HIGH TEMPERATURE PERFORMANCE OF SCRAP TIRE RUBBER MODIFIED ASPHALT CONCRETE

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ABSTRACT

Wheel track rutting tests on mixes modified with 30 mesh, 80 mesh, and very fine colloidal crumb rubber particles show that a very significant improvement in performance occurs with a reduction in the rubber particle size. The SHRP binder test for rutting, which was originally developed for homogeneous systems only, does not predict the performance improvement for smaller rubber particles. If these new scrap rubber binder systems are to be used in pavements then rutting tests on the asphalt-aggregate mixture should be conducted in order to accurately predict high temperature performance.

Keywords: crumb rubber modifier, particle size, rutting

1. INTRODUCTION

Excessive permanent deformation in the form of rutting associated with high temperature service and thermal cracking associated with low temperature service are two major problems affecting the performance of asphalt concrete pavements (1). Widespread adoption of radial tires, with pressures of 138 to 173 psi higher than their bias-ply predecessors and increased traffic volumes have accentuated these problems, especially rutting at high service temperatures. Without rutting, motorists would benefit from better steering control and less danger from hydroplaning in rain or skidding in icy conditions (2).

The demand for asphalt binders with a reduced temperature susceptibility is increasing, as user agencies are insisting on improved performance (3). Modification of the asphalt binder with high molecular weight polymers is one of the methods commonly employed for improving the thermal susceptibility of paving asphalts. Polyethylene, styrene-butadiene, and ethylene vinyl acetate copolymers have all been used successfully to improve upon the performance of asphalt binders (4). For the last three decades discarded rubber tires have also found end-use applications in asphalt binders in order to improve upon both the low- and high-temperature performance of the road surface. However, actual field trials have so far been inconclusive in their assessment of the performance/cost benefits of these materials (5). Use of reclaimed tire rubber for paving applications is also desirable from a solid waste management point of view.

2. BACKGROUND

Experimenting with scrap rubber for asphalt modification started in the 1920's (6). However, development of rubber modified asphalt binders, as they are now most often used throughout North America and in many other countries started in the 1960's, with the introduction of the McDonald process by the Roads Department of the City of Phoenix, Arizona (7). Since the developments in the late 1960's by McDonald and co-workers, various proprietary and generic technologies have evolved for the use of recycled rubber from scrap tires in asphalt binders and rubber modified asphalt concrete.

The dry process which was developed in the late 1960's in Sweden under the trade name Rubit was patented for use in the United States in 1978 under the trade name PlusRide (8). It differs from the wet process in that the crumb rubber is used as a portion of the aggregate and is directly mixed with the aggregate. This process uses crumbs of larger sizes (1/16-1/4 in; ~1.58-6.35 mm) at a loading of 3-4 wt% of the aggregate.This process also requires 1.5-3% more liquid asphalt than a conventional hot-mix. The increased asphalt content is needed to achieve a voids content below 3% in order to prevent premature ravelling of the pavement (9,10). The PlusRide technology has been proven effective in reducing the harmful effects of ice formation on roads (11,12). Other dry process techniques include those developed by the Army Corps of Engineers at the Cold Regions Research Laboratory (CRREL) and the Generic dry technology (13).

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In the wet process, when asphalt cement and crumb rubber are blended together, there is an interaction between these materials. This asphalt-rubber reaction is influenced by the blending/reaction temperature, the length of time the temperature remains elevated, the type and amount of mechanical mixing, the size and the texture of the crumb rubber modifier, and the aromatic component of the asphalt cement. Crumb rubber being a three dimensional network of natural and synthetic rubbers, reinforced with carbon black absorb the light oils from the asphalt cement during the "reaction" which results in swelling and softening of the crumbs. This in turn increases the viscosity of the modified binder (14). The wet process requires the use of at least 20% more liquid asphalt than is used in a conventional hot-mix pavement. In some cases 40-60% more asphalt is used, accounting for most of the increase in both cost and performance. The high initial cost combined with the uncertainty regarding future benefits is probably a factor which has hindered the large scale acceptance of asphalt-rubber technology. It is a fact that the cost of rubber modified pavements, in general, is currently anywhere from 60-150% above the cost of a conventional pavement (16). However, if modest amounts of fine crumb are applied to an asphalt binder, a pavement could be constructed with normal binder contents and aggregate gradations which would result in only a slight overall increase in cost. This approach has already been taken in recent years. Paving trials in Florida (17) and Ontario (18) have used asphalt binders which contain only 7-9% fine crumb rubber (80 mesh) directly blended into the asphalt cement. Initial laboratory and field results are quite promising but it is too early to draw any firm conclusions.

Crumb rubber being a cross-linked product, it has long been thought that devulcanization, partial devulcanization, or depolymerization would provide additional benefits in terms of storage stability and performance improvements. Epps (19) has found in an informal survey that there have been fewer pavements constructed with devulcanized rubber binder systems. The patent literature contains numerous claims on processes for devulcanizing waste tire matter: In 1971, Nikolinski and Dobreva (20) used various process oils to produce devulcanized rubber from waste SBR, nitrile rubber, butyl rubber and 1,4 cis polybutadiene. This is one of the earlier patents which clearly describes the use of aromatic oils in the process. Patents of C.H. McDonald (21), Nielsen and Bagley (22), Sergeeva et al. (23), and Ulicke and Cerner (24) all describe the use of aromatic oil for effecting devulcanization of scrap tire rubber in an asphalt medium. The main drawback with regards to the use of aromatic oils for devulcanization of waste rubber comes from the health hazard associated with these oils. The use of process oil or hydrocarbon liquid under high temperature and shear to render vulcanized rubber into a fluid form is described by Wakefield et al. in 1975 (25). Applications of shearing energy with addition of an aromatic oil to produce bitumen-asphalt compositions is described by van Bochove (26). According to this patent, better control over the material properties were made possible through the application of shearing forces. In 1992 and in 1994, Liang and Woodhams (27,28) described a process for devulcanization of scrap tire rubber in asphalt with the aid of aromatic oils and high shear and subsequently further stabilizing the devulcanized or disintegrated rubber particles by reacting the product with liquid polybutadiene and sulphur. The devulcanized system is mixed with a sterically-stabilized, polyethylene-modified asphalt binder as described in earlier patents by Hesp et al. (29,30). A recent paper by Zanzotto and Kennepohl (2) describes a high temperature, high shear process for devulcanizing scrap tire rubber in liquid asphalt. The authors report that the modified asphalt materials are being tested for their performance in paving mixes. It is apparent that morphology in the asphalt-rubber composition plays a crucial role in determining the properties of the crumb rubber modified binder systems and in the performance of crumb rubber modified asphaltic concrete. The work described here is concerned with achieving improved high temperature performance of asphaltic concrete mixes, taking into consideration the particle size of the asphalt rubber composition. Another paper by the same authors describes the work done on low temperature performance of the asphalt rubber mixes developed for this study (31).

3. EXPERIMENTAL

3.1 Materials

The asphalts used in this study were a 150-200 and an 85-100 penetration grade both obtained from the Lake Ontario refinery of Petro-Canada in Clarkson, Ontario made with crude from the Bow River area in Alberta, Canada.

The 30 mesh, cryogenically ground, passenger car tire rubber sample was obtained from Recovery Technologies of Mississauga, Ontario and the 80 mesh, ambiently ground, tire rubber sample was obtained from Rouse Rubber Industries of Vicksburg, Mississippi.

A dense-graded mix design meeting the Ontario HL-3 specification (32) for surface course mixtures, was used to prepare the asphalt rubber concrete samples for the evaluation of rutting resistance. Limestone coarse aggregate, limestone screenings and natural sand used for sample preparation were supplied by Dibblee Construction of Westbrook, Ontario.

3.2 Procedures

3.2.1 Sample Preparation

Two types of crumb rubber modified binders were prepared by slowly adding 10% by weight of crumb rubber (30 mesh and 80 mesh) to the 150-200 penetration grade asphalt at 170° ±10°C with moderate shearing. The third sample was prepared starting with 10% by weight of a 30 mesh crumb rubber in a 150-200 penetration grade asphalt. Particle size reduction was obtained with a thermo-mechanical process.

The asphalt concrete beams used, consisted of two lifts, each 38 mm from selected mix designs. The bottom lift of each beam was manufactured using a high stability (13600 N) Durham HL-4 mix. The top lift was manufactured using HL-3 mixes containing crumb rubber modified asphalt binder and the unmodified 150-200 and 85-100 penetration grade reference binders. The beams were prepared using a California Kneading compactor.

3.2.2 Dynamic Mechanical Testing

A Rheometrics Dynamic Analyzer RDA II was used for rheological testing. Hot asphalt samples were poured into a combined melts and solids (CMS) test fixture and allowed to cool to room temperature prior to testing. The CMS fixture consists of a 42 mm diameter cup and a bilevel plate which has an 8 mm diameter serrated surface concentric with and projecting from a 25 mm diameter plate. A temperature sweep was used to measure G^*, G', G'' and $\tan\delta$ at four temperatures between 52 and 70°C in intervals of 6°C. A frequency of 10 rad/s was used. Samples were conditioned for at least 11 minutes at each test temperature. A soak time of 180 s, during which time the temperature did not vary by more than 0.1°C, was used prior to each measurement.

3.2.3 Rutting Evaluation

Rutting tests were carried out using a wheel tracking machine purchased from Petro-Canada Ltd. It consists of three parts; a constant temperature reservoir, a wheel carriage assembly and a drive linkage assembly. All of these parts work in unison to produce a back and forth movement of a tire along the lengths of the beam sample (2).

The prepared beam samples were conditioned at 70°C for 6 hours and tested at 60°C after allowing the sample to equilibrate in the constant temperature reservoir. Samples were subjected to 8000 passes (4000 cycles) using a treaded tire (pressurized at 550 kPa) at 60° C to induce rutting. Profilometers were used to obtain the rutting profiles.

4. RESULTS AND DISCUSSION

4.1 Effect of Crumb Rubber Modifier on Rutting Performance

The rut depth results obtained for individual HL-3 asphalt concrete beams and the average values for each mix are presented in Table 1. The mean particle size of the crumb rubber modifier in these systems are also given.

The results show that the resistance to rutting for crumb rubber modified binders is significantly better than that of the reference sample. Improvements over the control sample were about 37%, 51%, and 60% for modified binders containing 30 mesh, 80 mesh and 0.4 µm crumb rubber respectively. It is to be noted that the variation in rut depths between the duplicate samples are reasonable (except for the mix prepared with an 85-100 pen asphalt), considering the fact that the preparation of the concrete beams for these tests involves a series of steps which have to be carefully performed.

Table 1 also gives the rut depth values obtained for an 85-100 pen grade asphalt which is commonly used in high temperature service conditions such as in Southern Ontario. These preliminary results also indicate that, by crumb rubber modification of a softer grade (150-200 pen) asphalt, it may be possible to obtain high temperature rutting resistance comparable to that of an 85-100 pen grade asphalt.

The mean particle size for the thermo-mechanically processed sample was found to be 0.4 microns with a standard deviation of 0.4 microns. This represents a decrease of 1500 times compared to the 30 mesh (590 microns) crumb rubber used for modification. In terms of rutting performance, only about a 25% decrease in rut depth was obtained for a particle size reduction from 30 mesh (590 microns) to 0.4 microns.

4.2 Effects of Crumb Rubber Modifier in Dynamic Shear Measurements

A comparison was made between normalized average rut depths and normalized peformance grades of all the three crumb rubber modified binders and the reference binder as shown in Figure 1. But this comparison does not seem to reveal any trend correlating the PG of a binder with the rutting performance.

The work of Hanson & Duncan (34) on crumb rubber binders also indicates that although the stiffness increases with concentration, there is little variation in $G^*/\sin\delta$ for different gradations of rubber. The gradations of rubber used in their work were GF 16, 40, 80 and 120 mesh sizes, as provided by Rouse Rubber Industries (33).

5. CONCLUSIONS

A thermo-mechanical process employed to incorporate larger 30 mesh size crumb rubber seems to be an effective method for the preparation of crumb rubber modified binder with significantly improved high temperature properties. A limited number of rutting experiments conducted on modified mixes, suggests that the resistance to rutting improves with a reduction in the particle size of the crumb rubber modifier. The SHRP binder test for rutting resistance, which was originally developed for homogeneous systems only, does not predict the performance improvement for crumb rubber modified systems containing smaller rubber particles. Rutting tests on a wheel tracking machine are found to be better for predicting rutting performance of crumb rubber modified systems.

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TABLE 1

Effect of Crumb Rubber Modified Binder on Rutting of HL-3 Mixes at 60°C after 8000 Passes of a Wheel Tracking machine

Binder System	Run 1 Rut Depth (cm)	Run 2 Rut Depth (cm)	Average* Rut Depth (cm)	Crumb Rubber Particle Size (Microns)
150 - 200	0.84	0.71	0.77	N/A
10% 30 mesh	0.45	0.53	0.49	590 †
10% 80 mesh	0.41	0.35	0.38	177 †
10% 0.4 μm	0.34	0.27	0.31	0.41 ‡
85 - 100	0.15	0.33	0.24	N/A

* *Average of Run 1 & Run 2* † *Sieve size reported by Rouse Rubber Industries*
‡ *Mean particle size as determined by optical image analysis*

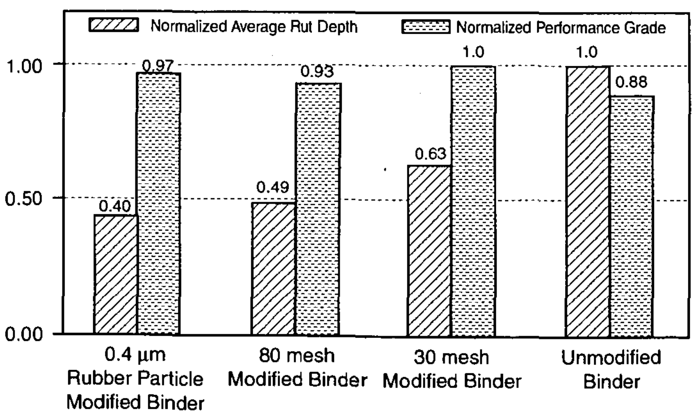

FIGURE 1. Comparison of normalized average rut depth with normalized performance grade