Utilization of Crumb Rubber in Asphaltic Concrete Mixtures – South Carolina's Experience

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ABSTRACT. South Carolina's legislature passed the SC Solid Waste Policy and Management Act of 1991 which requires the South Carolina Department of Transportation (SC DOT) to investigate the use of certain waste products (e.g., tires) in various aspects of highway construction. SC DOT has been conducting several research projects utilizing crumb tires in asphalt mixtures since 1991. To this date, there have been five rubberized asphalt projects constructed in the state. One of these projects was the dry process (PlusRide), three were constructed using the wet process, and one project was the trickle method. This paper reports on the mix design process, construction procedures and problems, and field testing procedures. The size of these projects ranged from 1,360 to 11,200 metric tons of rubberized asphalt mix. The newly established Rubber Asphalt Technology Service (ARTS) at Clemson University will also be discussed.

Keywords: ISTEA, Rubberized Asphalt, Dry and Wet Process

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INTRODUCTION

The United States, among many other countries around the world, is facing many challenges regarding its waste materials. The Environmental Protection Agency (EPA) estimates that within the next 10 years, the majority of the landfills in the country will be closed. Many states and local governments face major issues regarding opening and operating new landfills due to many factors such as regulations, design modifications, and cost. One major area of concern, in some parts of the country, is the disposal of waste tires. The United States produces over 270,000,000 million waste tires each year. The EPA estimates that each person generates one waste tire per year. The state of South Carolina generates approximately 4,000,000 waste tires each year. Several research projects were established to determine the effectiveness of using crumb rubber in asphaltic concrete mixtures using various methods of incorporating the rubber to the mixes.

Scrap tire recycling mandates are written into both the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Resource Conservation Recovery Act stating that federal-aid highway funding would be withheld from states if they do not comply with these Acts [1]. Section 1038 of the ISTEA (Use of Recycled Paving Material) addresses the use of scrap tires in asphaltic concrete mixtures and contains three primary requirements including: 1) the federal regulations regarding the use of scrap tires must be relaxed, 2) the performance, recycling, and environmental issues related to use of scrap tires in asphaltic concrete mixtures must be studied, and 3) each state must satisfy a minimum scrap tire utilization requirement. However, in 1995, the Section 1038(d) was repealed by the Senate.

In South Carolina, the legislature passed the SC Solid Waste Policy and Management Act of 1991 which requires the SC DOT to investigate the use of certain waste products (e.g., tires) in various aspects of highway construction. Because of this Act and environmental concerns, the SC DOT has been conducting several research projects since 1991. This paper reports on several issues involved with rubberized asphalt mixtures and also actual field projects, which utilized crumb rubber modifiers, constructed in the state are discussed.

BACKGROUND

There are approximately 270 million waste tires generated annually in the United States. Of these, 230 million are passenger car tires and 40 million are truck tires [2]. According to the industry figures, there are over 800 million scrap tires currently on the stockpiles in the United States.

A typical scrap tire (passenger car) weighs approximately 9 kilograms (20 pounds) and will provide approximately 60% rubber, 20% steel and 20% fiber and other waste products [3]. The paving industry uses 1 to 2 million tires per year. Each metric ton of Hot Mix Asphalt (HMA) which contains rubber can utilize 2 to 6 tires [4]. For example, if 50 million scrap tires were going to be utilized in asphaltic concrete mixtures, then 8 to 25 million metric tons of HMA would require modifications.

There are many factors to consider when a state agency uses rubber in its pavements including cost, specifications, type of equipment to be used, expertise of the contractor, potential recyclability of materials, etc. The reported advantages for using rubber in asphaltic concrete mixtures include: thinner lift, increased pavement life, retarded reflection cracking, decreased traffic noise, reduced maintenance costs, decreased pollution and increased environmental quality. However, to determine the validity of these claims (or reported benefits) each state highway agency must conduct several long term projects.

There are many issues and problems associated with the use of tires in asphaltic concrete pavements that must be researched and analyzed. Some of the issues and problems include: potential high initial costs; lifecycle economics; lack of product specifications; potential lack of scrap tire uniformity; the recyclability of the rubberized pavements; environmental concerns; and potential modifications made to the asphalt plants or equipment.

SOUTH CAROLINA'S FIELD EXPERIENCES

The major objectives of this research study were to: a) develop test procedures, specifications, and construction methods for construction of rubberized asphalt mixes; b) monitor the test field sections; and c) recommend the next steps to be taken by the SC DOT. Several projects have been completed in South Carolina to test the use of crumb rubber in asphalt mixes. These projects consisted of 1 Dry process, 3 Wet processes and 1 Trickle method. A summary of information and the location for each project are given in Table 1 and Figure 1, respectively. The following is a brief discussion of the field sections paved with rubberized mixtures.

Pelham Road Project - Dry Process

The SCDOT initiated a study in February 1992 to field test a rubberized asphalt mixture. The test section (Pelham Road) is located in Greenville County (North West of the state). Tires were collected from dump sites around South Carolina by Michelin Tire Corporation and were shredded and pulverized down to gradation specifications for addition into the asphalt mix. Before placing the rubberized asphalt mix on Pelham Road, approximately 240 tons of the rubber modified mixture were placed on a nearby road (Garlington Road). The trial section allowed for fine-tuning at the asphalt plant and placement refinement on the roadway. A 165-meter control section (a mixture without any rubber) was placed on Pelham Road for comparison purposes.

The rubberized asphalt was produced by means of the Dry method. The pulverized rubber was graded and packaged into 1,000 Kg (2,200 lb) bags, which were separated into coarse-ground rubber and fine-ground rubber. When introduced into the asphalt mixture, 80% coarse-ground rubber was added with 20% fine-ground rubber to form the composite gradation required. Table 2 shows a gradation analysis of the ground rubber.

Although some differences existed between the PlusRide and the Marshall mix design procedures, no special equipment was needed to perform the PlusRide mix design. The PlusRide mix design required the temperature of the specimen mixing and compaction to be raised by 5.6 to 11.1 C (10^o to 20^o F). In order to allow for proper heat distribution, the mixture was placed in an oven for one hour before it was molded and compacted at 75 blows per side. To minimize expansion after compaction, a weight of approximately 2.3 Kg (5 pounds) was placed on top of the specimen until it cooled.

Table 1 Summary of SCDOT Asphalt-Rubber Projects

Location	**Pelham Rd. Greenville Co.**	**SC24 Anderson Co.**	**US-76 Marion Co.**	**Hunt Club Rd. Richland Co.**	**US-321 Jasper Co.**
Date	April 1992	Oct. 1993	October 1994	October 1994	April 1995
Process	Dry	Wet	Wet	Trickle	Wet
Tonnage (Metric)	2,818	1,636	11,200	1,364	5,629
Weather	Sunny, 15.6 °C, Some rain	Partly cloudy, 15.6 °C	Partly cloudy, breezy, 15.6°C	Sunny & Mild	Sunny & Mild
Type Plant	Cedarapids Drum Mix, 181.8 TPH	Bitumina Drum Mix, 318.2 TPH	Standard Havens Drum Mix, 272.7 TPH	Cedarapids, batch plant, 182-227 TPH	Cedarapids, 3.6-ton batch 200-205 TPH
Cost/ Ton	$72.00	$71.00	$71.00	$26.00	$78.00
Traffic (1993 ADT)	4 lanes, 1.609 km long, 11,000 ADT	2 lane, rural, 8,000 ADT	4 lane divided hwy., 13,000 ADT	2 lane city st., few trucks, 4,000 ADT	2 lane, rural, 3,000 ADT

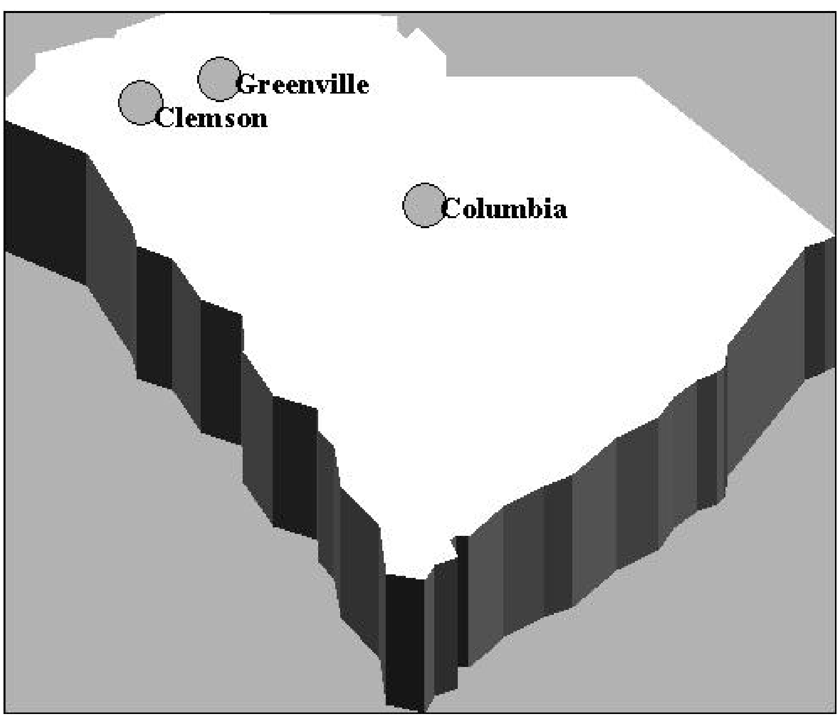

Figure 1 Locations of Rubberized Asphalt Projects in South Carolina

Table 2 Gradation Analysis of Granulated Rubber (Pelham Road Project)

Granulated Rubber (% passing)				
Sieve	Fine	Coarse	Combined	PlusRide Specifications
6.3 mm (1/4")	100	100	100.0	100
4.76 mm (No. 4)	100	82.4	85.9	76-100
2.00 mm (No. 10)	100	11.4	29.1	28-42
850 µm (No. 20)	94	---	18.8	16-24

Numerous combinations of materials at various percentages were tested before obtaining the final job mix design. When compared with conventional asphalt mixtures, mix design combinations using the PlusRide process yielded lower stabilities and higher flows, which are normal for this type of mixture. The optimum asphalt content of 7.7% was based on 3% air voids in the mixture. Using the Tunnicliff and Root Procedure for moisture susceptibility testing, the mix design Tensile Strength Ratio (TSR) was found to be 136.0%. Table 3 shows the Marshall Properties for the asphalt mixture.

Table 3 Marshall Properties of the Rubberized Asphalt Mixture (Pelham Rd.)

Marshall Properties (At 7.7% Asphalt Content)		
Property	Mix Design Value	Range
Air Voids, %	3.3	2.0-4.0
VMA, %	19.7	14.0 min.
Stability, kg (lbs.)	545.5 (1200)	454.5 (1000) min.
Flow, 0.01 cm (in.)	86.4 (34)	38.1-88.9 (15-35)
Density, kg/m^3 (pcf)	2190 (136.6)	---

The asphalt plant used for this project is normally capable of producing mix at the rate of approximately 185 metric tons per hour, but averaged 128 metric tons per hour with the rubber mix. The production rate was decreased to allow the mix to reach 157.2 C (315^{o} F). During the construction, the placement temperature was approximately 149 C (300^{o} F).

The pneumatic feed system that was to be used for blowing the rubber into the drum did not operate properly, so the recycled asphalt pavement (RAP) conveyor belt was used to introduce the crumb rubber to the mix. A special feeder system was used to introduce the crumb rubber to the mix by electronically weighing it onto the RAP conveyor system.

Asphalt cement contents calculated during this testing were inconsistent. The asphalt cement percentages varied by more than 1%. Although the percentage of air voids was below the allowable specification tolerance limit, the roadway compaction ranged from 97% to 100% of the field lab Marshall density.

The rubberized asphalt mixture was different from a conventional mixture in several ways. One noticeable change was in the compaction temperature requirements. The specifications required the mix to be immediately compacted behind the spreader and then to be continuously compacted until the mat temperature drops to 60 C (140^{o} F). The mat temperature was continuously monitored. A problem arose when it was discovered that, in general, the mat temperature would drop to 71 to 77 C (160^{o} F or 170^{o} F) rather quickly and remain at that temperature for an extended period of time. If the rollers continued rolling, the mat would start to crack. It was decided that the rollers should come off the mat before the temperature reached 60 C (140^{o} F). Additionally, the rollers were unable to begin rolling directly behind the spreader because the mix temperature was close to 149 C (300^{o} F) and the mix would occasionally pick-up on the roller drums. Dishwashing detergent was placed in the roller water to reduce mix pick-up.

The contractor continuously monitored compaction with the use of a nuclear density gauge. The rollers had to progress at a slow rate to avoid pushing and shoving in the mat at higher temperatures. Traffic had to remain off the surface for extended periods of time because the mat was constantly being rolled or monitored until it reached 60 C (140^{o} F).

Once the mix was placed, it was virtually impossible to do any additional handwork. This problem made transverse joints difficult to tie in and a normally loose mix immovable. Turning radii, which typically require handwork, were difficult to change once placed. The cost of the rubberized asphalt mix was approximately triple that of the original contract cost. The mix cost included $7.00 per ton for PlusRide royalties and bin rental.

This road section was cored on a periodic basis for five years to monitor the pavement performance. The cores were tested for extracted aggregate gradation, asphalt cement content, moisture susceptibility and visual stripping. Periodic friction tests were also performed. Initial testing indicated low TSR's and low skid resistance, however, additional testing showed an increase in tensile strength and density after approximately one year of service life. The friction test results, however, remained low. Visual inspections indicate that the condition of the road appears to be fair. It has been noted on each inspection that there are rubber crumbs on the pavement surface. Rubber crumbs are a common occurrence on dry-method rubberized asphalt projects and the amount of rubber lost from the mix is negligible and will decrease with time.

SC-24, Anderson Co. - Wet Process

Another asphalt rubber project (the wet process) was started in the Fall of 1993. The project was located near the airport on SC-24 in Anderson County. The roadway was approximately 14.5 km (9 miles) long and was divided into 4 subsections. Two subsections consisted of Surface Type 1 mix (9.7 km or 6 miles), one subsection of Surface Type 1A mix (2.4 km or 1.5 miles) and one subsection of Asphalt Rubber mix (2.4 km or 1.5 miles). The Surface Type 1A was placed adjacent to the Asphalt Rubber Mix for comparison. All sections were paved with a 79.5 Kg per 0.836 m^2 mix (175 pounds per square yard).

The 50 blow mix used 60% No. 789 stone, 25% regular screenings, 14% manufactured sand and 1% hydrated lime. Based on Marshall mix design testing, it was determined that the asphalt rubber binder content should be set at 7.3% with a design air void level between 3% and 4.5%. The Marshall properties of this mix design are shown in Table 4. Moisture susceptibility testing indicated a borderline TSR of 85.3%. In SC, the minimum acceptable TSR for mixtures using hydrated lime is 85%.

Table 4 Marshall Properties of the Rubberized Asphalt Mixture (SC-24)

Marshall Properties (At 7.3% Asphalt Content)		
Property	Mix Design Value	Range
Air Voids, %	4.0	3.0-4.5
VMA, %	20.6	16.0 min.
Stability, kg (lbs.)	818.2 (1800)	636.4 (1400) min.
Flow, 0.01 cm (in.)	33 (13)	20.3-55.9 (8-22)
Density, kg/m^3 (pcf)	2305 (143.8)	---

To obtain the desired performance properties, AC-10 was used as the base asphalt cement. The crumb rubber was added at the rate of 11.8 Kg (26 pounds) per ton, or 18% by total weight of the binder. To obtain the desired elasticity, a product named TBS-20 was added to the binder as part of the 18% of crumb rubber. TBS-20 consisted of ground tennis ball scraps obtained from rejected tennis ball production and was used because of the natural latex from which it was made.

The crumb rubber was added to the mixing tanks in 22.7 Kg (50 lb) bags which were hand fed into the machine. The rubberized binder was field tested for viscosity throughout the production using a hand-held rotational viscometer.

It took two days to place the mix. One problem encountered on the roadway was the tendency of the mix to push onto the shoulder during compaction. It was also felt that an additional pneumatic roller would be helpful in obtaining compaction. The roller pattern was established after several tries. The mix had to have a breakdown rolling before it cooled, however, too much rolling would push the mix onto the shoulder. Two breakdown rollers were eventually used to achieve density. The pneumatic roller was used, only after the mat cooled to 60 C (140°F), to try and reach any areas that may have been bridged during the initial compaction. Tire tracks were left in the mat in areas where the pneumatic roller was used before it had cooled properly.

This road test section has been performing satisfactorily to this point. Routine testing of roadway cores continues. The result of coring, in general, indicates that the asphalt rubber mixture is producing higher wet indirect tensile strength and tensile strength ratios than the control mixture. In addition, the results of the friction testing indicate that the rubberized mixture is performing better than the control mixture.

US-76, Marion Co. - Wet Process

The next project began in October of 1994, when approximately 11,000 metric tons (12,000 tons) of rubberized asphalt were placed at a section of US-76, in Marion County (Table 5). Surface Type 1A was placed adjacent to the asphalt rubber section and was used as a control section.

Table 5 Marshall Properties of the Rubberized Asphalt Mixture (US-76)

Marshall Properties (At 6.8% Asphalt Content)		
Property	Mix Design Value	Range
Air Voids, %	4.5	3.0-4.5
VMA, %	19.8	16.0 min.
Stability, kg (lbs.)	981.8 (2160)	636.4 (1400) min.
Flow, 0.01 cm (in.)	38.1 (15)	20.3-55.9 (8-22)
Density, kg/m^3 (pcf)	2320 (144.7)	---

The mix covered 4 lanes, each 8 km (5 miles) in length. This project was the Department's largest undertaken to test these materials. The optimum %AC was determined to be 6.8% with 4.5% air voids and 75% voids filled. The crumb rubber was added at the rate of 11.8 Kg (26 lbs) per ton, or 18% by total weight of the binder. Tennis ball scraps were mixed into the asphalt rubber binder on this project as well.

The roller pattern was established at 2 passes of the breakdown roller and 2 passes of the finish roller. No pneumatic roller was utilized on this project. Spots of rubber were noticed on the surface of the mix after compaction. The mix temperature on the roadway was held at a maximum of 154.4 C (310°F) to maintain consistent compaction. All roadway densities were satisfactory. This project was relatively trouble-free and proceeded at a rapid pace.

To this date, the mix has been performing satisfactorily. This pavement will be monitored on a routine basis by SC DOT.

Hunt Club Road, Richland Co. - Trickle Method

In early 1993, several State Highway Departments determined that if only a few pounds of crumb rubber were added to each ton of asphalt mix used statewide, the requirements mandated by the ISTEA legislation could have been met. This trace amount of rubber should be negligible as far as design and laydown practices are concerned. Production would have to be modified to allow for the crumb rubber to be fed into the system. The engineering properties of the mix would, most likely, not be enhanced. However, the State Highway Departments could use the required amount of crumb rubber without having to install elaborate mixing or pumping systems.

To test this procedure, two resurfacing projects (on Hunt Club Road in Columbia, SC and a short section of nearby I-20) were modified to allow the addition of crumb rubber at the rate of 1.8 Kg (4 lbs) per ton of mix. This amount translates into 0.2% crumb rubber by weight of aggregate. For every batch, workers would manually add 5.5 Kg (12 lbs) bag of rubber to the pugmill (2.72 metric ton batches). The wet mix time was set at 35 seconds. The rubber modified Surface Type 1 mix also had 10% RAP. Table 6 shows the mix design properties for this mix, however the trace amount of rubber had no discernable affect on the mix design. As per a supplemental agreement, the additional rubber handling increased the mix cost by $5.00 a ton for this portion of the project.

The mix was placed with no problems noted. The equipment and procedures were not changed to accommodate for the rubber modified mix. The purpose of this project was to determine if the rubber modified mix could be placed just like a conventional mixture. It appears that this mix can be placed just like a conventional mixture with only a few modifications to the process. Like the US-76 project, this project has not had enough time to properly judge the performance characteristics and will be routinely monitored by the SC DOT.

US-321 - Wet Process

The final SCDOT rubber modified project (a wet process) was completed by April 1995 in Jasper County. Except for the aggregate sources, this mix is essentially the same as SC-24 and US-76. There were no major problems noted during construction. The pavement will be monitored by the SC DOT for several years.

Table 6 Marshall Properties of the Rubberized Asphalt Mixture (Hunt Club Rd.)

Marshall Properties (At 5.6% Asphalt Content)		
Property	Mix Design Value	Range
Air Voids, %	4.3	3.5-5.0
VMA, %	17.0	16.0 min.
Stability, kg (lbs.)	1170 (2575)	636.4 (1400) min.
Flow, 0.01 cm (in.)	30.5 (12)	20.3-40.6 (8-16)
Density, kg/m^3 (pcf)	2315 (144.4)	---

CONCLUSIONS

The following is a brief finding of field research projects conducted by the SC DOT. The DOT has tested the use of crumb rubber in several areas of the state, using several contractors and several mixing processes to determine the economic and engineering feasibilities of these materials. Experts were brought in on each project to provide assistance with the technical aspects of the production. Several projects had crumb rubber added to the existing mixes by supplemental agreement while several projects were competitively bid.

It would be premature to judge the long term engineering (performance) characteristics of all of the mixtures, however, Pelham Road (PlusRide mix) has shown some level of deterioration in the 8 years since it was paved. Whether this is a function of the mix itself, the production or the placing techniques is hard to determine. The other asphalt rubber projects appear to be in satisfactory condition.

ASPHALT RUBBER TECHNOLOGY SERVICE (ARTS)

In order to investigate some of the issues discussed above, the South Carolina Department of Health and Environmental Control (DHEC) awarded Clemson University a grant to establish a program. The grant was awarded by DHEC's Office of Solid Waste Reduction and Recycling through their Waste Tire Trust Fund. A $2 fee is paid on each new tire sold in South Carolina which 44 cents of that fee is placed in this Trust Fund.

One of the major functions of ARTS is to provide technical assistance in the promotion, design, testing, and use of rubberized asphalt and other crumb rubber in civil infrastructure applications, for public works agencies in local governments across the state. Some examples of utilizing crumb rubber in civil engineering applications (excluding rubberized asphalt) include embankments, retaining walls, fill materials, etc.

One of the goals of ARTS is to make scrap tire recycling sustainable in South Carolina. In order to achieve this goal, ARTS will award grants to local government agencies for projects that fit the goals and objectives of the program. ARTS anticipates that approximately $950,000 per year for the next five years is available. Each year two Requests for Proposals (RFP) will be made available to appropriate agencies.

ARTS staff will design, procure, manage, and evaluate several field demonstration projects employing the technologies of Asphalt-Rubber application. In addition, other projects utilizing crumb rubber in civil infrastructure applications will be designed and managed each year. Based on ARTS prepared design plans and specifications and bid documents, demonstration projects will be performed by independent contractors under the direct supervision of the ARTS staff or selected experts. Such independent contractors will perform their work under a research contract with the ARTS staff. Demonstration projects will be monitored for a specific time for measurement of performance of the application.

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