A Combined Economic and Performance Analysis of Ground Tire Rubber Modified Asphalt Pavements

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The objective of this study was to determine the utility of using waste tires in the form of crumb rubber in the construction of asphalt pavements. Two test sections and one control section were constructed to meet this objective. The two test sections were built using two crumb rubber modified (CRM) asphalt processes. One process uses ground tire rubber blended with hot asphalt cement at the asphalt plant to form the hot mix asphalt. The other process blends ground tire rubber and asphalt cement at a remote blending facility and is then transported to the hot mix plant to produce the hot mix asphalt. Binders in the two test sections containing ground tire rubber and the control section met the specifications for a PG 64-28 asphalt. Each of the three test sections contain approximately 1,000 tons of 2-inch asphalt overlay placed over a cold-milled asphalt pavement surface. Transverse cracking began in the rubber modified sections after 22 months service and longitudinal cracking began after 29 months. After 56 months service transverse cracking has not been observed in the control sections. However, one longitudinal crack was observed in one of the control sections after this period.

Keywords: Asphalt rubber, crumb tire rubber, tire rubber modified asphalt, waste tires, economic analysis

Background

Departments of transportation have used rubber in hot mix asphalt (HMA) for decades. Neoprene, latex, and block co-polymers of styrene and butadiene have been used to improve the elastic properties of asphalts. This improvement to elastic behavior has been shown to improve low temperature cracking and high temperature deformation performance. This rubber modification to asphalt is routinely done to change the properties of the asphalt binder. However, late in the 1960's particulate rubber obtained from grinding waste tires began to be used in asphalt pavements. First used in spray applications like chip seals and interlayers, the technology spread to use in HMA, both as a modified binder and as an elastic aggregate. The motivation for trying ground tire rubber as an asphalt modifier began because of the 100 million waste tires generated in the U. S. annually and the lack of recycling and disposal options.

Although performance of HMA containing ground tire rubber as part of the aggregate matrix has had mixed results, other methods of incorporating ground tire rubber have shown promise. Two of these methods are the so-called 'wet' process and the 'Terminal Blend' process. These methods 'react' the ground tire rubber with the hot liquid asphalt cement to form a new, rubber modified asphalt binder. The Wet Process is done at the asphalt plant while the Terminal Blend process is done at an asphalt refinery or asphalt terminal. This research evaluated the cost effectiveness of HMA test pavements constructed using the Wet Process and Terminal Blend process compared with a control on a U. S. highway. All three asphalt binders were formulated to meet Superpave PG64-28 specification.

Literature Review

Ground tire rubber has been used as a modifier for asphalt binders since the late 1960's. The first use of this modified binder in pavements was in chip seals (McDonald, 1981). McDonald found that after thoroughly mixing crumb rubber with asphalt and allowing it to react for periods of forty-five minutes to an hour, new material properties were obtained. This material captured beneficial engineering characteristics of both base ingredients; he called it asphalt-rubber (Huffman, 1980). The mixing of crumb rubber with conventional asphalt binders results in stiffer binder (Dantas Neto *et al*., 2003; Way, 2003) with improved rutting and cracking properties.

One explanation for this is the absorption of some of the asphalt constituents in the rubber. When rubber absorbs these components, the rubber particles swell. The extent of swelling is dependent on the nature, temperature and viscosity of the asphalt (Treloar, 1975; Shuler, *et al* 1979). The bulk of the rubber absorbs the solvent, which increases the dimensions of the rubber network until the concentration of liquid is uniform and equilibrium swelling is achieved. Previous research has indicated that the crumb rubber particles reacting with asphalt binder swell and form a viscous gel due to absorption of some of the lighter fractions in the asphalt binder (Green & Tolonen, 1997; Heitzman, 1992; Bahia & Davies, 1994; Zanzotto & Kennepohl, 1996).

Many experimental studies and field test sections have been constructed and tested (Shuler, et al., 1982) using asphalt rubber as a chip seal or interlayer between an old cracked asphalt pavement and the new overlay. Performance of these test sections was documented based on an FHWA study (Shuler, et al., 1985) where over 200 field test sections were evaluated. The results of this research indicated a high level of performance variability, which ranged from 'very poor' to 'extremely good'. Work in this area has continued to develop asphalt rubber as a binder for sprayed seal applications and hot mix asphalt in hopes of reducing the performance variability.

Construction practices in Arizona, California and Florida have been compiled (Hicks et al., 1995) as well as an interim report on construction guidelines (Hanson, 1996) and a compilation of specification requirements (Shuler, 1982). These reports have been helpful to agencies that wish to develop specifications for crumb rubber modified asphalt.

Experimental Method

This experiment was designed to test the performance and cost effectiveness of asphalt overlays with ground tire rubber modified binders. The study was designed as a factorial with replication utilizing the three binder types shown below as treatment variables:

- Binder Type
  - Control PG 64-28
  - 'Wet' Process Crumb Rubber Modified PG 64-28
  - 'Terminal Blend' Process Crumb Rubber Modified PG 64-28

The 'Control' represents a conventional PG64-28 asphalt binder. The 'Wet Process' and 'Terminal Blend' binders are PG 64-28 that have been manufactured using ground tire rubber.

Test Section Construction

Test and control sections were constructed in July and August, 2009 by a local paving construction company under contract with the state DOT. These pavement sections are located on the US xy-by pass in the eastbound driving lane between 71st Avenue and 35th Avenue. The 'Control' sections are between 71st and 65th Avenue, the 'Wet Process' test sections are between 65th and 47th Avenue and the 'Terminal Blend' test sections are between 47th and 35th Avenue. Performance of the materials was determined by observing distress cracking within two 500 foot long segments established within each of the three pavement sections. These segments are shown in Figures 1, 2 and 3. Each five hundred foot long segment is subdivided into five 100 foot long sample sections. These are shown as the shaded areas on each figure. Samples 1-5 and 6-10 are the ‘Control’ sections, Samples 11-15 and 16-20 are the ‘Wet Process’ sections and Samples 21-25 and 26-30 are the ‘Terminal Blend’ sections.

A precondition survey was conducted on the test and control sections prior to milling and overlay operations and no significant differences were identified. This baseline data was used to compare performance of each section relative to the condition prior to rehabilitation. Visual condition surveys have been conducted since placement of the test and control sections since 2010.

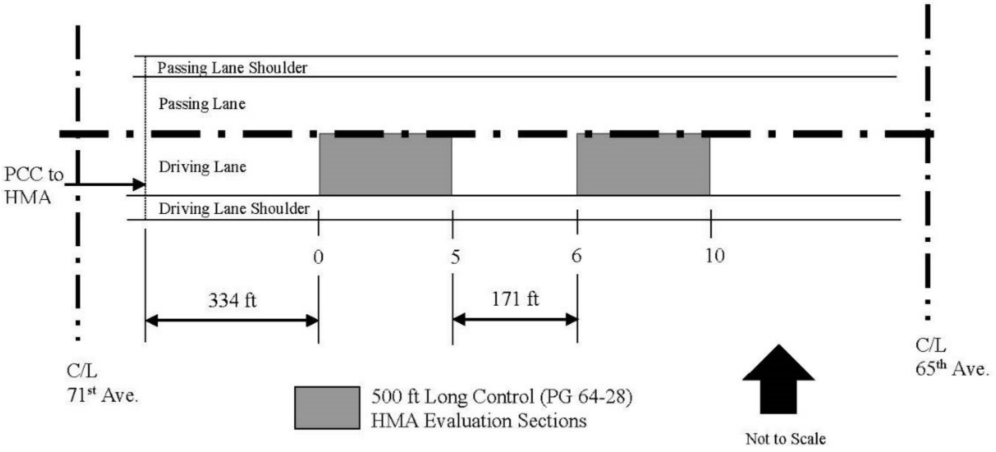

Figure 1: Location of Control PG 64-28 Evaluation Sections on US xy.

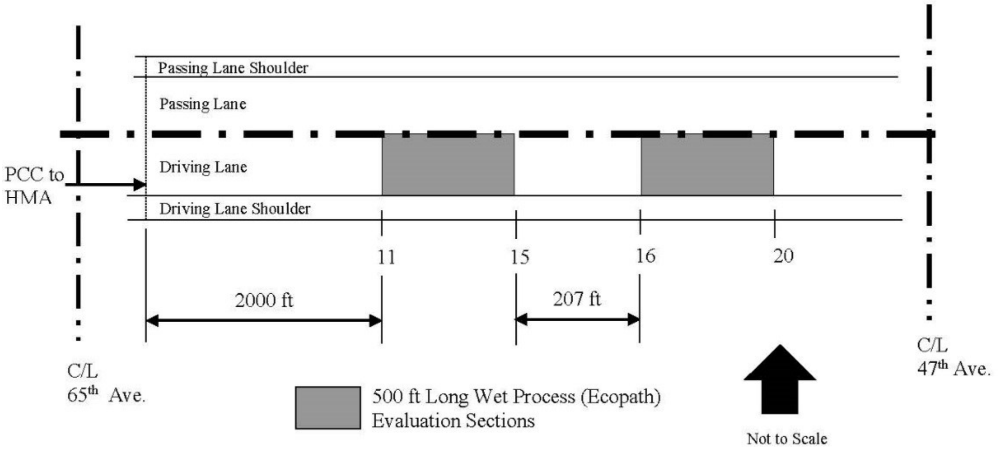

Figure 2: Location of Wet Process Evaluation Sections on US xy.

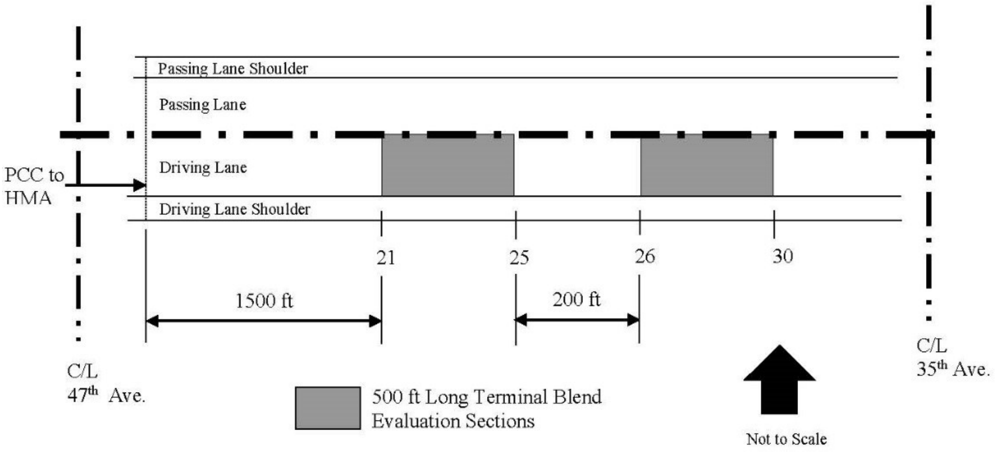

Figure 3: Location of Terminal Blend Evaluation Sections on US xy.

Construction

Construction of the 'Control' pavement sections was accomplished on July 27, the 'Terminal Blend' on August 3 and the 'Wet Process' on August 11, 2009. The project consisted of removing the top two inches of the existing pavement by cold milling and replacing this material with two inches of the test and control pavement materials. Properties of these materials are shown in Table 1 for the 'Control', 'Terminal Blend' and 'Wet Process' products.

Table 1

Mixture Properties As-Built

Average Property	Control	Terminal Blend	Wet Process
Asphalt Content, %	5.3	5.2	6.0
Air Voids, %	2.9	4.3	4.2
Voids in Mineral Aggregate, %	13.7	14.5	16.3
Voids Filled with Asphalt, %	80.1	70.6	74.1
Hveem Stability	39	47	37
AASHTO T283, dry, psi	84	80	86
AASHTO wet to dry ratio, %	99	79	98
Insitu Compaction, %	94.3	94.1	94.5

Placement of all three hot mix asphalt sections was accomplished using a conventional self-propelled asphalt laydown machine and rear discharge tractor trailer units that fed pavement materials directly into the paver hopper. Compaction was achieved using a steel vibratory breakdown roller followed by a seven-wheel pneumatic roller and finally a static steel finish roller. The 'Terminal Blend' asphalt rubber was produced in Channelview, Texas and shipped by tank truck to the asphalt plant. The 'Wet Process' asphalt rubber was blended at the asphalt plant by EcoPath. This process involved adding ground tire rubber to hot liquid asphalt cement in a mixing tank and then pumping the resulting blended mixture to the drum mixer. All three types of asphalt mixtures were produced in a Gencor counterflow drum mix asphalt plant.

Results

Economic Analysis

The quantity of material used and the associated costs for each of the three hot mix asphalt products evaluated in this study are provided in Table 2. The amount of material used for the 'Control' was significantly higher than that for the test sections since this study was incorporated into an ongoing resurfacing operation. However, no quantity discount was given on the cost of materials. The material cost per ton for the 'Terminal Blend' test section was $129.74/ton. It was determined that this amount was high due to the small amount needed for the test section. Therefore, this number was revised based on cost data from the City of xxxx where the 'Terminal Blend' material has been utilized since 2006. In a report by Khattak and Syme, the cost premium for the 'Terminal Blend' was 22 percent higher than conventional materials. Based on that information, the cost per ton for the 'Terminal Blend' was revised down from $129.74 per ton to $85.64 per ton.

Additional cost for the 'Wet Process' and the 'Terminal Blend' included modifications to the asphalt plant, $13,119 and $21,159 respectively. These modifications were necessary for the plant to accommodate the use of ground tire rubber modified asphalt materials and would be required for any application of either the 'Wet Process' or the 'Terminal Blend'. The 'Wet Process' also required mobilization costs of $35,505 due the necessity for the material to be mixed on site. This mobilization cost represents a minimum amount charged by the supplier of this material. Since both the modification costs and the mobilization cost per ton would decrease based on economies of scale as the amount of material placed increases, the cost per ton for the 'Wet Process' and the 'Terminal Blend' was calculated based on the total tons of 'Control' placed in the total project in which this study was embedded. The resulting cost per ton for modifications and mobilization for the 'Wet Process' is $0.54 and $1.57 respectively for a total of $2.11. For the 'Terminal Blend' the resulting modification cost per ton is $0.94. The adjusted cost per ton for the 'Wet Process' is $106.36 and $86.58 for the 'Terminal Blend'. The adjusted cost per ton was then used to calculate a material cost per mile for use in further analysis.

Table 2

Cost of Mixtures Assuming Routine Use (Non-Experimental)

	Control	Wet Process	Terminal Blend
Tons Placed	22,642	1,072	955
Material Cost/ton, $	70.20	104.25	85.64
*Asphalt Plant Modifications, $/ton		0.54	0.94
Mobilization, $		1.57	
**Adjusted Cost/ton, $	70.20	106.36	86.58
Tons/mi	766	766	766
Total Cost/mi, $	53,773.20	81,471.76	66,320.28

* Modifications were required to the asphalt plant to accommodate the use of the rubber modified asphalts, the cost per ton was calculated based on the total tons of the 'control'.

** Adjusted Cost/ton is the Total Cost adjusted for plant modifications and mobilization not reflected in the material cost/ton

In order for the first cost for the two test materials to be the same as the ‘Control’, the material cost for the ‘Wet Process’ would have to decrease by 51.51 percent and the ‘Terminal Blend’ would have to decrease by 23.33 percent. In the event that asphalt plant modification had already been conducted and were not needed, the per unit cost for the ‘Wet Process’ would decrease to $105.82 per ton, which is still 51 percent higher than the control. In the case of the ‘Terminal Blend’, without the plant modifications, the per unit material cost would still be 22 percent higher than the ‘Control’. In order for the higher costs to be justified, the service life of the test materials would need to be significantly longer than the ‘Control’. Average life spans for asphalt pavement overlays range from 15 to 20 years (FHWA, 2000). For the ‘Wet Process’ this means that the useable life would need to be between 23 and 30 years to justify the 50 percent increase in cost for this material. The useable life for the ‘Terminal Blend’ would need to be between 18 and 25 years to justify the 22 percent increase in cost for this material.

Performance Analysis

To evaluate the performance of the two test section and the control, distress was observed during condition surveys conducted from 2010 to 2014. These observations include transverse, longitudinal, and fatigue cracking. Results of the condition surveys for each 100 foot sample segment are shown in Figure 4 for transverse cracking, Figure 5 for longitudinal cracking and Figure 6 for fatigue cracking. The first transverse cracks were noted during the June 2011 observation for the ‘Wet Process’ section. Transverse cracking was not observed in the ‘Terminal Blend’ until the October 2012 observation. The ‘Control’ section never exhibited transverse cracking. Longitudinal cracking was first observed in the December 2011 observation for the ‘Terminal Blend’ sections. However, longitudinal cracking was not observed in the either the ‘Control’ or ‘Wet Process’ sections till the July 2013 observation. The longitudinal cracking in the ‘Control’ section was minimal. Fatigue cracking was first observed in October 2012 observation of the ‘Control’, ‘Wet Process’ and the ‘Terminal Blend’ sections, although this cracking was minimal for the ‘Control’ and ‘Wet Process’. Longitudinal and transverse cracking in the ‘Wet Process’ and ‘Terminal Blend’ test sections has steadily increased since approximately two years after construction. No transverse cracking has appeared in the control section, to date. A comparative analysis of the performance of the three materials has been done by averaging the quantity of distress over the five 100 foot sample segments for each evaluation period and plotting this distress over time. These summaries are shown in Figures 7, 8 and 9 for transverse, longitudinal and fatigue cracking. In all three cases, the ‘Control’ out performed both the ‘Wet Process’ and the ‘Terminal Blend’. Furthermore, between the ‘Wet Process’ and the ‘Terminal Blend’, the ‘Terminal Blend’ performed poorest.

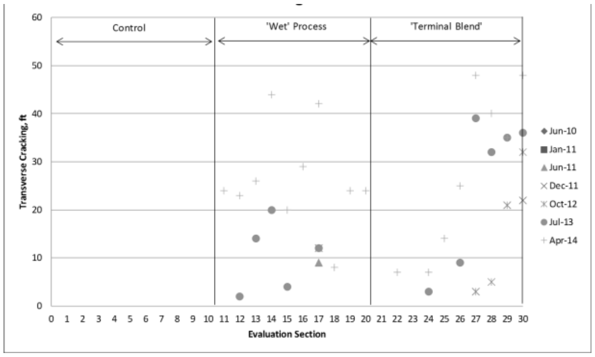

Figure 4. Transverse Cracking by Sample Segment

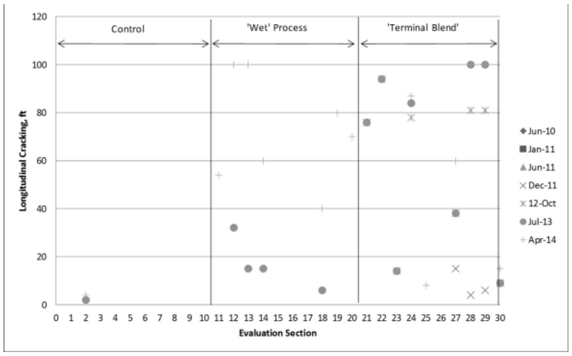

Figure 5. Longitudinal Cracking by Sample Segment

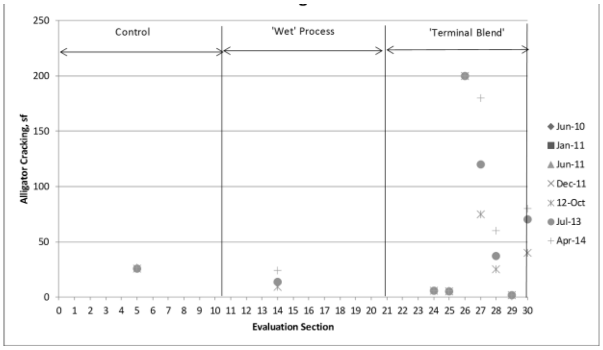

Figure 6. Fatigue Cracking by Sample Segment

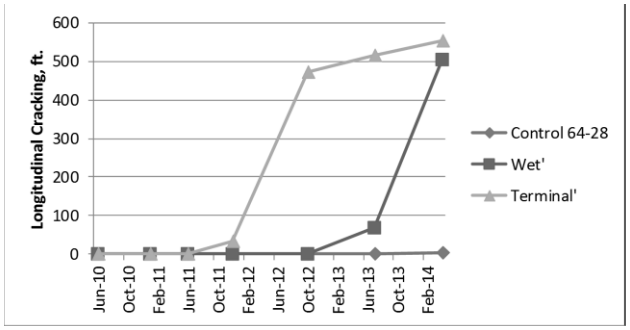

Figure 7. Longitudinal Cracking Over Time

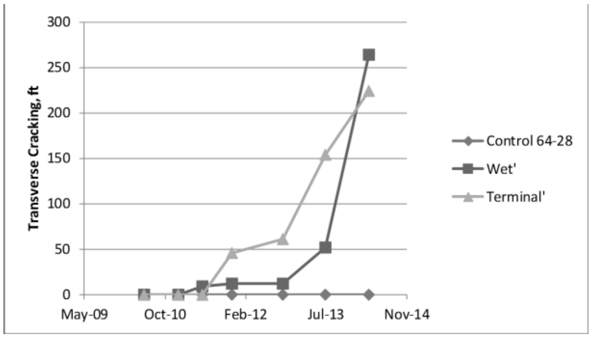

Figure 8. Transverse Cracking Over Time

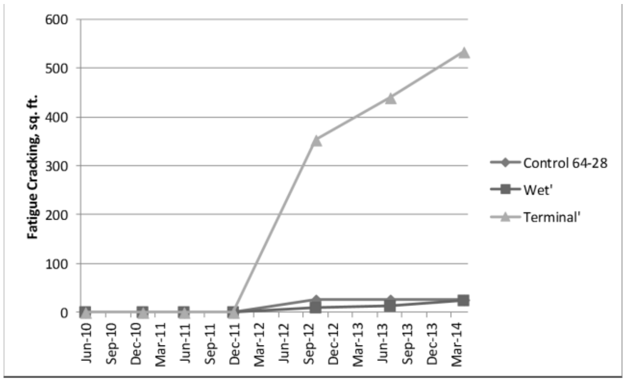

Figure 9. Fatigue Cracking Over Time

Fatigue cracking has steadily increased in the ‘Terminal Blend’ sections since three years after construction and is significantly greater than the ‘Control’ or ‘Wet Process’ sections. Fatigue cracking in the ‘Control’ and ‘Wet Process’ sections is approximately equal.

Conclusions

The purpose of this study was to evaluate the performance and cost effectiveness of asphalt overlays incorporating crumb rubber. The cost premium for the rubber modified asphalts ranged from approximately 23 to 52 percent higher than the control. To justify this cost premium, the rubber modified asphalt should have a useable life that is significantly longer than the control. However, performance data showed that performance of the rubber modified asphalt sections was well below that of the control. Longitudinal and transverse cracking in the ‘Wet Process’ and ‘Terminal Blend’ test sections has steadily increased since approximately two years after construction. No transverse cracking has appeared in the ‘Control’ section, to date, and only 4 feet of longitudinal cracking has occurred. Fatigue cracking has steadily increased in the ‘Terminal Blend’ sections since three years after construction and is significantly greater than the ‘Control’ or ‘Wet Process’ sections. Fatigue cracking in the ‘Control’ and ‘Wet Process’ sections is approximately equal. This study did not attempt to evaluate the maintenance costs for the two test sections since the combined results of the initial costs and performance analysis strongly supported the selection of the ‘Control’ over either the rubber modified asphalt options tested; however, this could be an area of further research.

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