Rubberized Asphalt Concrete Pavements in New Mexico

Market Feasibility and Performance Assessment

Prepared for the New Mexico Environmental Department and the South Central Solid Waste Authority

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Preface

The main purpose of this document is to provide an independent assessment of the performance of pavements with rubberized open-graded friction course overlays in New Mexico and a preliminary assessment of the feasibility of the crumb rubber modifier market in the state. This report also aims to provide complementary information to the *House Memorial 6 Final Report: Study the Use of Rubberized Asphalt* (2010), which resulted from the work of a Task Force composed of representatives from the New Mexico Department of Transportation, New Mexico Environment Department, New Mexico Development Department, and local government, industry and special interest groups in New Mexico.

This report was prepared in the first half of 2011 with the financial support from the New Mexico Environment Department and the South Central Solid Waste Authority. Support in terms of information and pavement condition data was also received from the New Mexico Department of Transportation. Representatives of state Departments of Transportation responded a nationwide survey and provided information about their practice. Information and cost estimates used in this report were kindly provided by some crumb rubber producers, paving contractors and equipment vendors. The input and support from all these agencies and companies are acknowledge and appreciated.

The intended main audience of this report includes administrators, decision-makers and engineers of the state, county, city and tribal government agencies in charge of funding, designing, constructing and maintaining the roadways and regulating and managing the disposal, storage and beneficial reuse of scrap tires and related products and industries in New Mexico. This report can also find interest among state agencies outside New Mexico.

The report is organized in seven sections, starting with definition of terms, materials and methods in section 1. This is followed by a description of the rubberized asphalt pavements in New Mexico and an assessment of pavement performance based on prior and new pavement distress data in section 2. A preliminary assessment of the feasibility of developing an asphalt rubber market in New Mexico and cost benefit considerations are covered in section 3. Section 4 summarizes the literature review with emphasis on the recent research findings about the material properties of asphalt rubber concrete and the issues associated with using the MEPDG design methodology for asphalt rubber pavements. Section 5 summarizes the results of the survey of state Departments of Transportation on the use of crumb rubber modifier in pavements applications. Section 6 summarizes cost-benefit studies and data available in the literature. Final remarks and recommendations are given in Section 7. Supplemental information and the responses to the state DOTs survey are provided in the appendices.

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Acronyms

AR	Asphalt-rubber
ASTM	American Society for Testing and Materials
CN	Control number
CRM	Crumb rubber modifier
cP	Centipoise (1 cP = 1 mPa.s)
DOT(s)	Department(s) of Transportation
DR	Distress rate
Ext	Distress extent rating
FR	Frontage Road
HMA	Hot mix asphalt
I	Interchange
IDT	Standard indirect tensile
IRI	International Roughness Index
LCCA	Life cycle cost analysis
M	Minus direction
MEPDG	*Mechanistic Empirical Pavement Design Guide*
MP(s)	Milepost marker(s)
NMDOT	New Mexico Department of Transportation
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
OGFC	Open-graded friction course
P	Positive direction
PG	Performance grade
PMAR	Polymer-modified asphalt-rubber
PMBP	Polymer-modified bituminous pavement
PSI	Pavement Serviceability Index (as defined by NMDOT)
PSR	Pavement Serviceability Rating (as defined by Arizona DOT)
RA	Rubberized asphalt (binder)
RAC	Rubberized asphalt concrete
ROGFC	Rubberized open-graded friction course
SAM	Stress-absorbing membrane
SAMI	Stress-absorbing membrane interlayer
SBS	Styrene-butadiene-styrene (polymer)
Sev	Distress severity rating
SP	Superpave
TDF	Tire-derived fuel
U.S.	United States of America
UTBC	Untreated base course

Executive Summary

The purpose of this report is to provide an assessment of the performance of pavements with rubberized open-graded friction course (ROGFC) overlays in New Mexico and a preliminary assessment of the feasibility of the crumb rubber modifier market in the state.

Crumb rubber is produced by shredding and grinding scrap tires into very small particles. Crumb rubber of certain gradation and particle size can be used to produce asphalt-rubber binders and rubberized asphalt binders, which are collectively referred to as crumb rubber modifier (CRM) modified binders in this report. These binders are produced by thoroughly mixing the CRM with asphalt cement and other additives; this blending procedure is called wet process. Terminal blend is the method in which the CRM is blended with the hot asphalt cement at the refinery or asphalt storage and distribution terminal. On the other hand, the field blend CRM modified binder is blended at the job site. Crumb rubber modifier can be used also as a substitute for a percentage of the fine aggregate in the asphalt concrete paving mixture; this application is called dry method. Depending on the manufacturing method, the properties and applications of the resulting products can vary widely.

In New Mexico, the experience with rubberized asphalt concrete pavements and surface treatments is somewhat limited. Few pavement projects constructed in the 1980s and 1990s by the New Mexico Department of Transportation (NMDOT) resulted in premature failures. Fortunately, the technology, procedures and specifications have improved significantly since those first trials. Two NMDOT pavements were constructed with thin ROGFC overlays on US 54 and US 62/NM 180 in 2002 and 2007, respectively. Recently, NMDOT Districts 1 and 2 have taken the initiative to construct several new pavements with thin ROGFC overlays. In 2010, NMDOT adopted special provisions for ROGFC in its specifications. In the last decade, local governments and cities have also used rubberized asphalt in rehabilitation treatments and overlays in a limited basis.

The performance assessment of the ROGFC pavements on US 54 and US 62/NM 180 was based on pavement condition data from the NMDOT's Annual Pavement Evaluation Program and new distress evaluation data collected in 2011 as part of this study. The distress rate calculated from the annual distress ratings was used as a pavement performance indicator. The ROGFC sample units on US 62/NM 180 showed good performance in the early life of this pavement structure (4 years), with no rutting and either very minor distress or no premature cracking in this pavement up to date. The statistical analysis of 110 ROGFC sample units located on US 54 also provided an indication of better pavement performance, in terms of distress rate, compared to a selected set of conventional (non-ROGFC) sample units located on the same highway and geographical area. The better performance of the ROGFC sample units was found in the short term and long term (9 years). It should be noted that these ROGFC pavements were not part of an experimental program and did not include control sections.

In general, the review of the literature showed that several properties of open-graded and gap-graded asphalt rubber mixtures are improved compared to dense-graded conventional asphalt mixtures. A number of laboratory experimental results available in the literature indicated that asphalt-rubber asphalt concrete mixtures tend to have higher rutting resistance, tensile strength and thermal cracking resistance. Some temperature-sensitive properties of CRM modified binders also showed improvements compared to those of polymer-modified binders and conventional binders. The material model calibrations implemented in the new *Mechanistic Empirical Pavement Design Guide* (MEPDG) methodology did not include asphalt-rubber asphalt concrete mixtures and CRM binders; therefore, testing and model calibration for these materials will be needed.

The development of a market for CRM modified binders in pavement applications in New Mexico has the potential to provide economic and environmental benefits for the state. For an initial assessment of such a market, the main components of this industry, equipment, current material producers and suppliers in the area, sources of scrap tires and initial investment costs were considered. The establishment of a facility to produce crumb rubber modifier in New Mexico would require a high initial capital investment, a constant annual demand for roughly 9,000 tons of CRM in the area and reliable local sources of approximately 1.25 million scrap tires per year. The crumb rubber producers in neighboring states of Texas and Arizona have the capacity to produce sufficient material to satisfy a potential increase in demand of CRM modified binder for New Mexico projects. The limited literature of life cycle cost analysis was summarized.

A survey of state Departments of Transportation (DOTs) about the use of crumb rubber modifier (CRM) in pavement applications was conducted. The reasons most frequently cited by state DOTs for using CRM modified binders in various pavement applications included better or comparable performance compared to conventional materials, cost effectiveness and significant incentives to use recycled scrap tires. On the other hand, state DOTs that have not used CRM modified binders referred the most to higher cost of CRM binders, uncertain field performance and not having a crumb producer in the state as the main reasons for not using these materials.

This study recommends monitoring and documenting the medium-term and long-term performance, maintenance and costs of new ROGFC sections and OGFC control sections in New Mexico, and considering the feasibility and cost-benefits of designing and constructing structural pavement layers using CRM modified binders in New Mexico highways. It is also recommended to determine the recyclability of ROGFC pavements once they require rehabilitation or reconstruction. Other recommendations are promoting the cost-effective use of CRM modified binders in asphalt concrete and pavement surface treatments and considering a funding mechanism to assist state and local governments in New Mexico to offset the higher costs of using CRM binders in pavement applications. A legislature mandate to use crumb rubber modifiers or rubberized asphalt in New Mexico are not advisable. The use of these materials should be driven by performance measures and life cycle cost analysis.

1. Asphalt Rubber – Related Terms and Characteristics

1.1 Crumb Rubber

Crumb rubber, also called ground rubber, is produced by shredding and grinding scrap tires into very small particles. In the process, most of the steel wires and reinforcing fibers or fluff of the recycled tires are removed (Figure 1). The fine grinding is done by either the ambient method or the cryogenic method. The crumb rubber is often sieved and separated in categories based on gradation to meet the requirements of a particular application or agency. In the crumb rubber market, there are three main classes based on particle size:

- Type 1 or Grade A: 10 mesh coarse crumb rubber;
- Type 2 or Grade B: 14 to 20 mesh crumb rubber;
- Type 3: 30 mesh crumb rubber.

Mesh size designation indicates the first sieve with an upper range specification between 5% and 10% of material retained.

Figure 1. Crumb rubber, steel and fibers samples from recycled scrap tires [Source: reRubber (2011)]

The ***ambient method*** consists of grinding the rubber at or slightly above ambient (room) temperature using a granulator or a crackermill (Caltrans, 2006). A granulator shreds and cuts the material with revolving steel plates into cubical, uniformly shaped particles with sizes ranging from 3/8 in. (9.5 mm) to 0.0167 in. (0.425 mm) (No. 40 sieve). The crackermill passes the material between rotating corrugated steel drums to produce irregular, elongated, torn particles with sizes ranging from 0.187 in. (4.75 mm) (No. 4 sieve) to 0.0167 in. (No. 40 sieve). Finer crumb rubber (smaller than No. 40 sieve) can be produced with the ***micromill*** process.

Even though the grinding of the tire rubber in the ambient method starts at room temperature, the friction generated when the material is granulated or cut increases the temperature considerably (Caltrans, 2006). The ground rubber particles produced by the ambient method have a sponge-like surface and very large surface area (Roberts et al., 1996); the later characteristic favors a fast reaction of the ground rubber and asphalt cement during blending.

Cryogenic tire grinding consists of freezing the scrap tire rubber using liquid nitrogen until it becomes brittle, and then cracking the frozen rubber into smaller particles with a hammer mill. The resulting material is composed of smooth, clean, flat particles. These characteristics may not aid, and may even delay, the reaction time of the ground rubber with the hot asphalt cement (Roberts et al., 1996). This method can be applied before grinding the rubber pieces with the ambient method (Caltrans, 2006).

1.2 Asphalt Binders Containing Crumb Rubber

Asphalt binder is the principal binding agent in hot mix asphalt (HMA) and surface preservation treatments for flexible pavements such as fog seal, chip seal and crack sealing. Asphalt binder includes asphalt cement and any material added to modify the original asphalt cement properties. Some asphalt binders need modification to meet specifications. Modifiers can change the properties of the binder by:

- lowering the viscosity at the construction temperature to facilitate pumping, mixing and compaction of HMA;
- increasing the viscosity at high service temperatures to reduce rutting and shoving;
- increasing relaxation properties at low service temperatures to reduce thermal cracking;
- increasing adhesion between asphalt binder and aggregates in the presence of moisture to reduce or prevent stripping.

Not all crumb rubber modifier (CRM) modified asphalt binders are appropriate in all applications. Crumb rubber can be used as an asphalt binder modifier to produce CRM modified hot mix asphalt (HMA) concrete or in several pavement surface preservation or rehabilitation treatments, such as rubberized fog seal and rubberized chip seal. Because of the complex nature of the rubber materials, their effect on the properties of the various types of asphalt binder and the HMA concrete mixtures are not always easy to predict without testing the modified binder (Roberts et al., 1996).

1.2.1 Asphalt-Rubber Binder

Asphalt-rubber (AR) binder consists of a blend of asphalt cement, ground recycled tire rubber (crumb rubber), and other additives such as extender oil, natural rubber and polymers, as needed. The rubber content should be at least 15% (by weight) of the total blend to provide acceptable properties of the material, according to the "*Standard Specification for Asphalt-Rubber Binder*" (ASTM D6114/D 6114M–09). Higher rubber contents, between 18% and 22% by weight, are often used or specified (Roberts et al., 1996; Caltrans, 2006). The ground rubber should be blended sufficiently in the hot asphalt cement (347^{o} F = 175^{o} C) to cause swelling of the rubber particles and a considerable increase of the viscosity (to a minimum of 1,500 cP). The viscosity is strongly affected by the crumb rubber content and particle sizes. Because the AR binder is mixed and blended at the job site, it is also called ***field-blend asphalt-rubber binder*** based on its manufacturing process.

The ASTM D6114/D 6114M – 09 Standard specifies that, among other characteristics, the ground recycled tire rubber for AR binder should contain less than 0.75% moisture (by weight), no visible nonferrous metal particles, no more than 0.01% ferrous metal particles (by weight), and should be free flowing.

The increase in viscosity of the AR binder is related to workability and affects some physical properties of the binder. Higher viscosity of the AR binder can help during the application process during pavement preservation techniques by reducing or preventing the flow of the binder into the gutter and filling wider cracks on the pavement surface (ISS, 2010). However, the binder viscosity affects the application rate.

A blend design profile for an AR or polymer-modified asphalt-rubber (PMAR) binder can be performed to determine the optimal proportions of asphalt cement, CRM and other components of the binder, and evaluate the compatibility and interactions among the various components and the stability of the blend over time (Sam W. Huddleston, personal communication, November 10, 2010).

1.2.2 Rubberized Asphalt

Rubberized asphalt (RA) binder is also referred to as ***terminal-blend or field-blend rubberized asphalt modified binder***, depending on the manufacturing process, or just ***rubberized asphalt***. In practice, rubberized asphalt is mostly terminal blended and consists of asphalt cement with crumb rubber modifier (CRM) binder (less than 15% by weight). Rubberized asphalt binder is often referred to as PG 76-22TR (tire rubber) or PG 76-22PM (polymer-modified) binder because these are the only RA binder types currently approved for the specifications of Caltrans (California Department of Transportation).

Historically, rubberized asphalt has contained up to 10% of CRM, thus it does not meet the requirements of ASTM D6114/D 6114M–09 for asphalt rubber. However, in recent years greater rubber contents have been used in RA binders in some projects (CalRecycle, 2010).

The RA binder is generally made with CRM smaller than 30 mesh and may contain 1% to 4% styrene-butadiene-styrene (SBS) polymer.

1.3 Dry Process and Wet Process

Using crumb rubber recycled from waste tires in asphalt mixtures and pavement rehabilitation treatments can be achieved in two different ways. Crumb or ground rubber can be used either as fine aggregate in the mixture or as processed rubber added to the asphalt binder. To implement these two approaches, the dry process and wet process of using crumb rubber were developed.

The ***dry process*** is any method that adds granulated or ***crumb rubber modifier*** (CRM) from scrap tires as a substitute for a percentage of the aggregate in the asphalt concrete mixture, not as part of the asphalt binder. The crumb rubber is mixed with the aggregate fraction before adding the asphalt cement. The resulting product is often called rubber-modified asphalt concrete mixture. Different gradations or sizes of granulated or CRM can be used depending on the application or procedure. The percentage of the crumb rubber added in the dry process varies; for example, Roberts et al. (1996) indicated that 3% to 5% of crumb rubber by weight of the aggregate is generally used; the *Asphalt Rubber Usage Guide* (Caltrans, 2006) refers to 1% to 3% of crumb rubber by weight of the aggregate in the asphalt concrete mixture.

The dry process is applicable to produce CRM-modified asphalt concrete mixtures. In this process, the asphalt cement is not modified significantly by the addition of the crumb rubber; however, the properties of the resulting HMA are modified (MEEF, 2011). The dry process can be used in dense-graded, open-graded and gap-graded mixtures to accommodate the rubber particles in the aggregate gradation, but cannot be used for cold mix, chip seals and surface treatments. The mixture design should take into account the lower specific gravity of the crumb rubber compared with that of conventional aggregates (Caltrans, 2006).

The dry process can be implemented in batch or drum-dryer plants. The granulated or crumb rubber is usually packed and stored in sacks at the plant (Figure 2). Good control of the feeding of rubber and temperature are critical because the rubber content and temperature affect the performance of the resulting asphalt mixture and pavement. For both batch and drum-dryer HMA plants, the addition of rubber normally requires adjusting the mixing time and temperature. Batch plants require a dry mix cycle to ensure that the heated aggregate is mixed with the crumb rubber before applying the asphalt cement (MEEF, 2011).

The ***wet process*** is the method of modifying the asphalt binder with CRM from scrap tires before the binder is added to form the asphalt concrete mixture (Figure 3). The resulting product is called asphalt rubber or rubberized asphalt. The wet process requires thorough mixing of the CRM with the asphalt concrete and other components of the modified asphalt binder at temperatures between 375° F to 435° F (190° C to 224° C) and requires maintaining the blend at temperatures between 375° F to 425° F (190° C to 218° C) for a certain specified minimum time, generally 45 minutes (Caltrans, 2006).

Figure 2. One-ton bulk bags of crumb rubber (Photo by Shuki, Wikimedia Commons)

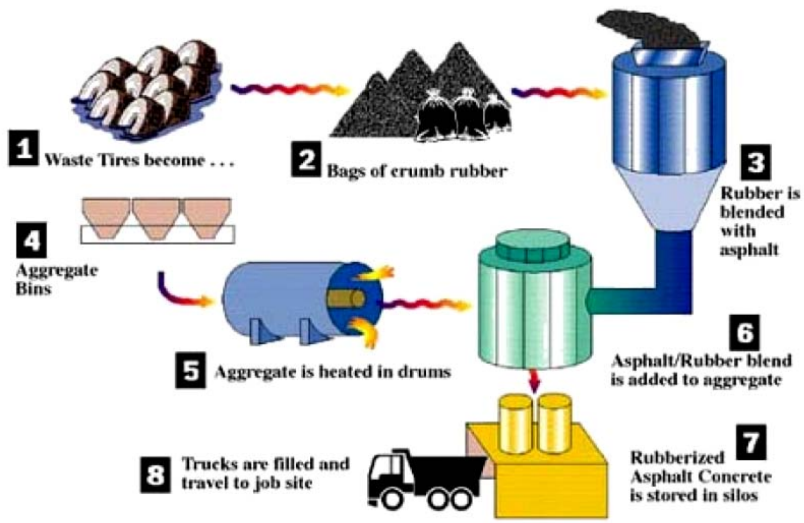


Figure 3. Illustration of the main stages of the crumb rubber wet process (Field blend) (Source: Utah Department of Transportation, 2003)

The thorough mixing and high temperature ("digestion temperature") during the wet process cause the swelling of the crumb rubber particles and the interaction (i.e, chemical and physical bonding [Roberts et al., 1996]) of the crumb rubber with the hot asphalt cement and other binder components. This process produces an increase of the binder viscosity; when the blend reaches a constant viscosity, the binder is ready to use. The extent of swelling of the rubber particles depends, in part, on the nature, temperature and viscosity of the liquid or solvent. This property of rubber is used to modify and enhanced the physical properties of the asphalt binder produced with the wet process to the advantage of specific applications.

During blending, the rubber particles can swell three to five times their original size, which changes the proportion of the crumb rubber in the mixture, and can breakdown partially. The particle size reduction increases with mixing time and decreases with increasing original crumb rubber size (ARTS, 2011).

The two main differences among the CRM modified asphalt binders produced with the wet procedure are the viscosity of the blend and the need for constant agitation to maintain relatively uniform distribution of the rubber particles in suspension in the modified binder. The CRM sizes mostly used in the wet process are smaller than No. 10 (0.0787 in. = 2 mm) or No. 16 sieve (0.0469 in. = 1.19 mm) (Roberts et al., 1996; Caltrans, 2006).

1.4 Production Methods of Crumb Rubber Modified Asphalts

There are several methods to produce CRM binder and asphalt mixtures based on the production or manufacturing process. The asphalt-rubber (AR) binder is a field-blended product; thus, the terms field-blend asphalt-rubber modified binder and field-blend asphalt-rubber asphalt concrete are often used. On the other hand, terminal-blend CRM products are generally blended at the refinery or asphalt storage and distribution terminal.

1.4.1 Terminal Blend

Terminal blend refers to the type of wet-process CRM product that is blended with the hot asphalt cement at the refinery or asphalt storage and distribution terminal as any other polymer-modified asphalt binder. It does not require subsequent agitation during transportation to the HMA mixing plant or job site before use. However, CRM modified blends that do not require agitation with paddles or augers after the initial reactions have been achieved could be also produced in the field (Caltrans, 2006). Terminal blend is often referred to as ***wet process-no agitation***.

Crumb rubber particles smaller than No. 50 sieve (0.0117 in. = 0.3 mm) are generally used to produce terminal-blend CRM modified binders because they can interact faster with the asphalt cement and other binder components at high temperatures and remain in suspension within the storage tank longer without the need for special agitation (Caltrans, 2006). Terminal blending is used to produce rubberized asphalt binder.

1.4.2 Field Blend

Field blend refers to the type of CRM modified binder that is blended at the job site using the wet process. The product of this procedure is mainly asphalt-rubber (AR) modified binders. Field-blend CRM modified binders maintain or exceed the rotational viscosity of 1,500 cP at 375^{o} F (190^{o} C) after the interaction period and, consequently, need to be agitated to maintain the rubber particles in suspension and evenly distributed in the tanks. Thus, the field blending process is also referred to as ***wet process-high viscosity*** when blending takes place in or near the job site. Field blending requires the use of mobile blending units and tanks.

1.5 Other Terms and Applications

In addition to CRM modified asphalt concrete, several surface preservation and maintenance applications of CRM modified binder have been used in the last decades. The ***stress-absorbing membrane*** (SAM) is a chip seal using hot asphalt-rubber modified binder. This application has been found to minimize reflective cracking from an underlying distressed asphalt or rigid pavement and help maintain serviceability of the pavement pending rehabilitation or reconstruction (Caltrans, 2006). The ***stress-absorbing membrane interlayer*** (SAMI) consists of a spray application of asphalt-rubber binder covered with aggregates. Some variations of the SAMI include asphalt rubber chip seal overlaid with an asphalt concrete mixture overlay that may or may not include CRM modified binder (SAMI-R), fabric (SAMI-F) or fine unbound aggregate (Caltrans, 2006). The ***rubberized asphalt concrete*** (RAC) is the HMA asphalt concrete produced by mixing asphalt rubber or rubberized asphalt binder with graded aggregate and can be dense-, gap- or open-graded.

2. Rubberized Asphalt Concrete Pavements in New Mexico

2.1 Background History, Location and Pavement Types

The states of California and Arizona are the largest users of crumb rubber in asphalt pavement applications in the United States, followed by Florida and Texas. In New Mexico, the experience with CRM modified binders in HMA concrete and pavement rehabilitation treatments is somewhat limited. Table 1 summarizes the projects constructed using CRM modified binders by the New Mexico Department of Transportation (NMDOT). The information about the NMDOT's experience with asphalt rubber projects prior to 2002 was obtained from an internal NMDOT document (Tenison, 2005).

In 1984, the NMDOT constructed the first project near Chama, New Mexico (NM) using coarse rubber as a fraction of the fine aggregate in the hot mix asphalt (HMA) mixture according to the dry process. A 9-month evaluation report for this project indicated that the pavement structure performed well during cold weather (winter months). However, the pavement lost structural capacity and failed during the hot weather (summer months); it "literally came apart" during the first summer experienced by this pavement.

In 1985, the NMDOT constructed a second project on state highway NM 206 near Lovington, NM that included an asphalt rubber overlay. The binder was modified with fine-grained crumb rubber and prepared with the wet process. The pavement surface showed excessive premature cracking within the first year following construction. After these two unsuccessful projects, the NMDOT did not use crumb rubber in asphalt pavements during the next 10 years. The technology, procedures and specifications have improved significantly since those first trials.

In 1994, six rubberized open-graded friction course (ROGFC) projects were constructed by a local entity and two were constructed by the NMDOT. In 1999, 28 ROGFC projects were constructed by the NMDOT. The performance of these ROGFC projects was reported as better than that of the conventional open-graded friction course (OGFC) pavements in New Mexico. According to an internal NMDOT memo, the cost of the ROGFC projects was estimated at that time as 33% higher than that of conventional OGFC projects (Tenison, 2005).

In July of 2002, NMDOT's District 2 constructed a new pavement with a thin ROGFC overlay on interstate US 54 from milepost marker (MP) 0 to MP 55, located in Otero County between Alamogordo, NM and the Texas state line. At this location, US 54 is mostly a four-lane divided highway. The construction included the following NMDOT projects: AC-MIP-054-1(30)00 (MP 0 to MP 6, CN 3391), AC-MIP-054-1(32)07 (MP 6 to MP 23, CN 3775), AC-MIP-054-1(33)23 (MP 23 to MP 30, CN 3776), AC-MIP-054-1(21)30 (MP 30 to MP 35, CN 2992), and AC-MIP-054-1(31)35 (CN 3774, MP 35 to MP 55).

Table 1. Summary of NMDOT's rubberized asphalt concrete pavement projects

Construction Year	Route	Approximated Length	Location	Notes [a]
1984	–	–	Near Chama, NM	Course rubber, dry process
1985	NM 206	–	Near Lovington, NM	Overlay. Fine crumb rubber, wet process
1994	–	–	–	Two ROGFC projects
2002	US 54	55 miles (88.52 km)	MP 0 to 55, between Alamogordo, NM and El Paso, TX	ROGFC overlay in reconstruction and rehabilitated pavements (District 2)
2007	US 62 / NM 180	1.969 miles (3.168 km)	MP 106.0 to 109.7, from east of Hobbs, NM to Texas state line	ROGFC overlay in full reconstruction and rehabilitated pavements (District 2)
2011	I 25 & University Interchange	0.954 mile (1.535 km)	Las Cruces, NM	ROGFC overlay in new ramp (District 1)
2011	I 10	15.177 miles (24.425 km)	MP 92.823 to MP 108.0, Luna County, NM	ROGFC overlay (District 1)
2011	US 54	5.691 miles (9.159 km)	MP 107.0 to MP 112.7, between Tularosa and Carrizozo, Lincoln County, NM	ROGFC overlay (District 2)
2011	US 54	6.345 miles (10.212 km)	MP 112.7 to MP 119, between Tularosa and Carrizozo, NM	ROGFC overlay (District 2)

[a] ROGFC: Rubberized open-graded friction course
– Information not available or unknown

The contractor for this project was FNF Construction Inc., based in Tempe, Arizona. The rubber for the asphalt-rubber modified binder was produced by Recovery Technologies Group (RTG). The ROGFC was placed using the wet process with PG 58-22 supplied by Western Refining, Inc., based in El Paso, Texas. Approximately 100,000 scrap tires were used to produce the CRM for the binder. These scrap tires were donated by Ford Motor Company as part of a national partnership to recycle or reuse approximately 6.5 million used tires resulting from a recall of tires from Ford vehicles in 2001 (Fickes, 2003). Ford Motor Company donated $200,000 to NMDOT for using crumb rubber from these recalled tires in the asphalt rubber concrete overlay on US 54 (Fickes, 2003).

According to NMDOT's as-built construction plans for new construction and rehabilitated sections on US 54, the ROGFC overlay was 0.6 in. (15 mm) thick, on plant-mixed asphalt concrete (PMBP) Type SP-III placed in two lifts and untreated base Type I-B. The thickness of the asphalt concrete and base layers varied throughout the project.

In the spring of 2007, NMDOT's District 2 constructed another project with a thin ROGFC on US 62/NM 180 from MP 106.0 to MP 109.7, located in Lea County, east of Hobbs, NM. The NMDOT's Project Number was AC-GRIP-(NH)-062-2(4)99 and the Control Number was CN G3542. The paving contractor was Armstrong Construction Company, based in Roswell, NM (currently Constructors Inc., Roswell, NM).

According to NMDOT's as-built construction plans, the project included 10,395 ft (3,168 m) of pavement reconstruction and 6,104.6 ft (1,860.7 m) of pavement rehabilitation, for an approximated total paved surface area of 93,021 yd^2 (837,189 ft^2 = 77,777 m^2). The ROGFC overlay was 5/8-in. (15.9-mm) thick. About 3,175 tons (2,880 metric tons) of rubberized asphalt concrete (terminal blend) with 6.68% of rubber modified binder and 1.02% of hydrated lime (anti-stripping agent), by weight of total mixture, were used for the construction of the ROGFC overlay. The CRM modified binder was PG 70-28TR from Wright Asphalt Products Co., based in Texas.

The full-reconstruction section on the US 62/NM 180 pavement consisted of 6-in. (152.4-mm) untreated base Type I, 5.75-in. (146.1-mm) PMBP Type SP-III asphalt concrete placed in two lifts, and finally the ROGFC overlay. The rehabilitated section consisted of 3-in. (76.2-mm) full-width cold mill, 5.75-in. PMBP Type SP-III asphalt concrete placed in two lifts, and the ROGFC overlay.

In summer of 2011, two new NMDOT projects that include ROGFC overlays are scheduled for construction in District 1 and several others in District 2 on US 54. The new ROGFC projects of Districts 1 and 2 are described in Section 2.3 of this report.

2.2 Performance Data of ROGFC Overlay Projects in New Mexico

The experience with rubberized asphalt concrete pavements and rubberized asphalt surface treatments in New Mexico is limited compared to the experience of California, Arizona, Florida and Texas, which spans several decades. Unfortunately, there was no systematic evaluation and documentation of the performance of the two most recent NMDOT's ROGFC projects constructed on US 54 and US 62/NM 180. The information available to the author of this report about the long-term structural performance of these pavements consisted mostly of anecdotal accounts from those who have visited these sites.

This report presents the evaluation of surface distress, roughness and rutting data for these two ROGFC overlay projects. The surface condition data are also compared in the medium and long terms to those of comparable OGFC projects on the same highways, with the same traffic and climatic conditions. It should be noted that these rubberized asphalt projects were not designed as field test sections to compare the performances of ROGFC and OGFC. The evaluation was carried out using past and newly collected surface condition data only.

2.2.1 NMDOT's Pavement Condition Data

The NMDOT has collected pavement condition data, i.e. surface distresses, rutting and roughness, during the last two decades along the New Mexico State Highway and Routes System. Until 2009, NMDOT evaluated annually approximately 15,500 lane-miles of state-maintained pavement. More than 98% of the sample units were flexible pavements. Prior to 2006, NMDOT district construction personnel carried out the pavement distress rating work. From 2006 through 2009, NMDOT contracted with New Mexico State University (NMSU) and the University of New Mexico (UNM) for the Annual Pavement Distress Evaluation Program. In 2000, 2001, 2010 and 2011, pavement distress data were not collected in New Mexico.

Pavement condition data were not measured or collected on shoulders or turning lanes, passing lanes, unpaved roads, bridges, or roadways under construction. Distress, rutting and roughness data were always collected in the far-right driving lane. On two-lane highways (one lane in each direction), data were collected in the positive direction only. [Note that for highways with predominant east-west orientation, the positive (P) direction is the east-bound lane and the minus (M) direction is the west-bound lane. For highways with predominant north-south orientation, the positive direction is the north-bound lane and the minus direction is the south-bound lane.] On multilane highways (four or more through lanes), pavement condition data were collected in both directions.

For the sole purpose of the pavement distress surveys, a sample unit was defined by the NMDOT as an area extending one tenth of a mile (0.1 mile = 528 ft = 161 m) in length and having a width equal to the right driving lane. The pavement sample units were approximately located at 1-mile intervals, starting or ending at each highway milepost marker (for the positive and negative directions respectively). The ratings of pavement distress and rutting were collected during manual (walk) surveys and did not include deterministic measurements. These distress ratings were meant to be used as part of the pavement condition assessment at the network level. These distress data are in the form of severity and extent ratings according to the *NMDOT's Distress Evaluation Chart for Flexible Pavements* (NMDOT, 2004) enclosed in Appendix A.

Up to 2011, the *NMDOT's Distress Evaluation Chart for Flexible Pavements* (Appendix A) considered eight types of distresses: raveling and weathering, bleeding, rutting and shoving, longitudinal cracking, transverse cracking, alligator cracking, edge cracking, and patching. (Note that raveling and weathering were rated as a single distress type; likewise, rutting and shoving were also rated as one distress type.) The distress evaluation chart for flexible pavements provided criteria for distress identification and assessment of the severity and extent on the pavement surface in a sample unit. The rut depth was visually/manually assessed by the raters using a 1.2-m (4-ft) long straightedge or rut bar (e.g., 4-ft oak bar or aluminum level) on both wheel paths at 6 to 9 locations along the sample unit.

Severity represents the degree of pavement deterioration. According to the NMDOT's Distress Evaluation protocol for flexible pavements (NMDOT, 2004), the extent of a particular distress was rated by estimating the area of the sample unit on which the distress was present and was qualitatively described by the severity levels of low, medium and high (Bianchini and Bandini, 2010). The extent was rated as low when the distress appeared in 30% or less of the sample unit area, medium if the distress was on 31 to 60% of the sample unit area, or high if the distress was on an area that extended more than 60% of the sample unit. Values of 1, 2 or 3 were assigned to severity and extent that were rated as low, medium or high, respectively.

According to the NMDOT's protocol used until summer of 2011 (NMDOT, 2004), the extent was rated only for the highest severity rating in a pavement sample unit. For a given distress type, severity and extent ratings of zero indicated that the distress was not present on the surface of the sample unit. The NMDOT's protocol assigned a minimum rating of severity equal to 1 and extent equal to 3 for the distress of weathering and raveling (NMDOT, 2004). At the time of the completion of this report, the NMDOT plans to implement revisions to its distress rating protocol and guidelines, starting in 2012, based on the recommendations of an ongoing research project.

The NMDOT's Pavement Evaluation Section collects automated data of pavement roughness and rut depth in interstates and other highway routes in New Mexico. In 2000, the NMDOT started measuring roughness and rutting data with a K. J. Law Dynatest T6600 High Speed Profilometer mounted on a van. A second T6600 Profilometer and van were acquired in 2003 for the data collection activities. This equipment uses three infrared displacement sensors and two precision accelerometers. The sensors are spaced 68 in. (172.7 cm). The rut depth data are stored in "raw data" files at user-defined intervals, such as 0.5, 1, 2 or 3 ft. Using the raw data, the rut depth is currently averaged and reported every 0.1 mile (161 m).

2.2.2 Pavement Condition Indicators

The NMDOT uses the Pavement Serviceability Index (PSI) as a measure of the pavement condition. This index ranges from 0 (very poor condition) to 5 (very good condition). For flexible pavements, the NMDOT's PSI is currently calculated from pavement roughness data and distress ratings (including rutting), through one of the following empirical expressions:

$$\text{PSI} = 0.041666\ \text{X}, \quad \text{if X} \leq 60 \tag{1}$$

or

$$\text{PSI} = [0.0625(\text{X} - 60)] + 2.4999, \quad \text{if X} > 60 \tag{2}$$

where X is given by

$$\text{X} = 100 - \left[\frac{0.6(\text{IRI} - 25) + (0.4\text{DR})}{2.9}\right] \tag{3}$$

where IRI is International Roughness Index, and DR is the Distress Rate defined as

$$\text{DR} = \sum_{i=1}^{n}\left[(\text{Severity Rating}_i)(\text{Extent Factor}_i)(\text{Weight Factor}_i)\right] = \sum_{i=1}^{\text{n}}(\text{DR}_i) \tag{4}$$

in which i denotes one of the eight types of distresses of flexible or rigid pavements (n = 8), and DR_i is the component of the distress rate (DR) value corresponding to the distress type i for a given pavement section. The extent factors and weight factors for the eight distress types in flexible pavements rated by NMDOT until 2011 are enclosed in Appendix B.

The NMDOT ranks the condition of the highway pavement network in New Mexico based on the calculated PSI values. The higher the PSI value, the better the pavement condition. The NMDOT considers that interstate highways with PSI lower than 3.0 are in deficient condition and those with PSI of 3.0 or greater are in non-deficient condition. For non-interstate highways, the limiting PSI value between deficient and non-deficient conditions is 2.5. At the time of the completion of this report, the NMDOT had plans to implement revisions to the PSI formulation and factors starting in 2012, based on the recommendations of an ongoing research project.

For a given year, the NMDOT calculates PSI values according to Equations 1 through 4 using distress ratings from the year's manual distress surveys and IRI data collected during the previous year (or previous pavement condition data collection cycle). Roughness data were not collected in 2006, 2010 and 2011; thus, the PSI values for 2007 were calculated using the IRI data collected in 2005. For these reasons, the performance assessment and discussions in this report were based on the distress rate (DR) and not on PSI values.

2.2.3 Collection of New Pavement Distress Data

The pavement condition data available from the NMDOT's Annual Pavement Evaluation Program were used to assess the performance of two NMDOT projects on US 54 and US 62/NM 180 that used thin ROGFC overlays. The NMDOT has not collected pavement condition data since 2009. Therefore, as part of the current project, new distress evaluation data were collected in 2011 for the ROGFC sample units located in these two highways. The evaluation included ratings of rutting and shoving.

Additionally, distress evaluation data were also collected in 2011 for selected sample units with thin OGFC overlays located on US 54 and US 62/NM 180. These sample units were selected for this performance comparison because they were likely exposed to traffic loads, service life and climatic conditions similar to those experienced by the ROGFC sample units of interest. Nevertheless, it should be stressed that the sample units and projects considered in this report were not originally designed to serve as test or experimental sections and their performance and maintenance throughout the years have not been documented systematically or in detail.

Experienced university technicians were selected to carry out the distress evaluation in 2011, under the supervision and training of the author. These new data complemented the existing NMDOT data. The raters received comprehensive refresher training that included classroom and field training sessions. The NMDOT protocol and rating criteria were applied to produce the 2011 data. At each sample unit, the raters recorded the milepost or location, visually/manually classified, rated and recorded the severity and extent of each of the eight types of pavement distresses, and documented any other relevant remarks.

According to the NMDOT's Pavement Distress Evaluation Protocol, the sample units are 0.1-mile long sections and are assumed representative of the whole mile. The later assumption is very important because of the limited number of sample units with ROGFC available for this study. In the positive direction, the sample units start at the corresponding milepost markers; in the negative direction, the sample units end at the milepost markers and mirror the corresponding sample units in the positive direction. Therefore, intermediate sample units (i.e., located halfway between NMDOT's sample units) were also evaluated in 2011 to confirm that the pavement distress ratings in the NMDOT sample units were consistent with pavement conditions at other locations throughout the mile of pavement represented by that sample unit.

2.2.4 Pavement Sample Units Evaluated and Compared

Tables 2 and 3 show the ROGFC and conventional pavement sample units on US 62/NM 180 and US 54, respectively, that were compared in this study and the years since their full reconstruction or rehabilitation. The distress evaluations in Year 0 were likely done shortly after construction, when the pavements were just weeks or few months old. The NMDOT distress data are from 2002 through 2009. The 2011 distress data were produced as part of this study. Complete records of maintenance work done on these pavements since construction were not available to this study and, therefore, were not considered in this performance assessment.

2.2.5 Discussion of Performance of ROGFC on US 62/NM 180

Six ROGFC overlay sample units located on highway US 62/NM 180 were considered. In 2007, this pavement was either fully reconstructed or rehabilitated (i.e., cold milling, HMA concrete placement and thin ROGFC overlay). The ratings of distress severity (Sev) and extent (Ext) for years 0, 1, 2 and 4 after construction are shown in Tables 4 through 6.

In two of these ROGFC sample units, very minor distress has started to develop in the fourth year of service life. In MP 107 P, low-severity bleeding with extension rating of 1 (i.e., 30% or less of the sample unit is affected by bleeding of severity 1) was reported in Year 4 (Table 4). In MP 108 P, low-severity longitudinal cracking with extension rating of 2 (i.e., 31% to 60% of the sample unit is affected by longitudinal cracking of severity 1) was also reported in Year 4 (Table 5). No distresses were present in the other four NMDOT sample units at Year 4 (MP 107 M, 108 M, 109 P and 109 M). Note that the current NMDOT's distress evaluation protocol assigns a minimum severity of 1 and extent of 3 to the distress of raveling and weathering.

In addition to the six NMDOT sample units, six sample units located halfway between the milepost markers, at mile points 107.5, 108.5 and 109.5 in the positive and minus directions, were evaluated on US 62/NM 180 in 2011. They were called "intermediate" sample units in this report. The purpose of obtaining these additional data was to determine whether the pavement distress ratings in the NMDOT sample units, which are 0.1-mile long, were representative of the pavement conditions at other locations throughout the whole mile of highway pavement.

Tables 7 and 8 show the 2011 data for NMDOT sample units and intermediate sample units with ROGFC overlay on US 62/NM 180. Four years after construction, the intermediate sample units did not have signs of surface distress except for medium-severity transverse cracking with extent rating of 1 in MP 108.5 P. No bleeding or longitudinal cracking was reported in the intermediate sample units.

Table 2. Years since full reconstruction or rehabilitation of sample units on US 62 / NM 180

	Years since Construction		
	Conventional Pavement Sample Units (no OGFC, no CRM used)		ROGFC Sample Units
Evaluation Year	MPs 90-93, 95-102 (P and M), 104 P	MPs 105, 106 (P and M)	MPs 107, 108, 109 (P and M)
2002	0	–	–
2003	1	–	–
2004	2	–	–
2005	3	–	–
2006	4	–	–
2007	5	–	0
2008	6	0	1
2009	7	1	2
2011	9	3	4

Note. P and M: Positive and Minus directions respectively. MPs: mileposts

Table 3. Years since full reconstruction or rehabilitation of the sample units on US 54

	Years since Construction	
	OGFC Sample Units (no CRM used)	ROGFC Sample Units
Evaluation Year	MPs 56-62 (P and M)	MPs 0-55 (P and M)
2002	0	0
2003	1	1
2004	2	2
2005	3	3
2006	4	4
2007	5	5
2008	6	6
2009	7	7
2011	9	9

Note. P and M: Positive and Minus directions respectively. MPs: mileposts

Table 4. Severity and extent ratings for MP 107 P and MP 107 M on US 62/NM 180

	MP 107 P								MP 107 M							
Years since Construction	0		1		2		4		0		1		2		4	
Evaluation Year	2007		2008		2009		2011		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.6		3.0		3.0		3.0		3.0	

Table 5. Severity and extent ratings for MP 108 P and MP 108 M on US 62/NM 180

	MP 108 P								MP 108 M							
Years since Construction	0		1		2		4		0		1		2		4	
Evaluation Year	2007		2008		2009		2011		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	**1**	**2**	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		21.0		3.0		3.0		3.0		3.0	

Table 6. Severity and extent ratings for MP 109 P and MP 109 M on US 62/NM 180

	MP 109 P								MP 109 M							
Years since Construction	0		1		2		4		0		1		2		4	
Evaluation Year	2007		2008		2009		2011		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		3.0		3.0		3.0		3.0	

The distress rate (DR), as defined in Equation (4), was used as an indicator of the pavement condition in terms of surface distresses. The higher the DR value is, the worse the pavement condition. The minimum value of DR is 3.0. The calculated DR values are shown in Tables 4 through 8. Four years after construction, the DR values for the ROGFC sample units ranged from 3.0 to 21.0, which are relatively low values. The surface conditions at Year 4 in the NMDOT sample units were consistent with the conditions in the intermediate sample units.

Four years is a relatively short time when evaluating or assessing performance of pavements. However, the available distress data through 2011 are indicative of good performance in the early life of this pavement structure, with no rutting and either very minor distress or no premature cracking in this pavement up to date.

Table 7. Distress ratings in 2011 for ROGFC sample units on US 62/NM 180 (Positive direction)

	Pavement Units											
Mileposts	107 P		107.5 P		108 P		108.5 P		109 P		109.5 P	
Distress ratings	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	**1**	**1**	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	**1**	**2**	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	**2**	**1**	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.6		3.0		21.0		19.8		3.0		3.0	

Table 8. Distress ratings in 2011 for ROGFC sample units on US 62/NM 180 (Minus direction)

	Pavement Units											
Mileposts	107 M		107.5 M		108 M		108.5 M		109 M		109.5 M	
Distress ratings	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		3.0		3.0	

2.2.6 Comparison of Performance of US 62/NM 180 Sample Units

To assess the performance of the pavement with ROGFC overlay on US 62/NM 180 in terms of surface distresses, adjacent pavements that did not have CRM modified binder were considered. The first one was NMDOT's Project AC-GRIP-NH-062-2(6)102 (CN G3532), constructed between 2007 and 2008 by Armstrong Construction Co. The project was a 2.53-mile long urban reconstruction through Hobbs, Lea County, NM from MP 104.08 to MP 106.61. The project included conventional flexible pavement with rigid pavement at intersections. The flexible pavement consisted of 6 in. (152.4 mm) of PMBP Type SP-III asphalt concrete, placed in 3-in. (76.2-mm) lifts, on new or existing untreated base course (UTBC). This project did not include an OGFC overlay.

Four NMDOT sample units are located in this project at MPs 105 and 106 (P and M directions). Tables 9 and 10 provide the distress ratings for these sample units. Approximately three years after construction (early summer of 2011), the flexible pavement did not show signs of premature cracking or bleeding. Low-severity rutting and shoving with extent 1 was reported at the third year of service in MP 105 P (Table 9). However, based on the information available, this was a localized occurrence of minor rutting and should not be considered as a sign of material or structure failure. A follow-up monitoring of the rutting in this sample unit is advisable. Overall, the early performance of the ROGFC sample units (MPs 107, 108 and 109) and the conventional sample units (MPs 105 and 106) is good and comparable.

Table 9. Severity and extent ratings for MP 105 P and MP 105 M on US 62/NM 180

	MP 105 P						MP 105 M					
Years since Construction	0		1		3		0		1		3	
Evaluation Year	2008		2009		2011		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	**1**	**1**	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		10.0		3.0		3.0		3.0	

The development of surface distresses over time in other NMDOT sample units with conventional (i.e., without ROGFC overlay) pavement sections along US 62/NM 180 was also considered. The distress data and DR values for sample units at MPs 90, 91, 92, 93, 95, 96, 97, 98, 99, 100, 101 and 102 in the positive and minus directions and MP 104 in the positive direction are provided in Appendix C. These sample units are located east of Hobbs,

Table 10. Severity and extent ratings for MP 106 P and MP 106 M on US 62/NM 180

	MP 106 P						MP 106 M					
Years since Construction	0		1		3		0		1		3	
Evaluation Year	2008		2009		2011		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		3.0		3.0	

NM. From the evaluation of NMDOT's distress data records, it was deduced that these pavements were constructed approximately in 2002. Based on this date, at the time of this report these pavement sections have been in service for approximately nine years.

Figure 4 shows the distress rate values for all US 62/NM 180 sample units considered (ROGFC and conventional units). Despite the large scattering of the data (coefficient of determination R^2 = 0.66 for conventional sample units), DR values show a tendency to increase with time as expected. Even though the distress data for the ROGFC pavement span four years only, it can be seen that the ROGFC pavement is performing well and better than most of the sample units of the conventional pavement constructed in 2002 (MPs 90-93, 95-102, and 104). Figures 5 and 6 show the variation of DR for each sample unit considered. It was observed that distress ratings of these sample units in Year 5 were, on average, more conservative (higher distress rate) than in subsequent years. This situation may have occurred due to the inherent variability of the ratings in visual/manual distress surveys and a possible overestimation of the severity and/or extent of one or more distresses by a rater in Year 5.

The standard sample deviation (S_{pi}), the sample mean value ($\overline{DR}$), the pooled sample variance (S_p^2) and the group comparison *t*-test of the DR data sets were calculated for Years 2 and 4 since construction. The pooled sample variance is the average of the two sample variances (for ROGFC and conventional sample units) weighted by the degrees of freedom. The *t*-test is a statistical hypothesis test to assess whether the means of two groups are statistically different from each other.

The data set of conventional sample units was characterized by $\overline{DR}$ = 7.7 and 21.6, and S_{pi} = 6.8 and 10.3 in Years 2 and 4 since construction, respectively. The data set of ROGFC sample units was characterized by $\overline{DR}$ = 3.0 and 6.1, and S_{pi} = 0.0 and 7.3 in Years 2 and 4 since construction, respectively.

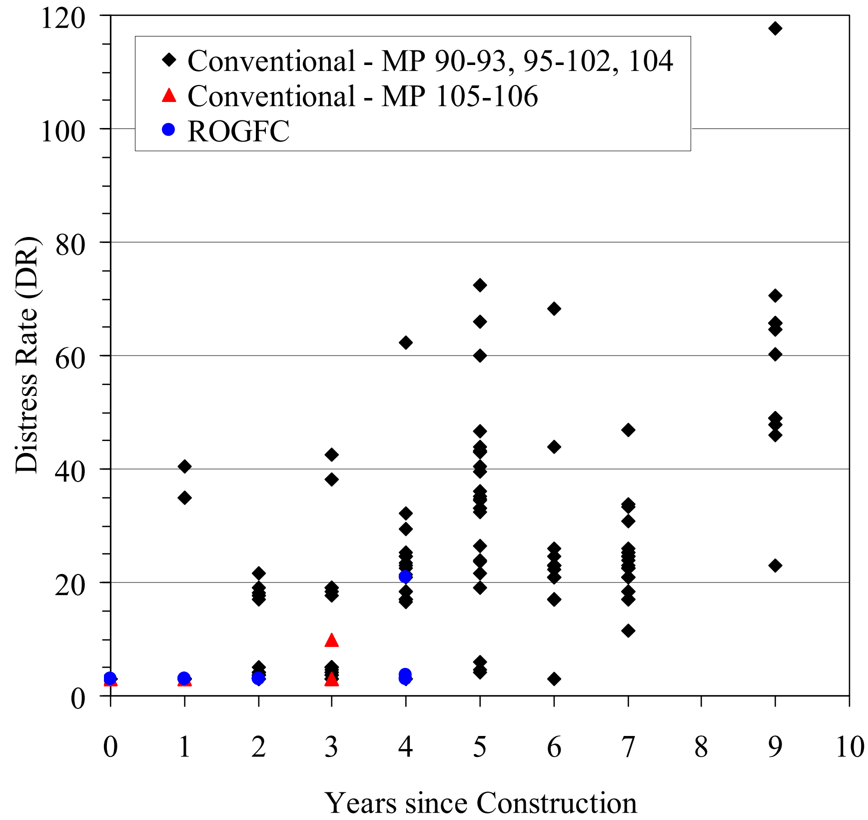


Figure 4. Distress rate for the sample units on US 62/NM 180

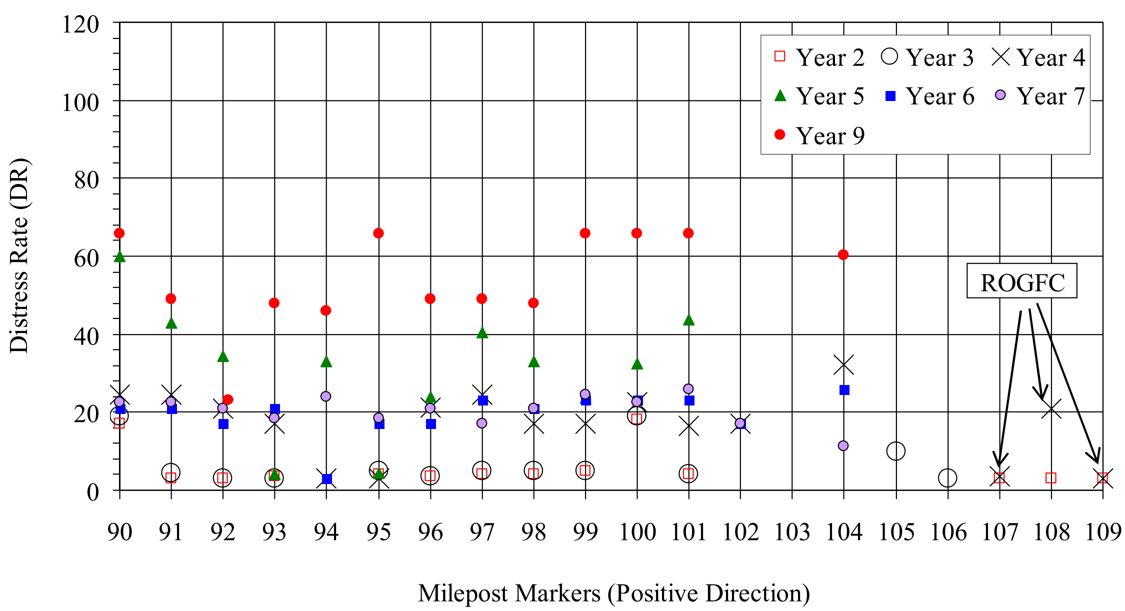


Figure 5. Distress rate values for sample units on US 62/NM 180 (Positive direction)

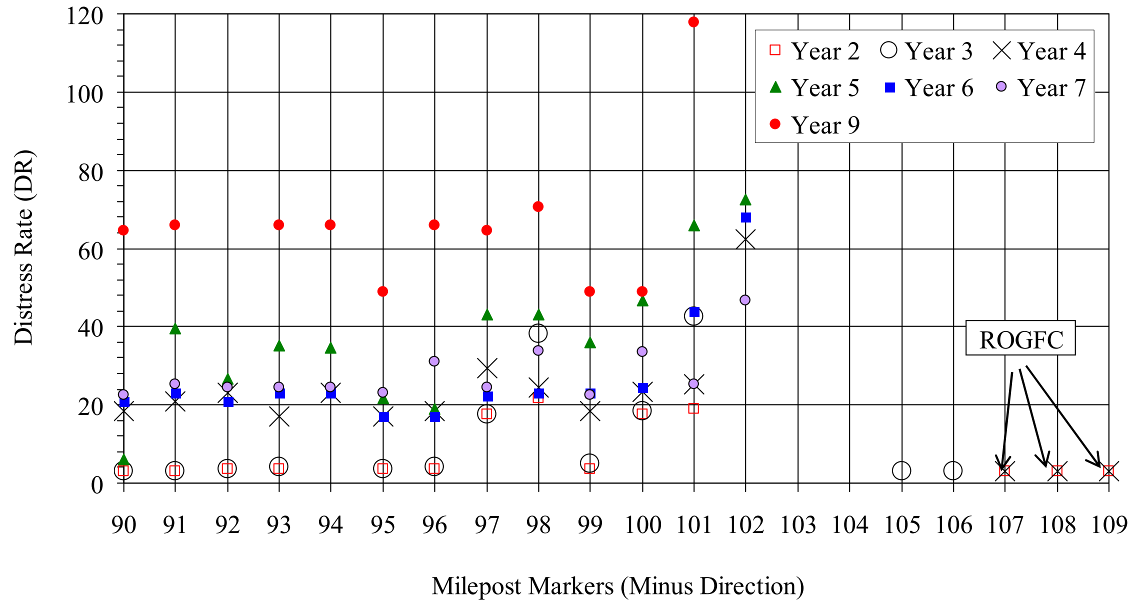


Figure 6. Distress rate values for sample units on US 62/NM 180 (Minus direction)

The statistical indicators for DR for Years 2 and 4 since construction were S_p^2 = 37.5 and 97.4, and t = 1.68 and 3.47, respectively. The *t*-test statistic confirmed that the ROGFC sample units on US 62/NM 180 had mean values of DR that are significantly different (smaller) than the conventional sample units at two and four years of service. In addition, the mean and standard deviation values of DR for ROGFC units are clearly smaller. These are indicators of better performance of the ROGFC units compared to the selected conventional pavements in the fourth year of service. However, it should be kept in mind that these pavements were not part of an experimental program and that there are several factors affecting the performance of these pavements that could not be considered in this comparison.

2.2.7 Discussion of Performance of ROGFC on US 54

The ratings of distress severity and extent for 110 ROGFC sample units located on US 54 were considered. In 2002, this pavement was either fully reconstructed or rehabilitated (cold milling and HMA concrete layer with an ROGFC overlay). Ratings of eight surface distresses including rutting are available for the ROGFC pavements from MP 0 to MP 55 (P and M directions) for 9 years of service.

Most of the sample units in this 9-year old pavement show longitudinal, transverse and edge cracking of low and/or medium severity. In 2011, low and/or medium severity alligator cracking and bleeding were reported only in four (3.6%) and eight (7.2%) sample units, respectively. About 24% of the ROGFC sample units had some level of rutting and shoving after 9 years. Figures 7, 8 and 9 show rutting (estimated using a 4-ft rut bar) and edge or longitudinal cracking in three ROGFC sample units in Year 9 (2011).

Figures 10 through 13 show the distress rate values for ROGFC sample units. After close evaluation of the distress data, Year 4 has been omitted from this evaluation because the ratings of bleeding for that year were abnormally high and likely overrated. From the experience of the author in pavement distress evaluation and rater training, the distress of bleeding is one of the most difficult distresses to identify and rate based on the current NMDOT's distress rating protocol.

The pavement in a number of ROGFC sample units shows good long-term performance in terms of DR. For example, about 21% of the sample units in the positive direction (Figures 10 and 11) have DR values less than 30 in Year 9. It is also remarkable that sample units MP 19, 20, 23 and 36 in the minus direction have developed no surface distresses or rutting in 9 years or service (Figures 12 and 13). On the other hand, the pavement in other sample units has shown considerable signs of surface deterioration in the long term; for example, sample units MP 11 through MP 16 (positive and minus directions) have DR values greater than 50 in Year 9.

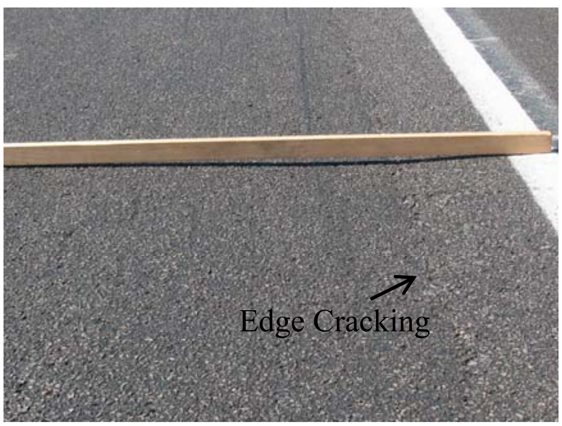
It should be stressed that the distress ratings considered here were obtained by means of visual/manual surveys for the purpose of a network level assessment and, therefore, certain level of variability in the data is expected and accepted due to the inherent subjectivity in the determination of the severity and extent ratings. The variation over time of the distress rate of a given sample unit may have been affected by maintenance work, which was not considered here.

2.2.8 Comparison of Performance of US 54 Sample Units

To assess the performance of pavements with ROGFC overlay on US 54 in terms of surface distresses, a number of adjacent pavements constructed between 2002 and 2008 that did not use CRM binder were considered. These NMDOT sample units were labeled as MP 56 to MP 119. In particular, NMDOT's project AC-TC-(MIP)-054-1(26)56 (CN 3230) was constructed in 2002 from MP 56 to MP 64. It consisted of full reconstruction sections and rehabilitation of existing roadway sections (microsurfacing). The project included full reconstruction of the pavement structure with a 0.6-in. (15-mm) thick OGFC overlay, 7.8-in. (200-mm) PMBP Type SP-III asphalt concrete layer, compacted in three lifts, and 6.9-in. (150-mm) base course (Type I-B).

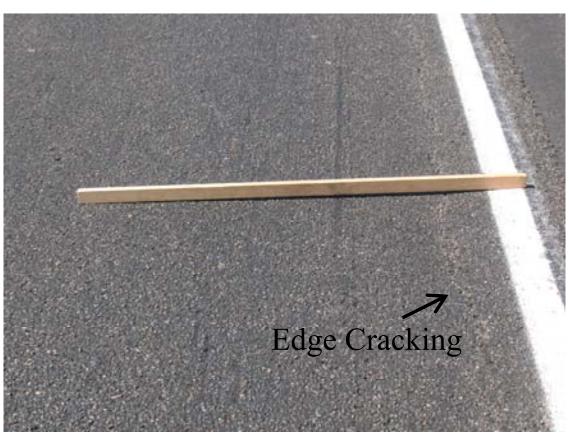
(a) (b)

Figure 7. Pavement surface in MP 3 (Minus direction) on US 54: a) medium severity rutting and low severity longitudinal cracking, and b) detail of a longitudinal crack (2011)



(a) (b)

Figure 8. Pavement surface in MP 4 (Minus direction) on US 54: a) medium severity rutting and low severity edge cracking, and b) view of the ROGFC sample unit



(a) (b)

Figure 9. Pavement surface in MP 5 (Minus direction) on US 54: a) low severity rutting and edge cracking, and b) view of the ROGFC sample unit (2011)

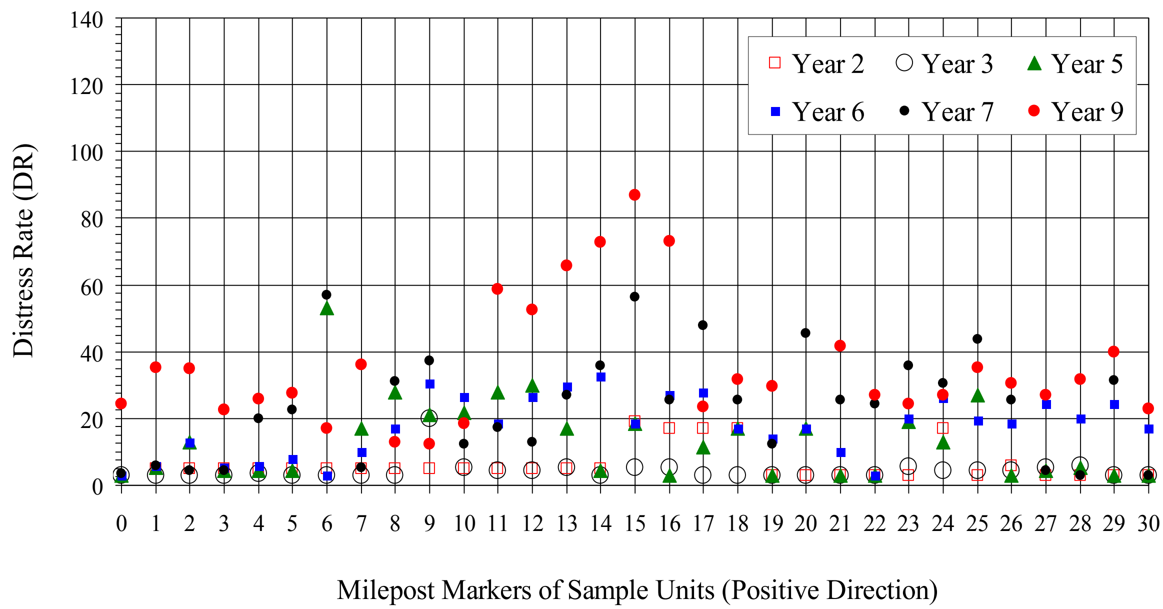


Figure 10. Distress rate for ROGFC sample units on US 54 from MP 0 to MP 30 (Positive direction)

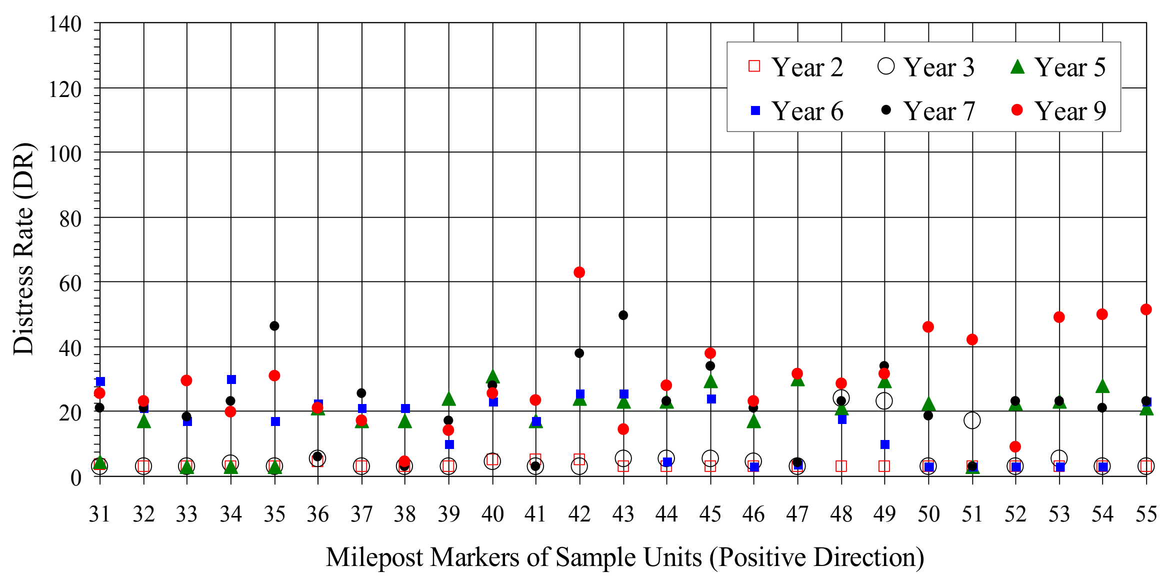


Figure 11. Distress rate for ROGFC sample units on US 54 from MP 31 to MP 55 (Positive direction)

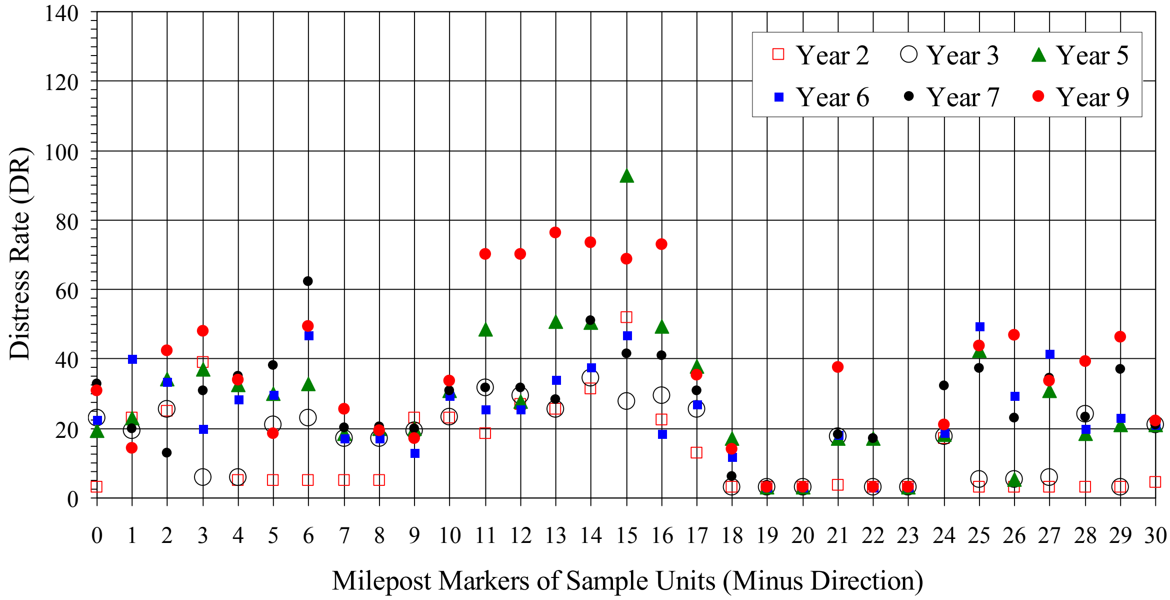


Figure 12. Distress rate for ROGFC sample units on US 54 from MP 0 to MP 30 (Minus direction)

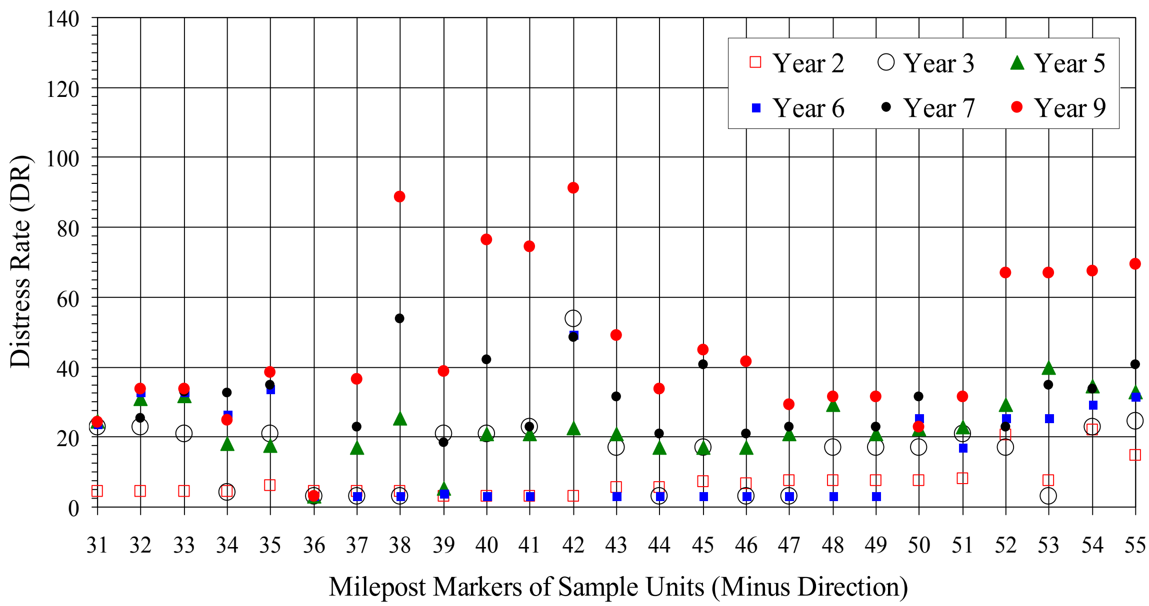


Figure 13. Distress rate for ROGFC sample units on US 54 from MP 31 to MP 55 (Minus direction)

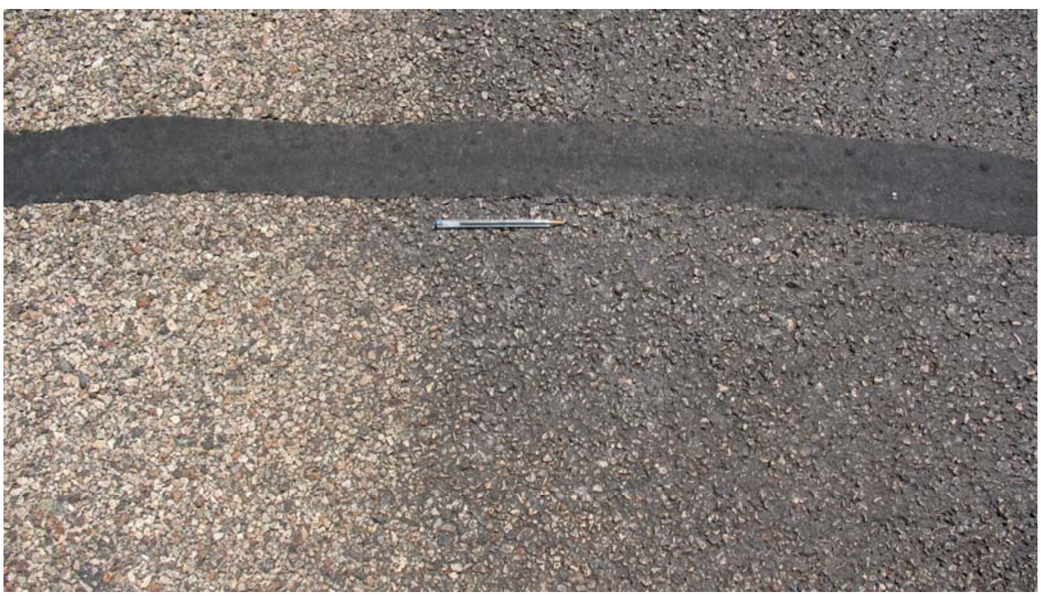
Figure 14 shows the end of the ROGFC pavement and beginning of the OGFC pavement at MP 55 sample unit. Close inspection of this ROGFC pavement surface shows considerably more binder on top of and among the aggregates compared to the OGFC pavement surface (Figure 14b). In Year 9 (2011), the OGFC sample units from MP 56 to MP 62 are affected mainly by medium severity longitudinal and edge cracking. As mentioned earlier, most of the ROGFC sample units have developed longitudinal, transverse and edge cracking of low and/or medium severity after 9 years of service.

The distress rate values for all the US 54 sample units considered are shown in Figure 15. In the first 7 years of service, the DR values of ROGFC sample units (Figure 15a) have less scattering and smaller standard deviation than conventional (non-ROGFC) sample units (Figure 15b). Note that 2006 distress data for these sample units were not considered because of a consistent overrating of bleeding. The statistics for the data sets and *t*-test are given in Table 11. For all years considered, the mean values of the distress rate ($\overline{\mathrm{DR}}$) of the ROGFC sample units are smaller than those of non-ROGFC units. This was also the case for the sample standard deviation values except in Year 9, likely because of the small size of the data set of conventional sample units for that year (n = 14 sample units).

From the *t*-test for Years 2, 3, 5 and 6, it was confirmed that $\overline{\mathrm{DR}}$ of ROGFC units is statistically different (and smaller) than $\overline{\mathrm{DR}}$ of non-ROGFC units. The *t*-test for Years 7 and 9 could not be used to support this conclusion ($t < t$ at $\alpha = 0.05$) probably due to the small size of the available data set of conventional pavements (n = 19 sample units in Year 7 and n = 14 sample units in Year 9) (Table 11). Additional data of conventional pavements are necessary for the statistical analysis of the long-term performance.

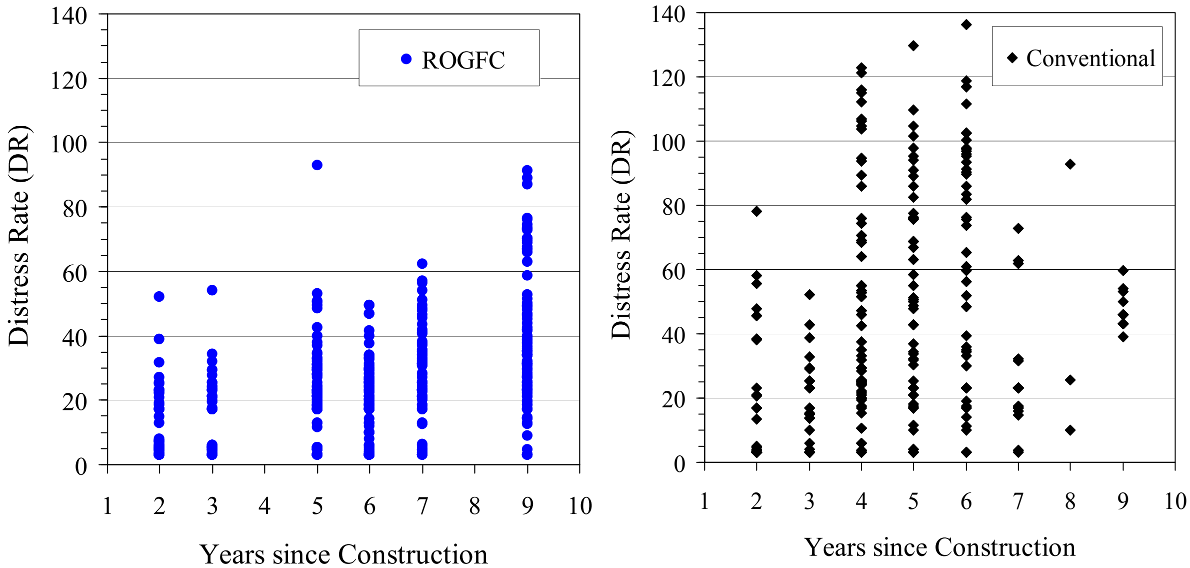
The distress rate values for the non-ROGFC sample units on US 54 are shown in Figures 16 through 18. There is indication that the set of ROGFC sample units on US 54 built in 2002 has performed better than conventional sample units in terms of the distress rate in the short and long terms. In particular, the majority of the sample units from MP 87 to MP 119 (Positive direction) have shown significantly higher DR in the long term compared to the rest of the data set. None of these pavements was part of an experimental program and there are several factors affecting the performance of these pavements that could not be accounted for in this comparison.

(a)



(b)

Figure 14. End of ROGFC pavement (lighter) and beginning of OGFC pavement (darker) on US 54 at MP 55 sample unit (Positive direction): a) view of the pavement, and b) sealed longitudinal crack (OGFC: left-hand side; ROGFC: right-hand side)



(a) (b)

Figure 15. Distress rate values for sample units on US 54: a) ROGFC and b) conventional (non-ROGFC) pavements

Table 11. Test statistic for US 54 sample units

Sample Unit Type	Years since Construction	$\overline{DR}$	S_{pi}	n	S_p^2	t	t at $\alpha = 0.05$
Non-ROGFC	2	12.0	17.4	57	149.3	2.15	1.65
ROGFC		7.7	8.4	111			
Non-ROGFC	3	18.4	13.9	38	123.9	3.65	
ROGFC		10.8	10.0	112			
Non-ROGFC	5	46.7	33.4	57	500.7	7.15	
ROGFC		20.7	13.9	112			
Non-ROGFC	6	61.1	38.3	51	555.9	10.69	
ROGFC		18.5	12.1	112			
Non-ROGFC	7	26.9	18.9	19	209.8	0.34	
ROGFC		25.7	13.6	112			
Non-ROGFC	9	46.8	5.6	14	432.2	1.53	
ROGFC		37.8	21.9	112			

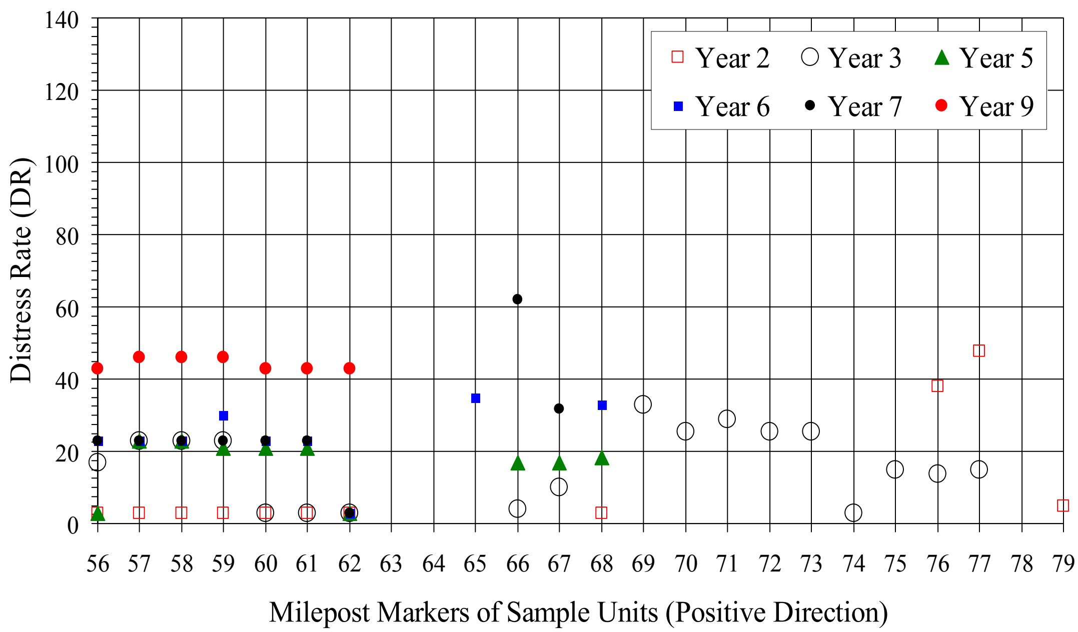


Figure 16. Distress rate for conventional (non-ROGFC) sample units on US 54 from MP 56 to MP 79 (Positive direction)

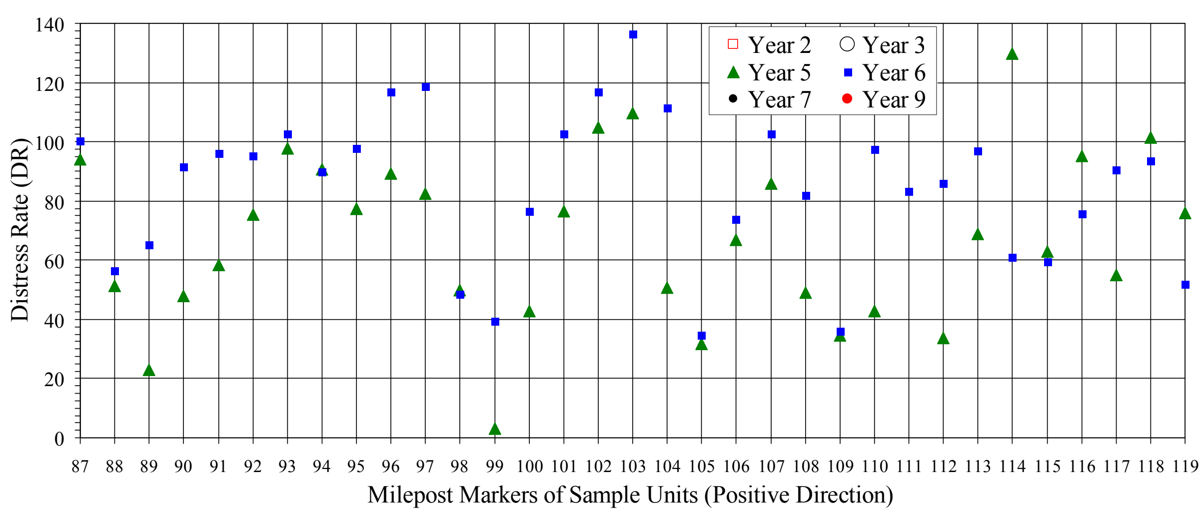


Figure 17. Distress rate for conventional (non-ROGFC) sample units on US 54 from MP 87 to MP 119 (Positive direction)

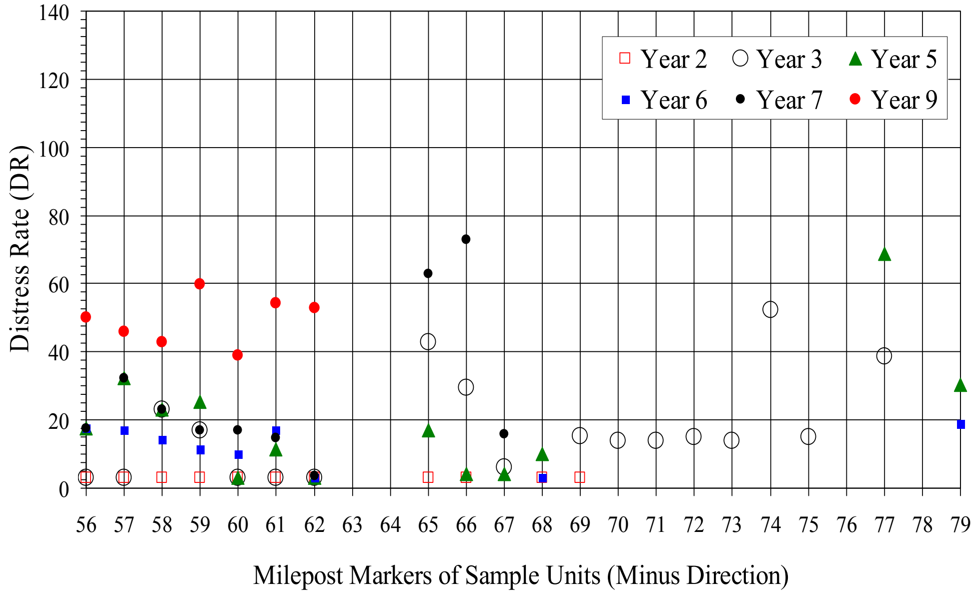


Figure 18. Distress rate for conventional (non-ROGFC) sample units on US 54 from MP 56 to MP 79 (Minus direction)

2.3 New ROGFC Projects in New Mexico

Two new NMDOT projects that include ROGFC overlays are scheduled to be constructed in District 1 in summer of 2011. The projects are required to comply with the NMDOT's *Special Provisions for Rubberized Open Graded Friction Course*, Section 404-A (See Appendix D and Section 2.4 of this report). One project entails the reconstruction of on-ramps of the interstate I-25 & University Avenue Interchange (I-25 northbound) in Las Cruces, Dona Ana County, NM. The Project Number is HSIP-(IM)-025-1(88)02 and the Control Number is CN D1038. The paving contractor is Smith & Aguirre Construction Co., Inc. based in Las Cruces, NM. The approximate length of the new pavement is 0.954 mile (1.535 km) and it will be constructed from May 30 through September 10, 2011 (Figure 19).

Approximately 598 tons (542.5 metric tons) of rubberized asphalt concrete and 35 tons (31.8 metric tons) of PG 70-28R$^+$ binder (CRM modified binder) will be used in the ROGFC overlay. Terminal blend for the production of the CRM binder was specified. The asphalt concrete for the ROGFC overlay will contain 5.8% binder and 1% lime as anti-stripping agent. The new pavement consists of a 0.625-in. (15.9-mm) ROGFC overlay on top of a 9-in. (228.6-mm) HMA Type SP-III layer, placed in three 3-in. (76.2-mm) lifts. The upper 3 inches of the existing pavement will be cold mill, followed by placing of 3-in HMA Type SP III layer and 0.625-in. ROGFC overlay.

For this project, the estimated cost of ROGFC was $82.00/ton compared to $81.00/ton for OGFC. With the inclusion of an ROGFC overlay in these pavements, the NMDOT expects to decelerate the negative effects of high temperatures in these pavements and contribute to a smoother and quieter ride for the traveling public (Ryan Tafoya, NMDOT Assistant Project Manager, personal communication, June 2011).

(a)

(b)

Figure 19. Construction of ramps in interstate I-25 and University Ave. Interchange with ROGC: a) first loop on-ramp of northbound, and b) second on-ramp of northbound

The second project in District 1 is No. 1100181 and includes 15.177 miles (24,425 km) of pavement rehabilitation on Interstate I-10 from MP 92.823 to MP 108.0 (eastbound and westbound lanes), located east of Deming, Luna County, NM. The project consists of 3.125-in. cold-mill, HMA Type SP III inlay and 5/8-in. (15.9-mm) ROGFC overlay. The inner 2 ft of the shoulders will receive a rubberized fog seal treatment. Approximately 14,251 tons (12,928 metric tons) of material will be used in the ROGFC overlay. The asphalt concrete mixture for the ROGFC overlay will contain approximately 1% hydrated lime as anti-stripping agent and 7.1% of the PG70-28^{+} (rubber-modified) binder.

Two new projects will be constructed in summer of 2011 on US 54, between Tularosa and Carrizozo, Lincoln County, NM. The projects include reconstruction or rehabilitation of the existing pavement with a thin ROGFC overlay (northbound and southbound lanes). According to the plans, Project AC-GRIP-BR-(NH)-054-2(38)107 (CN G3a12) includes pavement reconstruction along 5.691 miles (9.159 km) from MP 107.0 to MP 112.7; approximately 2,642 tons (2,396 metric tons) of HMA concrete will be used in the ROGFC overlay of this project. The contractor for this project is FNF Construction, Inc. Project G3AD200 (CN G3aD2) includes pavement reconstruction along 6.345 miles (10.212 km) from MP 112.7 to MP 119; approximately 2,950 tons (2,676 metric tons) of HMA concrete will be used in the ROGFC overlay of this project.

2.4 NMDOT Special Provisions for ROGFC

In 2010, the NMDOT approved a revised version of the *Special Provisions for Rubberized Open Graded Friction Course*, Section 404-A (Appendix D). This document covers the materials, mix design and related testing, construction requirements, method of measurement of the material used and basis of payment to the contractor. These provisions specify terminal-blend modified binder with a minimum of 10% CRM (by weight) from recycled scrap tires and a minimum of 2% styrene-butadiene-styrene (SBS) polymer (by weight). The *House Memorial 6 Final Report* (2010) has enclosed draft versions of NMDOT's *Special Provisions for Rubberized Asphalt Chip Seal* (Section 410-A) and *Special Provisions for Rubberized Asphalt Fog Seal* (Section 410-B). However, the special provision for rubberized asphalt chip seal was not approved likely because most of the chip seal is done internally by District personnel. The special provision for rubberized asphalt fog seal is in the process of approval by NMDOT.

2.5 Other Rubberized Asphalt and Asphalt Rubber Projects in New Mexico

An example of a local government project that used rubberized asphalt pavement is located in the Otero-Greentree Regional Landfill, owned by Otero County and Lincoln County and managed by the City of Alamogordo, NM. This landfill is located on highway US 54, 24 miles south of Alamogordo, NM. An ROGFC inlay in the new pavement of the access road was chosen because of the anticipated heavy truck traffic of the landfill.

In spring of 2008, tire rubber modified surface seal (TRMSS) was applied by NMDOT District 2 personnel on the south bound of NM 18, near the town of Eunice, NM. The TRMSS is a clay stabilized asphalt emulsion, with asphalt cement modified with terminal-blend ground rubber from recycled scrap tires. The specification sheet of this material (SealMaster®, 2011) indicates that TRMSS contains 10% to 16% of CRM and is formulated for application at ambient temperatures. In June 2008, TRMSS was applied on the southbound lanes on Interstate I-25, just south of the bridge at Budagher's Interchange with FR-2087, between Albuquerque and Santa Fe, NM. In July 2009, A.S. Horner, Inc., based in Albuquerque, NM, applied TRMSS in some pavement sections of the I-25/I-40 Interchange, frequently referred to as the Big I. This material was also applied on the parking lot of the NMDOT building in Santa Fe by the local contractor GM Emulsion LLC in October of 2009. Performance information on these projects could not be confirmed during the preparation of this report.

In 2010, the Navajo Nation contracted International Surfacing Systems, Inc., based in Arizona, to apply asphalt-rubber chip seal in Arizona and the northwest area of New Mexico.

In summer of 2010, the Navajo Engineering and Construction Authority (NECA), for the Bureau of Indian Affairs (BIA), also contracted International Surfacing Systems, Inc. to apply asphalt–rubber chip seal on US 491, in the vicinities of the town of Shiprock, located west of Farmington and north of Gallup, NM (Dick Armstrong, International Surfacing Systems, Inc., Personal communication, 2010). Based on the request for bids, the later project consisted of construction of 11.543 miles (18.576 km) of continuous cold recycled asphalt and placement of asphalt-rubber chip seal (Contract Number CTNBUXDOI66). The asphalt-rubber binder contained a minimum of 18% CRM from scrap tires and was applied at 0.55 to 0.7 gallons per yd^2 with about 30 lb of chips (aggregate) (Dick Armstrong, International Surfacing Systems, Inc., Personal communication, 2010).

3. Feasibility of Asphalt Rubber Market in New Mexico

3.1. Tire Statistics

In the United States, it is estimated that approximately one truck or passenger vehicle tire is discarded per person each year (RMA, 2009). Based on this estimate, New Mexico generates annually approximately 2 million scrap tires. In 2007, 89% of the nearly 4.6 million tons of scrap tires generated in the U.S. were reused in various markets. Unfortunately, scrap tires cannot be recycled into new tires because they are made of a thermosetting polymer material, which cannot be remolded. The largest market of tire reuse consists of burning whole or chipped tires for the production of heat or energy commonly used in pulp mills, cement kilns, and energy plants. The latest data indicate that 54.1% of the scrap tires reused in the U.S. in 2007 were burned for tire-derived fuel (TDF) and 12.2% were reused in civil engineering applications, mainly as tire shreds for road and landfill construction and septic tank leach fields (RMA, 2009).

Stockpiled tires can lead to two serious environmental and human health hazards: tire-pile fires and the creation of mosquito breeding grounds. A method of handling and storing scrap tires is baling. Bales are formed by compressing and fastening about 100 waste tires into modular blocks, resulting in a volume reduction of approximately 5:1. Tire baling facilities are mostly owned and operated in the U.S. by municipalities, counties, cities, landfills, recycling centers, and few private individuals. Statistics show that less than 1% of the scrap tires produced in the U.S. is baled each year, and most of the bales remain unused in the baling facilities (RMA, 2006).

The RMA (2009) reported that New Mexico generated 35,200 tons (31,933 metric tons) of scrap tires in 2007, of which 3,400 tons (3,084 metric tons) were land disposed, and that 1.3 million scrap tires were in stockpiles in New Mexico in 2007. Table 12 shows more recent scrap tire statistics for New Mexico. There are no fuel markets for waste tires in the state. The 2010 scrap tire statistics for New Mexico were not available at the time of completion of this report; however, preliminary data indicate that 2010 numbers for final use or destination of scrap tires will follow similar trends as in 2009 (Table 12). New Mexico stores and bales some of the waste tires generated for potential use in civil engineering and other beneficial applications in the future. In New Mexico, landfills are permitted to store small amounts of tires and/or tire bales temporarily as part of the facilities' operational plans (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011).

3.2. Recycling and Illegal Dumping Act

In 1994, New Mexico legislature passed the Tire Recycling Act. It was later repealed and replaced by the current *Recycling and Illegal Dumping Act* (New Mexico Code, Chapter 74 Environmental Improvement, Article 13) in 2005. The *Recycling and Illegal Dumping Act* created the ***Rubberized Asphalt Program*** (Section 74-13-18) and assigns the responsibility of developing and adopting rules for the administration of the program and specifications for the use of rubberized asphalt to the New Mexico Department of Transportation (NMDOT).

Table 12. 2009 Scrap tire statistics for New Mexico (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011)

Final Destination or Use	Number of Tires	% of Total
Landfilled	539,000	27.0
Land Reclamation - NM	275,000	13.8
Other NM beneficial use	99,000	5.0
State Rubber & Environmental Solutions (TX)	442,000	22.1
Out of state - other	454,000	22.7
Unknown [a]	191,000	9.5
Total [b]	2,000,000	100.0

[a] Difference between total and reported amounts

[b] Based on approximated New Mexico population and national average scrap tire generation (1 tire per person per year)

This act also created the ***Recycling and Illegal Dumping Fund*** (Section 74-13-19), according to which the fees and penalties collected pursuant Section 74-13-1 of this act shall be deposited into the fund. Additionally, the *Recycling and Illegal Dumping Act* created the ***Rubberized Asphalt Fund*** (Section 74-13-20); this fund is appropriated to the NMDOT and local governments to pay additional expenses that might result from using rubberized asphalt in pavement applications and to carry out the provisions of the Rubberized Asphalt Program, including hiring a term employee to administer the program. At least 50% of the fund shall be allocated to local governments. Unfortunately, this fund has not had any source of funding since its creation in the current act (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011) and, therefore, it has not been implemented.

In New Mexico, a fee is collected through the annual vehicle registration of passenger vehicles and trucks for the *Recycling and Illegal Dumping Fund*. In 2011, this fee is $1.50. Approximately two thirds of this fund is used for scrap tire grants for abatement of illegal tire dump sites and stockpiles, purchasing of tire-derived products and construction projects using waste tires. Agencies eligible for these grants include municipalities, counties, cooperative associations, pueblos, tribes, Indian Nations, land-grant associations and solid waste authorities. An annual application cycle for the *Recycling and Illegal Dumping Fund*, also called Scrap Tire Grants, has been implemented through the NMED Solid Waste Bureau and is currently available.

3.3. Asphalt Rubber Market

The development of a market for asphalt rubber and rubberized asphalt binders in pavement applications in New Mexico could potentially provide economic and environmental benefits for the state. To assess the feasibility of such a market, the following sections describe the main components of this industry, equipment, current material producers and suppliers in the area, sources of scrap tires and initial investment costs. Some of the anticipated difficulties or challenges of developing a market for asphalt rubber pavements are described. The limited literature of life cycle cost analysis and cost effectiveness is also summarized.

The asphalt rubber market includes scrap tire sources, crumb rubber producers, regulatory agencies, asphalt binder producers, paving contractors, and customers or agencies that own and/or manage the roadways in New Mexico. The latter include the New Mexico Department of Transportation, cities, counties or municipalities, tribes, pueblos, and private individuals or entities.

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA), Section 1038 established a mandate for the use of rubber modified asphalt pavements in a percentage of all federally funded highway projects in the U.S. starting in 1995; the percentage would increment in subsequent years. At that time, most rubberized asphalt-producing processes were patented or proprietary. A strong campaign against CRM asphalt binders raised many concerns about fume emissions, cost effectiveness, performance and recyclability. Before the mandate could take place, a moratorium was placed until those issues could be investigated and resolved. During this moratorium, the asphalt industry persuaded the U.S. Congress to repeal the mandate. During the period of 1991 to 1995, the federal mandate to use crumb rubber in asphalt pavements plus performance failures of unsuccessful asphalt-rubber pavements caused frustration among many state highway officials.

In the last decade, most of the U.S. market for asphalt rubber and rubberized pavements has concentrated in California, Arizona, Florida and Texas. The main users of CRM modified binder are state Departments of Transportation. Crumb rubber can be used to produce CRM modified binder with the wet process for various applications, such as thin overlays, structural overlays, rubberized open-graded friction courses, SAMs, SAMIs, rubberized chips seal, rubberized fog seal, seal coat, cap seal spray, and joint and crack sealing. Crumb rubber can be also used as an aggregate substitute (dry process) to produce rubber modified asphalt concrete.

3.4. Crumb Rubber Producers

The process of producing crumb rubber modified asphalt binder begins with the production of crumb rubber from scrap tires. The components of a scrap tire are approximately 70% rubber, 20% steel and 10% fiber (Figure 1). A specialized facility is required to process scrap tires into crumb or ground rubber that can be used for asphalt rubber pavements. Jai Tire, Inc. was a crumb rubber facility located in Albuquerque, NM. With less than three years in business, the plant was shutdown in October of 2008. However, this plant did not produce crumb rubber with the mesh size required for CRM binder and pavement applications (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011). Southwest Tire Processors, Inc. is a scrap tire recycling facility located in Socorro, NM that can produce shredded tires up to about 2 in, which is not appropriate for CRM binder. In 2000, a scrap tire storage pile at this facility caught fire and burned for two days and after eleven years still causes concerns of potential contamination of groundwater and soil in the area.

Currently, the closest processor of crumb rubber to New Mexico is State Rubber & Environmental Solutions, L.L.C., located in Denver City, Texas, approximately 40 miles east of Hobbs, NM and 330 miles southeast of Albuquerque, NM. The crumb rubber produced in this facility is primarily used for asphalt binder modification. This particular processor typically collects scrap tires within a 250-mile (400-km) radius of its plant. This facility processes about 1.25 million scrap tires per year (Dan Swanson, State Rubber & Environmental Solutions, L.L.C., Plant Manager, personal communication, 2011). The NMED records show that 442,000 scrap tires were hauled out of the state to this crumb rubber producer in 2009 (Table 2). Preliminary hauling data for 2010 indicate that about 192,500 scrap tires were hauled to State Rubber & Environmental Solutions, L.L.C. from New Mexico last year (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011).

Another producer of crumb rubber mostly for the asphalt industry in the region is Crumb Rubber Manufactures, with one of three plants located in the Phoenix area, Arizona. This producer operates a 100,000-ft^2 plant located on 50 acres of land in east Maricopa County, Arizona with a capacity of processing 8 million tires annually, of which about 70% of the crumb rubber is used in asphalt pavement applications. Along with their facility in Phoenix, located 415 miles (664 km) southwest of Albuquerque, Crumb Rubber Manufactures also operates facilities in Albany, New York and Los Angeles, California (Crumb Rubber Manufacturers, 2011). In 2009, 45,102 scrap tires from New Mexico were hauled to this crumb rubber producer (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011).

State Rubber & Environmental Solutions, L.L.C. utilizes domestic shipping containers to ease the loading and unloading of scrap tires. The containers are delivered to customers for loading scrap tires and brought back to the plant for processing. This provides a safe transportation and storage of the material and efficient movement into the processing plant. The containers are moved onto the processing line and are unloaded directly onto the processing equipment. At this particular crumb rubber processing facility, scrap tires are placed on a conveyor system feeding them in to a primary shredder (Figure 20a), which reduces the scrap tires to 3-in. nominal chips. These chips are then fed to another shredder to reduce the particle size to 3/4-in. (Figure 20b). This material can be processed further using a granulator to reduce the particles to a 1/4-in. maximum size (Figure 20c), which can be used in playgrounds and other athletic fields. This part of the process also reduces the fiber by 90%. The 1/4-in. material can then be fed into a refiner mill to reduce it to 200 mesh size (State Rubber & Environmental Solutions, L.L.C., 2011). At this point, 95% of the steel wire in the crumb rubber has been removed, and the remaining 5% steel wire is removed next using a belt magnet system (Figure 20d).

This type of crumb rubber processing plant can produce consistently approximately 4,500 lb (2.25 tons = 2 metric tons) of 30 mesh crumb rubber per hour. The material is stored depending on the final use of the product. Processed material can be either bagged or moved with a pneumatic system to an on-site bulk storage facility where it can be loaded later into trailers for delivery (State Rubber and Environmental Solutions, L.L.C. , 2011).

(a) (b)

(c) (d)

Figure 20. Conveyors to a) primary 3-in. shredder, b) to secondary 3/4-in. shredder, and c) to 1/4-in. granulator, and d) belt magnet system in a crumb rubber plant (Source: State Rubber and Environmental Solutions, L.L.C., 2011)

3.5 CRM Blending Systems

Producing CRM modified binder requires blending equipment with some modifications from those used in the standard asphalt binder production. Even though the equipment design can vary among manufactures, the blending process is similar. Materials are metered by weight sensors into a high-shear blending unit. After blending thoroughly the CRM into the hot asphalt cement and extender oil, the mixture is pumped into a heated tank where the interaction between the asphalt and rubber proceeds.

The properties of the resulting CRM modified binder are mainly dependent on the proportions of the components, material temperature, blending temperature, agitation method and blending time. Temperatures of storage tanks used to store asphalt cement are monitored closely. These tanks are maintained at temperatures of 375° F to 435° F (190.6° C to

224.9° C) and are insulated to retain heat. Material from the heating tank is moved to a reaction tank. It is common practice that the CRM modified binder be agitated for a minimum of 45 minutes at temperatures from 375°F to 425°F (190.6° C to 218.3° C) to reach the desired interaction between the asphalt and rubber. Reaction tanks are fitted with heating coils and augers to maintain proper temperature and agitation.

3.6 Equipment and Facility Costs and Investments

3.6.1 Crumb Rubber Producing and Blending Systems

A general price estimate of a new crumb rubber system was obtained for the purpose of this study from Columbus McKinnon Corporation, based in Sarasota, Florida. This price was provided solely as an estimate assuming that the required equipment is designed to produce 10/20 mesh crumb rubber from whole scrap truck and passenger vehicle tires at a rate of approximately 2,500 lb per hour (9,000 tons per year = 8,165 metric tons per year) and operate 24 hour per day and 300 days per year. With this type of equipment, the finished product would meet industry standards concerning wire and fiber content, so that all foreign material would be removed and all wire byproducts from processing would be separated for sale as scrap steel (Kaytee Moran, Columbus McKinnon Corp., personal communication, 2011).

The quoted crumb rubber system from Columbus McKinnon Corp. comprises four major stages that are briefly described next. Stage I shreds scrap tires to chip sizes of 4-in. to 6-in. Scrap tires are fed into the shredder by way of a conveyor system. Stage II processes the chips from the previous stage to a wire-free 3/4-in. material. This stage utilizes specially designed equipment that separates steel wire from the rubber. Stage III reduces the 3/4-in. material down to a 10/20 mesh crumb rubber. In this stage, the material feed is controlled by an automated system from a bulk storage unit. The majority of the foreign material and metal are removed by use of a cracker mill, which consists of two rotating corrugated steel drums breaking down the scrap tire rubber into various sizes. After mechanical separation, the material that does not meet the required size is processed again through the appropriate shredder.

Stage IV is the final stage and receives the processed crumb rubber for final cleaning and processing. Multiple drum magnets are used to remove the remaining contaminants from the material. The crumb rubber modifier is deposited into bulk storage bags by a semi-automatic bagging system and is weighed. An estimated cost breakdown of the equipment for each stage can be seen in Table 13 (Kaytee Moran, Columbus McKinnon Corp., personal communication, 2011). Other costs normally associated with the installation of the equipment are not shown or discussed in this report.

The cost of equipment purchasing of a new state-of-the-art asphalt-rubber mixing system (field blend) is estimated at approximately $1.2 millions. The typical system includes a portable mixing unit and a portable reaction tank that agitates and stores the mixture (Andy Guth, Director of Sales and Marketing, CEI Enterprises, personal communication, 2011).

Table 13. Estimated cost breakdown (for budget purposes only) of a new 8,200 tons/year crumb rubber system (Kaytee Moran, Columbus McKinnon Corp., personal communication, 2011)

Stage	Process	Estimated Cost of Equipment
I	Process scrap tire to 4-in. to 6-in. chips	$593,900
II	Process material from previous stage to wire-free 3/4-in. material	$975,665
III	Process material from previous stage to 10/20 mesh crumb rubber	$1,328,660
IV	Final cleaning and packing	$445,315
	Total Estimated Cost of Equipment	$3,343,540

3.6.2 Scrap Tire Supply and Market Feasibility

For the purpose of this study, equipment and facility costs were estimated based on the cost of the new equipment needed to produce CMR modified binder and asphalt concrete. To justify financially the purchase of a new complete mixing (or blending) equipment, a binder producer would need to produce a minimum of 100,000 tons (90,720 metric tons) per year of CRM modified binder. In the following paragraphs, it was assumed a rubberized asphalt concrete mixture containing 7% CRM binder (by weight of the total mixture) and a CRM modified binder containing 10% crumb rubber by weight of the binder. This represents 700 tons (635 metric tons) of CRM. Alternatively, an asphalt rubber concrete mixture with 7% asphalt-rubber modified binder containing 20% crumb rubber by weight was also considered.

When processing crumb rubber, approximately 65% of the total weight of a scrap tire results in crumb rubber material that can be used for CRM modified binder production. An average passenger vehicle tire weighs 22.5 lb (10.2 kg), of which about 2.5 lb (1.1 kg) are steel fibers. Based on these assumptions, the processing of a scrap car tire yields about 14.6 lb (6.6 kg) of crumb rubber (Kaytee Moran, Columbus McKinnon Corp., personal communication 2011). Using these assumptions, approximately 2.7 million scrap car tires would need to be processed to produce 100,000 tons of asphalt-rubber binder with 20% CRM content per year, or 1.37 million scrap car tires to produce 100,000 tons of rubberized asphalt binder with 10% CRM content per year.

The cost of a tire recycling facility varies depending on the particle sizes to be produced and its capacity, given by the quantity of scrap tires to be processed. The equipment and installation of a new turnkey facility capable of processing up to 2 million scrap tires per year is estimated to cost roughly $5 million dollars (Kaytee Moran, Columbus McKinnon Corp., personal communication, 2011). The profitability of a crumb rubber producing facility has been found to be particularly sensitive to crumb rubber prices, operating costs and raw material availability (Sunthonpagasit and Duffey, 2004).

This estimate of equipment cost does not include the cost of leasing or purchasing land to build the facility or constructing the building for the crumb rubber plant, which are important parts of the capital investment. For example, State Rubber & Environmental Solutions, L.L.C. operates its processing plant from an enclosed 3,750 ft^2 building located on 13 acres of land to accommodate storage and processing (Dan Swanson, State Rubber & Environmental Solutions, L.L.C., Plant Manager, personal communication, 2011). Crumb Rubber Manufacturers operates a processing facility in the Phoenix area within a 100,000 ft^2 building, constructed on 50 acres of land used for processing and storing (Crumb Rubber Manufacturers, 2011).

With such facilities already in place in the neighboring states of Texas and Arizona, it is possible to acquire from them crumb rubber that meets specifications needed for CRM modified asphalt pavements in New Mexico. These crumb rubber plants have capacity to recycle an additional 1 million tires from New Mexico (*House Memorial 6 Final Report*, 2010). With crumb rubber facilities located in Texas and Arizona, suppliers and distribution can be determined based on the location of the specific projects. Estimated cost of crumb rubber material from either plant could not be obtained for this study. Crumb rubber shipment costs vary based on the location of the projects or the location of the storage facility; in any case, these costs would fall under the responsibility of the purchasing party or the CRM modified binder supplier.

The scrap tires that are currently disposed or stored in landfills represent the fraction of the total scrap tires generated annually in New Mexico that would be available for local crumb rubber production if a CRM producer were established in the state. Based on the New Mexico statistics in Table 12, 539,000 scrap tires or about 27% of the total generated were landfilled in 2009. The remaining scrap tires generated annually in the state are used in other applications or their final use or location is unreported or unknown. Additional scrap tires could be obtained from the existing stockpiles and tire bale storing facilities throughout the state. According to RMA (2009), 1.3 million scrap tires were in stockpiles in New Mexico in 2007.

With roughly 540,000 to 750,000 scrap tires available per year (currently landfilled or in stockpiles), creating and sustaining in the long term a new crumb rubber processing facility does not seem feasible at the present from the points of view of upfront investment costs, sufficient local scrap tire supply and sufficient demand for CRM material for local paving projects. To satisfy the capacity and demand of a new CRM processing plant, scrap tires would have to be either imported into the state for processing or retained in the state instead of being hauled to out-of-state crumb rubber producers or consumers. Note that in 2009 approximately 44.8% of scrap tires generated in New Mexico were shipped out of state (Table 12). Preliminary hauling data for 2010 show a similar trend (Toni Duggan, Tire Recycling Coordinator, NMED Solid Waste Bureau, personal communication, 2011).

A four-stage crumb rubber system as described in Section 3.6.1 can process approximately 1.25 million scrap tires annually and producing 18 million lb (9,000 tons = 8,165 metric tons) of CRM per year. To secure a local market for 9,000 tons of CRM, an increase of the annual demand of 643,000 tons (583,300 metric tons) of asphalt-rubber modified asphalt concrete, which would contain about 45,000 tons (40,823 metric tons) of CRM binder, would have to be created in the area. Alternatively, new demand for 9,000 tons of CRM would require an increase of the annual demand in the area of 1,286,000 tons (1,166,000 metric tons) of rubberized asphalt concrete, which would contain about 90,000 tons (81,646 metric tons) of CRM binder.

The projects constructed by NMDOT using rubberized asphalt consist of a thin, non-structural ROGFC overlay, generally 5/8-in. (15.9-mm) thick, over conventional asphalt. In the fiscal year 2010, the NMDOT bid lettings included a total of 280.243 miles of reconstruction and/or rehabilitation of flexible pavements. In this length, seven bridges with miscellaneous paving were included. Four winning bids included thin ROFGC overlays for a total project length of 28.167 miles. In the fiscal years 2010 and 2011, the NMDOT bid lettings included lengths of 391.612 miles and 265.979 miles, respectively, of reconstruction and/or rehabilitation of flexible pavements. These are total project lengths and not paved lane-miles. It is also important to note that open-graded friction courses, with rubberized asphalt or not, are not appropriate for all projects and only a fraction of the total miles of new construction or rehabilitation may include ROGFC.

It was estimated that 1,286,000 tons of rubberized asphalt concrete could be produced annually with the CRM from the assumed new crumb rubber plant in New Mexico. This amount of rubberized asphalt would pave about 4,600 lane-miles (7,403 lane-km) of 5/8-in. ROGFC overlay. The NMDOT projects with ROGFC would consume a relatively small portion of the annual CRM production of a hypothetical new plant in New Mexico. To increase the demand for CRM in the state, rubberized asphalt or asphalt-rubber concrete would have to be used widely in structural overlays (i.e., thicker HMA concrete layers) in placed of conventional HMA pavements. Such a change in materials and pavement structural design approach should be justified mainly by demonstrated performance, cost-effectiveness data and experience.

3.6.3 Construction Equipment Requirements

The placement and compaction of CRM modified asphalt concrete mixtures utilize conventional HMA equipment. Vehicles used to transport HMA may be also used for the CRM modified asphalt concrete, including conventional end or bottom dump or horizontal discharge. No solvent-based release agents in haul truck beds should be used due to the adverse effects on the CRM binder (Caltrans, 2006). It is suggested that vehicles transporting CRM modified asphalt concrete mixture be covered to maintain the appropriate material temperature (Caltrans, 2006).

Conventional mechanical self-propelled pavers, equipped with vibratory speed and screed heaters and automatic screed controls with skid, can be used to place CRM modified asphalt concrete. Rollers used for this material should be steel-wheeled, with scrubbing pads and watering systems. The CRM modified asphalt concrete mixtures are more likely to need more energy for compaction than dense-graded HMA mixtures. Conventional sand spreaders can also be used as long as the equipment is able to provide uniform distribution for opening

RAC surfaces to traffic (Caltrans, 2006). In general, most paving contractors should be able to handle the placing of CRM modified asphalt concrete; however, prior experience and awareness of the need for modifications of the common HMA practice to adapt the procedures to the CRM modified asphalt concrete would be very valuable.

3.7 Scrap Tire Hauling and Tipping Fees

Costs associated with hauling tires are very variable and depend on transportation distance, fuel cost and scrap tire volumes among other factors. Transportation costs are generally paid by tire dealers; in some cases, transfer stations and landfills also pay for having scrap tires hauled from their facilities to recycling or processing facilities.

In addition to transportation costs, tire-hauling companies often have to pay a tipping fee to the landfill, transfer station, recycling facility or crumb rubber producer that receives the scrap tires. In New Mexico, state agencies do not pay for transportation costs or tipping fees for third-party scrap tires. Some costs of hauling scrap tires to project construction sites or transportation costs associated with scrap tire stockpile abatement projects, for example, could be covered as part of scrap tire grants through the *Recycling and Illegal Dumping Fund* (see Section 3.2), administered by the NMED Solid Waste Bureau.

3.8 Permits and Financial Requirements

Tire recycling facilities such as a crumb rubber producing plant in the state of New Mexico are required to apply for a Tire Recycling/Storage Facility permit through the New Mexico Environmental Improvement Board. The permit application (NMED, 2011) has no cost to the applicant. Facilities of this nature fall under the New Mexico Administrative Code (NMAC) 20.9.20.58 regarding financial assurance (NMAC, 2011) and the amount would be estimated from the cost of shutting down of the facility, including abating all scrap tires left at the site (Toni Duggan, Tire Recycling Coordinator, Solid Waste Bureau, NMED, personal communication, 2011). This estimate is to be requested by the owner or operator of the facility to a third-party individual company and filed with the NMED. This company would be responsible for disposal of all materials left in the event of the facility shutdown. During the operation of the facility, this estimate would be adjusted for any inflation and any other factors that could affect closure cost and filed annually with the NMED's New Mexico Environmental Improvement Board.

Tire recycling facilities also fall under strict operational requirements. The NMAC states that any person who stores scrap tires shall do so with the utmost regard for safety of employees and the public. Tires are to be stored without causing nuisance or potential hazards such as danger to public health or welfare to the environment. Tires should also be stored in a location that minimizes the potential for a fire. These precautions indirectly restrict the size and location of this type of facilities in New Mexico.

3.9 Cost Benefit Considerations

The California Department of Resources Recycling and Recovery has posted in the agency's website (CalRecycle, 2010) that rubberized asphalt concrete costs about 20% to 25% more than conventional mixtures. The New Mexico's *House Memorial 6 Final Report* (2010) refers to examples of projects where the cost difference for rubberized asphalt materials varies from 10% to 16%. Recent information from 2011 NMDOT projects with thin ROGFC overlays indicates that the cost difference has become much smaller: $82.00 per ton of ROGFC compared to $81.00 per ton of OGFC.

Using asphalt-rubber or rubberized asphalt may add to cost of materials and mobilization and/or setup of CRM modified binder mixing equipment. Size and duration of the project are important when choosing conventional, rubberized or AR modified mixtures. In some cases, the mobilization and setup costs cannot be justified for small amounts of asphalt concrete mixture.

In any case, the cost difference would depend on the job size and amount of material ordered. The cost benefit should also take in consideration the difference in amount of material needed. Reports in the literature often refer to a smaller layer thickness needed (about 33% to 50% thickness reduction) when asphalt-rubber or rubberized asphalt concrete are used instead of conventional materials (CalRecycle, 2010; Caltrans, 2005). For example, experimental results and field performance monitoring over two decades led to modifications to the Caltrans overlay design procedures to allow a thickness reduction of 2:1 for rubberized gap-graded asphalt concrete overlays only (Caltrans, 2005), with a minimum thickness of 1.5 in. (38.1 mm) of rubberized asphalt concrete. This thickness reduction is applicable when the material is used as a structural layer.

The following sections briefly describe the conclusions of several life cycle cost analysis and cost-benefit analysis for asphalt-rubber and rubberized asphalt pavements found in the literature. The California Department of Resources Recycling and Recovery has funded an ongoing study (August 2010 to December 2011) to perform a life cycle cost analysis (LCCA) of rubberized asphalt pavements, chip seals, multi-layer rehabilitation and thin overlays using CRM modified binders (CalRecycle, 2010).

3.9.1 Life Cycle Cost Analysis of ADOT Asphalt-Rubber and Conventional Pavements

A 25-year life cycle cost analysis reported in 2002 compared a conventional pavement and an asphalt-rubber pavement in Arizona (Jung et al., 2002), located on the west bound of Interstate I-40 from MP 191 to 194 and from MP 196 to 204, respectively. Four miles of each project were considered. At the time of the study, the average daily traffic on these pavements was approximately 20,000 with 4% annual growth rate and 20% of trucks. The performance indexes for the analysis were the International Roughness Index (IRI) and the Pavement Serviceability Rating (PSR), as defined by the Arizona DOT.

The conventional pavement selected in this analysis was built in 1985. It was a 20-year design consisting of 4-in. (102-mm) aggregate base, 6-in. (152-mm) bituminous treated base, and 11-in. (279-mm) asphalt concrete layer. By 1995, the level of deterioration and cracking of this pavement justified rehabilitation with an asphalt-rubber overlay. This rehabilitation was designed for 10 years of service; by 2002, the asphalt-rubber overlay showed signs of cracking but maintained a very good ride quality (Jung et al., 2002). The asphalt-rubber pavement consisted of 8-in. (203-mm) aggregate base with broken old concrete pavement, 3-in. (76-mm) conventional asphalt concrete layer, 2-in (51-mm) asphalt-rubber gap-graded asphalt mixture, and 0.5-in. (12.7-mm) asphalt-rubber open-graded friction course.

The cost benefit analysis considered user cost and agency cost, including initial construction (and overlay) and maintenance costs. The performance data available to this study covered 11 years only; therefore, IRI measurements were estimated for up to 25 years by fitting an exponential function to the available data. From the comparison of costs estimated for a 25-year period, this study concluded that the asphalt-rubber pavement was cost-effective. After 10 years, the maintenance cost of the conventional pavement began to be significantly higher than that of the asphalt-rubber pavement; a significant higher user cost for the conventional pavement started at about 15 years.

3.9.2 Initial Cost Comparisons

Two project design examples of conventional and rubberized asphalt pavements were originally presented by Lynn D. Nicholson in *RPA News* (1997) and later revised with updated material prices in the CalRecycle (2010) website. The purpose of these examples was to compare the advantages and disadvantages of these two types of pavement from the initial construction point of view. In the CalRecycle (2010) examples, asphalt concrete (AC) was priced at $100 per ton and rubberized asphalt concrete (RAC) was priced at $125 per ton.

The first example assumed a 4-in. (102-mm) conventional AC overlay, which required 1,584 tons of material with a total construction cost of $170,400 per lane-mile. Alternatively, a 2-in. (51-mm) RAC overlay could be used based on the *Reduced Thickness Design Guide* of Caltrans for asphalt rubber pavements. In this case, 754 tons of RAC would be needed with a total construction cost of $94,250 per lane-mile. (This example assumed pavement preparation costs for the AC pavement only.) In this example, the estimated initial cost savings using RAC were $76,150 per lane-mile.

The second example consisted of a reconstruction of the structural pavement section with a 4-in AC layer and a 17-in (432-mm) crushed aggregate base, resulting in a cost per lane-mile of $422,400. An alternative solution considered was resurfacing with a 4-in. conventional AC overlay for a total cost of $170,400. This solution would result in a 4-in. increase to the existing roadway elevation but the disruption to the traffic would be much less compared to the AC solution. The third solution consisted of 1-in. (25.4-mm) cold milling and resurfacing with a 2.5-in. (63.5-mm) RAC overlay with a total cost of $143,013. In the later case, the roadway elevation would be increased 1.5 in. and the disruption to the traffic would be much less compared to the AC solution. In this example and for the assumptions made, rehabilitation with an RAC overlay has the lowest initial cost, less impact to traffic and a relatively modest increase of the roadway elevation.

3.9.3 Life Cycle Cost Analysis of Asphalt-Rubber Hot Mixtures and Chip Seals

In the late 1990s, a 40-year life cycle cost analysis (LCCA) compared several scenarios including structural overlays, nonstructural surface courses and chip seals containing conventional or polymer-modified binders with the same applications with asphalt-rubber binders (Hicks and Epps, 1999). This analysis used the costs and design and preservation approaches typically implemented by several local agencies in Arizona and California at the time of the study. Estimates of expected life for the various rehabilitation and maintenance strategies were determined based on interviews with state and local agencies in Arizona and California. The LCCA included deterministic and probabilistic calculations.

The LCCA concluded that the asphalt-rubber applications were cost effective in many of the scenarios considered, but not for all applications included in the study. The cost effectiveness of the asphalt rubber in hot asphalt mixtures was dependent on the ability to reduce the layer thickness and/or longer pavement life when using asphalt-rubber modified binder instead of conventional or polymer-modified binder. The study noted that asphalt rubber was most cost effective mainly when reflection cracking was expected.

3.9.4 Cost Savings in Multi-Layer Pavement

Kirk and Holleran (2000) described the cost savings in a paving project located in the city of Helmet, CA using asphalt rubber in a multi-layer system compared to conventional asphalt concrete alternatives. In that project, reconstruction was the recommended strategy. Based on pavement deflections, the pavement engineer recommended three alternative designs: 1) 5.3-in. (135-mm) AC overlay; 2) 13-in. (330-mm) Class 2 aggregate base with a 3.5-in. (90-mm) AC layer; and 3) 1.9-in. (48-mm) AC layer with a 1.5-in. (39-mm) asphalt-rubber hot mix gap-graded overlay. According to Kirk and Holleran (2000), the cost savings of alternative 3 over 1 was $124,000 and alternative 3 over 2 was $382,000 at the time of the project. Because there was curb and gutter, alternative 1 was not viable as the thick AC overlay would have caused grade problems and, therefore, the city of Helmet decided to use asphalt rubber in this project (Kirk and Holleran, 2000).

3.9.5 Life Cycle Assessment Considering Environmental Impact

The Eco-indicator 99 is a life cycle impact assessment methodology and database (Pré Consultants, 2011) to calculate standard indicator scores of the environmental impact of materials or processes. The calculation of the scores is based on data from a life cycle assessment. The higher the indicator, the greater the environmental impact.

The life cycle assessment methodology was applied to the use of recycling materials for rehabilitation of asphalt pavements (Chiu et al., 2007). The study considered three recycling materials, including recycled HMA, asphalt rubber and Glassphalt, and the conventional HMA as rehabilitation alternatives. The short term (6 years) and long term (40 years) environmental impact scores were expressed in units of required power, or “eco-burden,” per lane-kilometer. The conventional HMA has an eco-burden of 3.45 kPt and 23.03 kPt per lane-km in the short and long terms, respectively.

In the short term, the study found that using asphalt rubber in rehabilitation activities would increase the eco-burden by 16% compared to conventional HMA. In the long term, however, the recycled HMA and asphalt rubber would reduce the eco-burden by 23% compared to conventional HMA. A large percentage of the eco-burden calculated came from the asphalt binder and the heat sources required to process these materials, which suggests that the environmental impact of these recycling paving materials may be reduced by reducing the heat requirements during manufacturing and placing (Chiu et al., 2007).

4. Research on Asphalt Rubber Properties and Performance from Laboratory Testing

This section summarizes the main findings, observations and conclusions of recent research and most cited relevant references on the properties and performance of asphalt-rubber (AR) modified asphalt concrete. Emphasis was given to the critical types of cracking and the material properties of the binders and asphalt mixtures used for the Mechanistic Empirical Design Guide (MEPDG) methodology. In addition, the main conclusions and recommendations of recent studies that evaluated and developed predicting models for the case of asphalt rubber mixtures are summarized. Most of the research literature focuses on asphalt-rubber and not on rubberized asphalt.

4.1 Physical Properties

A recent study compared the material properties of gap-graded and open-graded AR mixtures from 11 projects and several conventional dense-graded asphalt mixtures from other projects in Arizona (Rodezno and Kaloush, 2009). The properties of binders and mixtures considered in this study were those needed as inputs for the MEPDG design. The comparison of the Arizona data showed that the crumb rubber modifier increased in general the performance grade (PG) of the binder by at least one level and that AR binders had the better viscosity-temperature susceptibility (i.e., higher viscosities at higher temperatures and lower or unchanged viscosities at lower temperatures) (Rodezno and Kaloush, 2009). Pasquini et al. (2011) determined higher softening point and higher viscosity of the AR mixture due to the addition of asphalt rubber in the binder; these results were related to better performance of the AR mixture and support the documented field performance of AR pavements. Gopal et al. (2002) also concluded that crumb rubber modifiers could improve the low-temperature properties of the binders if carefully designed and evaluated for each combination of crumb rubber size, content and binder type.

A number of variables affect the properties of CRM modified binders. The crumb rubber content and size have considerable effect on some properties of the AR modified binder. Depending on the base binder considered, the addition of 10% and 15% crumb rubber (by weight of binder) could increase the PG of the CRM binder by at least one and two grades, respectively (Putman et al., 2005). The crumb rubber size could have a stronger effect on the viscosity of the CRM binder for the rubber produced with the ambient process, and a smaller influence on the failure temperature (Putman et al., 2005).

The study of Rodezno and Kaloush (2009) also compared results from confined and unconfined dynamic modulus tests. The conventional mixtures had higher unconfined dynamic modulus than gap-graded AR asphalt concrete mixtures; the latter had higher modulus than AR open-graded friction course mixtures regardless of the test temperature and frequency. On the other hand, the confining level and temperature affected the modulus values. Confining increased the modulus of all AR mixtures and test conditions, but had no significant effect on the modulus of conventional mixtures at low temperatures and a slight increasing effect at higher temperatures. Under a confining stress of 20 lb/in^2 (138 kPa), the gap-graded AR asphalt concrete mixtures had equal or higher modulus than conventional mixtures, especially at higher test temperatures of 100^{o} F and 130^{o}F (38^{o} C and 54^{o} C). Rodezno and Kaloush (2009) obtained new fitting coefficients for Witczak's equation of the dynamic modulus (NCHRP, 2004) specifically for AR mixtures.

Using the coaxial shear test developed at the EMPA (Swiss Federal Laboratory for Material Testing and Research), the dynamic modulus of two open-graded AR mixtures with 10.1% AR binder content (by weight) and 20% rubber (by weight) in the binder was evaluated by Partl et al. (2010). The results showed that the AR mixtures had lower stiffness than open-graded asphalt concrete mixtures with 5.5% (by weight) polymer-modified binder. Partl et al. (2010) suggested that the lower stiffness of the two AR mixtures was due probably to the higher binder content (10.1%) and smaller maximum aggregate size of these mixtures.

4.2 Thermal Cracking

Thermal cracking is an important type of distress in flexible pavements. There are two main types of thermal cracking: a) thermal cracking caused by cold (low) temperatures, and b) thermal cracking (also referred to as thermal fracture) caused by material fatigue due to cyclic temperature changes in regions with large differences between diurnal and nocturnal temperatures. Because thermal cracking is purely a tensile failure of the material, the resistance of the asphalt concrete to thermal cracking is mainly provided by the binder. Higher tensile strength has been generally associated with higher thermal cracking resistance. Pasquini et al. (2011) found that a gap-graded mixture with 20% rubber in the binder had higher tensile strength, as determined by the indirect tensile strength (ITS) test, and higher energy to failure. They concluded that the RA mixture had a higher thermal cracking resistance than gap-graded and dense HMA mixtures without rubber asphalt binder.

Nevertheless, results from other laboratory experiments reported in the literature (e.g., Kaloush et al., 2002; Zborowski and Kaloush, 2007) have indicated that AR asphalt concrete has significantly lower tensile strength compared to conventional dense-graded HMA mixtures. In other studies, the rubber asphalt mixtures have exhibited much better field performance in terms of thermal cracking than conventional HMA pavements as observed and documented in a number of pavement sections in Arizona. Laboratory experimental studies also observed better thermal cracking resistance in asphalt rubber (AR) mixtures (e.g., Raad et al., 1993; Epp, 1997).

Zborowski and Kaloush (2007) recognized that the available thermal cracking models did not properly predict and characterize the superior thermal cracking resistance of AR mixtures compared with conventional mixtures. Using laboratory test results in a large database containing 39 mixtures from 10 projects, Zborowski and Kaloush (2007) proposed an improved predicting model that takes into account the total fracture energy and creep compliance in addition to the tensile strength maximum limit of the material. For this new model, modifications to the standard indirect tensile (IDT) creep test protocol are needed to determine the energy to failure and total fracture energy.

4.3 Permanent Deformation

The experimental studies documented in the literature reported that gap-graded asphalt rubber mixtures have considerably better rutting resistance than stone mastic asphalt and dense-graded asphalt concrete mixtures, despite containing a relatively large asphalt-rubber content in the binder (e.g., Kaloush et al., 2002; Wong and Wong, 2007; Fontes et al., 2010; Pasquini et al., 2011). The greater interlocking of the course aggregate structure in gap-graded mixtures contributes to a higher resistance to permanent deformation or rutting. However, stone mastic asphalt and asphalt-rubber asphalt concrete have gap-graded aggregate. Pasquini et al. (2011) attributed the significantly greater resistance to permanent deformation of the asphalt-rubber mixture tested in their study to the asphalt rubber content in the binder.

An experimental study by Fontes et al. (2010) studied four AR mixtures with rubber content in the binder between 15% and 20% by weight and a dense-graded conventional asphalt. They found better resistance to permanent deformation in AR mixtures with higher softening points, gap-graded aggregate structures, and AR modified binders produced with continuous blending. In general, the AR mixtures in this study were much more superior in terms of permanent deformation and cumulative plastic strain than the conventional mixture.

Reducing the particle size of the crumb rubber in the AR modified binder of a dense-graded mixture design seems to increase considerably the rutting resistance, producing permanent deformation values comparable to those of mixtures especially designed for high-temperature regions to reduce rutting (Coomarasamy et al., 1996).

4.4 Fatigue Cracking

From indirect tensile tests, the fatigue resistance with respect to the number of cycles to failure of a gap-graded AR mixture was found to be similar to that of a stone mastic asphalt mixture but greater than that of a polymer-modified asphalt mixture (Pasquini et al., 2011). In another study, two wet-process AR modified asphalt mixtures had greater fatigue resistance than a polymer-modified asphalt concrete mixture, and much greater fatigue resistance than a dry-process AR modified asphalt mixture and an asphalt concrete mixture without rubber (Gallego et al., 2007). Greater fatigue resistance of AR mixtures, as determined with CAST, compared to conventional porous or semi-porous asphalt mixtures was also found by Partl et al. (2010). In agreement with a number of studies in the literature, Miranda et al. (2008) reported good fatigue resistance of open-graded and gap-graded AR mixtures with high crumb rubber contents. They also noticed that aging caused a slight reduction in the fatigue life of the specimen compared to a virgin specimen.

4.5 Moisture Sensitivity

Experimental results of Partl et al. (2010) seem to indicate that AR mixtures have significantly less moisture sensitivity compared to conventional porous or semi-porous asphalt mixtures. For assessing the water susceptibility using two different methods, Batista et al. (2009) tested two types of asphalt rubber mixtures with modified binders containing 18% to 22% of rubber. They applied the U.S. military standard MIL-STD-620A and the European standard EN 12697-12. When applying the standard method MIL-STD-620A, the samples showed very high values of retained strength, which means no or very little water sensibility of the asphalt rubber mixtures. For the same mixtures, however, the results applying the European standard method showed 67% and 86% retained strength for the two mixtures.

4.6 Evaluation of Models for Asphalt Rubber Modified Mixtures for Implementation in the MEPDG Methodology

The MEPDG design methodology (NCHRP, 2004) includes three hierarchical levels of analysis with decreasing degree of accuracy from Level 1 (most accurate and detailed analysis, based on specific material properties and conditions) to Level 3 (least accurate analysis, based on nationally calibrated models and general conditions). The predicting material properties and distress models currently available in the MEPDG were developed, calibrated and validated for conventional mixtures, mostly dense-graded asphalt mixtures. These models do not necessarily represent well the behavior and properties of AR mixtures. Thus, the performance of these models for AR mixtures should be evaluated.

4.6.1 Dynamic Modulus and Fatigue Cracking

Rodezno and Kaloush (2009) showed that Witczak's equation of the dynamic modulus (NCHRP, 2004), which was originally obtained and calibrated for conventional mixtures and was implemented for Levels 2 and 3 in the MEPDG deign methodology, under-predicted considerably the dynamic moduli of AR mixtures in a relatively large Arizona database. Rodezno and Kaloush (2009) obtained new fitting coefficients for Witczak's equation specifically for AR mixtures data. However, these coefficients are not available in the current MEPDG for Levels 2 and 3 analyses.

To overcome this limitation, they advised using the modified coefficients to calculate the dynamic modulus and then input this value in the MEPDG option available for Level 1 analysis, which was originally intended for use with specific local data. The observation was made that the designer should be aware that the results would correspond to Levels 2 or 3 analysis even though the option for Level 1 would be used. The effect of confining during the laboratory tests of the dynamic modulus should be taken into account.

Interestingly, a recent study by Pasquini et al. (2011) arrived at opposite conclusions regarding the dynamic modulus values of a gap-graded asphalt rubber mixture. They found that the dynamic modulus values calculated with Witczak's equation were higher than the experimental values for that particular material. The greatest differences were for the modulus predicted using the MEPDG default binder characteristics and the smallest differences were for the modulus calculated using binder viscosity data from Superpave tests.

4.6.2 Fatigue Cracking

Evaluation of the fatigue cracking model adopted in the MEPDG design (NCHRP, 2004) showed that the area of fatigue cracking was significantly over-predicted for AR mixtures in all cases considered when using either the default MEPDG regression coefficients or the laboratory-based regression coefficients for the model (Rodezno and Kaloush, 2009) compared to field distress surveys. The fatigue cracking model predictions using the regression coefficients specifically obtained for the gap-graded AR asphalt concrete mixtures and the confined dynamic modulus produced the smallest differences between the predicted and the field performance values.

Other studies arrived at different conclusions regarding the predicting capability of fatigue resistance of the MEPDG model. For a given stiffness modulus, the MEPDG-predicted and the experimentally determined fatigue lines (i.e., initial microstrain versus loading cycles to failure in double logarithm scale) were found to be similar (Pasquini et al., 2011).

4.6.3 Performance Grade

The MEPDG does not include performance grade (PG) data for AR mixtures. Rodezno and Kaloush (2009) recommended selecting the PG in the MEPDG design (NCHRP, 2004) that best matched the values available for AR mixtures.

4.6.4 Permanent Deformation

Predictions of permanent deformation, or rutting, using the MEPDG methodology (NCHRP, 2004) were evaluated by Rodezno and Kaloush (2009) and Pasquini et al. (2011). For a selected asphalt rubber project in Arizona, Rodezno and Kaloush (2009) found that the rutting predictions for the AC layer and total pavement structure were closer to those recorded in the field if the confined dynamic modulus of the AR concrete layer was input, instead of the unconfined modulus. Pasquini et al. (2011) also found that the plastic strain calculated using confined dynamic modulus data from triaxial cyclic compression tests was very different from the plastic strain calculated with MEPDG default model coefficients. The regression coefficients of prediction models for dynamic modulus and permanent deformation available in MEPDG were obtained from unconfined tests.

The MEPDG limits to one the set of calibration or regression coefficients for the rutting model that can be input in a given analysis, and limits the AC layer thickness to no less than 1 in. (25.4 mm). To address the limitation of the program when the thickness of the open-graded ROGFC layer is less than 1 in., Rodezno and Kaloush (2009) suggested either assuming a 1-in. thick ROGFC layer and subtracting the excess thickness from the underlying gap-graded AR asphalt concrete layer, or ignoring the upper ROGFC layer if not considered as a structural layer.

5. Survey of State Departments of Transportation

A survey was carried out to learn about the use of crumb rubber modifier (CRM) in pavement applications by state Departments of Transportation (DOTs). The survey was sent by e-mail to materials, pavement or construction sections or groups of 50 state DOTs and District of Columbia (DC) DOT in 2011 (a total of 51 agencies). The survey questionnaire contained eight questions, enclosed in Appendix E. Six questions applied to those agencies that have used or currently use crumb rubber in pavement applications, and three questions applied to those agencies that have not used crumb rubber in pavement applications.

Forty-two agencies (82%) returned the completed questionnaire before the publication of this report. The names and contact information of the responders and their responses are provided in Appendix F. Relevant observations and information drawn from the survey results are summarized next (based on responses received).

- Of the 42 agencies who responded, about 55% of them have used and/or currently use crumb rubber in one or more pavement application, and the remaining agencies (45%) have not used crumb rubber in flexible pavements (Figure 21).

- When the agencies who ***have not used or tried crumb rubber*** in pavements (19 agencies) where asked the reason(s) for not using it, 10 of them (53% in this group) referred to the higher cost of CRM, 11 agencies (58%) indicated that it is not cost effective for their agency, 8 agencies (42%) responded that there is no crumb rubber producer in their state, and 8 agencies (42%) did not use it because the performance of CRM asphalt is still uncertain (Figure 22). Other reasons for not using CRM included poor past performance of pavements (or no performance improvement) with CRM asphalt (4 responses), lack of experience with CRM or contractors in the area not using it (2 responses), and not having sufficient incentives to try or use this material (2 responses) (Figure 22). Several agencies indicated that SBS modified asphalt has had excellent performance so they prefer to specify or require it.

- When the agencies who ***have used or tried crumb rubber*** in pavements (23 agencies) where asked the reason(s) for using it, 14 of them (61% in this group) indicated that these pavements perform either better than or equivalently to conventional pavements (without CRM), and 7 agencies (30.5%) indicated that it is (or may be) cost effective for their agency (Figure 23). Interestingly, 6 agencies reported having significant incentives for using CRM as a means of recycling scrap tires, and 3 agencies use it because of political (environmental) reasons or their states have legislation that requires/mandates it in a given percentage of roadways (California and Florida). Two agencies have tried CRM in pavements in a trial or experimental basis only (very limited use), and one agency indicated that the CRM use was based on a local decision (Figure 23). Some agencies indicated better performance in terms of reduction of thermal or reflective cracking and minimization of studded tire wear.

(Note that responders could provide one or more reasons, as applicable to their particular case. For individual answers, refer to Appendix F.)

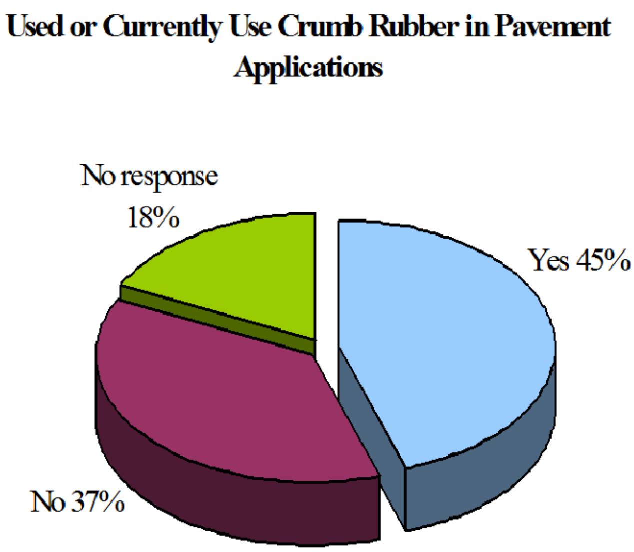


Figure 21. Current and/or past use of crumb rubber in pavement applications by state DOTs

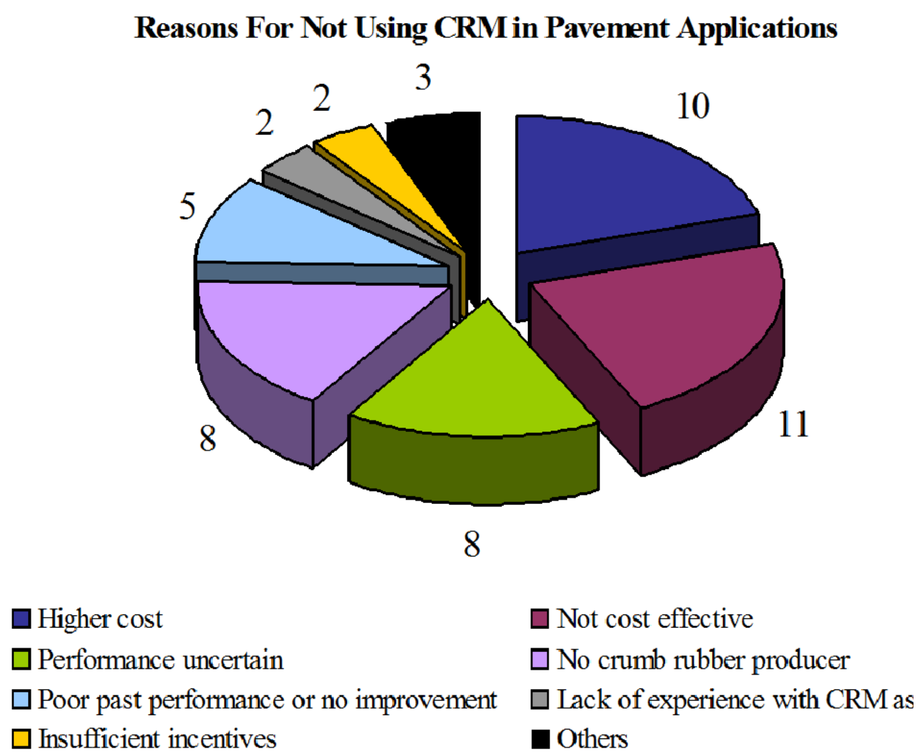


Figure 22. Reasons for <u>not</u> using crumb rubber in pavement applications by state DOTs

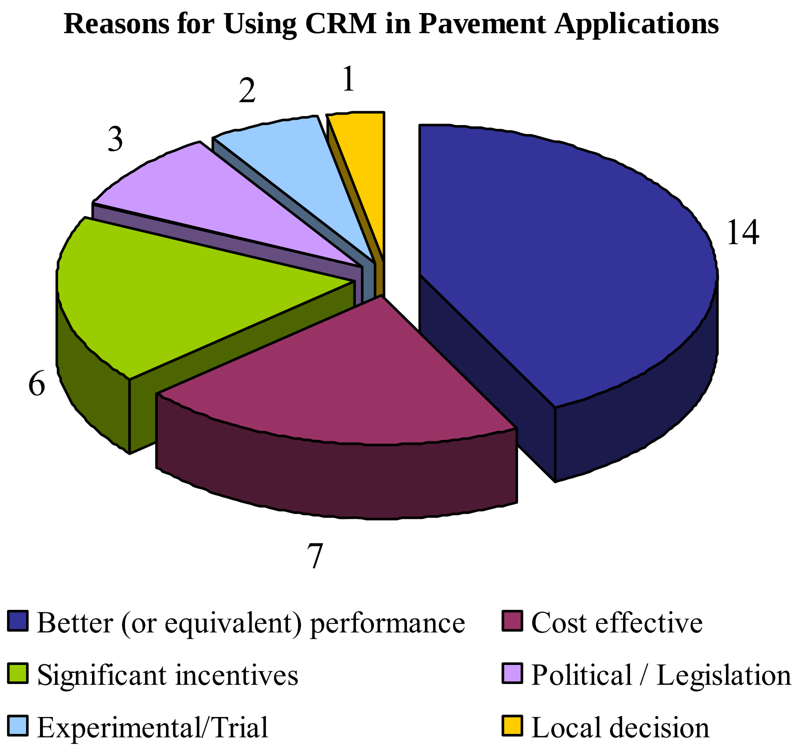


Figure 23. Reasons for using crumb rubber in pavement applications by state DOTs

- Among the 23 agencies that ***have used or tried crumb rubber*** in pavements, 17 agencies (74% in this group) use/have used terminal blend, 9 agencies (39%) use/have used field blend, and 6 agencies (26%) use/have used crumb rubber in the dry process (Figure 24). These statistics represent past and/or current use and do not imply that those methods are being all used at the present by those agencies. In some cases, agencies reported having tried one of these methods just once in an experimental or trial basis. However, the majority of the agencies in this group have had experience with terminal blending.

(Note that responders could check all the methods their agencies have used or tried, as applicable to their particular case. For individual answers or comments, refer to Appendix F.)

- Two agencies reporting CRM usage have not applied this material recently. Twenty-one agencies reported having used it within the given period (2006 to present), some of which had been on an experimental basis (Figure 25). In recent years, these agencies have used CRM binder mostly for surface treatments, such as chip seal, fog seal and NovaChip®, crack sealing (13 agencies) and in thin overlays (< 2.4 in. = 60 mm) (12 agencies). The next most used application in recent years was SAMI or SAM (5 agencies), followed by thick structural overlays (> 2.4 in. = 60 mm) (3 agencies) and ROGFC overlays (3 agencies). One agency reported using CRM modified asphalt in mill-and-fill projects.

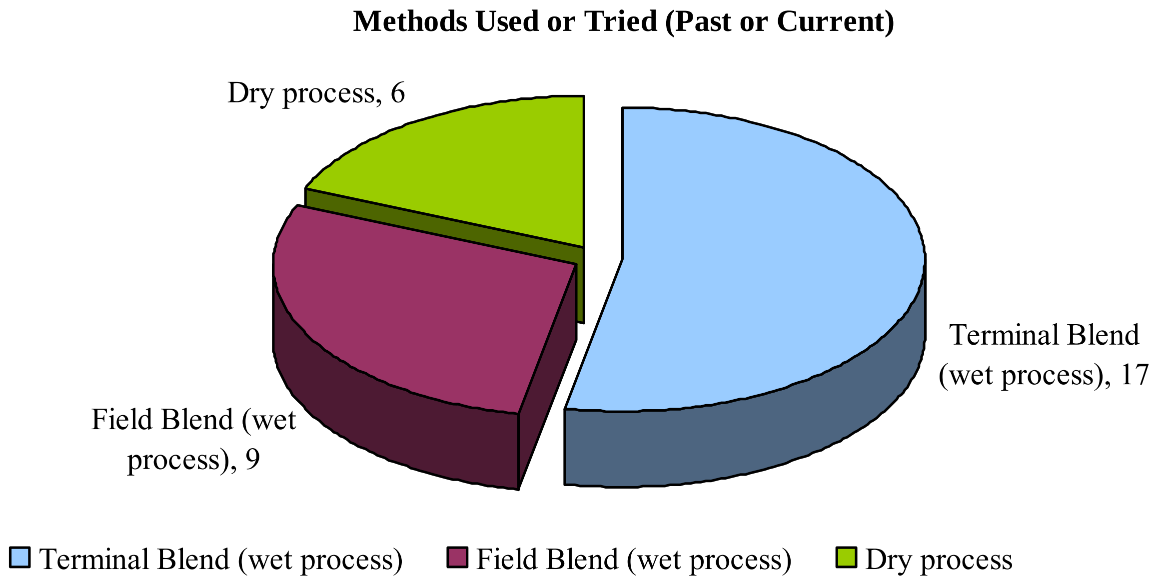


Figure 24. Production methods currently and/or formerly used or tried by state DOTs

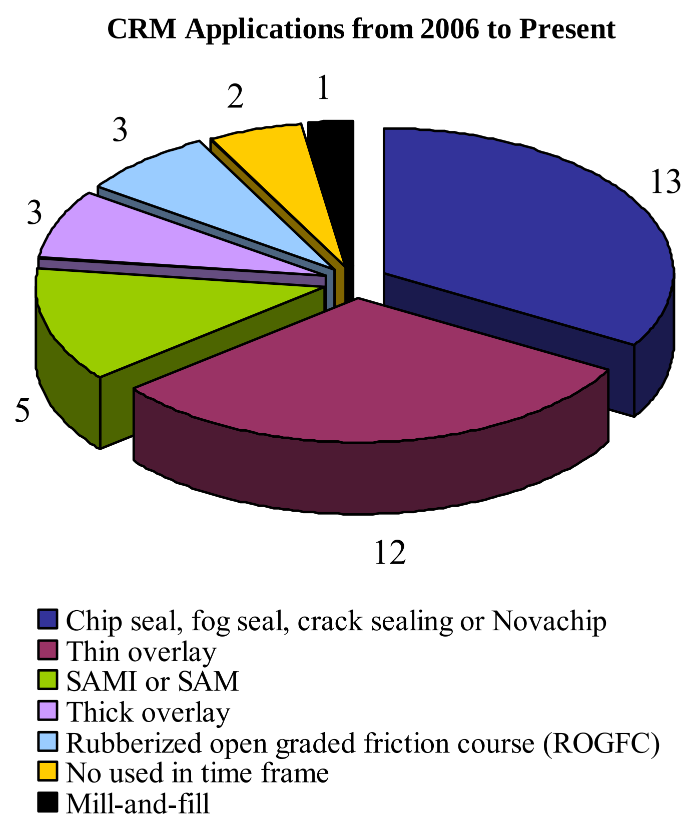


Figure 25. Type of applications used or tried by state DOTs from 2006 to the present

- Few agencies indicated that they currently provide (or plan to provide) to contractors the choice of using either CRM modified binder or SBS modified binder when the project calls for modified binder or using CRM in pavement preservation methods.

- One agency (Indiana DOT) reported using crumb rubber (shredded tires) in embankments because it is more cost effective and uses more scrap tires than CRM asphalt applications.

- For several state DOTs, the negative experiences and premature failures of pilot projects or experimental sections in the late 1980s and the 1990s still persuade administrators and engineers against trying CRM applications again. However, the development of technologies and methods, together with over three decades of field experience and research, has significantly improved the state of practice of CRM asphalt applications in the United States.

- Several states have specifications and/or special provisions for asphalt rubber modifiers, rubberized open-graded friction courses and other crumb rubber surface treatments and applications. Theses include New Mexico, California, Florida, Arizona, Rhode Island and New Jersey DOTs, among others. In other cases, specifications do not recognize CRM as a modifier but do not disallow it either (e.g., Utah and Wisconsin).

6. Final Remarks and Recommendations

6.1 Performance

Poor or less-than-expected performance and some premature failures of asphalt rubber pavements in the nineteen eighties and nineties caused disappointment and frustration of many administrators and engineers who had to deal with the consequences of those unsuccessful trials. Skepticism and uncertainty about the performance of asphalt rubber pavements and preservation treatments are still present among a number of state DOTs. In the survey of state DOTs performed in this study (Section 5), 42% of the 19 agencies that have not used crumb rubber modifier in pavement applications stated that they do not use it, in part, because the performance of the asphalt rubber pavements is still uncertain.

The experience of state DOTs in California, Arizona, Florida and Texas with CRM modified asphalt concrete and asphalt-rubber surface treatments spans over two decades. Fortunately, the experience gained by these agencies and many contractors with these applications has lead to significant improvements of the methods, equipment and practice and the establishment of standards and specifications for CRM binders, AR modified asphalt concrete and a variety of rubberized asphalt surface treatments. It is fair to say that the quality expected from CRM binders produced today is different, and much better, than that of the original materials produced one or two decades ago. Additionally, the lessons learned from many pilot and routine projects, both successful and unsuccessful, have led some state agencies and contractors to determine adequate or optimal field placement conditions and identify the limitations of CRM binder applications.

The review of the research literature showed sufficient evidence, based on experimental results, that asphalt rubber modified binders and asphalt-rubber HMA concrete materials can have improved or comparable properties compared to non-CRM materials and conventional asphalt concrete mixtures. The interpretation and comparison of the available experimental data should be done with caution and consideration of all the factors that can affect the material properties. It is believe that this issue may have contributed to some contradictory conclusions about material performance and properties reported in the literature.

The evaluation of the NMDOT's distress data of ROGFC and non-ROGFC sample units showed that the ROGFC pavements have performed well in the short term (2 to 4 years) and the long term (5 to 9 years). When the distress rate value of the sample units was used as the indicator of performance, the ROGFC pavements had comparable or better performance than non-ROGFC pavements for the selected sample groups. Unfortunately, the ROGFC pavements on US 54 and US 62/NM were not originally conceived as experimental projects and thus their performance and maintenance throughout their service life were not collected and documented systematically and in sufficient detail.

6.2 Cost Considerations

Higher costs of CRM asphalt concrete compared to conventional materials has been a recurrent statement among both skeptics and advocates. Nevertheless, in the current survey, nearly 31% of the agencies that reported having used crumb rubber modifier stated that the use of this material is, or may be, cost effective for their agency and 26% of these agencies stated that they have significant incentives for using CRM from scrap ties in pavement applications. The environmental, social and financial benefits of recycling scrap tires, the expected better or comparable service life compared to conventional methods and materials, and the documented sound reduction properties of asphalt rubber pavements have jointly a strong weight on balancing higher costs for the agency or owner and collective benefits for the community. Unfortunately, there are very few LCCA studies for rubber asphalt pavements, and these analyses are mostly 10 to 20 years old. It is needed an updated, comprehensive LCCA for the rubber asphalt materials and methods used today.

In times of budgetary limitations, state agencies and local governments may find difficult to justify the use of more expensive materials while seeking better long-term performance without the support of data and comprehensive life cycle analyses. On a positive note, recent cost and bid information seems to indicate that the price difference between conventional and asphalt rubber concrete may be dropping. The use of asphalt rubber products in pavements in New Mexico should be based on documented performance, particular project conditions or requirements, and life cycle analyses.

Preliminary considerations of available materials (i.e., scrap tires generated and in stockpiles), current and anticipated local CRM demand, and cost of equipment to produce CRM indicate that establishing a new crumb rubber facility in New Mexico would not be financially feasible at this time. Fortunately, existing facilities in neighboring states could handle an increase in the demand of crumb rubber that would result from new rubberized asphalt projects in New Mexico. A significant fraction of scrap tires generated annually in the state is already exported to adjacent states for beneficial uses.

6.3 Recommendations

The following recommendations are presented based on the results of this study and the experience and data documented in the literature. Some of these recommendations are focused on NMDOT activities because this is the state agency in charge of the construction and maintenance of the state highway network and, therefore, the agency with the greatest potential for using CRM modified binders in New Mexico.

Design, Performance and Construction

i) To monitor and document the medium-term and long-term performance, maintenance actions and costs of NMDOT's new ROGFC pavement sections and control OGFC pavement sections in New Mexico. The data collection and documentation should be systematic and in sufficient detail, so that it can be used for performing life cycle cost analyses (LCCA) and cost benefit analyses (CBA) of these pavement sections. The results of LCCA and CBA for rubber asphalt pavements could greatly assist NMDOT in its priority and investment decisions concerning the use of CRM binders in highway pavement applications. In addition, performance data could help confirm or improve the NMDOT specifications for rubberized asphalt concrete in ROGFC overlays/inlays.

ii) To consider the feasibility and cost-benefits of designing and constructing structural pavement layers using CRM modified binders in New Mexico highways. Using CRM modified binders in structural layers could increase significantly the amount of scrap tires that would be processed into crumb rubber for beneficial use. The need for recycling a considerably greater number of scrap tires in the area could justify the economics of establishing and sustaining a new CRM processing facility in New Mexico. However, a greater demand for rubberized asphalt or asphalt-rubber in New Mexico highway projects would not guarantee by itself that the CRM used in these projects be produced from scrap tire originated in New Mexico.

iii) To determine what issues, if any, may arise regarding the recyclability of ROGFC in New Mexico when the existing ROGFC pavements would eventually require rehabilitation or reconstruction. Another issue to be considered is the effect of type and size of the crumb rubber on the asphalt concrete properties if used with reclaimed asphalt pavement (RAP) material in the construction and recycling of structural layers.

Scrap Tire Legislature and Policies

iv) To promote the cost-effective use of CRM modified binders in asphalt concrete and pavement surface treatments in city-, county- and state-maintained roads as well as those constructed by private initiatives and tribes or Pueblos in New Mexico. This task can be accomplished, in part, by the broad dissemination of accurate technical information and performance data, emphasizing the facts, research and unbiased reviews of case studies. The target audience would include the agencies that could potentially use, or increase the use of, CRM modified asphalt in the state. It is preferable that the dissemination efforts be delivered by an unbiased entity or group. These dissemination efforts could include educating the public and create awareness about the importance of processing scrap tires for beneficial uses in civil and transportation projects in New Mexico.

v) It is not advisable to create legislation mandating NMDOT to use CRM modified binder or rubberized asphalt. The interest and will to use recycled materials (including scrap tires) in beneficial applications already exists in this agency. The use of CRM modified binders should be driven solely by performance measures, LCCA and cost-benefit data.

vi) To encourage the use of rubber asphalt in New Mexico. A mechanism that could help achieve this task is implementing the existing Rubberized Asphalt Fund, created by the Recycling and Illegal Dumping Act. This Fund has not had a source of funding since its creation and, therefore, it has never been in effect. After a funding mechanism has been secured for the Rubberized Asphalt Fund, it could be administered as a grant program, similar to the Recycling and Illegal Dumping Fund or Scrap Tire Grants, by NMED and/or NMDOT. The Rubberized Asphalt Fund is intended to help NMDOT and local governments pay additional expenses that might result from using rubberized asphalt.

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APPENDICES

Appendix A

NMDOT's Distress Evaluation Chart for Flexible Pavements

DISTRESS	SEVERITY	EXTENT
Raveling & Weathering: The wearing away of the pavement surface, due to dislodged aggregate particles and loss of asphalt binder. Normally the extent will be throughout the test section.	Low: Aggregate or binder has started to wear away on (1) pavement surface. Some dislodged aggregate can be found on the shoulder. Med: Aggregate or binder has worn away. Surface texture is (2) rough and pitted. High: Aggregate and/or binder has worn away, and surface (3) texture is severely rough and pitted.	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Bleeding: A film of bituminous material on the pavement surface.	Low: Film is evident, but aggregate can still be seen. Spotty. (1) Med: Film is clearly seen, covers most of the aggregate, and is (2) a little sticky. High: Film is predominant, very sticky, and material is thick (3) enough to shove.	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Rutting and Shoving: Longitudinal surface depressions in wheel path. (Check with a 4-foot rut bar.)	Low: ¼-inch to ½-inch in depth. (1) Med: ½-inch to 1-inch in depth. (2) High: More than 1-inch in depth. (3)	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Cracks: **Longitudinal Cracks:** Wheel Track Mid-Lane Center Line **Transverse Cracks:** Full Width	Low: Sealed or non-sealed with a mean width of less than (1) ¼-inch. May have very minor spalls. Med: A. Sealed or non-sealed, and moderately spalled. Any (2) width. B. Sealed, but sealant separated, allowing water to penetrate. C. Non-sealed cracks that are not spalled, but are over ¼-inch wide. D. Low severity alligator cracks exist near crack, or at the corners of intersecting cracks. E. Causes a significant bump to a vehicle. High: A. Severely spalled. (Any width.) (3) B. Medium to high severity alligator cracks exists near the crack, or at the corners of intersecting cracks. C. Causes a severe bump to a vehicle.	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Alligator Cracks: Pattern of interconnected cracks resembling chicken wire or alligator skin.	Low: Hairline, disconnected cracks. 1/8-inch wide, or less. (1) no spalls. Med: Fully developed cracks greater than 1/8-inch wide. (2) Lightly spalled. High: Severely spalled. Cells rock. May pump. (3)	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Edge Cracks: Cracks which occur on the edge of the pavement.	Low: ¼-inch wide, or less. No spalls. (1) Med: Greater than ¼-inch wide. Some spalls. (2) High: Severely spalled. (3)	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)
Patching: An area where the original pavement has been removed and replaced with similar or different material. Types of Patching: Hot Mix Patch. Skin Patch. Other types (Please note on "note section" of the evaluation card.)	Low: Patch is present, and is in good condition. (1) Med: Somewhat deteriorated. Low to medium of any type of (2) distress on patch. High: Patch is deteriorated to point of soon or immediately (3) needing replacement.	Low: 1% to 30% of test section. (1) Med: 31% to 60% of test section. (2) High: 61% of test section, or more. (3)

Appendix B

Factors for Extent Ratings and Weight Factors for Flexible Pavements

Distress Type	Weight Factor	Extent Level	Extent Rating	Extent Factor
Raveling and Weathering	2	Low	1	0.3
		Medium	2	0.6
		High	3	1.0
Bleeding	3	Low	1	0.3
		Medium	2	0.6
		High	3	1.0
Rutting and Shoving	14	Low	1	0.5
		Medium	2	0.8
		High	3	1.0
Longitudinal Cracking	20	Low	1	0.7
		Medium	2	0.9
		High	3	1.0
Transverse Cracking	12	Low	1	0.7
		Medium	2	0.9
		High	3	1.0
Alligator Cracking	25	Low	1	0.7
		Medium	2	0.9
		High	3	1.0
Edge Cracking	3	Low	1	0.5
		Medium	2	0.8
		High	3	1.0
Patching	2	Low	1	0.3
		Medium	2	0.6
		High	3	1.0

Appendix C

Severity and Extent Ratings for Selected NMDOT Sample Units in US 62/NM 180

Sample Units in the Positive Direction (US 62/NM 180)

	MP 90 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	0	0	1	3	0	0	1	2	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	1	1	1	1	1	3	2	2	1	2	1	2	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	2	1
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	1	1	2	1	0	0	1	1	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		17.0		19.0		24.5		60.0		21.0		22.5		65.8	

	MP 91 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	3	2	3	1	2	1	2	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		4.5		24.5		43.0		21.0		22.5		49.0	

	MP 92 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	2	2	1	1	1	1	2	1	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		21.0		34.5		17.0		21.0		23.0	

	MP 93 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**1**	0	0	0	0	**1**	**2**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**1**	0	0	**1**	**2**	**1**	**1**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**2**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		3.0		17.0		4.2		21.0		18.5		47.8	

	MP 95 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**2**	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	**1**	**3**	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**1**	**1**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	**1**	**1**	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		4.2		5.0		3.0		4.5		17.0		18.5		65.8	

	MP 96 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**2**	**1**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**2**	**1**	**2**	**1**	**1**	**1**	**2**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**1**	0	0	0	0	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		3.6		21.3		24.0		17.0		21.0		49.0	

	MP 97 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**2**	**1**	**3**	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**3**	**2**	**2**	**1**	**3**	**1**	**1**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		4.2		5.0		24.5		40.5		23.0		17.0		49.0	

	MP 98 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**2**	**1**	**3**	0	0	**1**	**3**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**2**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**2**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		4.2		5.0		17.0		33.0		21.0		21.0		47.8	

	MP 99 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**3**	**1**	**3**	0	0	**1**	**2**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**1**	**2**	**1**	**3**	**1**	**3**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	**1**	**1**	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		5.0		5.0		17.0		23.7		23.0		24.5		65.8	

	MP 100 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	2	1	3	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	1	1	1	1	1	2	2	1	1	3	1	2	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	2	3
Distress Rate (DR)	3.0		3.0		18.2		19.0		22.5		32.5		23.0		22.5		65.8	

	MP 101 P																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	2	1	2	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	0	0	2	2	1	3	1	3	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	2	1
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	1	1	2	2	0	0	1	3	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		4.2		4.2		16.5		43.8		23.0		26.0		65.8	

	MP 102 P									
Years since Construction	0		1		4		6		7	
Evaluation Year	2002		2003		2006		2008		2009	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	2	1	1	3	1	3
2. Bleeding	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	1	3	1	1	1	1	1	1
5. Transverse Cracking	0	0	1	3	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		35.0		17.0		17.0		17.0	

	MP 104 P											
Years since Construction	0		1		4		6		7		9	
Evaluation Year	2002		2003		2006		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**2**	**1**	**1**	0	0	**1**	**2**
3. Rutting & Shoving	0	0	0	0	**1**	**3**	0	0	0	0	**1**	**2**
4. Longitudinal Cracking	0	0	**1**	**3**	**1**	**1**	**1**	**1**	0	0	**2**	**1**
5. Transverse Cracking	0	0	**1**	**3**	0	0	**1**	**1**	**1**	**1**	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		35.0		32.2		26.0		11.4		60.2	

Sample Units in the Minus Direction (US 62/NM 180)

	MP 90 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**1**	0	0	**1**	**2**	**1**	**2**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**1**	0	0	**1**	**1**	**2**	**2**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		18.5		6.0		21.0		22.5		64.6	

	MP 91 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**2**	**2**	**2**	**1**	**3**	**1**	**3**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**2**	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.0		3.0		21.0		39.6		23.0		25.4		65.8	

	MP 92 M															
Years since Construction	0		1		2		3		4		5		6		7	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	2	1	1	3	1	3
2. Bleeding	0	0	0	0	1	1	1	1	0	0	2	1	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	3	0	0	1	2	1	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	2	3	0	0	1	1
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		23.0		21.0		26.5		21.0		24.5	

	MP 93 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	1	1	2	0	0	1	2	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	1	2	1	1	3	1	3	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	2	1	0	0	1	1	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		4.2		17.0		35.2		23.0		24.5		65.8	

	MP 95 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	1	1	2	1	1	1	3	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		3.6		17.0		21.6		17.0		23.0		49.0	

	MP 96 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**2**	**1**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**1**	**1**	**2**	0	0	**1**	**3**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	0	**1**	**1**	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		4.2		18.5		19.0		17.0		30.9		65.8	

	MP 97 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	**2**	**1**	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**3**	**1**	**2**	**1**	**3**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0	**2**	**1**
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**2**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		17.6		17.6		29.4		43.0		22.2		24.5		64.6	

	MP 98 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	**1**	**1**	**1**	**1**	0	0	**1**	**2**	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	**1**	**2**	**1**	**1**	**1**	**3**	**2**	**2**	**1**	**3**	**1**	**3**	**2**	**3**
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**	**2**
6. Alligator Cracking	0	0	0	0	0	0	**1**	**1**	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	**1**	**3**	**1**	**1**	**2**	**1**	0	0	**1**	**2**	**2**	**3**
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		21.6		38.1		24.5		43.2		23.0		33.8		70.6	

	MP 99 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	1	1	3	0	0	1	3	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	0	0	0	0	1	1	2	1	1	3	1	2	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	1	1	2	1	0	0	1	1	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		3.6		5.0		18.5		36.0		23.0		22.5		49.0	

	MP 100 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Longitudinal Cracking	0	0	0	0	1	1	1	1	1	2	2	3	1	3	2	1	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Alligator Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	1	1	1	2	2	1	1	1	1	2	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		17.6		18.5		23.4		46.6		24.5		33.4		49.0	

	MP 101 M																	
Years since Construction	0		1		2		3		4		5		6		7		9	
Evaluation Year	2002		2003		2004		2005		2006		2007		2008		2009		2011	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
2. Bleeding	0	0	0	0	1	3	1	3	0	0	1	1	0	0	0	0	0	0
3. Rutting & Shoving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
4. Longitudinal Cracking	0	0	0	0	1	1	1	3	1	3	2	3	2	2	1	3	2	3
5. Transverse Cracking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
6. Alligator Cracking	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	2	2
7. Edge Cracking	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	2	2	3
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		3.0		19.0		42.5		25.4		65.9		43.8		25.4		117.8	

	MP 102 M											
Years since Construction	0		1		4		5		6		7	
Evaluation Year	2002		2003		2006		2007		2008		2009	
	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext	Sev	Ext
1.Raveling & Weathering	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
2. Bleeding	0	0	0	0	0	0	**1**	**2**	0	0	**1**	**1**
3. Rutting & Shoving	0	0	0	0	**2**	**1**	**1**	**1**	0	0	**1**	**3**
4. Longitudinal Cracking	0	0	**1**	**3**	**1**	**3**	**2**	**2**	**2**	**3**	**2**	**1**
5. Transverse Cracking	0	0	0	0	**3**	**1**	**3**	**1**	**3**	**1**	0	0
6. Alligator Cracking	0	0	**1**	**1**	0	0	0	0	0	0	0	0
7. Edge Cracking	0	0	0	0	0	0	0	0	0	0	0	0
8. Patching	0	0	0	0	0	0	0	0	0	0	0	0
Distress Rate (DR)	3.0		40.5		62.2		72.4		68.2		46.8	

Appendix D

NMDOT's *Special Provisions for Rubberized Open Graded Friction Course*,
Section 404-A

Appendix E

2011 Survey of state DOTs "Use of Crumb Rubber in Asphalt Concrete or Other Surface Treatments"

Please provide your contact information
Agency:
Name of person responding:
Position:
Complete address:
Email:
Phone:
Date:

Question 1: Has your agency used (or does it currently use) crumb rubber modifier (CRM) from scrap tires in hot mix asphalt (HMA) concrete or surface treatments (chip seal, fog seal, Stress Absorbing Membrane Interlayers, etc.)?

(   ) Yes
(   ) No

If your answer to question 1 is Yes, skip questions 2 and 3 continue to question 4.

Question 2: What are the main reasons for NOT using CRM in paving applications in your agency? (Mark all those that apply and/or write in your answer)

(   ) The higher cost of using CRM binder.
(   ) Using CRM asphalt is not cost effective for your agency.
(   ) The performance of CRM asphalt concrete and surface treatments is uncertain.
(   ) There is not sufficient incentive to recycling scrap tires in pavement applications.
(   ) There is not a crumb rubber producer in the state.
(   ) Other (write in): ________________________________
(   ) Other (write in): ________________________________

Question 3: Provide any other comment you wish to share.

If your answer to question 1 was No and you answered questions 2 and 3, you are done with the survey. Thanks!

<u>Question 4</u>: What are the main reasons for using CRM in paving applications in your agency? (Mark all those that apply and/or write in your answer)

( ) Using CRM asphalt is cost effective for your agency.
( ) The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.
( ) There are significant incentives to recycling scrap tires in pavement applications.
( ) Other (write in): ________________________________
( ) Other (write in): ________________________________

<u>Question 5</u>: What CRM applications have your agency used from 2006 to present (Mark all those that apply and/or write in your answer)

( ) Thin overlays (<60 mm)
( ) Structural overlays (> 60 mm)
( ) Chip seals and/or fog seals
( ) Stress Absorbing Membrane Interlayers (SAMI)
( ) Other (write in): ________________________________

<u>Question 6</u>: What crumb rubber method or process is used?

( ) Terminal blend (wet process)
( ) Field blend (wet process)
( ) Dry process

<u>Question 7</u>: Describe your recent experience (last 5 years) with the use of CRM asphalt binders and performance of asphalt rubber pavements.

<u>Question 8</u>: Provide any other comment and file you wish to share.

Appendix F

2011 Survey Responses

Contact information of survey responders:

Agency	Name	Position	Address	Email	Telephone
Alabama DOT	Gary Loyd, E.I.	Assistant to State Bituminous Engineer	Alabama DOT 3704 Fairground Road Montgomery, AL 36110	loydg@dot.state.al.us	(334) 206-2392
Alaska DOT&PF	Steve Saboundjian, Ph.D., P.E.	State Pavement Engineer	Alaska DOT&PF Statewide Materials 5800 East Tudor Road Anchorage, AK 99507	steve.saboundjian@alaska.gov	(907) 269-6214
Arizona DOT	Paul T. Burch, P.E	Chief Pavement Design Engineer	Arizona DOT 1221 N. 21st Ave. Phoenix, AZ 85009	PBurch@azdot.gov	(602) 712-8085
Arkansas State Highway and Transportation Department	Michael C. Benson	State Materials Engineer	Arkansas State Highway and Transportation Department 11301 W. Baseline Little Rock, AR 72209	Michael.Benson@arkansashighways.com	(501) 569-2185
California DOT	Haiping Zhou, Ph.D.	Transportation Engineer	Caltrans Office of Asphalt Pavements, MS-91 2389 Gateway Oaks Suite 200 Sacramento, CA 95833	haiping_zhou@dot.ca.gov	(916) 274-6022
Colorado DOT	Michael (Steve) Olson, P.E.	Materials and Geotechnical Branch Asphalt Program Manager	Colorado DOT 4670 North Holly Street Unit A Denver, CO 80216	Michael.Olson@dot.state.co.us	(303) 398-6576
Connecticut DOT	(No Response)				
Delaware DOT	James (Jim) Pappas, P.E.	Assistant Director - Design	Delaware DOT 800 Bay Road Dover, DE 19903	james.pappas@state.de.us	(302) 760-2379
District of Columbia DOT	Wasi Khan	Materials Engineer	DC DOT 55 M Street SE Washington DC 20003	wasi.khan@dc.gov	(202) 671-2316

Agency	Name	Position	Address	Email	Telephone
Florida DOT	Jim Musselman, P.E.	State Bituminous Materials Engineer	Florida DOT 5007 NE 39th Avenue Gainesville, FL 32609	jim.musselman@dot.state.fl.us	(352) 955-2905
Georgia DOT	Peter Wu, P.E.	Assistant State Materials & Research Engineer	Georgia DOT Office of Materials & Research 15 Kennedy Drive Forest Park, GA 30297	pwu@dot.ga.gov	(404) 608-4840
Hawaii DOT	(No Response)				
Idaho DOT	Michael J. Santi, P.E.	Assistant Materials Engineer	Idaho DOT P.O. Box 7129 Boise, Idaho 83707-1129	mike.santi@itd.idaho.gov	(208) 334-8450
Illinois DOT	Thomas G. Zehr, P.E.	HMA Implementation Engineer	Illinois DOT 126 E. Ash St. Springfield, IL 62704	thomas.zehr@illinois.gov	(217) 524-7268
Indiana DOT	Ronald Walker	Materials Engineer	Indiana DOT 120 S Shortridge Rd. Indianapolis, IN 46219	rwalker@indot.in.gov	(317) 610-7251
Iowa DOT	Scott Schram, Ph.D., P.E.	Bituminous Engineer	Iowa DOT Office of Materials 800 Lincoln Way Ames, IA 50010	scott.schram@dot.iowa.gov	(515) 239-1604
Kansas DOT	(No Response)				
Kentucky DOT	Allen H. Myers, P.E.	Director Division of Materials	Kentucky Transportation Cabinet Department of Highways 1227 Wilkinson Boulevard Frankfort, KY 40601-1226	Allen.Myers@ky.gov	(502) 564-3160
Louisiana DOT	William (Bill) King, Jr., P.E.	Asphalt Materials Research Engineer	Louisiana DOTD/LTRC 4101 Gourrier Ave. Baton Rouge, LA 70808	bill.king@la.gov	(225) 767-9129
Maine DOT	(No Response)				

Agency	Name	Position	Address	Email	Telephone
Maryland SHA	Rebeccah Smith	Assistant Division Chief, Asphalt Technology Division, Office of Materials Technology	Maryland State Highway Administration 7450 Traffic Dr., Bldg. 4 Hanover, Maryland, 21076	rsmith8@sha.state.md.us	(443) 572-5112
Massachusetts DOT	(No Response)				
Michigan DOT	Curtis Bleech	HMA Operations Engineer	Michigan DOT 8885 Ricks Road PO Box 30049 Lansing, MI, 48909	bleechc@michigan.gov	(517) 322-1237
Minnesota DOT	Curt Turgeon, P.E.	State Pavement Engineer	Minnesota DOT 1400 Gervais Avenue Maplewood, MN 55109	curt.turgeon@state.mn.us	(651) 366-5535
Mississippi DOT	Jeremy Robinson, P.E.	Lab Operations Engineer	Mississippi DOT P.O. Box 1850 Jackson, MS 39215	wjrobinson@mdot.state.ms.us	(601) 359-9770
Missouri DOT	(No Response)				
Montana DOT	Matt Strizich, P.E.	Materials Engineer	Montana DOT P.O. Box 201001 Helena, MT 59620-1001	mstrizich@mt.gov	(406) 444-6297
Nebraska DOR	(No Response)				
Nevada DOT	Reid G. Kaiser, P.E., CPM	Chief Materials Engineer	Nevada DOT 1263 South Stewart St. Carson City, NV 89712	rkaiser@dot.state.nv.us	(775) 888-7520
New Hampshire DOT	Denis M. Boisvert, P.E.	Chief of Materials Technology	New Hampshire DOT P.O. Box 483 5 Hazen Drive Concord, NH 03302-0483	dboisvert@dot.state.nh.us	(603) 271-1545
New Jersey DOT	Robert J. Blight	Project Engineer Materials	New Jersey DOT 930 Lower Ferry Road, B. 2 P.O. Box 607 Trenton, NJ 08625-0607	robert.blight@dot.state.nj.us	(609) 530-4445

Agency	Name	Position	Address	Email	Telephone
New Mexico DOT	Parveez Anwar, P.E.	State Asphalt Engineer	New Mexico DOT P.O. Box 1149 1120 Cerrillos Road Santa Fe, NM 87504	Parveez.Anwar@state.nm.us	(505) 827-5656
New York State DOT	Zoeb Zavery, P.E.	Materials Engineer, CE 2	New York State DOT 50 Wolf Road Albany, NY 12232	zzavery@dot.state.ny.us	(518) 485 5277
North Carolina DOT	Christopher (Chris) A. Peoples, P.E.	State Materials Engineer	North Carolina DOT 1801 Blue Ridge Rd. Raleigh, NC 27607-6401	cpeoples@ncdot.gov	(919) 329-4000
North Dakota DOT	Joe A. Davis	Bituminous Engineer	North Dakota DOT 608 East Boulevard Ave. Bismarck, ND 58505-0700	jdavis@nd.gov	(701) 328-6912
Ohio DOT	Dave Powers, P.E.	Asphalt Materials Engineer	Ohio DOT 1600 West Broad St. Columbus, Ohio 43223	david.powers@dot.state.oh.us	(614) 275-1387
Oklahoma DOT	Kenneth Ray Hobson, P.E.	Bituminous Engineer	Oklahoma DOT Materials Division 200 NE 21st Street Oklahoma City, OK 73104-3204	khobson@odot.org	(405) 522-4986
Oregon DOT	Mike Stennett, P.E. (w/input from Larry Ilg, P.E.)	Assistant Pavement Materials Engineer	Oregon DOT 800 Airport Rd SE Salem, OR 97301	Michael.J.Stennett@odot.state.or.us	(503) 986-6574
Pennsylvania DOT	Scott T. Nazar	Section Chief for Pavement Materials	Pennsylvania DOT Bureau of Maintenance and Operations 400 North Street (6th floor keystone Bldg) Harrisburg, PA 17120	snazar@state.pa.us	(717) 425-7640
Rhode Island DOT	Bryan Engstrom	Civil Engineer (Materials & QA)	Rhode Island DOT 2 Capitol Hill Providence, RI 02903	bengstrom@dot.ri.gov	(401) 222-2524

Agency	Name	Position	Address	Email	Telephone
South Carolina DOT	(No Response)				
South Dakota DOT	Rick Rowen	Bituminous Engineer	South Dakota DOT 104 S Garfield Ave. Pierre, SD 57501	rick.rowen@state.sd.us	(605) 773-3427
Tennessee DOT	(No Response)				
Texas DOT	Gerald D. Peterson, P.E.	Asphalt and Chemical Branch Manager	Texas DOT Construction Division/ Materials and Pavements 125 E. 11th Street Austin, TX 78701-2483	Jerry.Peterson@TxDOT.gov	(512) 506-5821
Utah DOT	Kevin VanFrank, P.E.	Engineer for Asphalt Materials	Utah DOT 4501 South 2700 West P.O. Box 145950 Taylorsvill, Utah 84119	kvanfrank@utah.gov	(801) 965-4426
Vermont AOT	Mark W. Ljungvall, P.E.	Materials Engineer	Vermont AOT 1 National Life Drive Montpelier, VT 05633-5001	mark.ljungvall@state.vt.us	(802) 828-6930
Virginia DOT	William R. Bailey III, P.E.	Assistant State Materials Engineer	Virginia DOT 1401 East Broad Street Richmond, VA 23219	bill.bailey@vdot.virginia.gov	(804) 328-3106
Washington State DOT	Joe DeVol	Bituminous Materials Engineer	Washington State DOT Box 47365 Olympia, WA 98504-7365	devolj@wsdot.wa.gov	(360) 790-5421
West Virginia Division of Highways	Larry R. Barker	Asphalt Section Supervisor	West Virginia Division of Highways Materials Division 190 Dry Branch Drive Charleston, WV 25306	larry.r.barker@wv.gov	(304) 558-7473
Wisconsin DOT	Judie Ryan	Engineering Specialist - HMA	Wisconsin DOT 3502 Kinsman Blvd Madison, WI 53704	judith.ryan@dot.wi.gov	(608) 246-5456

Agency	Name	Position	Address	Email	Telephone
Wyoming DOT	Bruce Morgenstern, P.E.	Asphalt Engineer	Wyoming DOT Materials Program 5300 Bishop Blvd. Bldg. 6101 Cheyenne, WY 82009-3340	Bruce.Morgenstern@dot.state.wy.us	(307) 777-4271

<u>Question 1:</u> Has your agency used (or does it currently use) crumb rubber modifier (CRM) from scrap tires in hot mix asphalt (HMA) concrete or surface treatments?
<u>Question 2:</u> What are the main reasons for NOT using CRM in paving applications in your agency?
<u>Question 4:</u> What are the main reasons for using CRM in paving applications in your agency?

N/A means "not applicable"

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
Alabama DOT	Yes	N/A	- Alabama was interested in the cost savings when the price of SBS was high.
Alaska DOT&PF	Yes	N/A	To minimize studded tire wear.
Arizona DOT	Yes	N/A	- Using CRM asphalt is cost effective for your agency - The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials. - There are significant incentives to recycling scrap tires in pavement applications.
Arkansas State Highway and Transportation Department	No	- The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your Agency. - There is not a crumb rubber producer in the state.	N/A

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
California DOT	Yes	N/A	- Using CRM asphalt is cost effective for your agency. Might be for large job - The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials. In general, it is very effective in retarding reflective cracking. - There are significant incentives to recycling scrap tires in pavement applications. For local agencies (cities and counties), yes. - Mandatory requirement by CA AB 338.
Colorado DOT	No	- The performance of CRM asphalt concrete and surface treatments is uncertain.	N/A
Connecticut DOT	(No Response)		
Delaware DOT	Yes	N/A	- To check performance versus conventional materials.
District of Columbia DOT	No	- The higher cost of using CRM binder - Using CRM asphalt is not cost effective for your agency - There is not a crumb rubber producer in the state.	N/A
Florida DOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials. - State of Florida legislation.
Georgia DOT	Yes	N/A	- Using CRM asphalt is cost effective for your agency. - There are significant incentives to recycling scrap tires in pavement applications.
Hawaii DOT	(No Response)		

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
Idaho DOT	No	- The higher cost of using CRM binder - Using CRM asphalt is not cost effective for your agency. - The performance of CRM asphalt concrete and surface treatments is uncertain. - There is not a crumb rubber producer in the state.	N/A
Illinois DOT	Yes	N/A	- Using GTR modified AC can reduce or eliminate the need to use fibers in some (SMA) mixes, resulting in cost savings.
Indiana DOT	No	- We use CRM in embankments which is more cost effective and uses more tires.	N/A
Iowa DOT	No	- The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your agency.	N/A
Kansas DOT	(No Response)		
Kentucky DOT	Yes	N/A	- Kentucky has very little experience with CRM. We constructed one resurfacing project in 1993 that involved ground-tire rubber added to the asphalt binder. We also completed an asphalt membrane interlayer placed directly on the subgrade and covered with conventional asphalt pavement in 1995. This project involved a spray application of asphalt binder covered with a mixture of recycled-tire chips and aggregate.
Louisiana DOT	Yes	N/A	- Using CRM asphalt is cost effective for your agency. - Equal Performance vs Conv Asphalt.

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
Maine DOT	(No Response)		
Maryland SHA	No	- The cement industry uses most of the available scrap tire in Maryland as fuel in the cement making process.	
Massachusetts DOT	(No Response)		
Michigan DOT	No	- Contractors not using	N/A
Minnesota DOT	No	- The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your agency. - The performance of CRM asphalt concrete and surface treatments is uncertain. - There is not sufficient incentive to recycling scrap tires in pavement applications. - There is not a crumb rubber producer in the state. - Past experience showed no advantage_-thermal cracks. - Use of polymers has shown excellent performance.	N/A
Mississippi DOT	No	- The performance of CRM asphalt concrete and surface treatments is uncertain.	N/A
Missouri DOT	(No Response)		
Montana DOT	No	- Using CRM asphalt is not cost effective for your agency. - There is not a crumb rubber producer in the state.	N/A
Nebraska DOR	(No Response)		
Nevada DOT	Yes	N/A	- There are significant incentives to recycling scrap tires in pavement applications. - Political – Environmental reasons.

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
New Hampshire DOT	No	- It had been tried in the 1990s with poor results.	N/A
New Jersey DOT	Yes	N/A	- Using CRM asphalt is cost effective for your agency. - The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials. - There are significant incentives to recycling scrap tires in pavement applications.
New Mexico DOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.
New York State DOT	Yes	N/A	- So far, the performance HMA with CRM is equal to our conventional mix on the experimental project. It is our intent to provide contractors a choice of either using CRM or SBS when project calls for modified binder. CRM used in maintenance products such as thin lift–gap graded courses are offered as an alternative for specifiers. Chip Seal using CRM were used as part of an initiative to use waste tires.
North Carolina DOT	No	- The performance of CRM asphalt concrete and surface treatments is uncertain. - NC DOT had some pilot projects in the late eighties with crumb rubber with poor results.	N/A
North Dakota DOT	Yes	N/A	- Meets our specifications and good performance.

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
Ohio DOT	Yes/No	Not currently using due to: - The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your agency. - There is not sufficient incentive to recycling scrap tires in pavement applications.	- We used in the 1990s for a time.
Oklahoma DOT	Yes	N/A	- It is a local decision.
Oregon DOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.
Pennsylvania DOT	Yes	N/A	- There are significant incentives to recycling scrap tires in pavement applications.
Rhode Island DOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.
South Carolina DOT	(No Response)		
South Dakota DOT	No	- There is not a crumb rubber producer in the state.	N/A
Tennessee DOT	(No Response)		
Texas DOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.
Utah DOT	No	- We rely on the free market to meet performance specifications. CRM may or may not be used.	N/A
Vermont AOT	Yes	N/A	- The performance of CRM asphalt concrete and surface treatments is better than that of conventional materials.

Agency	Question 1: Used or use CRM?	Question 2: Reasons for NOT using CRM	Question 4: Reasons for using CRM
Virginia DOT	No	- The higher cost of using CRM binder. - There is not a crumb rubber producer in the state. - No experience with product.	N/A
Washington State DOT	No	- The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your agency. - The performance of CRM asphalt concrete and surface treatments is uncertain. - Previous use of CRM in both open graded and dense graded applications in this state have shown reduced, or little to no, service life improvement.	N/A
West Virginia Division of Highways	No	- The higher cost of using CRM binder. - The performance of CRM asphalt concrete and surface treatments is uncertain. - There is not a crumb rubber producer in the state. - Have had great success with the use of polymer-modified binders and emulsions in problem pavement areas.	N/A
Wisconsin DOT	Yes	N/A	- Potential for reduction of cracking.
Wyoming DOT	No	- The higher cost of using CRM binder. - Using CRM asphalt is not cost effective for your agency. - The performance of CRM asphalt concrete and surface treatments is uncertain.	N/A

Question 5: What CRM applications have your agency used from 2006 to present?
Question 6: What crumb rubber method or process is used?
Question 7: Describe your recent experience (last 5 years) with the use of CRM asphalt binders and performance of asphalt rubber pavements.

Agency	**Question 5: CRM applications from 2006 to present**	**Question 6: Method or process**			**Question 7: Recent experience with CRM (last 5 years)**
		Wet process		Dry process	
		Terminal blend	Field blend		
Alabama DOT	- Thin overlays (<60 mm) - Surface Mix	X			Alabama Department of Transportation has an experimental test section, which contains approximately 500 tons. The test section is performing well.
Alaska DOT&PF	- Mill-and-Fill: Milling 1.5"~40mm HMA, then filling with 1.75"~45mm rubber HMA.			X	Please refer to our recent publication: http://www.dot.state.ak.us/stwddes/research/assets/pdf/fhwa_ak_rd_10_03.pdf
Arizona DOT	- Thin overlays (<60 mm). - Structural overlays (> 60 mm). - Chip seals and/or fog seals. - Stress Absorbing Membrane Interlayers (SAMI).	X	X		CRM asphalt binders are regularly utilized in open graded friction courses with good performance. Recently we have constructed several structural overlays using Terminal Blend Rubber products (PG 70-22 TR+, PG 76-22 TR+) with good success. CRM gap graded mixes have not been utilized as much by the Department the past several years due to performance issues.
Arkansas State Highway and Transportation Department	N/A	N/A	N/A	N/A	N/A

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
California DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals. - Stress Absorbing Membrane Interlayers (SAMI).	X	X	X	Less than desirable due to premature failures on some projects.
Colorado DOT	N/A	N/A	N/A	N/A	N/A
Connecticut DOT	(No Response)				
Delaware DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals.	X	X		Our HMA overlay is only 3 years old but is performing fine; surface treatment is performing well.
District of Columbia DOT	N/A	N/A	N/A	N/A	N/A
Florida DOT	- Thin overlays (<60 mm). - Stress Absorbing Membrane Interlayers (SAMI). - Open graded friction courses.		X		FDOT has been using CRM asphalt binders routinely in friction courses and SAMI layers since 1994. We have seen an improvement in rutting resistance and cracking resistance as compared to unmodified binders. However, while performance is better than unmodified binders, it is not quite as good as performance with polymer (SBS) modified binders.
Georgia DOT	- There are significant incentives to recycling scrap tires in pavement applications.	X		X	Since 2008, GDOT contractors have placed more than 150,000 tons of CRM modified asphalt on Georgia's interstates and state routes. Except one project with wet process, everything else has been placed with dry process. All projects with CRM are still performing so far with only a couple of small sections on ramps (about 20 ft – 25 ft) had premature raveling which was corrected.
Hawaii DOT	(No Response)				
Idaho DOT	N/A	N/A	N/A	N/A	N/A

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
Illinois DOT	(Left Blank)	X			(No comments)
Indiana DOT	N/A	N/A	N/A	N/A	N/A
Iowa DOT	N/A	N/A	N/A	N/A	N/A
Kansas DOT	(No Response)				
Kentucky DOT	- None, our one and only CRM project occurred in 1993.	X			Kentucky has no CRM experience in the past five years.
Louisiana DOT	- Structural overlays (> 60 mm).		X	X	We have had great success using the CRM in HMA. With shortages and increased cost of polymers, this is a good alternative.
Maine DOT	(No Response)				
Maryland SHA	N/A				
Massachusetts DOT	(No Response)				
Michigan DOT	N/A	N/A	N/A	N/A	N/A
Minnesota DOT	N/A	N/A	N/A	N/A	N/A
Mississippi DOT	N/A	N/A	N/A	N/A	N/A
Missouri DOT	(No Response)				
Montana DOT	N/A	N/A	N/A	N/A	N/A
Nebraska DOR	(No Response)				

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
Nebraska DOR	(No Response)				
Nevada DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals.	X	X		Nevada DOT uses terminal blend in about 50,000 wet tons annually and are very pleased w/ its performance. We have had one successful project using the WET process for crumb rubber and it was a concrete overlay in Las Vegas. We have tried crumb rubber in the northern portion of the state but only get roughly 6 months to 2 years of life from it (very bad).
New Hampshire DOT	N/A	N/A	N/A	N/A	N/A
New Jersey DOT	- Thin overlays (<60 mm). - Rubber Modified Open Graded Friction Course.	X			We've used rubber only in Rubber Modified Open Graded Friction Course in thin overlay applications. We've completed about 5 to 6 projects since 2007 on some heavily trafficked interstates. Overall our experience has been good with respect to the mix and the final ride quality. Some issues we've experienced are: a. Our most prevalent issue is with winter maintenance of these Rubber Modified Open Graded Friction Course surfaces. They require larger quantities of salt and more frequent treatments. The plows have also done some damage to these surfaces early in the life of these pavements. We are currently monitoring these pavements to determine if we will get the design life or if they will fail prematurely due to the plow damage.

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
New Jersey DOT (continued)	- Thin overlays (<60 mm) - Rubber Modified Open Graded Friction Course.	X			b. During construction of a few projects, some rubber swelling issues showed up as blobs on the pavement surface immediately after the laydown. This was removed and replaced by each contractor. c. We tried one rubber modified SMA that failed air voids. By specification, our target air void range was 2 to 7%. The contractor averaged 10 percent air voids for the project resulting in a significant penalty. After further forensic investigation (coring and lab testing the cores for air voids, permeability, TTI overlay testing, APA rut testing and TSR) it was determined that the layer was structurally sound however, susceptible to stripping (low TSR) and needed to be surface sealed. It was determined that the mix was not properly designed and experienced rubber swelling which contributed to the high air voids. We just completed an ultra-thin friction course overlay about 2 weeks ago.
New Mexico DOT	- Chip seals and/or fog seals. - Open Graded Friction Course.	X			Recently, we are using CRM in Open Graded Friction Courses and Fog Seal. I believe the performance of Rubberized OGFC & Rubberized Fog Seal Applications is working out good.

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
New York State DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals. - Surface Treatments (Novachip).	X			Experience has been positive. NY has allowed an option of using a PG binder modified with either SBS or CRM in limited HMA contracts NY as long the specified grade and the elastic recovery of 60+ is met. In the meantime, NY has an ongoing research project to determine if the binder modified with terminal blend CRM with rubber particles can be accurately graded using PG grading system. Experience with CRM in chip seals has been mixed. The product has performed well in terms of sealing the pavement. However, it has had some issues with bleeding/raveling. We have not placed any CRM chip seals in the past two years.
North Carolina DOT	N/A	N/A	N/A	N/A	N/A
North Dakota DOT	- Crack Sealing.	X			(No recent experience)
Ohio DOT	- Thin overlays (<60 mm).	X			Placed 3 projects in 2009 as part of grant with Ohio Department of Natural Resources (DNR).
Oklahoma DOT	- Chip seals and/or fog seals.	X			Most of the work has been with AC15-5TR or AC20-5TR for chip seals and some TRSS-1 for fog seals.
Oregon DOT	- Chip seals and/or fog seals.	X			Hot chip seals used on higher volume roads with the goal of improving pavement surface with least disruption to traveling public. Performance of the AC15-5TR has been good.

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
Pennsylvania DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals.		X	X	Three case studies: ftp://ftp.dot.state.pa.us/public/bureaus/design/SEMP/FACTS/Crumb%20Rubber%20District%203-0.pdf ftp://ftp.dot.state.pa.us/public/bureaus/design/SEMP/FACTS/Crumb%20Rubber%20District%201-0.pdf ftp://ftp.dot.state.pa.us/public/bureaus/design/SEMP/FACTS/Rubberized%20Asphalt%20Seal%20CoatRubber%20District%208-0%20%282%29.pdf
Rhode Island DOT	- Thin overlays (<60 mm). - Chip seals and/or fog seals. - Stress Absorbing Membrane Interlayers (SAMI).	X	X		We have had good experience using CRM in a few different applications. Performance and construction during these applications have gone well with little modification to standard procedures. However, it would be beneficial to have more guidance when testing larger mesh sizes in the DSR when blended with binder.
South Carolina DOT	(No Response)				
South Dakota DOT	N/A	N/A	N/A	N/A	N/A
Tennessee DOT	(No Response)				

Agency	Question 5: CRM applications from 2006 to present	Question 6: Method or process			Question 7: Recent experience with CRM (last 5 years)
		Wet Process		Dry process	
		Terminal blend	Field blend		
Texas DOT	- Structural overlays (> 60 mm). - Chip seals and/or fog seals. - SMA, crack attenuating mixtures.	X	X		AC-20-5TR is a terminal blended, highly cured, rubber modified chip seal binder that has become the premium material in recent years. At times, it has been used for as much as 40% of our program. Users feel that they get excellent chip retention and resistance to flushing and tracking. Use in hot mix is mostly traditional field blended asphalt rubber binder. We have used this successfully in most of our open graded mixes to help with cracking resistance and to prevent draindown of binder in permeable mixes.
Utah DOT	N/A	N/A	N/A	N/A	N/A
Vermont AOT	- Chip seals and/or fog seals.		X		The process consisted of an application of a combined reacted mixture of hot paving grade asphalt and ground rubber followed immediately with an aggregate cover material. Within one year, the aggregate was no longer apparent and the surface became very slick. The worst area was cold-planed and paved with bituminous concrete. The remainder had a bituminous concrete overlay placed over the material.
Virginia DOT	N/A	N/A	N/A	N/A	N/A
Washington State DOT	N/A	N/A	N/A	N/A	N/A

Agency	**Question 5: CRM applications from 2006 to present**	**Question 6: Method or process**			**Question 7: Recent experience with CRM (last 5 years)**
		Wet Process		Dry process	
		Terminal blend	Field blend		
West Virginia Division of Highways	N/A	N/A	N/A	N/A	N/A
Wisconsin DOT	- No WisDOT applications (for the stated time frame).	X		X	None within that time period.
Wyoming DOT	N/A	N/A	N/A	N/A	N/A

<u>Question 3 (For those who responded 'No' to Question 1):</u> Provide any other comment you wish to share.
<u>Question 8 (For those who responded 'Yes' to Question 1):</u> Provide any other comment and/or file you wish to share

Agency	Question 3 or 8: Comments
Alabama DOT	(No comments)
Alaska DOT&PF	(No comments)
Arizona DOT	(No comments)
Arkansas State Highway and Transportation Department	A research project was completed in the mid 1990's. The additional cost was considered excessive and there were production and placement issues related to the addition of the crumb rubber.
California DOT	(No comments)
Colorado DOT	(No comments)
Connecticut DOT	(No Response)
Delaware DOT	(No comments)
District of Columbia DOT	Uncertain of environmental effects in urban areas?
Florida DOT	The State of Florida Legislature passed legislation in 1988 requiring FDOT to research the use of CRM asphalt and, if feasible, adopt specifications requiring their use. The specifications were adopted in 1994. In the early 2000's, we also started using polymer modified binders, and our usage of CRM asphalt dropped. However, it is still used on approximately 50% of our projects today.
Georgia DOT	Rubber is a product that provides long-term supply. This is a more cost-effective and competitive way to modify asphalt and it provides an outlay for scrap tires that may otherwise end up in landfills.
Hawaii DOT	(No Response)
Idaho DOT	(No comments)

Agency	Question 3 or 8: Comments
Illinois DOT	- AASHTO M-320, the specification for Performance-Graded Asphalt Binders, is not applicable for grading Ground Tire Rubber (GTR) modified asphalt because of the size of the discrete rubber particles. As a result, issues arise when trying to specify GTR modified AC in place of conventional PG Binder. - Terminal blend (wet process) is available. IDOT is open to a wet process where the GTR particles are completely. "digested", resulting in a homogeneous product that can be graded according to AASHTO M-320. - IDOT has had a specification for GTR modified asphalt for years and allows it as an experimental feature. However, IDOT does not require the use of GTR modified HMA. As a result, especially taking into account the difficulty grading available GTR modified asphalt, very few, if any, IDOT projects which include GTR have been constructed since the 1990's. The Illinois State Toll Highway Authority has paved quite a lot of projects using GTR modified asphalt. (Contact: Steve Gillen – Materials Engineer, (630) 241-6800 Ext 6898, sgillen@getipass.com).
Indiana DOT	(No comments)
Iowa DOT	The industry has not pushed on rubber modifiers, which has been a primary reason for not pursuing further implementation.
Kansas DOT	(No Response)
Kentucky DOT	(No comments)
Louisiana DOT	(No comments)
Maine DOT	(No Response)
Maryland SHA	MDSHA did a few pilot projects in the early 1990's, and found that it was not cost effective as it would greatly reduce the paving that we would be able to accomplish with the added cost. We used terminal blended material imported from Canada and the dry process, which required special plant equipment and produced much blue smoke. We realize that the technology has changed since that time, but our industry partners have a much greater interest in recycling the asphalt pavement (RAP) material that is milled when we are re-paving a roadway.
Massachusetts DOT	(No Response)
Michigan DOT	(No comments)
Minnesota DOT	(No comments)
Mississippi DOT	Our main concern with using CRM binders is the binder demand of the rubber additive. We are concerned that the rubber may reduce the effective asphalt content and lead to mixes that are susceptible to cracking. Our current design procedure does not take into account long term asphalt demand of the crumb rubber.

Agency	Question 3 or 8: Comments
Missouri DOT	(No Response)
Montana DOT	(No comments)
Nebraska DOR	(No Response)
Nevada DOT	(No comments)
New Hampshire DOT	(No comments)
New Jersey DOT	I've attached our Rubber Modified Open Graded Friction Course specification for your review and use.
New Mexico DOT	We did not use CRM in HMA or Structural Overlays in recent years. We used CRM in HMA (wet process) a few years ago and it did not work out well to continue using CRM in HMA projects. Terminal Blend Rubberized Asphalt may work out better, but we still have to try to check it out.
New York State DOT	(No comments)
North Carolina DOT	NC DOT has been approached again by two separate vendors and one contractor recently to explore the use of Ground Tire Rubber (GTR). We are considering future pilot projects and are awaiting some independent testing results.
North Dakota DOT	(No comments)
Ohio DOT	We have looked in the past at the wet, dry and Plus Ride processes. We now are curious about the newer processes using finer ground CRM and a binding agent but do not find the cost attractive.
Oklahoma DOT	It is unlikely that we would use CRM in a conventional mixture since 2/4 projects in the distant past had poor performance.
Oregon DOT	This last year ODOT opened up the Hot Chip Seal binders to include polymer modifiers (AC-15P). Performance appears to be equivalent (so far) and the price is competitive.
Pennsylvania DOT	(No comments)
Rhode Island DOT	I attached both our Paver Placed Elastomeric Surface Treatment (PPEST) and Rubberized Chip Seal specifications. The Rubberized Chip Seal is used as a SAMI in some instances.
South Carolina DOT	(No Response)
South Dakota DOT	(No comments)
Tennessee DOT	(No Response)

Agency	Question 3 or 8: Comments
Texas DOT	Chip seals have been our largest use of tires in TxDOT. Use may be somewhat reduced in upcoming years because the TR binders are typically higher in cost, and we have considerable pressure to use less expensive materials where it's appropriate, such as on low volume roads.
Utah DOT	Not used by specification.
Vermont AOT	Given the problems encountered in the project mentioned above, we have suspended use of this material.
Virginia DOT	(No comments)
Washington State DOT	(No comments)
West Virginia Division of Highways	(No comments)
Wisconsin DOT	Current WisDOT specifications don't recognize CRM as a stand-alone product. Specs also don't disallow but we typically don't see it optioned for use on our state highway projects. However, some of the local municipalities see it used more often (based on limited pools of contractors able to produce it).
Wyoming DOT	(No comments)