Development of Polymerized Asphalt Rubber Pelleted Binder for HMA Mixtures

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ABSTRACT. There are over 300 million scrap tires produced in the USA each year. There are many applications that these scrap tires could be utilized including in paving operations. This paper will describe the benefits of producing the newly developed patching materials, in pellets; containing crumb rubber, stiffeners and virgin binders. The binders utilized in these pellets satisfy the requirements of ASTM D8-02 (minimum of 15% crumb rubber in the asphalt binder). The laboratory testing results of the mixtures containing these pellets are as follows: TSR (tensile strength ratio) of over 96%; average rut depth of 2.84 mm (Asphalt Pavement Analyzer); stability of 995 kg; flow (0.01 in) of 15.8; and %VMA of 20.2. Test results and field trials have indicated that these pellets can be successfully utilized in a variety of HMA type mixes and improve performance of the mixtures.

KEYWORDS: ***wet process, asphalt rubber, pellets, scrap tires, crumb rubber, pavement preservation***

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1. Introduction

Each year, worldwide, almost 1 billion tires are manufactured for passenger cars, utility vehicles, off-road vehicles, trucks, and other types of tires. At the same time, every year, an almost equal number of tires is permanently removed from vehicles and categorized as a by-product around the world. For instance, each year in the EU, approximately 3.5 million tons of passenger car, utility vehicle and truck tires defined as waste is produced [1].

In addition, there are over 300 million scrap tires produced in the USA each year. There are many applications that these scrap tires are used including in paving operations. Figure 1 shows the scrap tire disposition in the United States for 2009 [2]. Over 40% of the scrap tires are used for tire-derived fuel; and approximately 20.6% is ground rubber while only 5.5% is used in civil engineering applications [2].

One area of utilization that has been gaining momentum, in recent years, has been the use of crumb rubber modifiers (CRM) in asphalt binders. The utilization of crumb rubber modifier (CRM) in asphalt binders has proven to be beneficial from many stand points (i.e., environmental, technical, and economical) including, but not limited to, the following: better performance of asphalt mixtures by increasing the resistance of the pavements to permanent deformation and thermal and fatigue cracking; longer life; decreasing noise level; etc. [3-12].

Many agencies around the country are having a difficult time, due to budget restrictions, to manage their pavement preservation

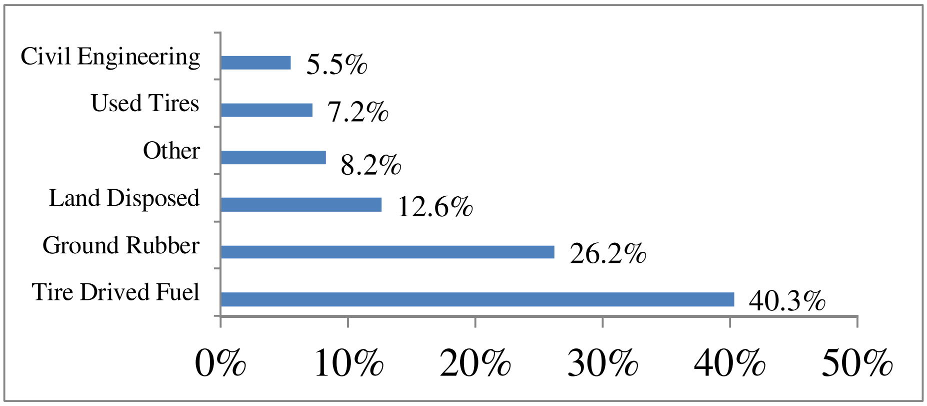

Figure 1. *Utilization of Scrap Tires in USA (RMA Data, 2009)*

programs including having a cost effective patching repair materials [13-17]. The Federal Highway Administration and Strategic Highway Research Program (SHRP) conducted several very comprehensive testing programs in this area many years ago [18-21]. For example, the results indicated that, in general, many of the materials used (e.g., cold mix) to fix the pot holes do not last long and in many locations (e.g., colder climate states) and the same pot hole must be fixed several times each year.

The number of pot holes and utility cuts depends on many factors (e.g., environment, traffic, etc.). For example, cities such as San Diego have over 30,000 pot holes compared to Chicago with over 350,000 pot holes and over 60,000 utility cuts. There is a major need to develop new products for maintenance of asphalt pavements that are cost effective and at the same time environmentally sustainable. With the recent advent of various technologies for the Pelletization of asphalt, it is now possible to utilize modified binders for pavement preservation applications (e.g., pot hole repairs).

One of the newly developed patching materials, in pellet format (a patented process and product); contain virgin binder, crumb rubber, some form of stiffeners (e.g., hydrated lime), and chemicals. The first step is to produce an Asphalt Rubber (AR) binder before making the pellets. This AR binder meets the ASTM definition D8 and specification D6114. The pelleting processes adds the AR to a stiffener producing the "dry" pellets that are less than 2 cm (3/4"), in most cases, and are added to the heated aggregate and mixed thoroughly to produce a polymerized mix. These pellets could be used for many applications such as pavement maintenance, overlay applications (OGFC, for instance), etc.

There have been many patches completed around the country (California to New York) utilizing the pellets by various City, County and agencies with great success. These pellets have the basic asphalt rubber (AR) binder that satisfies the requirements of ASTM D8-02 containing a minimum of 15% crumb rubber by weight of the binder. Several independent laboratories testing of these materials have been conducted and some of the results are reported in this paper.

2. Literature Review

Many researchers studied the Zero-Shear Viscosity (ZSV) of asphalt rubber binders. ZSV is the rheological parameter identified and proposed for evaluation of the anti-rutting performance of binders. It was concluded that similar to conventional polymerized binders, the asphalt rubber binder (20% CRM concentration), at a rapid time and a slow shear rate, will not reach steady flow conditions compared to virgin binders. The results indicated that the high rubber content causes a non-linear relationship between shear stress and shear rate near the zero-shear conditions. It was also concluded that the rheological approach can be applied with good results to bitumen modified by CRM [22-25].

A laboratory study investigated the permanent changes to crumb rubber that occur as a result of the interaction with asphalt binders. Researchers utilized Gel Permeation Chromatography (GPC) to measure the molecular size distribution of a typical asphalt binder. Chromatogram of these binders was measured using a high-performance gel-permeation chromatography (HP-GPC or GPC), Waters Breeze equipment with computerized data acquisition software, consists of a manual injector, a dual head pump, refract index meter (RI detector), a series of two columns (HR 3 and HR 4E) and a column oven. The Morphological and elemental analyses of particles from each sample of rubber were accomplished using a Hitachi S-3400N scanning electron microscope equipped with an Oxford INCAEnergy Energy Dispersive System (EDS) [26-29].

The findings of research projects indicated that after removal of asphalt binder from crumb rubber particles, the dimensions of the crumb rubber are reduced as a result of interaction with asphalt binder. In addition, the size reduction of rubber material increases with mixing, or digestion, duration and with decreasing crumb rubber size. They also concluded that the binder source has an effect on the breakdown of crumb rubber material in CRM binders. The breakdown of crumb rubber particles resulted in the liberation of short fibers and filler material included in the rubber compounds as determined through scanning electron microscopy.

The conclusions regarding the various aging durations and temperatures for different CRM binders were as follows: a) The addition of ambient rubber, if not aged, can significantly increase the G*/ sinδ value at a relatively high temperature and decrease G* sinδ value; b) HP-GPC analysis indicated that the binder aging increases the number of large molecular size (LMS) particles of asphalt binder and decreases the small molecular size (SMS) particles; c) the use of GPC could be valuable in determining the aging characteristics of the modified asphalt binder; d) After a long-term aging process, the rheological property analysis of binders shows that the crumb rubber of CRM binder is critical for improving the aging resistance; and e) The statistical analysis illustrated that the CRM binder generally possesses engineering properties similar to a typical SBS binder at various aging temperatures and durations [26-29].

Other research projects indicated that the CRM binders enhance the performance of asphalt mixtures by increasing the resistance of the pavements to permanent deformation and thermal and fatigue cracking [30-31]. This type of crack (fatigue) is often associated with loads that are too heavy for the pavement structure or more repetitions of a given traffic loading than provided for in design [32-36]. The fatigue cracking of rubberized mixtures containing warm mix additives was studied. The research findings were as follows: a) The increase in the mixing and compaction temperatures due to the addition of crumb rubber can be offset by adding the warm asphalt additives. This lowers the mixing and compaction temperatures of rubberized mixtures comparable to conventional HMA; and b) Fatigue life values from control mixtures are generally lower than other rubberized mixtures with or without WMA additive [32-36].

3. Laboratory Testing and Evaluation

A portion of several independent laboratory testing results are reported in this section. One of the test sections was on I-285 (Atlanta, Georgia) that Georgia DOT selected to use the pellets to repair an open graded friction course (OGFC). This section of the pavement has 250,000 ADT with 30% traffic volume. Some of the materials used in the field were sampled and tested by Georgia DOT (GDOT). The aggregate gradation used for this test section is shown in Table 1. The volumetric properties of this OGFC mixture in addition to rut resistance of the materials were determined. The results indicated that the mixture had over 17% air voids and produced a rut depth of 2.84 mm using Asphalt Pavement Analyzer (APA) machine.

Table 1. *Aggregate Gradation for OGFC Mixture*

Sieve Size	% Passing	
	% Minium	% Maximum
19.0 mm (3/4 in)	100	100
12.5 mm (1/2 in)	85	100
9.5 mm (3/8 in)	60	85
4.76 mm (No. 4)	25	42
0.074 mm (No. 200)	0	2

In addition, NYC DOT conducted some limited laboratory testing for several Marshall samples and the results indicated the following: stability of 995 kg; flow (0.01 in) of 15.8; and %VMA of 20.2%.

In another study, a laboratory comparison of moisture susceptibility and studded tire wear of pellet pave mixes with different mixtures was conducted in Norway [37]. Several mixtures were evaluated: a) 10% binder containing CRM; b) 20% CRM binder; c) mixture containing 1.5% hydrated lime; d) pellet pave materials; and d) the control mixture. Marshall samples were prepared utilizing a local aggregate source satisfying the tolerances shown in Figure 2. For this project, a 70/100 binder was used in accordance with Norwegian Standards. The specifications for the binder used in this research are shown in Table 2. The crumb rubber samples were prepared using a high shear mixer and blending time of 30 minutes at 170 ^{o}C. Table 3 shows the volumetric properties of the Marshall specimens for various mixtures.

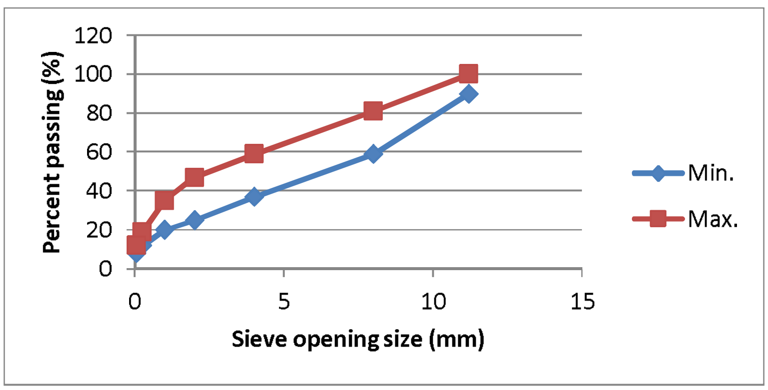

Figure 2: *Aggregate gradations used for the Norway study*

Table 2: *Specified properties of 70/100 binder used in testing (Nynas, 2012)*

Test	Method	Unit	Min.	Max.
Penetration at 25°C	NS-EN 1426	Mm/10	70	100
Ring and ball softening point	NS-EN 1427	°C	43	51
Flashpoint (COC)	NS-EN-ISO 2592	°C	230	
Solubility	NS-EN 12592	% weight	99.0	
Viscosity at 60°C	NS-EN 12596	Pa s	90.0	
Kinematic viscosity at 135 °C	NS-EN 12595	mm^2/s	230	
Fraas	NS-EN 12593	°C		-10
Resistance to hardening at 163°C				
Change in mass	NS-EN 12607-1	% weight		0.8
Retained penetration	NS-EN 1426	%	46	
Softening point after hardening	NS-EN 1427	°C		9.0

Table 3: *Volumetric Properties of Marshall samples (25 blows)*

		Air voids (%)	VFA (%)	VMA (%)
10% crumb rubber	Average	3.98	78.35	18.31
	St. Dev.	0.81	3.49	0.69
20% crumb rubber	Average	4.96	76.12	20.70
	St. Dev.	0.78	2.96	0.65
1.5% hydrated lime	Average	2.71	83.82	16.72
	St. Dev.	0.49	2.47	0.42
Pellet pave	Average	3.99	82.91	23.27
	St. Dev.	0.67	2.51	0.53
Reference	Average	3.20	81.45	17.13
	St. Dev.	0.78	3.73	0.67

The moisture susceptibility of the mixtures was evaluated and the results of indirect tensile strength and tensile strength ratio are depicted in Figures 3 and 4; respectively. The results indicated that even though the TSR values of most mixtures were satisfactory and close together, the dry and wet ITS values of the mixture made with the PelletPAVE were much higher (e.g, over 200%).

In addition, the effects of studded tires on various mixtures were evaluated. The schematics of the testing equipment used to measure the wear is shown in Figure 5. The results of the testing are shown in Figure 6. In this test, the lower values indicate the lower the simulated wearing of the mixture due to studded tires. The wearing number, in effect, is how much weight was worn away from the mixture. In general, the PelletPAVE materials performed well and are anticipated to do well in areas that studded tires are being used for many months of the year.

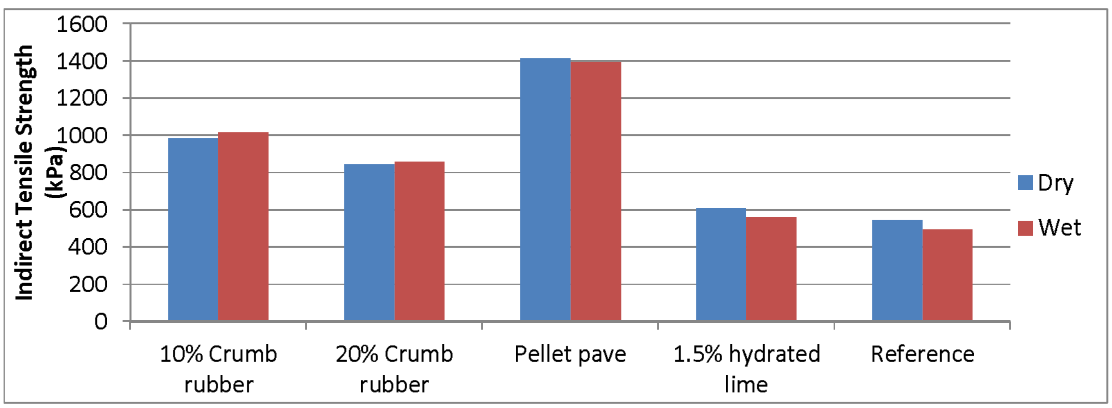

Figure 3. *Dry and Wet Indirect Tensile Strength (ITS) of Various Mixtures*

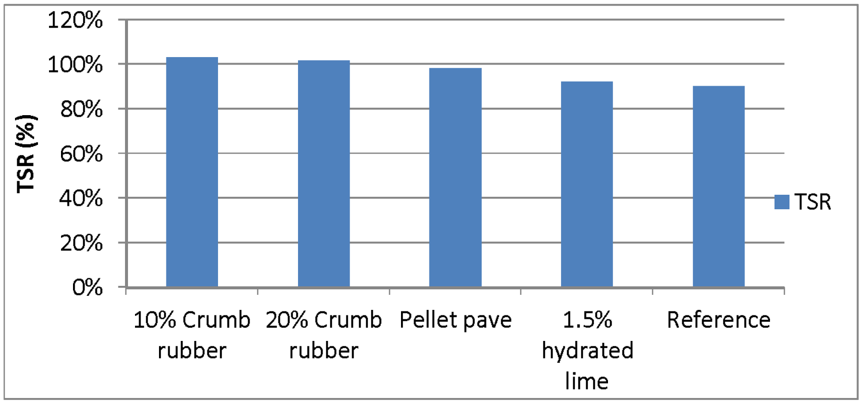

Figure 4. *Tensile Strength Ratio (TSR) of various Mixtures*

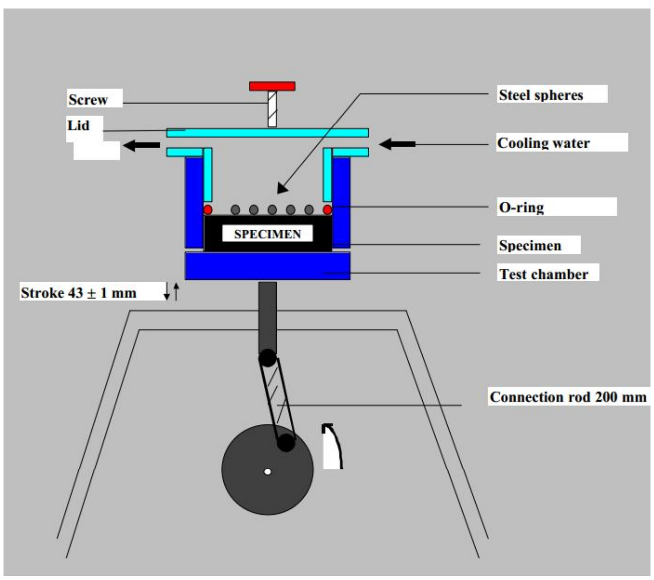

Figure 5 *Illustration of studded tire wear (Prall) test [38]*

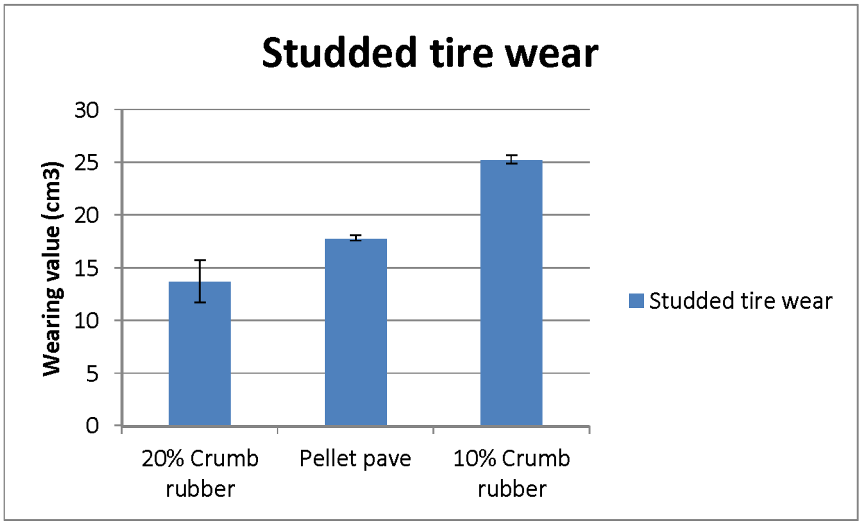

Figure 6. *Studded Tire Wear Results*

4. Summary and Conclusions

Many researchers around the world have been investigating the effectiveness of the CRM in paving mixtures. One of the new technologies used in this area is the utilization of pelletized asphalt rubber that contains some form of stiffeners (e.g., hydrated lime) and some other chemicals. These pellets could be used in many applications such as mainline paving, utility patching applications, pavement maintenance (e.g., pot hole), remote paving applications, areas that polymerized asphalt could not be obtained easily, etc.

Test results and field trials have indicated that these pellets can be successfully utilized in a variety of HMA type mixes and improve performance of the mixtures. Many of the independent laboratory testing results have indicated that these pellets have an excellent moisture susceptibility properties (e.g., over 95% TSR values) and very good resistance to rutting (2.85 mm APA values for samples containing over 17% air voids).

The field testing of these materials around the United States has proven to be effective materials for pavement maintenance. Many of these test sections have been placed for almost one year without any sign of distress.

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