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Interim Report

USE OF WASTE TIRES (CRUMB RUBBER) ON COLORADO HIGHWAYS

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16. Abstract
The objective of this interim report is to provide a synopsis of the progress made after one year on the feasibility of using waste tires (crumb rubber) in the construction of asphalt pavements. As part of the evaluation, two pilot test sections and one control section were constructed. Two pilot test sections were built containing crumb rubber modified (CRM) asphalt. One process uses ground tire rubber blended with hot asphalt cement at an asphalt plant to form the hot mix asphalt. This will be referred to as the wet process. The other process blends ground tire rubber and asphalt cement at a remote blending facility. The blend is then transported to a hot mix plant where the modified hot mix asphalt is manufactured. This process will be referred to as the terminal blend method. In addition, a control section was constructed containing a conventional binder. Binders in the two test sections containing ground tire rubber and the control section met the specifications for a PG64-28 asphalt. Each of the three test sections contain approximately 1,000 tons of 2-inch asphalt overlay placed over a cold-milled surface in the eastbound driving lane of US 34 near Greeley. The test and control sections were constructed in the summer of 2009.

Implementation
The ultimate goal of this project is to develop specifications, guidelines, and best management practices for the construction of asphalt pavements modified with ground tire rubber.

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EXECUTIVE SUMMARY

The objective of this interim report is to provide a synopsis of the progress made after one year on the feasibility of using waste tires (crumb rubber) in the construction of asphalt pavements. As part of the evaluation, two pilot test sections and one control section were constructed. Two pilot test sections were built containing CRM asphalt. One process uses ground tire rubber blended with hot asphalt cement at the asphalt plant to form the hot mix asphalt. This will be referred to as the wet process. 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 manufacture the modified hot mix asphalt. This process will be referred to as the terminal blend method. In addition, a control section was constructed containing a conventional binder. Binders in the two test sections containing ground tire rubber and the control section met the specifications for a PG64-28 asphalt. Each of the three test sections contain approximately 1,000 tons of 2-inch asphalt overlay placed over a cold-milled surface in the eastbound driving lane of US 34 near Greeley.

The goal of this research project is to evaluate the performance of crumb rubber test sections and as appropriate, develop Colorado-specific materials and construction specifications for ground tire modified asphalt pavement. Also, the research project aims to develop guidelines and best management practices for the construction of ground tire modified asphalt pavements.

After one year transverse cracking has begun to appear on the driving lane shoulder of the terminal blend section and the passing lane shoulder of the control section.

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INTRODUCTION

The Colorado Department of Transportation (CDOT) has used rubber in hot mix asphalt (HMA) for over 25 years. Since the early 80's, CDOT used AC-20R which was an AC -20 base grade of asphalt cement with a styrene-butadiene-rubber polymer blended at a terminal plant and shipped to the various locations throughout Colorado. Since CDOT's AC-20R was performing well, CDOT retained the ductility value along with the toughness and tenacity requirements for the newly initiated PG 64-28 grade of binder when the Department switched to the SuperPave performance graded HMA specifications in 1995. In 1994, CDOT built three trial sections in Colorado where crumb rubber was blended into the dense graded HMA using the dry method (crumb rubber is added as a component of the aggregates). Based on the information from Research Report Number CDOT-DTD-R-99-9, these trial sections proved to be a feasible asphalt pavement alternative and were performing well. The research noted that this process increased the cost per ton by 21 percent when the crumb rubber was added at a rate of 20 pounds per ton. It was recommended that CDOT not pursue any use of crumb rubber until it became cost-effective. Other state DOTs have tried the dry method with their dense graded HMA but opted not to continue using the process because of similar concerns and other problems. Therefore, CDOT will not pursue investigating this method at this time.

The use of crumb rubber in chipseal using the wet method was also investigated in the late 80's with the results and findings documented in the Research Report Number CDOH-DTP-R-86-3. The finished product performed comparably well with the conventional chipseal materials used for pavement rehabilitation but was found to be more expensive. With the influx of improved crumb rubber technologies, it is thought that the asphalt pavement life could be longer and the use of crumb rubber employing the wet and terminal blend method might prove cost-effective. For this reason, CDOT is revisiting the use of crumb rubber in HMA utilizing pilot test sections to gather the required information for developing specifications for wet and terminal blend methods.

It is proposed to evaluate the feasibility of using waste tires (crumb rubber) in the construction of asphalt pavements. As part of the evaluation, two pilot test sections and one control section using the Superpave Performance Grade, PG 64-28 asphalt binder in dense graded HMA will be built. The two pilot test sections will be built with CRM asphalt mix using the wet method (crumb rubber is first reacted with asphalt binder in an open system plant before mixing with the aggregates) and the terminal blend method (a special form of the wet process in which reaction takes place in a closed system plant). Each test section will consist of approximately 1,000 tons of 2-inch asphalt overlay placed in the same single lane of the roadway. The control section will be constructed with the conventional polymer modified binder, PG 64-28 without the crumb rubber modifier.

Objectives

This research has eight objectives:

1. To develop pilot specification for building two test sections with crumb rubber modified (CRM) asphalt cement pavements using wet and terminal blend methods.
2. To determine if CRM asphalt cement pavements can be designed and produced for a typical dense graded HMA for Colorado that either meets or exceeds the CDOT's design/construction (including placement and compaction) criteria.
3. To determine if the asphalt binder for the wet and terminal blend method either meets or exceeds PG 64-28 requirements for CDOT's ductility/toughness, and tenacity specifications.
4. To compare the cost-effectiveness of the wet and terminal blend methods with that of the conventional method using PG 64-28 binder. Determine the cost differential from using crumb rubber from out-of-state versus estimated costs from using an in-state source of crumb rubber.
5. To determine the energy consumption, types, and levels of air pollutants associated with the production of pavement mix using the wet, terminal blend, and plain PG 64-28 binders.
6. To develop guidelines and best management practices for the successful method(s) of incorporating crumb rubber in dense graded HMA pavements.
7. To update the initial pilot specification to produce a special project provision as appropriate using the information obtained from monitoring this project and other applicable data derived from the experiences of federal, other state, and local agencies.

8. To perform annual pavement condition surveys for a maximum of five years and submit results/analysis to CDOT. To prepare a report documenting the construction and monitoring of pavement performance during the first 21 months of service life.

TASK 1 - LITERATURE REVIEW

Granulated tire rubber has been used as a modifier for asphalt cement binders since the late 1960's. The first use of this modified binder in pavements was as a chip seal binder in Phoenix, Arizona (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 consitituents 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 and Tolonen, 1997; Heitzman, 1992; Bahia and Davies, 1994; Zanzotto and Kennepohl, 1996; Kim *et al*., 2001). Furthermore, Leite *et al*. discovered that the proportion of the crumb rubber in the mixture changes significantly since a rubber particle can swell to 3 to 5 times its original size when blended with an asphalt binder (Leite *et al*., 2003).

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 pooled fund study (Shuler, et al 1985) where over 200 field test sections were evaluated. Although the results of this research indicated a range of performance from very poor to extremely good, work continued to develop asphalt rubber as a binder for sprayed seal applications and hot mix asphalt. The National Cooperative Highway Research Programs (NCHRP) "Synthesis of Highway Practice 198 – Uses of Recycled Rubber Tires in Highways" provides comprehensive review of the use of recycled rubber tires in highways based on a review of nearly 500 references and on information recorded from state highway agencies' responses to a 1991 survey of current practices (Epps 1994).

A study from Virginia (Maupin 1996) reported that the mixes containing asphalt rubber performed at least as well as conventional mixes. In Virginia mixes, the inclusion of asphalt rubber in HMA pavements increases construction cost by 50 to 100 percent as compared to the cost of conventional mixes. Nevada (Troy, et al 1996) conducted research on CRM pavements and concluded that the conventional sample geometry in Superpave binder test protocols cannot be used to test the CRM binders and that the Hveem compaction is inadequate for mixtures containing CRM binders. The Louisiana Department of Transportation and Development (LADOTD) started a research project to evaluate different procedures of CRM applications in 1994 in which the long-term pavement performance of the CRM asphalt pavements was compared to that of the control sections built with conventional asphalt mixtures (LTRC 1996).

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.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, Section 1038 mandated the use of rubber modified asphalt pavements. However, AASHTO was opposed to the mandate because facts regarding fume emissions, cost-effectiveness, durability, longevity, and recyclability were unknown. Therefore, congress was persuaded to repeal Section 1038 of ISTEA, making asphalt rubber use in federally funded projects optional. The economic savings related to using asphalt rubber has been presented using the FHWA Life Cycle Cost Analysis (Hicks, et al 1999).

The Texas Transportation Institute conducted a study of two recycled crumb rubber pavments (Crockford, 1995). The study concluded that recycling was possible and that emissions from the project were no more severe than conventional asphalt hot mix. Recycling of an asphalt rubber pavement occurred in Los Angeles, California. (Youssef, 1995). The pavement was cold milled and added to the virgin mixture at 15 percent of the total mix. Air sampling during paving and recycling determined that employee exposure to air contaminates were below the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL), and in most cases below detection limits.

Fume emissions have been studied extensively in a number of asphalt-rubber projects since and in all cases been determined to be below the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limits. (Gunkel, 1994).

Combustion technologies are effective in the disposal of large quantities of waste tires and should be used where feasible and acceptable to the public. However, the combustion of tires does not provide a continuous public benefit and results in a net energy loss when all is considered. Although approximately 15,000 BTUs are recaptured when a pound of tire is combusted, 30,000 BTUs were expended to produce a pound of tire. In contrast, the United States Department of Energy has estimated that over 90,000 BTUs (2” of asphalt rubber mix replacing 4” of hot mix asphalt overlay) per pound of rubber used can be saved by utilizing asphalt-rubber through reduced materials usage and its long lasting performance (Gaines and Wolsky, 1979).

TASK 2 – PLANNING

Construction of Test and Control Sections

Construction of the test and control pavement sections was accomplished in the summer of 2009 before Project 34.24 began; therefore coordination of these activities was not under the control of the Project 34.24 contractor. However, all available information regarding materials utilized, properties of the materials (both in-situ and loose), air quality monitoring, and noise data has been assembled and documented.

Economic Analysis

Economic analysis will be conducted to determine the overall life cycle costs of the two hot mix asphalt rubber pavements compared with the control hot mix asphalt pavement. These life cycle costs will consider the costs of all components including the crumb rubber, the hot mix asphalt, equipment modifications, construction process modifications, and quality control and assurance.

Air Emissions

Since asphalt rubber must be produced at higher temperatures than conventional hot mix, asphalt emissions have historically been significantly greater than on conventional hot mix asphalt projects. Therefore, the data collected by the air quality testing specialist hired to determine and monitor the quality of air emissions during construction generated from paving operation and from stacks of asphalt plants will be compiled, managed, and analyzed.

Condition Surveys

Two evaluation sections, 500 feet in length, have been established within each test and control pavement section for measuring pavement performance by visual condition surveys. Annual condition surveys will be conducted of the two test and control sections. All cracking, rutting, raveling, flushing, joint separation, and segregation will be recorded. If significant distress is observed, a request of CDOT will be made to obtain samples and conduct laboratory testing in an effort to determine the cause of the distress.

Reporting

A report will be prepared documenting construction and pavement condition after one and two years. Condition surveys will be conducted annually for five years. Reports will be provided annually documenting performance during this period.

TASK 3 – DATA COLLECTION

Condition Surveys

The location of the 500 foot evaluation sections within each test and control pavement section and the results of condition surveys conducted through January 2011 are presented below in Figures 1, 2, and 3.

Table 1 is a summary of the air temperatures recorded during the field condition surveys.

Table 1. Air Temperatures During Condition Surveys

	Survey Date	
	June 1, 2010	January 18, 2011
Temperature, F	74	32

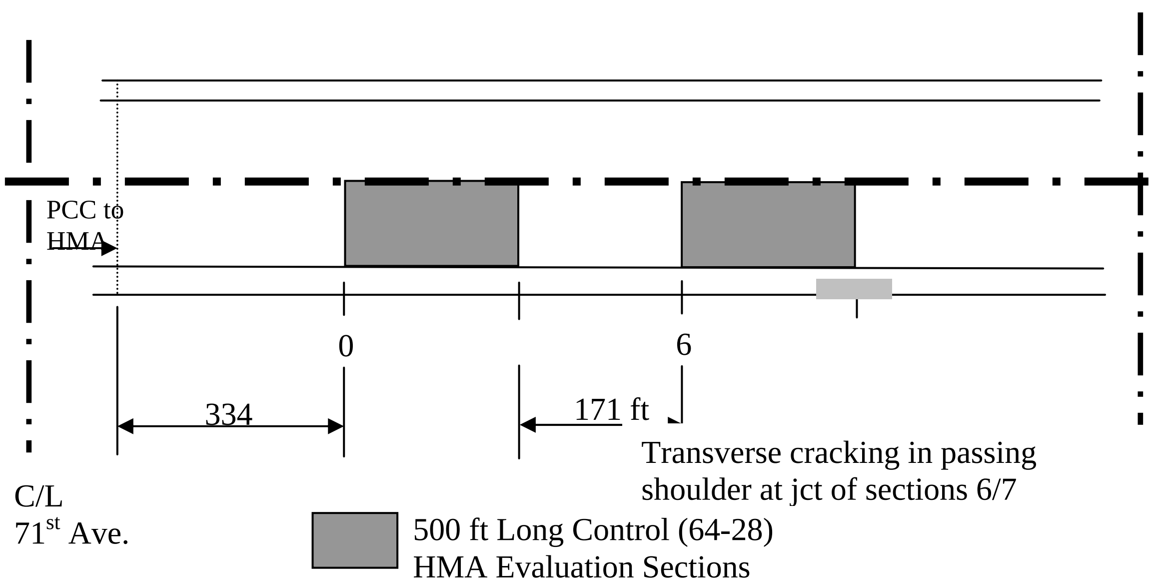


Figure 1. Location of Control Evaluation Sections on US 34

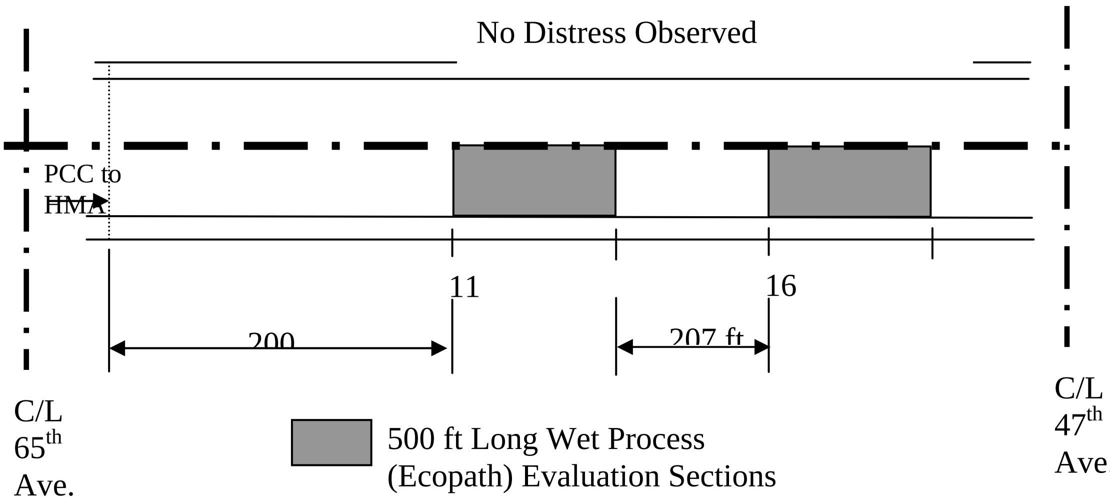
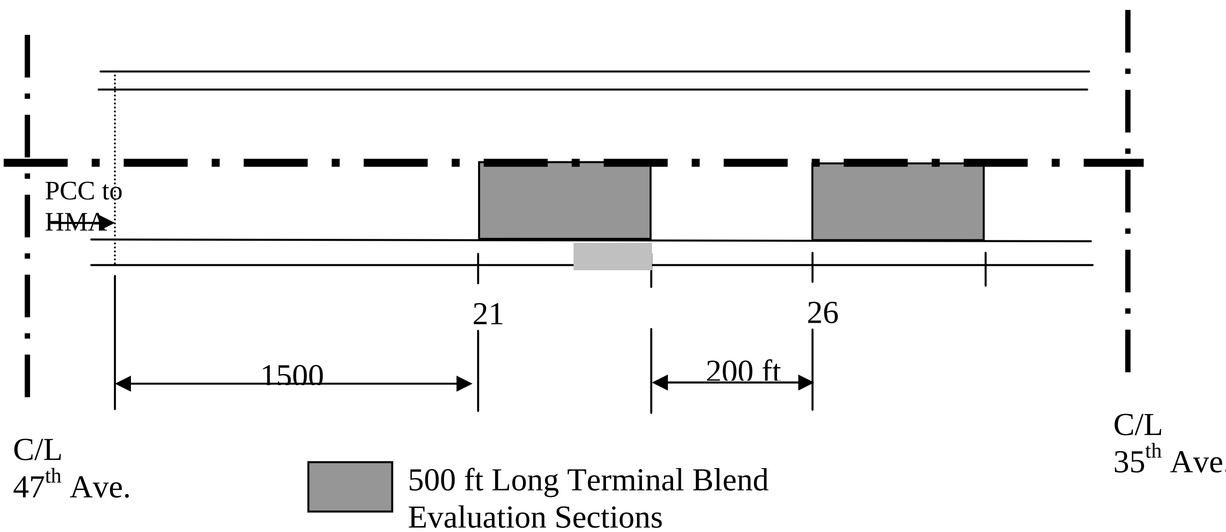


Figure 2. Location of Wet Process Evaluation Sections on US 34



Note 1: 2' transverse cracks on shoulder at 24+69, 24+75, and 24+85

Note 2: 4' transverse crack on shoulder at 25+27

Figure 3. Location of Terminal Blend Evaluation Sections on US 34

Economic Analysis

The following is a life cycle cost analysis of three asphalt pavement overlays placed on US 34 near Greeley in 2009. The overlay materials analyzed consist of hot mix asphalt containing a control PG64-22, a binder containing ground tire rubber blended at a terminal away from Greeley (terminal blend), and a binder containing tire rubber blended at the hot mix plant (wet process blend). The difference in cost of these three hot mix asphalt products is summarized below in Table 2.

Table 2. Cost of Mixtures Placed on US 34, Greeley

	Control	Wet	Terminal
tons placed >	22,642	1,072	955
Sale Cost/ton, $	70.20	104.25	129.74
Sale Cost, $	1,589,501	111,790	123,989
Plant Mods, $		13,119	21,159
Mobilization, $		35,505	
Total Costs, $	1,589,501	160,415	145,148
Adjusted Cost/ton, $	70.20	149.60	151.88
Tons/mi	766	766	766
Cost/mi, $	53,745	114,530	116,280

The analysis below was conducted to determine the life cycle costs of the three hot mix asphalt products. Since the performance of the rubber mixtures is unknown and the initial costs of the three products were significantly different, an approximate equal net present value for all three mixtures was calculated by determining what maintenance costs would be required over the ten year analysis period to make the control section equal the rubber sections.

The result of this analysis is shown in Table 3.

Table 3. Maintenance Costs Required for Aproximately Equal Net Present Value

	Control	Wet	Terminal
Cost/mi, $	53,745.12	114,530.29	116,280.42
Maintenance Costs/yr beginning 2014	15,000	0	0
Total Maintenance Costs to 2019*	60,470	0	0
Net Present Value, $	114,215	114,530	116,280

- Assumes a 3% annual increase in costs

Therefore, for the three alternatives to have approximately equal net present value, the control section would require $15,000 in annual maintenance starting in 2014 and ending in 2019 compared with no maintenance for the ground tire rubber sections.

Energy Utilization Comparison

CRM asphalt is composed of crumb tire rubber derived from the grinding of scrap tires blended with hot asphalt binder. CRM used in this study is either blended with asphalt at a terminal and shipped to the asphalt plant (terminal blend) or it is blended with asphalt at the asphalt plant (wet method). Both of these processes are used to make a modified asphalt which when mixed with aggregates produces a hot mix asphalt. The energy used to produce ground tire rubber and hot mix asphalt has been evaluated (Gaines 1979) using the amount of BTUs of energy required per pound of each product as shown in Table 4.

Table 4. BTU Utilization for Asphalt Rubber and HMA

Process	BTUs/Pound	
	Asphalt Rubber	**HMA**
Tire Shredding	-750	0
Transportation of Shred	-750	0
Granulation	-1542	0
CRM Transportation	-750	0
Steel Recovery	+817	0
Asphalt Used	-90,000	-90,000
Aggregate Used	-47,000	-47,000
Gain+/Loss-	**-139,975**	**-137,000**

Since the wet process and terminal blend process both require similar processes to obtain the crumb rubber and the blending with asphalt, they are not substantially different with respect to energy consumption. However, the energy required to produce conventional hot mix asphalt is substantially less since no energy is required to produce the rubber.

However, one study (Sousa 2001) concluded a significant energy gain could be realized if the asphalt rubber hot mix were placed at half the thickness of conventional hot mix asphalt. The gain realized was 90,000 BTUs per pound of asphalt saved and 47,000 BTUs per pound of aggregate saved.

CONCLUSIONS

1. Construction of two experimental ground tire rubber modified asphalt pavements was successful using both the terminal blend and wet process.
2. Establishment of two 500 foot long evaluation sections within the ground tire rubber test sections and one control section has resulted in two condition surveys, to date, with some cracking in the shoulders of the control section passing lane and the terminal blend driving lane section.
3. Because the ground tire rubber pavements cost more to construct than the control pavement, for the three pavement types to have approximately equal net present value, the control section would require $15,000 in annual maintenance starting in 2014 and ending in 2019 compared with no maintenance for the ground tire rubber sections.
4. The energy consumption of the ground tire rubber pavements is approximately 3000 BTU/lb greater than the conventional asphalt pavement.

RECOMMENDATIONS

The ground tire rubber pavements were constructed in the summer of 2009 with performance monitoring in the form of visual condition surveys commencing in June 2010 and January 2011. Condition surveys should continue so that performance of the pavements can be compared until each pavement section has become sufficiently distressed that economic evaluation of the costs can be accomplished.

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