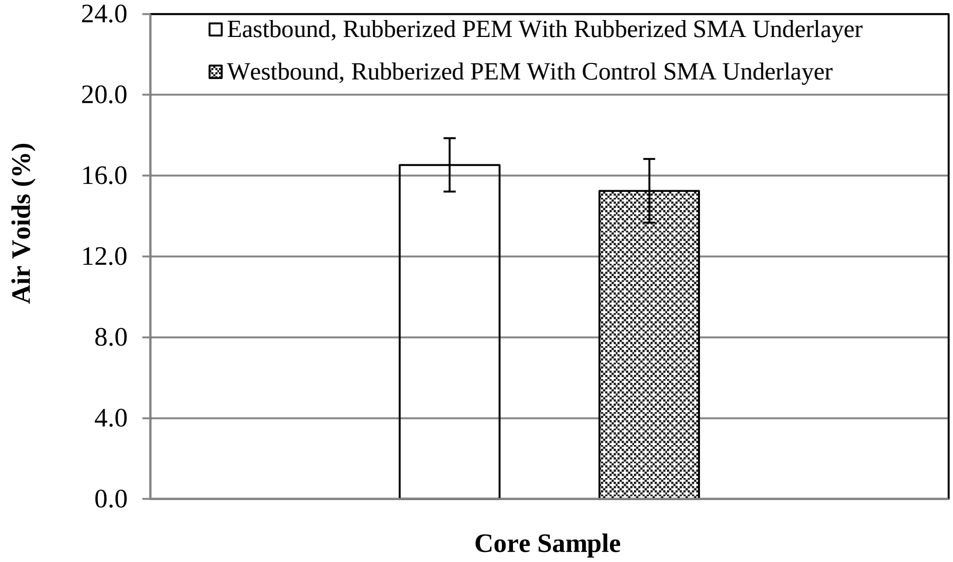

Figure 5-21 Air Voids

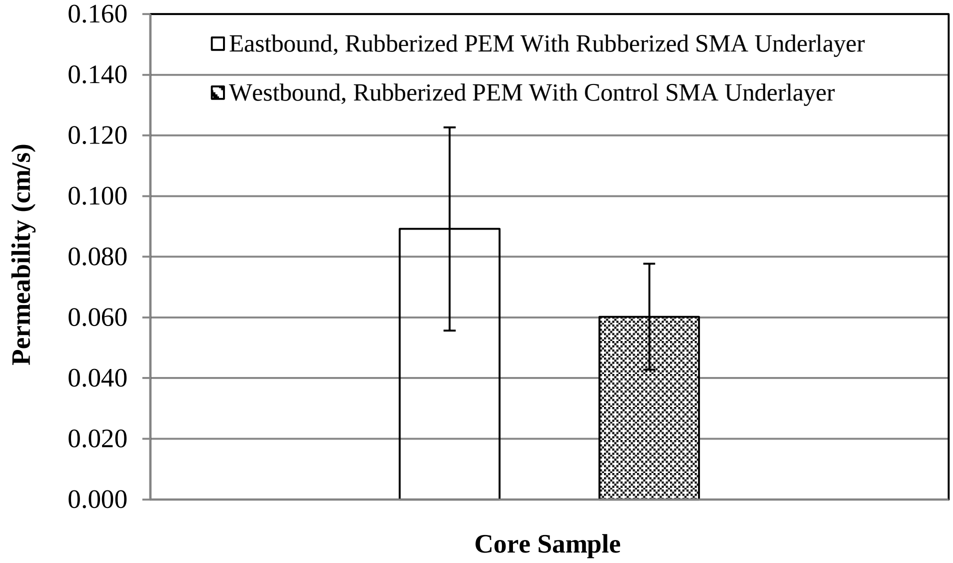

Figure 5-22 Permeability

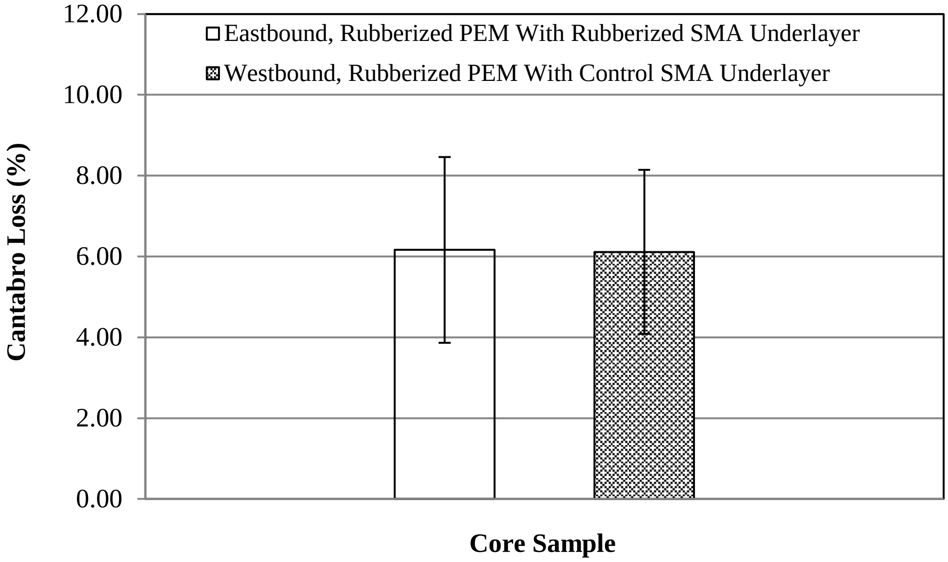

Figure 5-23 Cantabro Loss

5.5 I-75 Perry

Table 5-8 Laboratory Test Results, PEM Core Samples, I-75 Perry

Sample ID		Thickness of Samples (inch)	Bulk Specific Gravity	Air Voids (%)	Permeability (cm/s)	Cantabro Loss** (%)
Rubberized	1-A*	0.9	2.01	16.8	0.139	Broken
	2-A*	1.5	2.05	15.1	0.078	2.3
	3-A*	1.5	2.06	15.0	0.106	1.2
	4-B*	1.0	1.99	17.8	0.154	14.5
	5-B*	1.6	2.00	17.3	0.124	2.1
	6-B*	1.2	2.06	14.8	0.100	1.4
Control	7-A*	1.0	2.04	18.5	0.149	9.1
	8-A*	1.1	2.06	17.6	0.088	6.4
	9-A*	1.1	2.05	18.1	0.141	3.4
	10-B*	1.1	2.01	19.8	0.168	Broken
	11-B*	1.1	2.08	16.8	0.118	3.9
	12-B*	1.1	2.02	19.2	0.163	9.9

*A and B represent core samples from the wheel path and center lane, respectively.
** Cantabro loss is not corrected.

Table 5-9 Average of Test Results, PEM Core Samples, I-75 Perry

Item	Location	Rubberized PEM, Average	Control PEM, Average	Difference between Rubberized and Control PEM
Bulk Specific Gravity	Between Wheel Paths	2.02	2.04	-0.02
	Wheel Path	2.04	2.05	-0.01
Air Voids (%)	Between Wheel Paths	16.6	18.6	-2
	Wheel Path	15.6	18.6	-3
Permeability (cm/s)	Between Wheel Paths	0.126	0.150	-0.024
	Wheel Path	0.108	0.126	-0.018
Cantabro Loss* (%)	Whole Lane	8.6	5.8	2.8

*Cantabro loss is calibrated for 1.1-inch thick core samples.

Tables 5-8 and 5-9 summarize the laboratory test results for I-75 Perry samples. Bulk specific gravity values for both the wheel path and center lane were slightly lower for the rubberized PEM pavement than the control (Fig. 5-24). The air voids of the rubberized PEM wheel path and center lane were 3.0% and 2.0% lower, respectively, than those of the control PEM (Fig. 5-25). Permeability values for the rubberized PEM were lower than the control's due to fewer air voids. Differences of permeability values for the wheel path and center lane were 0.018 and 0.024 cm/s, respectively (Fig. 5-26).

Figure 5-27 shows that even though its void ratio was lower, the rubberized PEM had higher Cantabro loss values than the control. The test comprised 10 revolutions, and loss was calibrated to the value of a 1.1-inch core sample using the regression equation. These results did not distinguish wheel path from center lane because we had too few core samples.

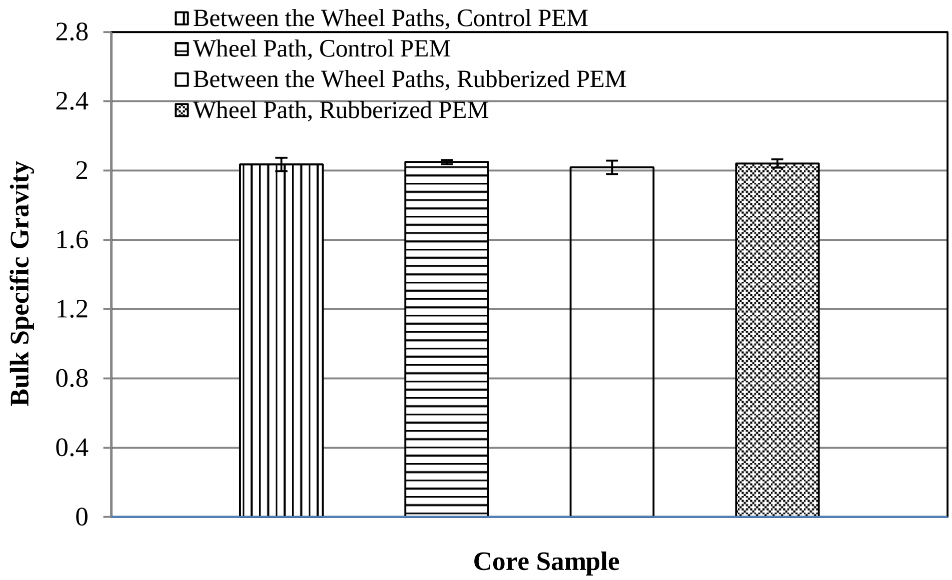

Figure 5-24 Bulk Specific Gravity

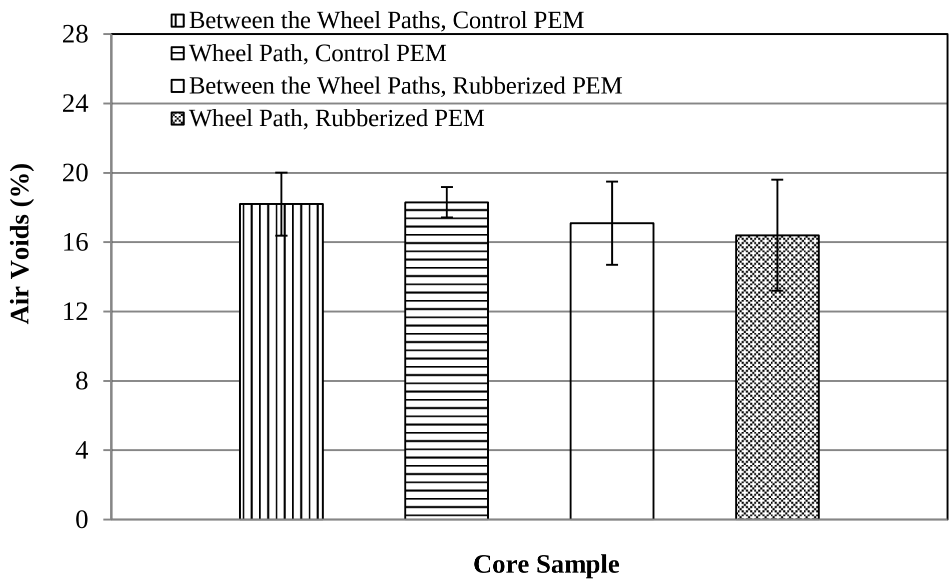

Figure 5-25 Air Voids

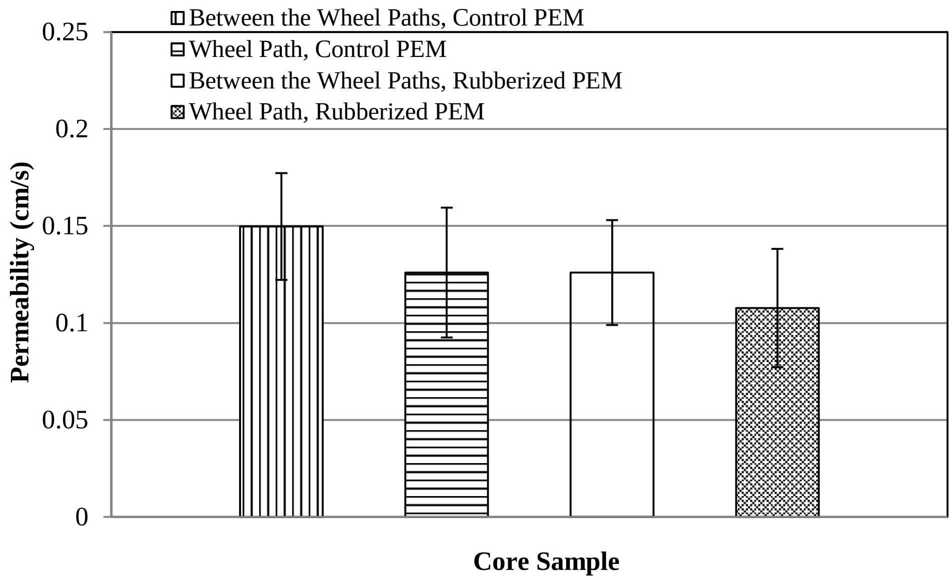

Figure 5-26 Permeability

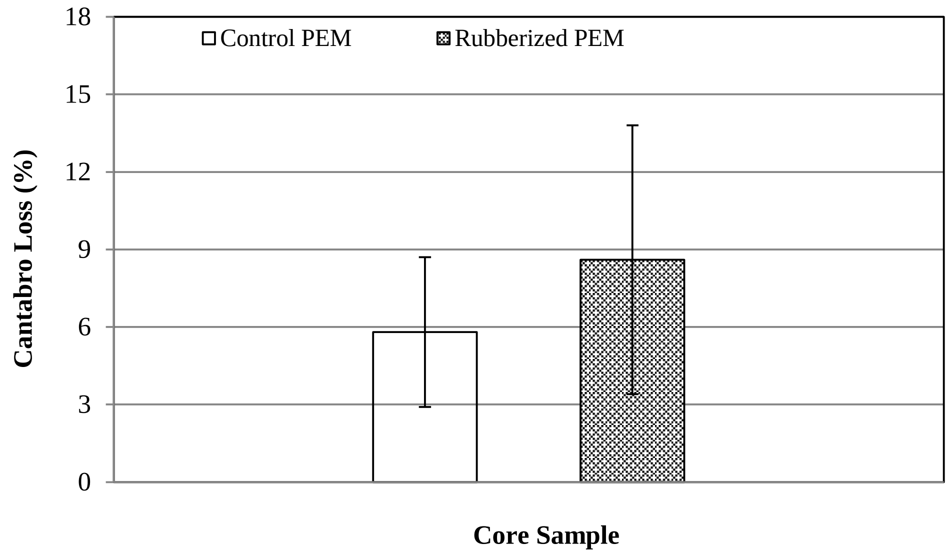

Figure 5-27 Cantabro Loss

5.6 Effects of Time on Rubberized PEM Properties

Table 5-10 shows changes in the measured properties of core samples with service life. Note that the 5-year rubberized PEM had similar bulk specific gravity, slightly fewer air voids, and better permeability than the 3-year samples, while the 5-year control *PEM had slightly lower bulk specific gravity, slightly more air voids, and better* permeability than the 3-year samples, possibly due to differences in the properties of the original mixtures.

Cantabro loss after 5 years was higher than after 3 years for both rubberized and control samples. After 40 revolutions, the 3-year core samples from I-75 Valdosta showed some abraded particles (Fig. 5-13), while the 5-year core samples from I-75 Perry broke into pieces (Fig. 5-14). In both rubberized and control PEM, Cantabro loss increased with service life.

Table 5-10 Core Sample Property Changes over Time

Properties		Three Years			Five Years
		I-75 Valdosta	I-20 Augusta	Average	I-75 Perry
Rubberized PEM	Bulk Specific Gravity	2.02	2.02	2.02	2.03
	Air Voids (%)	18.6	16.1	17.4	16.8
	Permeability (cm/s)	0.13	0.077	0.103	0.117
	Cantabro Loss* (%)	13	5.7	9.4	Broken
Control PEM	Bulk Specific Gravity	2.08	None	2.08	2.04
	Air Voids (%)	17.1	None	17.1	18.2
	Permeability (cm/s)	0.083	None	0.083	0.138
	Cantabro Loss* (%)	4.2	None	4.2	Broken

* Core samples from I-75 Valdosta, I-75 Perry, and I-20 Augusta were subjected to 40 revolutions.

5.7 Conclusions

Laboratory performance tests support the following conclusions:

(1) After 3 years' service, the rubberized PEM mixture had lower bulk specific gravity, better permeability, and much more Cantabro loss than the I-75 Valdosta control PMAC pavement. After 5 years' service, it had lower bulk specific

gravity, lower permeability, and much more Cantabro loss than the control PMAC pavement.

(2) Tests showed that Cantabro loss increased with service life for both rubberized and control PMAC PEM. However, it deviated greatly due to the difficulty of measuring the nonstandard-sized aged samples.

(3) Rubberized and control PMAC SMA underlayers had similar effects on surface PEM.

(4) 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.

Chapter 6 Summary, Conclusions, and Recommendations

6.1 Summary and Conclusions

This report presents a preliminary evaluation of the long-term performance of rubberized PEM pavements as compared to PMAC PEM pavement. Visual field inspection and laboratory investigation support the following conclusions:

(1) After three years' service, the field performance of the rubberized PEM pavement was similar to that of the control. The distresses of cracking, rutting, raveling, bleeding, pushing, and potholes were not found in the rubberized PEM pavement from both I-75 Valdosta and I-20 Augusta. Only two profiles of the PMAC PEM pavement near milepost 10 of I-75 Valdosta showed insignificant rutting of 1/16 inch. Skid resistance of the I-75 Valdosta rubberized PEM test section was slightly better than that of the control PMAC PEM based on the results from the portable skid test.

(2) After five years, the field performance of the rubberized PEM pavement was similar to that of the control PMAC PEM pavement. Neither showed any bleeding or pushing, while all profiles of both showed rutting. The I-75 Perry rubberized PEM pavement had shallower ruts than the control PEM pavement. Both I-75 Perry PEM test sections had reflection cracking. The length and severity for the rubberized pavement were similar to that of the control PMAC and had nothing to do with the materials.

(3) I-20 Augusta rubberized and control PMAC SMA underlayers did not have different effects on the performance of the PEM surface layers. The distresses of

cracking, rutting, raveling, bleeding, pushing, and potholes were not found in the PEM surface pavement.

(4) The 3-year rubberized PEM had lower bulk specific gravity, better permeability, and much more Cantabro loss than the control PMAC pavement. The 5-year rubberized PEM mixture had lower bulk specific gravity, lower permeability, and much more Cantabro loss than the control pavement.

(5) Cantabro loss tests using a modified number of rotations showed increased values with service life for both rubberized and control PEM. The deviation of the Cantabro loss test results was large due to the difficulty of measuring the nonstandard-sized aged samples and did not accurately reflect the pavements' durability.

(6) The rubberized SMA core sample was slightly more stable and had lower flow than the control PMAC SMA. Hence, SMA with crumb rubber added in the dry process has similar or better resistance to permanent deformation than the control PMAC SMA pavement.

6.2 Recommendations

Since PEM has a very high void ratio, aging has serious effects. Binders in rubberized PEM must be strong enough to last for the expected period. First, we must evaluate the durability and stability of binders recovered from rubberized PEM and SMA after subjecting them to long-term weathering, according to PG grade.

Second, the mechanism by which binders interact with crumb rubbers added in the dry process must be examined; does the crumb rubber modify the binder or the mixture?

Third, long-term performance data on PEM pavement sections from I-75 Valdosta, I-20 Augusta, and I-75 Perry and SMA pavement sections from I-20 Augusta must continue to be collected to correlate the properties of the mixtures in the lab and field and identify the key lab tests that can predict field performance.

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