Evaluation of the Use of Scrap Tires in Transportation Related Applications in the State of Washington

Report to the Legislature as Required by SHB 2308

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LIST OF ACRONYMS

AASHTO: American Association of State Highway and Transportation Officials
AC: asphalt concrete
ADOT: Arizona Department of Transportation
AR: asphalt rubber
AR-AC: asphalt rubber-asphalt concrete
ARC: asphalt rubber concrete
AR-HMA: asphalt rubber hot-mix asphalt
ASTM: American Society of Testing & Materials
Caltrans: California Department of Transportation
CRM: crumb rubber modifier
CRM-HMA: crumb rubber modified hot-mix asphalt
DGAC: dense-graded asphalt concrete (dense-graded mix)
EPA: U.S. Environmental Protection Agency
FDOT: Florida Department of Transportation
FHWA: U.S. Department of Transportation, Federal Highway Administration
HMA: hot-mix asphalt
ISTEA: Intermodal Surface Transportation Efficiency Act
LTPP: Long Term Pavement Performance Program
NCHRP: National Cooperative Highway Research Program
NIOSH: National Institute for Occupational Safety and Health
ODOT: Oregon Department of Transportation
OGFC: Open-Graded friction course; same as PFC
PAV: pressure aging vessel
PBA: performance-based asphalt specification
PCCP: portland cement concrete pavement
PFC: porous friction course, same as OGFC
PG: performance grade
RAC-G: Rubber Asphalt Concrete – Gap Graded
RAP: reclaimed asphalt pavement
RUMAC: rubber-modified asphalt concrete (dry process)
SAM: stress absorbing membrane
SAMI: stress absorbing membrane interlayer
SBR: Styrene-butadiene
SHRP: Strategic Highway Research Program
SMA: stone matrix asphalt
Superpave: SUperior PERforming asphalt PAVEments
TAK: The first generic dry technology system
TxDOT: Texas Department of Transportation
USDOT: United States Department of Transportation
WSDOT: Washington State Department of Transportation

EXECUTIVE SUMMARY

House Bill 2308 (2002) directed the Washington State Department of Transportation to evaluate scrap tire use in civil engineering and road building applications. Specifically, HB 2308 directed evaluation of scrap tires for lightweight fills and rubber modified hot mix asphalt (HMA) pavement. In carrying out this study WSDOT conducted extensive literature searches on both lightweight fills and pavements, surveyed all 52 AASHTO members on their use of scrap tires, reviewed the FHWA protocol for constructing lightweight fills, and reviewed the history of lightweight fill and crumb rubber projects in Washington State.

Findings

Scrap tires are feasible in lightweight fills with fill heights less than 10 feet, given appropriate engineering design. Lightweight scrap tire fills have been subsidized in the past and would continue to need to be subsidized to be competitive.

Scrap tires, once shredded, may also be feasible materials for regular fills and embankments. Additional research on this use is needed.

Scrap tires, converted to crumb rubber, are also feasible as an additive to liquid asphalt in the construction of hot mix asphalt pavement in the hot weather areas of Eastern Washington south of Interstate 90 and east of the Cascade Range. Using crumb rubber modified hot mix asphalt (CRM-HMA) in the preservation program would increase construction costs by an estimated $4.9 million per year without any increase in overall performance life.

Study Results and Conclusions

Lightweight Fills

Scrap tires are feasible in lightweight fills with fill heights less than 10 feet, given appropriate engineering design and following the Federal Highway Administration (FHWA) guidelines. Risk for spontaneous combustion, while greatly reduced, is still present in fills less than 10 feet in height. Lightweight fills built with scrap tires in excess of 10 feet pose a much greater risk of spontaneous combustion, as happened on three shredded tire fills (two in Washington State and one in Colorado). While feasible, the market for lightweight fills less than 10 feet in height is very small, on the order 1000 cubic yards every four years. Lightweight scrap tire fills have been subsidized in the past and would continue to need to be subsidized to be competitive.

Crumb Rubber Modified Hot Mix Asphalt (CRM-HMA)

Scrap tires, converted to crumb rubber, are also feasible as an additive to liquid asphalt in the construction of hot mix asphalt pavement. Crumb rubber can successfully modify liquid asphalt and rubber modified liquid asphalts have been successfully used in hot weather

climate areas of Washington State in the construction of HMA pavement. Widespread use of crumb rubber in HMA has been slow to develop because of high initial cost and in-place performance that fails to either meet or exceed the performance of typical HMA pavements. More expensive initial costs and lower or similar life cycle costs keep the rubber-modified asphalts from competing in the low-bid free marketplace.

Using CRM-HMA in the preservation program would increase construction costs by an estimated $4.9 million per year without any increase in overall performance life of the pavement. Due to climatic restrictions, the use of rubber modified HMA would be limited to locations in Eastern Washington, south of Interstate 90 and east of the Cascade Range. .

Regular Fills

Scrap tires, once shredded, may also be feasible materials for regular fills and embankments. Unknown impacts on future construction/maintenance of fills built with scrap tires remain and could affect future construction and maintenance costs. Research on these potential impacts should be completed prior to the adoption of a scrap tire standard specification allowing tires to be considered as a fill material. At present, scrap tires would need to be subsidized in order to compete with traditional fill materials.

Other Potential Civil Engineering and Road Building Applications

Other engineering uses of scrap tires exist, including using whole scrap tires as anchors for tieback walls, as facing for geotextile walls and as scour protection for bridge piers, and using shredded scrap tires as alternative daily cover for landfills, as reinforcement in foamed concrete crash attenuators on piers, as horizontal drains and as frost heave protection in subgrade installations. Except for alternative daily cover, the market size, and potential consumption of scrap tires, for these engineering applications is small. Scrap tire use in a number of civil engineering and road building applications is feasible from an engineering standpoint; however, most potential uses will require subsidies in order to compete with other materials.

Conclusions

Markets for lightweight scrap tire fills, even if economically competitive, are very small, on the order of 1000 cubic yards over four years. Markets for other applications of scrap tires also exist (storm water devices, landscaping covers, etc.) but again, with very small markets. The potential market in HMA pavements is much greater, but rubber modified HMA pavements are not economically competitive with conventional HMA pavements. This lack of economic viability explains the limited usage of rubber modified HMA pavements, particularly in the northern tier states, where climate restricts the paving season.

Scrap tires, when used in civil engineering and road building applications, generally meet two parts of the three-pronged test for recycled materials. Scrap tires for lightweight fills and for HMA pavements are no more toxic than other typical construction materials. With specific engineering consideration, limitations and design consideration, scrap tires can be modified to meet the engineering properties necessary for lightweight fills and for HMA pavements. It is on the third leg of the test, economic competitiveness that scrap tires fail to meet the free market test. Unless subsidized, scrap tires for lightweight fills do not compete in a free market against other materials such as wood chips. For pavements, based on life cycle costs, rubber modified HMA pavements are not competitive with unmodified HMA pavements. Current specifications for Performance Graded Asphalt Binders allow the use of rubber-modified binders, yet none are currently used in the market due to higher unit costs.

1. INTRODUCTION

1.1 *Purpose of Report*

As the volume of waste generated in our society and the cost of disposal continue to increase, there is increased pressure and incentive to recover and recycle waste materials for use in secondary applications. Highway agencies have become participants in these recycling efforts.

Approximately 281 million tires are discarded each year by American motorists, or approximately one tire for every person in the United States. About 30 million of these tires are reused or retreaded, leaving roughly 250 million scrap tires to be managed annually. Around 85 percent of these scrap tires are automobile tires; the remaining 15 percent are truck tires. The largest use of waste tires in highways is as a binder modifier for hot mix asphalt (HMA) pavements. Waste tires are also used in fills and embankments, erosion control, retaining walls, membranes, revetments for slope protection, safety hardware, railroad crossings, valve box coverings, planks and posts, draining aggregate, and culverts (Epps, 1994).

From a pavement and geotechnical engineering perspective, recovered materials should be used in such a way that the expected engineering performance of the design will not be compromised. Waste and by-product materials differ vastly in their types and properties and in the applications for which they may be suited. Experience and knowledge regarding the use of these materials vary from material to material, as well as from state to state. To recover these materials for potential use, engineers, researchers, generators, and regulators need to be aware of the properties of the materials, how they can be used, and what limitations may be associated with their use.

Any use of scrap tires in highway applications will depend on the economics, performance, environmental, health, and safety considerations associated with the various end products.

1.2 *House Bill 2308*

House Bill 2308 (2002) directed the Washington State Department of Transportation to evaluate scrap tire use in civil engineering and road building applications (see Appendix A). The purpose of this document is to assist policymakers to determine the suitability of using scrap tires in highway applications.

This report includes: (1) an analysis of the feasibility of using scrap tires in lightweight fills given the standards and specifications adopted by the Federal Highway Administration and other states; and (2) an analysis of the feasibility of using rubber-modified asphalt in highway projects, including any changes in the cost of such procedures from the costs reported in the department of transportation's 1992 report to the legislature (Swearingen et al, 1992) on the use of recycled materials in highway construction (see Appendix B for Report to Legislature).

HB 2308 further stipulates that any construction project that receives state funding must apply legislatively adopted product standards to the materials used in the project. The standards do not need to be applied if the administering agency and project owner determine that applying the standards would not be cost-effective or the products were not readily available. This report also includes information on life cycle cost analysis and material availability.

1.3 Material Availability

An estimated 4.7 million used tires were generated in Washington State in 2001. The Washington State Department of Ecology (2002) has information on the end use of 65 percent, or 3,010,170 tires. Of these three million tires, 35 percent were recycled.

Scrap tires from Washington vehicles do not necessarily remain within the state. According to the Oregon Tire Recycling Task Force (2002), 60 percent of the scrap tires deposited in Oregon landfills are imported from other states – primarily Washington and Idaho.

The Washington State Department of Ecology's Scrap Tire Report (2002) includes a listing of 23 regional tire recycling firms and products. The list includes companies in Washington, Oregon, Utah, Montana, and British Columbia that recycle tires for many different purposes and products. (Dave Nightingale, Washington State Department of Ecology, personal communication, 6/16/03).

1.4 Incorporating Recylced Tires: The Three-Pronged Test

To be used on a highway construction project, post-consumer recycled materials must pass a three-pronged test:

1. Toxicity requirements
2. Engineering properties
3. Economic requirements

<u>Toxicity Requirements</u>

Post-consumer recycled materials incorporated into highway construction projects must not contain toxic materials, either as part of their main constituency or as contaminants. Toxicity tests and leaching tests are used to confirm the non-toxic nature of the material.

Lightweight Scrap Tires Fills

Studies of scrap tires in shredded tire fills show minimal leaching risk when the fill is placed above the ground water table. Six metals with primary drinking water standards, i.e., pose an actual or suspected health risk, were tested for the following: barium, cadmium, chromium, copper, lead and selenium. All were found to generally be below the regulatory allowable limits. Metals with secondary drinking water standards, i.e., they are of aesthetic concerns only, were tested for the following: aluminum, calcium, iron, magnesium, manganese, sodium and zinc. Only iron and manganese were detected in levels exceeding the secondary drinking water standard.

Rubber Modified HMA Pavement

A recent National Cooperative Highway Research Program (NCHRP) study (Project 25-09) found that while crumb rubber exhibited significant toxicity, toxicity was eliminated or greatly reduced in its amended form (i.e., after the crumb rubber was incorporated into the HMA pavement.)

Engineering Properties

Recycled materials must meet the same engineering property specifications as virgin materials, satisfying the engineering design of the highway facility.

Lightweight Scrap Tires Fills

WSDOT experienced a dramatic failure in lightweight scrap tire fills, as did Garfield County. In 1995, WSDOT constructed a lightweight shredded tire fill for an initial cost of $557,000, on SR-100 near Ilwaco, Washington. The lightweight fill repaired a landslide, which had removed approximately 150 feet of two-lane roadway to a depth of 20 foot below the preexisting highway surface. After the fill was constructed, on December 28, 1995, an unusual longitudinal crack, approximately 75 feet long, was observed at the centerline of the highway. On January 6, 1996, steam was observed emitting from the crack. In late February and early March, settlement of the highway and embankment increased significantly. The lightweight scrap tire fill had spontaneously combusted, resulting in oil seeping out of the base of the fill, contaminating a sump at the outfall of the base of the fill. A contract for removal and environmental cleanup resulted in a total of 13,700 tons of shredded tire chips, contaminated soil cover, drainage blanket, and native soils being removed at a cost of $3.2 million. The cost to reconstruct the embankment with a rock shear key was $1.35 million, for a total cost of over $4.55 million.

A shredded tire embankment in Garfield County was constructed in late fall, 1994 on Fallings Springs Road near the community of Pomeroy. This was entirely a county project and the WSDOT was not involved in the design or construction. It is worth discussion because of the tire embankment fire that occurred in the same year following construction. Primarily farm traffic and local residents used the existing gravel road. Prior to this project, the road had a hairpin curve that skirted the head of a ravine and the shredded tire embankment was constructed across the ravine to eliminate the sharp curve. A lightweight fill was not required at this site. The 225 foot long tire embankment had a maximum height of 49.5 feet with a 32-foot wide roadway section and 1.5H:1V side slopes. Approximately 16,500 yd^3 (12,000 tons) of shredded tires was required to construct the embankment. Production, delivery and placement of the tire shreds were the responsibility of Tire Shredders, Inc. of Goldendale, Washington. All costs were paid with funds from the Washington State tire recycling and clean-up fund administered by the Department of Ecology (DOE). Construction was completed in the spring, 1995. In October of 1995 a local resident reported steam coming from a fissure in the fill located about eight feet below the elevation of the road surface. Steam continued to flow from this vent until January 17, 1996 when open flames were first observed. The county road was immediately closed to traffic. The Washington DOE has reported the cost for initial construction was approximately $1.0 million. The costs of removing and disposing of the shredded tire embankment was $2.5 million paid by the Washington DOE.

Because of this spectacular and expensive failure, in January of 1996 a letter from then Assistant Secretary of Transportation, Stan Moon proclaimed an immediate moratorium on the use of shredded tires in highway fills. This moratorium remains in affect until such time that WSDOT can have a high degree of confidence that lightweight tire fills can be built safely without adverse, and costly, environmental impacts.

Following the three lightweight scrap tire fill fires of 1995 (two in Washington and one in Colorado) the FHWA Office of Engineering, issued a memorandum recommending that, pending further research and evaluation, scrap tire use should cease on all Federal-aid construction projects on the National Highway System. Subsequently, the FHWA issued *General Guidelines for All Tire Shred Fills,* July 1997, which were later adopted as ASTM D 6270 Design Guidelines. The guidelines set stringent specifications on scrap tire fills, including limiting fill heights to ten feet or less.

Other states, notably Minnesota, have built successful lightweight scrap tire fills, usually with fill heights less than ten feet. These relatively shallow height lightweight fills have performed well without exhibiting signs of spontaneous combustion.

Rubber Modified HMA Pavement

Most applications for rubber modified HMA pavements have experienced pavement lives near to those of unmodified HMA pavements. Dense graded HMA pavements constitute the majority of asphalt pavements built in this state. Dense graded pavements constructed with rubber-modified asphalt exhibit slightly shorter pavement lives than conventional HMA pavements (11 year vs. 15 year pavement lives). Performance of other crumb rubber modified pavements is on par with their conventional counterparts.

One of the vital elements of HMA performance is adequate compaction. Compaction is primarily a function of mix design, paving equipment (paving machine and rollers), and air temperature. Of these, air temperature is obviously the least controllable. Therefore, Washington State, like all states, specifies the time of year that HMA paving can take place to maximize the potential for adequate air temperatures and therefore maximum possibilities for obtaining the specified compaction level. The construction of rubber modified HMA pavement requires not only higher mat temperatures, but also higher and consistent air temperatures to ensure that adequate compaction is obtained. It is this basic element of rubber modified HMA that restricts the use of this pavement type in Washington State.

<u>Economic Requirements</u>

Recycled materials must compete against virgin materials in the marketplace. The private sector contractors that build WSDOT transportation projects judge recycled materials against virgin construction materials based on cost. WSDOT's budget and funding constraints does not allow for subsidizing recycled materials.

Lightweight Scrap Tires Fills

Except for the SR-100 Ilwaco project all lightweight scrap tire fills built by WSDOT have had the cost of the scrap tires subsidized by the Washington DOE. All costs associated with the processing and transportation of the shredded tires to the fill sites was paid under the DOE statewide cleanup and recycle program, negating cost comparisons to other lightweight fill materials.

Using the Unstable Slope Management System, four potential lightweight fill projects were identified that might be constructed in the 03/05 and 05/07 bienniums. Preliminary estimates by the WSDOT geotechnical division predict less than 1000 yd^3 of lightweight material would be necessary on these projects. Even if these projects were constructed using 100 percent scrap tires, this represents a very small market for lightweight scrap tire fills. At a historical cost of $14/$yd^3$ for scrap tires hauled and placed in the fills, this would represent a market of approximately $14,000.00 over the next four years.

Other Embankments and Fills

Common embankments refer to projects in which the lightweight properties of scrap tires were not an engineering requirement, i.e., the embankment was built over foundation soils that would neither fail under the embankment loading nor undergo excessive settlement. Projects using scrap tires as fill in common embankments have not been as well documented as those employing tires for their lightweight characteristics. Based on the survey results of other states usage of scrap tires and the literature review, the reason that scrap tires have been used in so few common embankments appears to be that it is usually uneconomical to do so. The experience of WSDOT has been that common borrow for earth embankments averages about $6/$yd^3$. The literature review, and WSDOT's experience at Ilwaco, indicates that shredded tires cost in excess of $14/$yd^3$. Therefore, in order to make the use of shredded tires economical in common embankments a subsidy of $8/$yd^3$, or more, would be required. Transportation costs significantly impact these unit costs, i.e., longer haul distances will increase the costs.

Rubber Modified HMA Pavement

Arizona, Caltrans and Texas found that rubber modified HMA pavements are more expensive than conventional HMA pavements. Caltrans found that comparable costs could be obtained with rubber modified HMA pavements only when used with reduced paving depths in gap graded or open-graded friction courses. Unfortunately for Washington State, open-graded friction courses (which is the predominately used rubber modified pavement type) perform poorly under studded tire wear, resulting in relatively short pavement lives and increased paving costs.

WSDOT's experience indicates that rubber modified HMA pavements have not delivered increased pavement lives necessary to balance out their increased initial costs, as shown in the table below.

Rubber Modified Asphalt Mix Type	Actual Service Life of Rubber Modified Asphalt	Average Service Life of Conventional Asphalt	Pavement Life Necessary for Rubber Modified Asphalt to be Cost Effective
Dense Graded	11	15	20
SAM	7	7	18
SAMI	15	15	54
OGFC	11	8	15
Class G	10	7	8
PlusRide	5	15	25

Currently on WSDOT paving contracts, contractors are free to use rubber modified asphalt binder in the HMA paving mixtures. Due to the added cost of the rubber-modified binder, these asphalts are not currently competitive on the open market.

2. GEOTECHNICAL USES FOR SCRAP TIRES

2.1 Tire Shred and Chip Processing[1]

Shredding of scrap tires produces chunks of rubber ranging in size from large shreds to smaller chips. A tire shredder is a machine with a series of oscillating or reciprocating cutting edges, moving back and forth in opposite directions to create a shearing motion, that effectively cuts or shreds tires as they are fed into the machine. Usually, tire shreds are irregular in shape and the larger dimension possibly being two or more times as much. The chips, on the other hand, are cubical in shape. Some shreds or chips may have pieces of steel belt exposed along the edges. In most cases the production of tire shreds or tire chips involves primary and secondary shredding.

The size of the tire shreds produced in the primary shredding process can vary from as large as 12 to 18 inches long by four to nine inches in width, down to as small as four to six inches in length, depending on the manufacturer, model, and condition of the cutting edges. The shredding process results in exposure of steel belt fragments along the edges of the tire shreds.

Production of tire chips requires two-stage processing of the tire shreds (i.e., primary and secondary shredding) to achieve adequate size reduction. Secondary shredding results in the production of chips that are more equidimensional than the larger size shreds that are generated by the primary shredder, but exposed steel fragments will still occur along the edges of the chips.

In the final production tire shreds normally range in size from three inches to 12 inches, while tire chips are usually sized from a maximum of three inches down to a minimum of ½ inch. The size and shape of tire shreds or chips from tire shredding can vary depending on the type of shredding machinery used.

2.2 Overview of Washington Experience with Lightweight Fills

Construction of roadway embankments on soft foundation soils, such as peat or soft clays, has been a problem throughout the country in highway construction. The two main approaches for coping with the problem is to improve the engineering properties, e.g. shear strength and compressibility, of the foundation soils or reduce the weight of the embankment using light weight fill material thereby reducing the load applied to the soft foundation soils.

The construction and maintenance of highways in landslide prone areas has also been a concern for highway engineers. The three main approaches for coping with the landslide problem are: avoid the problem, reduce the forces to cause movement (i.e. light weight fill) and/or increase the forces resisting the movement.

The Washington State Department of Transportation (WSDOT) has been using lightweight fill materials in highway construction for over 30 years primarily in the construction of highway

[1] http://www.tfhrc.gov/hnr20/recycle/waste/st1.htm

embankments over soft, weak compressible soils and for landslide correction. The WSDOT experience with lightweight fill materials is limited to wood fiber, EPS-geofoam, cellular concrete and shredded tires. A brief description of these materials and WSDOT projects is described below.

Wood Fiber

In 1972, the first lightweight fill using wood chips was constructed on the Washington State highway system as an emergency repair caused by a landslide that destroyed a section of road (Kilian, 1992). Wood fiber was selected for two primary reasons. First, wood chips can be used as an all-weather material. Rain does not effect the placement and compaction of the embankment. Secondly a lightweight fill can be used to reduce the driving forces of the unstable ground that causes instability. On average, wood fiber fills are less than 50 percent the weight of conventional earth embankments. Additional, wood fiber was readily available and could be obtained on short notice form local western Washington saw mills. Timber companies located on the coast of Washington have been using wood fiber material to construct non-engineered fills over very weak marine sediments for many years prior to the WSDOT project.

When the decision was made to use wood fiber under permanent roadways two critical concerns faced the WSDOT. First – would the wood fiber resist decay sufficiently so as to have an embankment life in excess of 75 years? Early estimates speculated wood fiber to have a design life of 15 to 30 years. Results from investigations by the WSDOT of "old" sawdust piles reportedly found 70 year old piles where the inner core (two to three feet inside the outer face) had no decomposition.

The second critical issue was the risk of spontaneous combustion that could result in the wood fiber fill catching fire. Biological oxidation increases temperature to approximately 167ºF followed by a chemical reaction that increases temperature to ignition. Controlling the wood fiber temperature and reducing the availability of oxygen are methods to preventing temperatures rising to the point of ignition (Bowes, 1956).

Since the first lightweight wood fiber fill was constructed in 1972, more than twenty additional fills have been constructed between 1973 and 2003. They were all constructed in high to moderate rainfall areas of Western Washington. The average age of these fills is about 26 years. A large majority of the wood fiber fills were constructed as a landslide correction with six projects designed as a lightweight fill over soft soils. The WSDOT has not experienced spontaneous combustion in any of the wood fiber fills constructed to date.

A WSDOT study was conducted in 1992 to evaluate the long-term performance of the wood fiber fills (Kilian, 1992). Over half the wood fiber samples obtained from these fills were found to be nearly fresh and none were found to be completely decomposed. In all but one case, the pavement quality over the wood fiber fills surpassed the comparative highway segment rating indicating the wood fill's performance exceeded that of the adjacent area. In the future the WSDOT will continue using wood fiber as a primary source material when the geotechnical design requires a lightweight fill material.

EPS-Geofoam

EPS-geofoam is used in fill applications where an extremely lightweight material is required to reduce stresses on underlying soils or lateral pressures to retaining walls, abutments or foundations. Expanded polystyrene (EPS) is a very common product that is widely used for packaging and in building construction. Manufacturing of EPS blocks begins with expandable polystyrene resin beads that are generally less than three millimeters in diameter and contain microscopic cells filled with a blowing agent. The usual blowing agents are pentanes or butanes and constitute about five percent of the bead weight. When exposed to steam under controlled pressure, the cell walls soften and the blowing agent expands. Individual resin beads enlarge by up to 40 times in volume to form pre-puffs. After a holding period to allow stabilization at room temperature, the pre-puffs are poured to fill a rectangular molding box. All six sides of the mold are fixed and more steam is injected through small perforations along the confining walls. The pre-puff in the molding box further expand and fuse to form a block.

EPS-geofoam has been used as a lightweight fill worldwide since the early 1970's beginning with road projects in Norway. The use of EPS-geofoam in the U.S.A. for a lightweight fill dates back to at least the 1980's. EPS-geofoam is quite strong, but has a very low density – one percent of traditional earth materials. It is produced in block form and is easily positioned at the work site.

The first WSDOT project using EPS-geofoam was constructed in 1993 on SR516 near Lake Meridian (Kent, Washington). The project utilized a vertical EPS-block embankment with a treated wood face to reconstruct a portion on an embankment that was experiencing settlement problems caused by a rotational embankment failure. The design required a lightweight material significantly lower in weight than the more conventional lightweight fills such as wood fiber or shredded tires. Since this first project, two additional projects have been designed and constructed using EPS-geofoam. A large project on SR509 in the Port of Tacoma was recently constructed using approximately 33,000 cubic yards of EPS-geofoam. The EPS-geofoam was selected because of its low density, high strength properties and ease of construction. The EPS-geofoam was placed between two concrete retaining walls over 25 feet in height. This was the largest EPS-geofoam project in the Pacific Northwest. As of 2003, three projects have been constructed in Washington State by the WSDOT and all projects are performing extremely well with little or no maintenance required.

Cellular Foam Concrete

Cellular foam concrete is typically a mixture of cement, water and preformed foam. Design mixtures using fly ash, sand and other materials may be included for specific densities and strengths. Cellular foam concrete may be designed for densities ranging from 20 to over 100 lb/ft^3. These lightweight concretes are generally produced on-site and pumped into place and finished prior to setting.

A predetermined quantity of preformed foam is added to a concrete slurry or grout while mixing to produce cellular foam concrete. The foam volume controls the density of the concrete by creating stable air cells within the concrete mixture. These air cells are coated with cement paste, which upon setting results in a discrete cell structure.

The first WSDOT project using cellular foam concrete was constructed on SR11 south of Bellingham in 1993. The project required the re-placement of an existing multi-span half bridge structure. Typically, a bridge replacement would require the removal of the bridge followed by the construction of the new bridge. Maintaining traffic during construction would require the erection of a temporary detour bridge. Using cellular foam concrete eliminated the need for a temporary detour bridge. This project consisted of the construction of a permanent tieback supported soldier pile wall in front of the old bridge followed by pouring lightweight cellular foam concrete between the soldier pile wall, ground and bridge thereby fully encapsulating the old structure in lightweight concrete. During construction, traffic continued to use the old bridge. Using a lightweight cellular concrete reduced the lateral loads being applied to the soldier pile wall. This was a very successful project and has been used on two other projects in the state with similar success.

2.3 Washington's Experience with Shredded Tires

WSDOT began using shredded tires as a lightweight fill beginning in 1993. The Washington State legislature in the early 1990's passed a state law requiring tire dealers to collect $1 per tire from customers disposing of old tires. The money went into a central fund administered by the Washington State Department of Ecology (DOE). Approximately $15 million collected under the program was then dispersed to tire processing companies statewide for cleanup and recycle. As a result of this legislation two projects were constructed by the WSDOT between 1993 and 1995 using shredded tires. One additional project was constructed by the WSDOT in 1995 using non-subsidized shredded tires. The following is a brief description of each of these projects.

US101 Contract 4215 and 4337

Tire Shredders Inc. of Goldendale contacted the WSDOT regarding our interest in using shredded tires as a lightweight fill material. The WSDOT had two projects in design where wood fiber was being proposed as a lightweight fill for a landslide correction. These two projects are located south of Cosmopolis, Washington on US101. The WSDOT researched and evaluated the material properties and concluded when compared to wood fiber, shredded tires exhibited similar in-place densities and strength properties. The WSDOT evaluation was largely based on a successful shredded tire project constructed by the Oregon Department of Transportation. Tire Shredders Inc. transported the shredded tires to a stockpile location approximately one mile from the project sites. All costs associated with the processing and transportation of the shredded tires was paid under the DOE statewide cleanup and recycle program.

The two projects consisted of placing sliver fills on and against an existing wood fiber fill embankments. The wood fiber embankments were constructed as landslide mitigation projects in the early 1970's. The placement of the lightweight fill on the headscarp of the landslide resulted in a significant reduction of the driving forces causing instability. The problems we were correcting were caused by the presence of a very steep slope face, which approached 45 degrees. The landslide was stable but the wood fiber fill embankment slope face was unstable resulting in pavement cracks in the northbound lanes of US101. The objective of the projects were to remove the unstable sections of wood fiber fill and replace the material with shredded tires and reconstruct the slope at a more stable repose (approximately 26 degrees). The embankments ranged in height from 20 to 30 feet and the sliver fills were approximately 15 feet wide and eight to ten feet thick. Figure 1 illustrates the project construction.

Figure 1. Lightweight Tire Fill Construction

The completed projects have performed extremely well since construction. Since construction, no pavement distress has occurred indicating the larger landslide is stable and the mitigation correction of building a flatter slope face was successful. Because of the subsidy paid by the DOE recycling program, the cost of using shredded tires was very competitive compared to wood fiber. The bid price for placing and compacting the shredded tires was \$4.50 to \$6.00/yd^3, which is comparable to the bid prices the WSDOT pays for common earth embankments.

<u>SR100 – Fort Canby Loop Road Slide – C4765</u>

In December 1994, a landslide occurred in native siltstone underlying a portion of SR-100 near Ilwaco, Washington (Gacke et.al. 199X). The landslide removed approximately 150 feet of two lane roadway to a depth of 20 feet below the preexisting highway surface. Because of the unsuitable nature of the foundation soils, geotechnical recommendations for remediation included two options:

1. Constructing an embankment with a shear key and conventional earthen fill material, or
2. Construction an embankment using shredded tires as a lightweight embankment material.

The highway was rebuilt using shredded tires as a lightweight embankment largely because shredded tires were found to be the most cost effective way to rebuild the highway. Using a lightweight fill eliminated the need for the excavation of a deep shear key into the underlying soil and rock.

Tire shreds for this project were obtained for Waste Recovery in Portland, Oregon at a unit bid price of $\$14.00/yd^3$ including haul and compaction.

To keep the shredded tires mass above the water table, a four foot rock drainage layer replaced excavated slide debris. The remaining embankment was reconstructed with shredded tires with a four foot thick gravel cap placed between the shredded tires and highway pavement. A two foot thick soil cap was placed on the sideslopes.

On December 28, 1995, an unusual longitudinal crack, approximately 75 feet long, was observed at the centerline of the highway. On January 6, 1996, steam was observed emitting from the cracks. In late February and early March, settlement of the highway and embankment increased significantly and on March 14, 1996, oil was observed seeping with the groundwater into a sump at the outfall of the rock drainage blanket. The WSDOT contacted the DOE and developed plans to contain the oils and contaminants, remove the burning shredded tire embankment and environmental cleanup. Figure 2 shows a picture was taken prior to the removal of the shredded tire embankment.

Figure 2. SR100 Ilwaco Fire During Embankment Removal

A contract was award in March 1996 for removal and environmental cleanup. A total of 13,700 tons of shredded tire chips, contaminated soil cover, drainage blanket, and native soils were removed at a cost of (without tax) $3.2 million. The cost to reconstruct the embankment with a rock shear key was $1.35 million.

In January of 1996 a letter from then Assistant Secretary of Transportation, Stan Moon proclaimed an immediate moratorium of the use of shredded tires in highway fills. This moratorium is to remain in affect until such time that the WSDOT can have a high degree of confidence tire fills can be built safely with adverse environmental impacts. Minimal research has been conducted over the last seven years to study the causes of tire fires. As a result this moratorium remains in affect today.

<u>Falling Springs Road – Garfield County</u>

This shredded tire embankment was constructed in late fall, 1994 on Fallings Springs Road near the community of Pomeroy in Garfield County. This was entirely a county project and the WSDOT was not involved in the design or construction. It is worth discussion in this section because of the tire embankment fire that occurred in the same year following construction.

Primarily farm traffic and local residents used the existing gravel road. Prior to this project, the road had a hairpin curve that skirted the head of a ravine and the shredded tire embankment was constructed across the ravine to eliminate the sharp curve. A lightweight fill was not needed at this site. A six foot diameter corrugated metal pipe was placed through the embankment to carry an intermittent stream. The 225 foot long tire embankment had a maximum height of 49.5 feet with a 32 foot wide roadway section and 1.5H:1V side slopes. Approximately 16,500 cubic yards (12,000 tons) of shredded tires was required to construct the embankment. The source of the tires was the Maak tire pile in Spokane, Washington.

Production, delivery and placement of the tire shreds were the responsibility of Tire Shredders, Inc. of Goldendale, Washington. All costs were paid with funds from the Washington State tire recycling and clean-up fund administered by the DOE. Construction was completed in the spring, 1995. A flash flood occurred on July 6, 1995 that resulted in a large tree stump becoming lodged in the inlet of the six foot culvert causing water to rise against the upstream side of the embankment to about 30 feet. It took approximately two hours for the water to drain. On October 7, 1995 a local resident reported steam coming from a fissure in the fill located on the upstream side of the tire embankment about eight feet below the elevation of the road surface. Steam continued to flow from this vent until January 17, 1996 when open flames were first observed. The county road was immediately closed to traffic. The construction cost of the shredded tire embankment was approximately $1,000,000. The cleanup costs were $2,500,000 (Hibbler, 2003, Washington Department of Ecology).

<u>Lightweight Fill Cost Data</u>

As shown in Table 1, there is a significant range in density/unit weight and costs, so the technical and economic benefit of using lightweight fill materials can vary widely. Factors that influence cost of the various types of lightweight fills include quantity required for the project, transportation costs, availability of materials, contractor's experience with the product, placement and compaction costs. Additionally, the cost of using some waste materials will dependent on the availability of federal or state government incentive or rebate programs. The lightweight fill types indicated in Table 1 are arranged by density/unit weight. We have provided approximate range in costs nation wide and a range in costs the WSDOT has experienced from recent projects.

Table 1. Summary of Various Lightweight Fill Materials.

Lightweight Fill Type	Range in Unit Weight (lbf/ft^3)	Nationwide Cost ($/yd^3)	WSDOT Cost ($/yd^3)
EPS-Geofoam	0.75 – 2.0	26.72 – 49.70(1)	60.00(2)
Foam Concrete	21 – 48	49.70 – 72.63(3)	55.00 – 80.00(3)
Wood Fiber	34 – 60	9.17 – 15.29(2)	4.50 – 20.00(2)
Shredded Tires	38 – 56	15.29 – 22.94(2)	4.50 – 14.00(2,4)

Notes: The range in prices corresponds to projects completed from 1993 – 2000. Current costs may differ due to inflation. Nationwide cost data referenced source Starks, 2002.

(1) FOB (freight on board) at the manufacturing site. Transportation costs should be added to this price.
(2) Price includes transportation costs.
(3) Mixed at job site using pumps to inject foaming agents into concrete grout mix.
(4) The $6.00 cost paid by WSDOT included a subsidy paid by the statewide tire disposal fund administered by the Washington State Department of Ecology. The statewide tire disposal fund law is no longer active. The higher bid of $14.00 reflects costs associated with tire shredding.

It is important to note the range in costs associated with using traditional earth materials in Washington State. Common borrow for embankment construction generally range between $4.00 and $6.00/yd^3 including haul and compaction. The costs of using more expensive lightweight fill material must be offset by the benefits gained from their use. Benefits are usually measured in reduced construction time resulting in opening the highway to traffic much earlier.

2.3 Case Histories of Scrap Tire Usage Nationwide

Introduction

In preparation of this report, it was necessary to consider previous geotechnical uses by other states. The primary objective of this section is to attempt to present a representative cross-section of applications, successful and unsuccessful, that various states have employed. The various design methodologies are also examined. Finally and perhaps most importantly, it is a goal to compare the common features of the successful designs. The case histories found during the literature search are summarized in Table 2. Some of the case histories summarized in the table are discussed separately below. For those not discussed the reader can refer to the reference cited. Unless it is indicated in the table, the project was successful from both the point of view that it solved the immediate geotechnical engineering problem, e.g., landslide repair, and, up to the time of the published citation, had not created some other problem such as a fire or ground water contamination.

Table 2: Case Histories of Geotechnical Uses of Scrap Tires

State	Reference(s)	Project Name	H_{max} (ft)	Type of Fill	Drainage Layer?	If Unsuccessful, Reason for Failure	FHWA 1997[1]	Usage[2]	Est. Unit Weight (lb/ft^3)	Quantity[3]	Year Built	Additional Comments
Embankments Over Soft Ground												
CA	CalTrans, 2002 and 2001	I-880 Dixon Landing Road On-Ramp	<10	M			Yes	S		0.9M	2001	Embankment was constructed using at least two layers of pure tires, wrapped in geotextile and separated by a layer of soil.
ME	Humphrey, et al., 1998 and Whetten and Weaver, 1997	Topsham Brunswick Bypass (Merrymeeting Bridge, North Abutment)	14	M	No		No	S	56	0.4M	1996	Larger shreds on bottom 10ft, smaller shreds in top 4ft; impermeable clay to limit air/water access; 20 in of settlement; temp lower in larger shreds
ME	Humphrey, Dunn and Merfeld, 2000 and Humphrey, et al., 1998	Portland Jetport Embankment	10	M	No		Yes	S	49	1.2M	1997	First designed using 1997 FHWA Interim Guidelines
MN	Civil Engineering News, 1997 and Civil Engineering, 1997	Carlton Co. (CSAH 11and Pine County 48)	14	M	No		ID[7]	S	~20	0.52M	1996	Placed in 4ft lifts
MN	Drescher and Newcomb, 1994 and Engstrom and Lamb, 1994	Ramsey Co. Rd. No. 59 (Centerville Rd.)	3	M	No		No	S		0.1M	1990	
MN	Ibid.	Eden Prairie	9	M	No		Yes	S	---	0.2M[6]		
MN	Ibid.	Prior Lake	3	M	No		No	S	---	0.4M[6]	1991	Initial 6 in settlement following application of 2ft thick subbase; no further detrimental settlement. 100 % Passing 4 in
MN	Ibid.	Milaca	3	M	No		Yes	S		0.05M		
MN	Ibid.	Pine City	15	M	No		Yes	S	22	0.9M	1992	
MN	Drescher and Newcomb, 1994, Engstrom and Lamb, 1994 and Public Works, 1990	Benton Co., near Rice	3	M	?	Longitudinal cracking in wheel paths, some rutting and some cracking indicative of an embankment failure.	Yes	S	30	0.052M	1989	Computed unit weight. Maximum tire length was 12 inches.

State	Reference(s)	Project Name	H_{max} (ft)	Type of Fill	Drainage Layer?	If Unsuccessful, Reason for Failure	FHWA 1997[1]	Usage[2]	Est. Unit Weight (lb/ft^3)	Quantity[3]	Year Built	Additional Comments
MN	Engstrom and Lamb, 1994	Lake Co., near Finland, CSAH #7	4	M	No		Yes	S		0.2M[6]	1990	4x12 in shreds; above GWT; No noticeable settlements reported.
MN	Drescher and Newcomb, 1994	Minneapolis Convention Center	3	M	---		Yes	S	---	0.13M	---	Tires used to reduce weight on below grade parking structure.
MN	Drescher and Newcomb, 1994	Scott Co.	6	M[5]	?		No	S	---	---	1991	Tires used as lightweight fill over an existing water main. Maximum tire length, 3 inches.
MN	Drescher and Newcomb, 1994	Athens Twp. Rd. T194	3	M	---	---	ID	S	---	---	1991	Excavated and replaced roadway fill over soft ground. The 3 ft height was the loose lift thickness.
SD	Follow-up response to WSDOT Scrap Tire Use Survey	---	15	M	Yes		ID	S	---	0.06M	1996	Lightweight fill over a box culvert to reduce required thickness of top slab of culvert
VA	Hoppe, 1994 and ENR, 93	Rt. 646 Connector, near Williamsburg	20	X	No		No	E	71	1.7M	1993	Claimed to be largest tire fill to date. Virginia DEQ subsidized \$150000 to use tire shreds; this is about \$0.15/tire or about 1/5 – 1/6 the cost of landfill disposal.
Manitoba	Shalaby and Khan, 2002		6.4	M	No		Yes	E	63	0.3M	1999	Unit wt. estimated from geometry and number of tires used in embankment.
Common Embankments												
ME	Humphrey, 1998	Rt. 9 near Crawford	---	M	---		ID	S	---	0.3-0.7M	---	Objective in using tires was to remove them from a nearby stockpile. Maine DOT paid the equivalent cost for common borrow, the while Maine Dept. of Environmental Protection subsidized the remaining cost for the tires. No absolute cost data was given.

State	Reference(s)	Project Name	H_{max} (ft)	Type of Fill	Drainage Layer?	If Unsuccessful, Reason for Failure	FHWA 1997[1]	Usage[2]	Est. Unit Weight (lb/ft^3)	Quantity[3]	Year Built	Additional Comments
IA(?)	Gebhardt, Kjartanson and Lohnes, 2001	Proposed design parameters for a scrap tire fill crossing a ravine	15	M	---		No					Authors proposed design strength parameters based on direct shear tests. For tire shreds they proposed ϕ=38°, and for scrap tires on glacial till, c = 0.1 psi and ϕ=33°,
NY	Dickson, et al., 2001	Rt. 17, Westbound Off Ramp to the new North Road Bridge	10	M	No		Yes	S	38	0.3M	1999	Trench drains were used below the embankment. Ground water quality was monitored.
WA	Humphrey, 1996	Falling Springs Rd., Garfield Co.	49	M	No	Fire	No	S	---	0.9M	1995	"Stringy" shreds <2in wide and 12 in long were used in bottom 20 ft of embankment. This material was described as generally steel belts encased in a minimal amount of rubber. Shreds of at least 10 in, some with both sidewalls still intact, were used in the upper portion of the embankment. Little initial settlement. Between Jan-Feb 1996, 4 to 6 ft of settlement occurred in the roadway.
WI	Bosscher, Edil and Eldin, 1993 and Eldin and Senouci, 1992	Experimental embankment; included lysimeters to monitor leachate.	5	M, L, X	No		No	E	19-35	---	1990	Embankment settlement in the section with the 2 in shreds was larger than in the section with 4 in shreds. Lower unit weights were realized in sections with larger shred size.
Landslide Remediation												
CO	Cheng, 2003	I-76 between Broadway and Huron	5	M	---		ID	S	---	---	1991	
LA	Morvant, 2003 and Technology Today, 1997	LA-8 Landslide Repair, near Harrisonburg	---	M, X	Yes.		No	S	---	0.9M	1997	DEQ subsidy of $0.15/tire; top portion was a monofill, bottom portion was soil/tire mixture for increased weight to act as a buttress.

State	Reference(s)	Project Name	H_{max} (ft)	Type of Fill	Drainage Layer?	If Unsuccessful, Reason for Failure	FHWA 1997[1]	Usage[2]	Est. Unit Weight (lb/ft^3)	Quantity[3]	Year Built	Additional Comments
OR	Upton and Machan, 1993 and Read, Dobson and Thomas, 1991	US42 Landslide Repair, near Roseburg	12.5			Cracking, rutting in wheel path. Excavation showed soil cap was only 1.5-2 ft thick, replacement with the specified thickness of 3 ft solved the cracking problem.				0.6M	1990	
WA	Gacke, Lee and Boyd, 1997 and Humphrey, 1996	SR-100 Landslide Repair at Ilwaco	26	M	No	Fire	No	S		0.7M	1995	Used 2 – 6in tire shreds that were produced by shearing and ripping. There was more exposed steel in ripped shreds. The fill was constructed 4 ft above the ground water table, and four feet of cover was placed over the fill. There was approximately 2 in. of initial settlement.
WA	WSDOT Records	SR-101 Cosmopolis	30	M	No			S			1993	Sliver fills over existing wood chips.
WY	Hager, et al., 1998, Dahill, 1994, Scrap Tire News, 1994 and Transportation Topics, 1994	WYO 28, Near Lander (Double Nickel Landslide)	11	M	Yes		Yes	S	53	0.5M	1995	Used entire supply of scrap tires in the state.
Backfill for Retaining Walls												
CO	Humphrey, 1996	Glennwood Canyon	70	M(?)		Fire	ID	---	---	---	1995	
ME	Humphrey, et al., 1998 and Whetten and Weaver, 1997	Topsham-Brunswick Bypass (Rigid Frame Bridge)	20	M	No			S		1336 yd^3	1996	Rigid wall; lateral earth pressures reduced 40 %
ME	Tweedie, Humphrey and Sanford, 1998a,b and c	Experimental Wall	16	M	No		No	E	43.1-44.3	130 yd^3 or ~0.008M		Relative to expected pressures from granular backfill: At-rest pressures were 45% less Active pressures were 35% less

State	Reference(s)	Project Name	H_{max} (ft)	Type of Fill	Drainage Layer?	If Unsuccessful, Reason for Failure	FHWA 1997[1]	Usage[2]	Est. Unit Weight (lb/ft³)	Quantity[3]	Year Built	Additional Comments
SD	Reid, Soupir and Schaefer, 1998	Experimental Wall	5	M	No	---		E	---	2.3 yd³	---	Reduced passive lateral earth pressure on model abutment wall.
SD	Prevention of voids below approach slabs	An experimental study utilizing tire shreds below the approach slab and behind the abutment. The use of tires for the abutment wall backfill, reduced passive pressures on the retained fill and was therefore thought to reduce the mechanism causing voids to develop	1990 (?)	Reid, Soupir and Schaefer, 1998								
TX	Tire bales	A landslide on I-30 was repaired by backfilling the failed area with tire bales. The bales contained about 100 tire each, and weighed about 2000 lb. A total of 36,000 tires were utilized.	2002	TCEQ, 2003								

1. *Does the project meet the FHWA 1997 Interim Guidelines? The project received a "No" if it failed to meet any requirement of the guidelines, e.g., size distribution of shreds, maximum recommended embankment height, no measures to prevent the access of water and air to the tire fill, etc. The exception to this rule was with regard to particle size distribution. In many cases it was difficult, or impossible, to determine if the tire shreds met the size distribution specified by the Interim Guidelines. Therefore, if the project met all other guidelines, it was given a "Yes".*
2. *E = experimental; S = in service, i.e., the installation was intended to receive traffic*
3. *Unless otherwise noted, the given quantity is millions of tires.*
4. *Include any other significant uses such as anchors for tie back walls, whole tire walls, crash attenuators, etc.*
5. *Two 3 ft layers, separated by a geotextile*
6. *Computed using given volumes and assuming γ =40 lb/ft³ and 20 pounds per tire.*
7. *ID = insufficient data.*

Lightweight Fills

This category of projects includes those in which a backfill material that is lighter in weight than conventionally available construction materials, e.g., gravel, is required. There are two traditional situations in which this is the case: (1) roadway embankments that must be built over soft ground and (2) landslide remediation. Another application is the use of lightweight fills behind retaining walls to reduce the lateral earth pressure that must be resisted by the wall. Due to the specialized nature of this application, it is discussed separately.

Minnesota has extensive experience using scrap tires as lightweight fill in roadway embankments over soft ground, as the number of case histories from Minnesota in Table 2 illustrates. Many of the Minnesota projects were built by local agencies and not by the Minnesota Department of Transportation (MnDOT). Humphrey (1996) reports that there are 56 projects in Minnesota other than those administered by MnDOT. Therefore, at this writing, the list of projects in Minnesota given in Table 2 likely represents less than 20 percent of the total number of projects.

Minnesota has numerous roads that pass over areas containing peat, which is very compressible. Hence, many existing roadway embankments were experiencing intolerable settlements. In general, these areas were excavated to native ground and then backfilled using scrap tires. Heights of the scrap tire fills in most projects, as seen in Table 2, were only about three feet. However, Minnesota also had successful embankments that were nine, 14 and 15 feet in height. At this time, no known exothermic reactions, leading to catastrophic fires, have occurred in any of the Minnesota projects.

Landslides are often caused by the excessive weight of material near their head scarp. Once a failure has occurred, the material that slid is removed and the original ground line is restored using a lightweight fill. The lighter weight material reduces the forces acting to initiate a landslide (driving forces). This type of landslide remediation is nearly always used in conjunction with other measures such as drainage and regrading of the original slope. Since water is a contributing factor to nearly all landslides, some improvements to the surface and/or subsurface drainage of a site are typically made as part of the remediation, and typically the original angle of the slope is reduced, thus further increasing the stability.

In Washington, WSDOT has used lightweight fill to remediate numerous landslides. Usually the lightweight fill has been constructed using wood chips. However, the one successful scrap tire application in Washington was the use of scrap tires as lightweight backfill for a landslide remediation near Cosmopolis. This project has already been described in Section 2.2 and therefore is not further discussed herein. The failed scrap tire embankment at Ilwaco, Washington was intended as a landslide remediation. This case also has been described in Section 2.2.

Several other states have successfully employed scrap tires as lightweight fills for landslide remediation. In this context, "successfully" refers not only to the fact that the landslide movement was halted, but also to the fact that the scrap tire fill did not combust, nor degrade the ground water quality. Several of these projects are described below, and others are listed in Table 2.

The Oregon Department of Transportation (ODOT) was successful in stabilizing a landslide on US 42, west of Roseburg (Upton and Machan, 1993 and Read, Dodson and Thomas, 1991). The landslide resulted when the roadway was widened by 20 feet and raised by four feet; the additional loading reactivated an old landslide. The remediation was to remove the new embankment material, replace it with a lightweight fill, construct a toe buttress and use a rock drainage blanket below the lightweight fill. Instead of sawdust, scrap tires were selected as the lightweight fill due to concerns that ground water at the site would cause sawdust to degrade. The scrap tires were also economical because at the time the Oregon Department of Environmental Quality (ODEQ) was offering a $20 per ton subsidy for the beneficial use of scrap tires. Including the subsidy, the final in-place cost of the scrap tire fill was $\$13/yd^3$.

The maximum thickness of the scrap tire fill for the US 42 landslide repair was 12.5 feet (Read, Dodson and Thomas, 1991). Initial settlements of up to 1.8 feet occurred following placement of a three foot soil cap. Settlements subsequent to placement of the pavement layers were minimal. The 12.5 foot height of the scrap tire fill for the US 42 landslide repair exceeds by 2.5 feet the maximum height recommended by the FHWA 1997 Interim Guidelines. However, water level measurements indicated that ground water was below the elevation of the drainage blanket, and therefore, it did not enter the scrap tire fill. The three foot soil cap prevented surface infiltration. However, the drainage blanket did allow for air to access the scrap tire fill. Nevertheless, to the knowledge of the writers, this scrap tire fill has successfully remediated the landslide and has neither experienced an exothermic reaction nor has it degraded the ground water at the site.

Common Embankments

Common embankments refer to projects in which the lightweight properties of scrap tires were not an engineering requirement, i.e., the embankment was built over foundation soils that would neither fail under the embankment loading nor undergo excessive settlement. Projects using scrap tires as fill in common embankments have not been as well documented as those employing tires for their lightweight characteristics. Based on the survey results, discussed below, and the literature review, the reason that scrap tires have been used in so few common embankments appears to be that it is usually uneconomical. In the case of the Garfield County, WA embankment, the scrap tires were provided free of charge to the county. The Garfield County embankment has been described in Section 2.2.

As a response to impending legislation that would require the increased use of recycled materials in transportation projects, the New York State Department of Transportation (NYSDOT) built an embankment to enable them to develop design procedures and specifications, gain construction experience and then to monitor the performance of an embankment constructed of scrap tires (Dickson, Dwyer and Humphrey, 2001). The NYSDOT scrap tire embankment was constructed as a section of the embankment for the west bound off ramp from Route 17 onto the new North Road Bridge, east of Binghamton, NY, near Windsor and Kirkwood. The scrap tire portion of the embankment was approximately 650 feet long. Scrap tires formed the core of the embankment, and they were limited to ten feet in height, as per the FHWA 1997 Interim Guidelines, i.e., ASTM D 6270-98. The total quantity of scrap tires used was 2760 tons, or about 267,000 tires. The particle size distribution of the scrap tires was also in compliance with ASTM D 6270-98. The scrap tires were separated from the original ground, as well as the overburden, with geotextile. The scrap tires were placed in one foot loose lifts then compacted with eight passes of a smooth-wheeled, nonvibratory roller with a gross weight of 20,000 pounds. Overlying the scrap tire portion of the embankment was three to five feet of embankment fill. A surcharge of four to eight feet was placed over the embankment in order to minimize post-construction settlement. Trench drains were placed along the length of the embankment to prevent the accumulation of water within the scrap tire fill. This was done despite the fact that the embankment was supposed to be constructed above the ground water table.

Performance of the NYSDOT scrap tire embankment has been satisfactory. Temperature sensors in the control section and in the scrap tire portion indicated that in the summer the warmest temperatures were near the surface and the coolest temperatures were within the fill; the opposite trend was measured during the winter. The similar fluctuations of sensors within the scrap tires and the control section to changes in ambient air temperature indicate that no internal self-heating was occurring. Approximately 1.2 feet of settlement occurred under the surcharge loading; this is about 12 percent vertical strain. Time-dependent settlement (creep) resulted in additional settlements of about 0.4 to one inch, which corresponds to a vertical strain of only 0.3 to 0.9 percent of the original scrap tire fill height of ten feet. Most of this time-dependent settlement had occurred within 30 days. The initial and time-dependent settlements of the scrap tire fill are consistent with similar projects.

An incentive program to encourage the contractor to use scrap tires from existing scrap tire stockpiles, instead of from the current waste stream, was created in conjunction with the NYSDOT scrap tire embankment. Besides the NYSDOT, the New York State Department of Economic Development's (NYSDED) Empire State Development Corporation and the New York State Department of Environmental Conservation (NYSDEC) were involved in the incentive program. Stockpiles that could be completely eliminated based on the contract quantities were identified. Each stockpile was assigned a fixed dollar amount calculated as $2.50 times the distance to the site for a 20-ton truck plus $91 per ton of tires. The incentive had a $500,000 cap. Upon completion of the project, the contractor had been paid $235,100, or $85 per ton through the incentive program, and the in-place cost of the scrap tires was $12.50/yd^3, which is compatible with conventional embankment materials.

Although the incentive program resulted in six stockpiles being eliminated it was reported as being somewhat problematic to implement. Establishing the incentive program involved the initial survey to identify the sites, then a final survey of the sites to ensure that they had been completely cleaned by the contractor. Other problems cited (Dickson, Dwyer and Humphrey, 2001) included: (1) legal access restrictions to the sites that resulted in inaccurate information in the initial surveys (2) unexpected waste products within the stockpiles and (3) physical access for the contractor that required haul road construction, thus increasing the contractor's cost. From the NYSDOT experience with this single project, it can be seen that the potential is high for the administration of contracts involving similar incentives to be more complex than those involving conventional construction materials. Obviously, increased experience and market development would tend to diminish contract administration problems.

The incentive's goal of cleaning up existing stockpiles somewhat justified the problems with its administration. However, Dickson, Dwyer and Humphrey (2001) discuss the fact that it may be economical to use tires from the existing waste stream where tipping fees are paid to the scrap tire processors. The tipping fees cover portions of the processing and transportation costs thereby making scrap tires a more viable option.

Documentation reviewed during the literature search regarding scrap tire usage in other common embankment situations is presented in Table 2. Only three projects were known by the authors to have been constructed. In all three of these projects a major objective was to provide a means of disposal for scrap tires and some form of incentive to the contractor, or contracting agency, was made.

The literature review found mostly discussion regarding the technical and initial economic aspects of constructing common embankments with scrap tires. The authors of this report are of the opinion that using scrap tires in common embankments may have some adverse effects on future construction/maintenance. Among these effects are: (1) a scrap tire fill may increase the difficulty of placing culverts via pipe jacking or microtunneling. This method of culvert installation has become relatively commonplace and is desirable because of its minimal impact to traffic. (2) A scrap tire fill may require the use of deeper foundations for signs and luminaries (due to the reduced lateral stiffness of a scrap tire fill versus a soil fill). (3) The compressibility of a scrap tire fill may limit the types of retaining walls that could be constructed on the embankment.

Where a lightweight fill is required the costs of overcoming these difficulties can be more easily justified. However, the cost of impacts upon future construction and maintenance caused by a scrap tire fill in a common embankment should be considered in the process of deciding whether to use scrap tires in a common embankment situation.

Retaining Wall Backfill

Using scrap tires as backfill for conventional retaining structures has been investigated by several authors (Humphrey, et al., 1998; Tweedie, Humphrey and Sanford, 1998a,b,c; Reid, Soupir and Schaefer, 1998; Whetten and Weaver, 1997 and Cecich, et al., 1996). However, the literature review and responses to the 2003 WSDOT Survey indicate that relatively few projects have been completed. The primary advantages of using scrap tires as backfill for retaining walls is that scrap tires have a compacted unit weight of approximately one-third to one-half that of soils, as has been discussed. The lower unit weight of the scrap tires means that the wall will experience less lateral loading from the backfill, since lateral load is proportional to the vertical stress. Therefore, cost savings can be realized in the structural design of the wall. This savings is in addition to that arising from the presumably lower material cost for the scrap tires over conventional granular backfills. Cecich, et al. (1996) reported average cost savings of up to 60 percent may be possible when using scrap tires instead of conventional granular backfill for retaining walls.

A particularly interesting application of scrap tires for retaining wall backfills involves the use of scrap tires mixed with soils to provide a freely draining backfill for mechanically stabilized earth (MSE) walls. Primarily due to their low cost and ease of constructability, MSE walls are currently quite popular amongst state departments of transportation. A mixture of 25 percent tire chips and sand, by volume, was used as backfill in an experimental, 13 feet high, MSE wall by Abichou et al. (2001). The tire chips ranged in size from two to 22 inches, and they were produced from steel-belted tires. The goal of the authors was to determine if the wall could be designed with standard MSE wall design methods if the 25 percent tire chip backfill was used. It was determined that wall deformations, strains in the reinforcement layers and lateral earth pressure coefficients were similar to those obtained using conventional backfill materials. Hence the work of Abichou et al. indicates that using tire chip/soil mixtures for MSE wall backfill is feasible. While the mixing of scrap tires in the backfill of MSE walls may be technically feasible, it is doubtful the costs associated with the shredding, transportation and mixing would justify the minimal quantity of tires that could be utilized in this manner.

A potential disadvantage to placing a monofill of scrap tires (i.e., not mixed with soil) as retaining wall backfill is their high compressibility. Although the compressibility of the tires leads to lower lateral pressures on the wall, it could also be disadvantageous. Heavy surcharge loadings may cause excessive settlements immediately behind the retaining structure. This would be extremely detrimental to roadways that were situated near the wall face. Cecich et al. (1996) cite adverse leaching affects as being a potential disadvantage. However, several studies, as discussed below, have indicated that scrap tire fills do not generate significant amounts of hazardous leachate.

2.4 Environmental/Leaching Characteristics of Scrap Tires

There has been much concern over the environmental effects of scrap tire fills. These concerns have focused on whether scrap tires are a hazardous waste and their effects on ground water quality. Relative to the number of studies available on mechanical properties of scrap tires, there are a limited number of investigations into the environmental effects of scrap tires. The studies can be divided into laboratory and field studies. The laboratory studies have been conducted to determine if scrap tires are a hazardous waste; the field studies have been conducted in an attempt to determine the actual effects that scrap tires may have upon the ground water.

Investigators using TCLP (toxicity characteristics leaching procedure) to determine whether scrap tires are a hazardous waste or not, include Downs, et al., 1996, Ealding, 1992 and Zelibor, 1989. The TCLP measures the concentrations of regulated metals and volatile and semi-volatile organic compounds (VOC, SVOC, respectively) in samples of effluent and compares them to the regulatory values. A summary of the results for metals from the three TCLP studies cited is contained in Table 3. Results from these and other TCLP studies have shown that for regulated metals and organics, the concentrations produced are below the regulatory values.

Zelibor tested for a total of 42 substances, including 24 VOC's, ten SVOC's and eight metals. Most of these substances were detected at trace levels that were one to two orders of magnitude below their TCLP Regulatory Limit. Zelibor found only four organic substances that have TCLP regulatory limits.

In addition to TCLP testing, Ealding (1992) conducted one year long leaching tests in which 500 gram scrap tire samples were placed into two to three liters of extraction fluid. Ealding only tested for metals, 12 in the TCLP tests and 17 in the long-term tests. The results indicated that metals leached most readily in an acidic environment, which in her study was pH = four. In the one-year tests, iron and zinc were leached in the highest concentrations. Iron reached a saturation concentration of 30,000 mg/kg within two weeks, and zinc reached its maximum concentration of 150 mg/kg in about two months. All metal concentrations were, however, below regulatory limits.

Downs, et al. (1996) tested for a total of eight metals and 67 VOC's and SVOC's. The metals results are summarized in Table 3. The only organic compound with TCLP regulatory limits that was detected in their study was 1.2-dichloroethane. It was detected at a maximum concentration of 0.007 milligrams/liter, which is well below its regulatory limit of 0.5 milligrams/liter. The TCLP testing that has been reported in the literature, does not define scrap tires as being a hazardous waste (Humphrey, Katz and Blumenthal, 1997; ASTM D 6270-98). Field studies have shown similar favorable results.

Field studies investigating the effects of scrap tires placed above the ground water table have been reported by Humphrey and Katz (2000), Humphrey, Katz and Blumenthal (1997), Bosscher, Edil and Eldin (1993) and Edil and Bosscher, (1992). Humphrey and Katz reported results from five years of data collecting and testing. Their study involved the placement of two collection basins directly beneath a two foot thick scrap tire fill, which was in turn overlain by up to five feet of granular soil. As a control, one basin was overlain only by granular soil. Six metals with primary drinking water standards, i.e., they pose an actual or suspected health risk, were tested for in their study: barium, cadmium, chromium, copper, lead and selenium.

Table 3: TCLP Metals Results

TCLP Regulated Metal	Regulatory Limit (mg/L)	Downs, et al., 1996 (mg/L)	Ealding, 1992 (mg/L)	Zelibor, 1991 (mg/L)
Arsenic	5.0	ND	---	ND
Barium	100.0	0.149	---	0.03-0.6
Cadmium	1.0	0.107	0.002	---
Chromium	5.0	0.084	0.003	0.01-0.04
Lead	5.0	0.034	0.0196	0.01-0.02
Mercury	0.2	ND	0.108	0.0004
Selenium	1.0	ND	---	ND
Silver	5.0	ND	<0.001	---

Barium and chromium were found in similar concentrations in all basins, indicating that they occur naturally within the soil. Concentrations of barium and chromium were below their regulatory allowable limits (RAL) of two and 0.1 mg/L, respectively. Results for the metals with primary drinking water standards that were tested by Humphrey and Katz are summarized in Table 4.

Table 4: Results for Metals with Primary Drinking Water Standards (adapted from Humphrey and Katz, 2000)

Metal	RAL (mg/L)	Measured Concentration (mg/L)
Barium	2.0	<0.2 (maximum)
Cadmuim	0.005	0.0005
Chromium	0.1	0.07
Copper	1.3	0.009
Lead	0.015	0.002
Selenium	0.05	0.00017

The metals with secondary drinking water standards, i.e., they are of aesthetic concerns only, were tested for the following: aluminum, calcium, iron, magnesium, manganese, sodium and zinc. Only iron and manganese were detected in levels exceeding their secondary drinking water standard. Iron in excess of its RAL of 0.3 mg/L was found on several dates. Manganese concentrations, however, consistently exceeded its RAL of 0.05 mg/L by factors of ten to 400. Bosscher, Edil and Eldin (1993) also reported elevated concentrations (0.3 – 3.2 mg/L) of manganese, but they attributed them to natural occurrences. Humphrey and Katz (2000) reported that "negligible levels of organics were found".

A field study investigating the effects of scrap tires placed below the ground water table has been reported by Humphrey and Katz (2001) and Downs, et al. (1996). With regard to the leaching of organics, when placed below the ground water table, scrap tires will leach organic compounds in low concentrations. In addition, when placed below the ground water table, scrap tires release manganese and iron in concentrations that exceed their secondary drinking water standards. However, metals with secondary drinking water standards are not considered health hazards; they only affect the aesthetics, e.g., color, odor, of the water. Due to the unknown effect of the organics Downs, et al. (1996) and ASTM D 6270-98 recommend that scrap tire fills be placed above the ground water table.

2.5 Potential Causes of Exothermic Reactions in Scrap Tire Fills

Ignition of a scrap tire fill, or stockpile, must be preceded by an exothermic (heat generating) reaction. Currently, the exact mechanism, or mechanisms, involved in the initiation of exothermic reactions in scrap tire fills remains unknown. However, based on observation and investigation of heating and fires that have occurred in scrap tire embankments, as well as in scrap tire stockpiles, several factors that appear to be contributors to the creation of exothermic reactions have been isolated. These contributory factors enhance one, or more, of the processes that lead to the initiation of a sustained exothermic reaction. The design guidelines discussed in Section 2.6 attempt to control these contributing factors. Likely processes creating the exothermic reaction are discussed below. Most of the discussion in this section has been taken from Humphrey (1996).

Humphrey (1996) summarized the cases of four stockpiles that experienced exothermic reactions. Based upon his discussion, there appear to be several commonalities that contributed to heating of these stockpiles. In the first case, the stockpile originated from tires being processed for use as tire derived fuel (TDF). The process resulted in there being a high ratio of steel to rubber remaining in the waste product as well as a quantity of crumb sized rubber particles. The fire occurred in the bottom three feet of the pile (the height of the pile was not stated). In order to prevent further fires, the stockpile was maintained in a loose state, which permitted air access to the pile and thus removal of any heat being generated. Another stockpile at the same facility, that contained only rubber derived from glass belted tires, experienced heating but did not combust.

The second fire occurred in a tire stockpile that was 200 feet long, 100 feet wide and 45 feet high. The heating occurred in a zone ten to 20 feet from the bottom of the pile. In this case, the size of the stockpile may have prevented this zone from cooling.

The third case involved two hot spots that developed in a stockpile consisting of two inch tire chips. The stockpile was ten to 50 feet high. The hot spots developed at the mid-height of the stockpile at portions where the stockpile height was 30 and 50 feet. In the fourth case, hot spots developed in 15 to 20 foot high stockpiles of two inch tire chips. Where the hot spots occurred within the stockpiles involved in the fourth case were not given. Stockpiles at the same facility that contained only four inch tire chips experienced no heating.

From Humphrey's discussion of these stockpile heating incidences, the commonalities appear to be: large stockpile thickness, which provide insulation to heating layers, little access to air (a consequence of the large thickness and/or tightness of the pile) and finally the fact that heating appears more likely to occur in piles with smaller particle sizes. As an illustration of this last point, Eremina, Zhurbinskii and Steblev (1991) report that rubber crumb with a median particle size of 30 – 40 μm will spontaneously combust in layers as small as 0.4 inch. Although scrap tire fills are composted of tires with much larger particle sizes, this fact does demonstrate the importance of particle size to the initiation of exothermic reactions. Humphrey (1996) did not discuss the accessibility to water by the stockpiles he considered. However, since these were large stockpiles, it is probably reasonable to assume that they were open-air, and thus had access to water through precipitation. Given the above set of commonalities, the proposed mechanisms for initiation of an exothermic reaction are (Humphrey, 1996):

a. oxidation of exposed steel wires
b. microbes generating acidic conditions
c. oxidation of rubber
d. microbes consuming exposed steel belts
e. microbes generating acidic conditions
f. microbes consuming liquid petroleum products

Some of these processes are discussed below.

The oxidation reaction for iron, at neutral pH and aerobic conditions, is:

$$4Fe + 3O_2 + 6H_20 \rightarrow 4Fe(OH)_3 \qquad \text{Equation 2}$$

This reaction releases 2623 Btu/pound of iron that is oxidized. Given that it takes 25 Btu to raise the temperature of one cubic foot of tires by one degree Fahrenheit (the volumetric heat capacity), Humphrey (1996) shows that it would take only 0.095 lb of steel to raise the temperature of one cubic foot of tires by ten degrees Fahrenheit. Although the calculation is based on the assumption that no energy is lost to the surrounding environment, it clearly demonstrates that the oxidation of the steel contained in scrap tires may be a major contributing factor to the generation of exothermic reactions and hence ignition of scrap tire fills. As will be discussed in Section 2.6, the amount of exposed steel in tire shreds must be minimized, and it should be noted that tire shreds produced by shearing have less exposed steel than those produced by a hammer mill (Humphrey, 1996).

The oxidation of steel is affected by temperature and pH. Humphrey (1996) cited a study that showed raising the temperature from 65 to 70°F doubled the oxidation, i.e., corrosion rate. The corrosion rate also greatly increases when the pH drops below about four. One important effect of an acidic environment is that some organic acids, such as humic and tanic, increase the solubility of $Fe(OH)_3$, which is the product of oxidation, i.e., rust. Normally rust acts as a protective coating for the underlying material that has not been oxidized. However, in the presence of these acids the iron stays in solution by forming complexes with the organic acids. The result is that the effectiveness of rust as a protective coating is reduced.

Bacteria can play a role in the oxidation of steel. Specifically, Humphrey (1996) discusses two types of bacteria (Sphaerotilus and Leptothrix) the can oxidize the iron contained in the complexes formed with the organic acids mentioned above. Sulfur oxidizing bacteria, e.g., Thiobacillus, can also play a role in reducing the pH of the ambient environment by producing sulfuric acid. However, they require the availability of elemental sulfur. Elemental sulfur is added to tire rubber, about one percent by weight to rubber, to increase bond strength between rubber molecules. Humphrey (1996) states that normally the elemental sulfur would be expected to be chemically bound to the rubber; however, as the tire ages, some of the sulfur could be released. The oxidation of the iron in organic complexes by bacteria as well as the oxidation of sulfur is an exothermic reaction. Hence these reactions may have a role in creating the conditions necessary for the ignition of a scrap tire fill.

Microbes that consume hydrocarbons are likely present in scrap tire fills. However, their role in generating an initial exothermic reaction is questionable. The reasons for the doubt include: a source of hydrocarbons must be present, the microbes operate only under specific temperature and pH conditions and only if the proper inorganic nutrients are available. With regard to the hydrocarbon source, there is no evidence that the microbes can consume vulcanized rubber. Hence the source of hydrocarbons would have to be external to the scrap tire fill, e.g., a spill occurring during construction or tire shreds contaminated prior to being placed into the fill. Necessary inorganic nutrients include nitrogen and phosphorous.

Although the oxidation of the rubber itself may seem to be an obvious contributor, its role in creating an exothermic reaction is doubted. Tire manufacturer's maintain that tire rubber is stable up to a temperature of 250°F and therefore would not contribute to an initial exothermic reaction. Nevertheless, Humphrey (1996) suggests that the oxidation of crumb-sized rubber should be investigated.

Sugawa (1993), as cited by Nightingale (1997) and Nightingale and Green (1997), employed a so-called heat ignition theory, to model the observations of a large tire stockpile fire that occurred in Japan. Sugawa also conducted laboratory tests in an attempt to confirm the theory. His result was a plot of air temperature against the thickness of the pile. The plot contains three zones: one that defines areas where the potential for ignition is not likely, a zone where ignition is likely and, finally, a transition zone between the two. Nightingale (1997) plotted data for the Ilwaco and Garfield County fires on Sugawa's plot. Data for Ilwaco fell within the transition zone, and data for the Garfield County site fell on the boundary between the transition zone and likely ignition. Additional research and field data will be required before Sugawa's method can be relied upon to predict the maximum heights for scrap tire fills. Nightingale (1999) is conducting laboratory tests to investigate several of the variables/mechanisms thought to initiate exothermic reactions in tire fills. However, the results have thus far been inconclusive.

2.6 FHWA Interim Guidelines for Shredded Tire Embankments

Following the three scrap tire fill fires of 1995 (two in Washington and one in Colorado) the FHWA Office of Engineering, issued a memorandum recommending that, pending further research and evaluation, scrap tire use should cease on all Federal-aid construction projects on the National Highway System. An ad hoc committee, consisting of members from industry, government and academia, was formed to investigate the recent fires in scrap tire fills. Highway agencies requested that the committee also produce a set of design guidelines so that scrap tire use could continue. These design guidelines were issued in a memorandum (FHWA, 1997) titled "Interim Guidelines for Shredded Tire Embankments". The principal author of these design guidelines was Dana Humphrey, currently of the University of Maine. Eventually these guidelines were adopted as ASTM D 6270 (ASTM 1998). Currently, these are the primary standard of practice for highway agencies designing scrap tire fills. The main purpose of the design guidelines is to minimize the factors contributing to the creation of exothermic reactions within the tire fill. The guidelines only address the design of monofills. The guidelines are summarized in Table 5, which has been adopted from a table presented by the Rubber Manufacturers Association.

2.7 Physical Properties of Scrap Tires

<u>Introduction</u>

This section presents a summary of the engineering properties of scrap tires placed as fill. An attempt has been made to make generalizations concerning the engineering properties of scrap tire fill, such that the reader can gain an understanding of both the characteristics that make scrap tires advantageous and those that make them disadvantageous to use in highway engineering projects. One limitation is that much of the available data is from laboratory studies, which cannot duplicate field conditions. For instance, in laboratory studies scrap tires are seen to undergo initial vertical strains of up to 50 percent. However, the initial vertical strain of in-place scrap tire fills has been observed to be generally less than 20 percent.

Table 5: Summary of ASTM D 6270 Design Guidelines

<table>
<tr><th colspan="2">General Guidelines for All Tire Shred Fills July 1997</th></tr>
<tr><td colspan="2">All tires shall be shredded such that the largest shred is the lesser of one quarter circle in shape or 2 ft (0.6 m) in length; and at lest one sidewall shall be severed from the tire shred</td></tr>
<tr><td colspan="2">Tire shreds shall be free of contaminants such as oil, grease, gasoline, diesel fuel, etc., that could create a fire hazard</td></tr>
<tr><td colspan="2">In no case shall the tire shreds contain the remains of tires that have been subjected to a fire</td></tr>
<tr><th>Class I Fills, < 3 ft (1m) Thick</th><th>Class II Fills, 3 – 10 ft (1 – 3 m) Thick</th></tr>
<tr><td>Maximum of 50% (by weight) passing 1.5 in (38 mm) sieve</td><td>Maximum of 25% (by weight) passing 1.5 in (38 mm) sieve</td></tr>
<tr><td>Maximum of 5% (by weight) passing 0.2 in (4.75 mm) sieve</td><td>Maximum of 1% (by weight) passing 0.2 in (4.75 mm) sieve</td></tr>
<tr><td></td><td>Tire shreds shall be free from fragments of wood, wood chips and other fibrous organic matter</td></tr>
<tr><td></td><td>The tire shreds shall have less than 1% (by weight) of metal fragments that are not at least partially encased in rubber</td></tr>
<tr><td></td><td>Metal fragments that are partially encased in rubber shall protrude no more than 1 in (25 mm) from the cut edge of the tire shred on 75% of the pieces and no more than 2 in (50 mm) on 100% of the pieces</td></tr>
<tr><td></td><td>Infiltration of water into the tire shred fill shall be minimized</td></tr>
<tr><td></td><td>Infiltration of air into the tire shred fill shall be minimized</td></tr>
<tr><td></td><td>No direct contact between tire shreds and soil containing organic matter, such as topsoil</td></tr>
<tr><td></td><td>Tire chips should be separated from the surrounding soil with a geotextile</td></tr>
<tr><td></td><td>Use of drainage features located at the bottom of the fill that could provide free access to air should be avoided</td></tr>
</table>

This may be the result of differences in the size of the tire shreds tested in the laboratory versus the size of shreds used in the field. In addition to observed settlements in the field, the laboratory results of Edil and Bosscher (1992) tend to support this conclusion.

The leaching characteristics of scrap tires are an important consideration in deciding whether to use them in engineered fills. In spite of this, the leaching characteristics of scrap tires have not been as extensively investigated as have their mechanical properties. However, there are several fairly conclusive studies that are discussed in a separate section.

Specific Gravity

The specific gravity of a substance is the ratio of its unit weight to the unit weight of water (62.4 lb/ft^3). Hence a substance with a specific gravity of two has a unit weight that is twice that of water. Most soils have a specific gravity of 2.65 to 2.7. A number of specific gravity tests for scrap tires that were cited in the literature are summarized in Table 6. The actual unit weight of scrap tires is discussed in the following section. From the table, it is clearly seen that the specific gravity of scrap tires is between one and 1.2. This implies that scrap tires are significantly lighter weight, per unit volume, than soil and thus indicates the usefulness of scrap tires as a lightweight fill.

Table 6: Specific Gravity of Tires Shreds

Specific Gravity	Comments	Reference
1.11 1.08 1.18 1.18 1.12		Benda, 1995
1.05		Yeung and Boddu, 1995
1.05 1.02 1.10	Glass and steel belts Glass only Steel only	Humphrey and Manion, 1992
1.14 1.27 1.24	Glass only Glass and steel Glass and steel	Humphrey, et al., 1993
1.18	Glass and steel	Bressette, 1984
1.23		Tweedie, Humphrey and Sanford, 1998c
1.06 1.12		Moo-Young, et al., 2001
1.08		Newcomb and Drescher, 1994
1.07		Masad, et al., 1996
1.21 1.25 1.27	Particle Size: < 2 in 2 to 4 in 4 to 6 in	Foose, 1993
1.15		Youwai and Bergado, 2003

Unit Weight

The reduced unit weight of scrap tires, over that of soil, is the most often cited advantage of using scrap tires. Soil unit weights are generally between 110 – 125 lb/ft^3. A generally accepted value for the unit weight of in place scrap tires is 40 lb/ft^3; however, values of up to 50 lb/ft^3 have also been recommended. Regardless of the value used, the in-place unit weight of scrap tires is about one third to one-half that of soil. Unit weight values for scrap tires resulting from various levels of laboratory compactive effort as well as some in-place unit weights are summarized in Table 7. The usefulness of scrap tires as lightweight fills is evident.

Table 7: Unit Weights of Tire Shreds

Unit Weight (lb/ft^3)	Compaction Method	Particle Size	Reference
Laboratory Compaction			
35.1 – 37.3	Modified	12 mm max.	Cecich, et al., 1996
31.5 – 37.5		38 mm max.	Benda, 1995
41 40 40	Modified Standard 60% Standard		Humphrey and Manion, 1992
38.6 – 40.1	60% Standard		Humphrey, et al., 1993
27.5 – 31.3	Shaken/vibrated in mold		Westerberg and Mácsik, 2001
43.0 28.6	Modified Loose	400 to 50 mm	Moo-Young, et al., 2001
31.3		D_{50} = 30 mm	Newcomb and Drescher, 1994
42.8 – 46.9	Standard	16 mm max.	Youwai and Bergado, 2003
25 35	Loose Modified	5 to 25 mm	Ahmed and Lovell, 1993
In-Place or Field Compacted			
43.1 – 44.3	Walk behind, vibratory tamping foot roller compactor, static weight, 2600 lb	1.5 to 3 in 38 to 76 mm	Tweedie, Humphrey and Sanford, 1998c
33 45 53	In trucks D-8 Dozer ~5.5 ft Surcharge		Upton and Machan, 1993
42.3 – 47.6	1152 lb/ft^2 Surcharge		Benda, 1995
31.3 – 43.8	626 – 1044 lb/ft^2 8354 lb/ft^2		Westerberg and Mácsik, 2001
38	20,000 lb smooth, steel-wheel roller; then loaded with up to 5 ft of fill and 8 ft of surcharge that remained for 4 mo.	4.75 to 300 mm	Dickson, Dwyer and Humphrey, 2001

Compressibility

The high compressibility of scrap tires is often cited as their main disadvantage for use in roadway embankments. Compressibility of tires is divided into two components, an initial settlement immediately following loading and a secondary or creep settlement that occurs under constant loading. The creep settlement may continue long after the initial loading of the scrap tire fill. Initial vertical strain in scrap tire fills is attributed to the bending and reorientation of the tire shreds and, as the fill is compressed and becomes denser, the compression of individual chips (Edil and Bosscher, 1992). Ahmed and Lovell (1993) include a minor, irrecoverable component that consists of the rearrangement/sliding of the tire shreds during initial loading.

The compressibility of scrap tires complicates two aspects of embankment construction: (1) obtaining final grade and (2) obtaining adequate compaction of overlying soil and pavement structures. However, it has been found in field applications that a delay in paving will allow for initial settlement of the scrap tire fills to occur. Secondary (creep) settlements have generally been less than one percent of the height of the scrap tire fill. Adequate compaction of soil caps and pavement subgrades can be accomplished provided that the cap thickness is large enough, generally two to six feet (Humphrey, et al., 1993). Often it is possible to obtain only about 80 percent of the required compaction on the first lift or two. However, adequate compaction is usually achieved on subsequent lifts.

Laboratory studies (Westerberg and Mácsik, 2001; ASTM, 1998; Drescher and Newcomb, 1994; Edil and Bosscher, 1992; Humphrey, et al., 1993 and Humphrey and Manion, 1992) indicate that even under small stresses tire shreds will undergo large initial settlements. However, as the stress continues to increase, the incremental vertical strain decreases. Typical results illustrating this behavior are summarized in Figure 3.

When tire shreds are unloaded then reloaded, vertical strains during rebound and reloading (cyclic strains) of about 12 percent have been measured by (Humphrey, et al., 1993), as shown in Figure 4. Similar values for maximum cyclic strain have been measured by other researchers, e.g., Edil and Bosscher (1992), Newcomb and Drescher (1994) and Bressette, 1984.

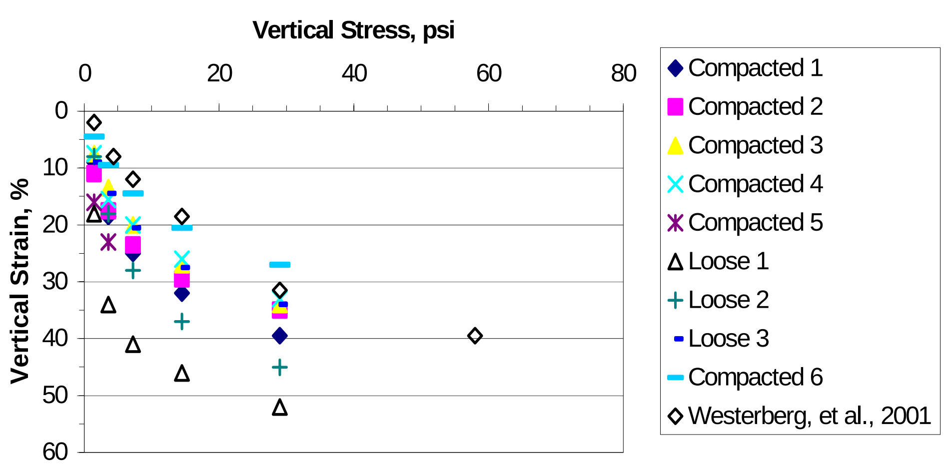

Figure 3. Initial Vertical Strains of Tire Shreds

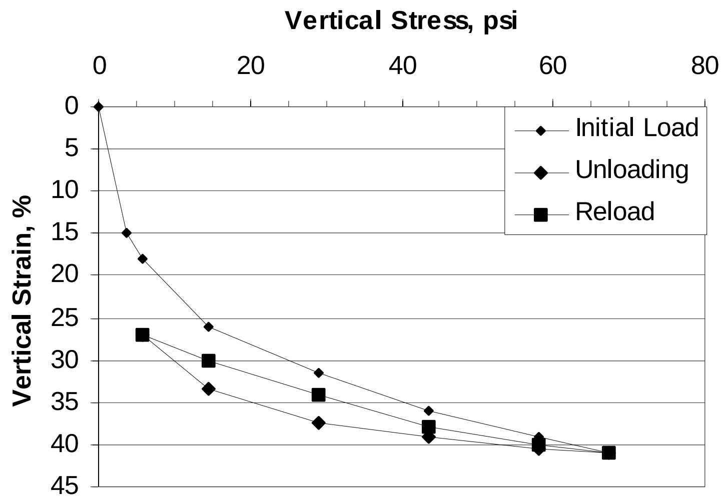

Figure 4. Typical Behavior of Tire Shreds During Loading and Unloading Cycles (adapted from Humphrey, et al., 1993)

Shear Strength

The shear strength of scrap tire fills is required in order to enable the stability of the fills to be determined. Most of the shear strength data that has been reported in the literature are the results of laboratory testing rather than full-scale tests. The shear strength of scrap tires is generally characterized by two parameters, cohesion, c, and angle of internal friction, ϕ. *Physically*, cohesion can be thought of as the physico-chemical attraction between particles. *Physically* the tangent of the angle of internal friction is the coefficient of friction between individual particles. Cohesion is *determined* from the location of the y-intercept of the trend line describing the results from strength testing. For instance, in Figure 5 the cohesion is zero. The angle of internal friction is *determined* as the angle of the trend line in Figure 5.

Although the body of laboratory testing is not conclusive with regard to what strength parameters to use in analyses, two trends appear to be evident: (1) as determined in the laboratory, there appears to be little correlation between the particle sizes of the tires and their shear strength, e.g., Benda, 1995, Humphrey, et al., 1993, Foose, 1993, and (2) field observations indicate that shear strengths in the field appear to be larger than those measured in the laboratory (Gebhardt, Kjartanson and Lohnes, 1998, Benda, 1995 and Wu, Benda and Cauley, 1997). Based on the literature review, the current standard of practice for retaining wall analysis appears to be to use a low friction angle of $\phi \approx 30°$ and no cohesion. In the case of stability analyses, standard of practice is to use a larger friction angle, $\phi \approx 40°$and no cohesion value. The reason no cohesion is used is that laboratory testing seems to indicate that significant cohesion does not develop until there has been a substantial amount of displacement.

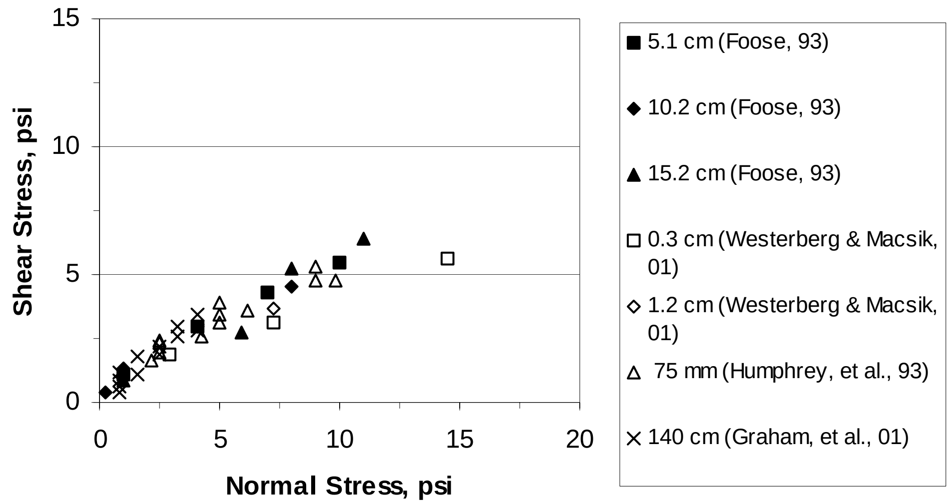

Figure 5. Shear Strength of Tire Shreds as Determined in Direct Shear Tests

Laboratory results from direct shear testing are presented in Figure 5. The direct shear test is one of the two most common laboratory methods that have been used to obtain shear strength of tire shreds. As is evident in the figure, regardless of the particle size, all of the results fall along the same general trend line. The fact that shear strengths in the field appear to be larger than laboratory determined values is based on observations of angles of repose of up to 43°F in loose and up to 80°F, in compacted tire fills and that near vertical cuts into tire fills will stand unsupported (Tweedie, Humphrey and Sanford, 1998a; Upton and Machan, 1993). This behavior indicates larger shear strengths are operative in the field than in the laboratory.

Possible causes for the differences in laboratory and field strengths are interrelated. One is that either cohesion in the field is much larger than that measured in the laboratory, or the angles of internal friction are much larger, while the cohesion remains low. A second reason is that differences in structure between a full-scale tire fill and that of the small samples being tested in the laboratory are so great that it is impossible to obtain reliable strengths from laboratory testing. If this is the case, the likely cause is the large difference in particle size, and its effect on the structure of the fill. Laboratory tests, in contrast, have shown no strong dependence on particle size, as shown by the direct shear results in Figure 5.

Triaxial extension testing has produced results indicating higher strengths than those reported in direct shear, e.g., Wu, Benda and Cauley, 1997 and Benda, 1995. Triaxial tests can be, and usually are, run in compression. During the triaxial (extension or compression) test a cylindrical specimen can be subjected to controlled loading in both the lateral and axial directions. In contrast, the direct shear test allows for controlled loading in only the vertical direction. By allowing for controlled loading in two directions, stresses and stress changes that occur in the field can be more closely approximated in the laboratory. Nevertheless, triaxial extension test results still do not quite agree with field observations. Furthermore, although the triaxial test is a much more versatile test than the direct shear test, the particle sizes that can be tested are limited by the nature of the typical triaxial test apparatus. Triaxial compression tests have shown results similar to those obtained in direct shear, Youwai and Bergado (2003), Benda (1995) and Bressette (1984).

Coefficient of Lateral Earth Pressure

The coefficient of lateral earth pressure, K, is the constant of proportionality between the vertical and horizontal stress exerted by a frictional material. Mathematically, this is expressed as:

$$\sigma_h = K\sigma_v \qquad \text{Equation 1}$$

Where: σ_h = horizontal earth pressure
σ_v = vertical earth pressure, which is a function of the unit weight of the material
K = coefficient of lateral earth pressure

In a frictionless material, such as water, the coefficient of lateral earth pressure is equal to unity. This occurs because a frictionless material does not possess internal shear strength and therefore it cannot redistribute the vertical stress caused by its own weight. However, because tire, like soil, particles are frictional materials vertical stresses are distributed within the material in various directions, thus making the horizontal stress less than the vertical stress.

The coefficient of lateral earth pressure is dependant upon the amount of wall rotation that will be allowed. For cohesionless backfill, a wall rotation, away from the backfill, that is equivalent to a displacement at its top of about 0.01 – 0.001H (Terzaghi, 1934) is sufficient to develop a condition known as the *active state*. In the active state the lateral earth pressures are at a minimum. The lateral earth pressure coefficient for this condition is called the active earth pressure coefficient, K_a. Most retaining walls in highway projects are designed for the active state.

If no rotation of the wall is permitted, the condition is termed the *at-rest condition* and lateral earth pressures are generally higher than they are for the active state. The lateral earth pressure coefficient for this condition is called the at-rest earth pressure coefficient, K_o. Maximum lateral earth pressures are obtained for a condition known as the passive state, which is not discussed in this report. Typical lateral earth pressure values for granular soils are summarized in Table 8.

Table 8: Typical Values of the Coefficient of Lateral Earth Pressure for Granular Soils

ϕ (°)	K_o	K_a
30	0.5	0.33
40	0.36	0.22

Knowing the value of the coefficient of lateral earth pressure for scrap tires makes it possible to estimate the magnitude of the horizontal stresses that they will exert on a retaining structure. Values of the coefficient of lateral pressure for scrap tires have been investigated both in laboratory tests (Humphrey, et al., 1993; Newcomb and Drescher, 1994) and in full size field tests (Tweedie, Humphrey and Sanford, 1998a,b and Abichou, et al., 2001). Only the results for the field tests are discussed. Representative laboratory and field values are shown in Table 9.

Table 9: Typical Values of Lateral Earth Pressure Coefficient for Scrap Tires

Particle Size (mm)	Coefficient of Lateral Earth Pressure		Condition	Comments	Reference
	Field	Lab			
2 – 76		0.5 – 0.8	At-Rest		Humphrey, Sanford, Cribbs and Manion, 1993
38 – 76	0.25		Active	Recommended K_a for design	Tweedie, Humphrey and Sanford, 1998a,b
38 – 76	0.55 0.33 0.27		At-Rest	250 lb/ft^2 surcharge at depths of 0, 6.5 and 13 ft, respectively	Tweedie, Humphrey and Sanford, 1998b,c
50 – 550	0.25 – 0.35		Not Specified	K-values measured following surcharging of instrumented MSE Wall; 25% by volume tires to sand mixture.	Abichou, et al., 2001
6 – 50		0.4 – 0.8	At-Rest		Newcomb and Drescher, 1994

Tweedie, Humphrey and Sanford (1998a) investigated scrap tires in the active state. They found that following a wall rotation of about 0.01H the horizontal stresses would increase for several days then remain constant at a value about 35 percent less than that expected for conventional backfill materials. They attributed the increase in horizontal stress to creep in the scrap tire backfill. A value of 0.25 for K_a was recommended for design.

Tweedie, Humphrey and Sanford (1998b,c) also performed full-scale tests to investigate the at-rest condition. They found that K_o in the upper three feet of the backfill was near that for soils over a range of surcharge from 0 to 750 lb/ft^2. Between depths of three to six feet, however, K_o decreased to values less than those for typical backfill soils, as shown in Figure 6. For design, they recommended average K_o values (as determined from their several results) for a given depth and surcharge. The average values of K_o for a 250 lb/ft^2 surcharge, which is the surcharge typically applied to retaining walls to account for traffic loading, are reported in Table 9. Average values of K_o at additional surcharge values are shown graphically in Figure 6.

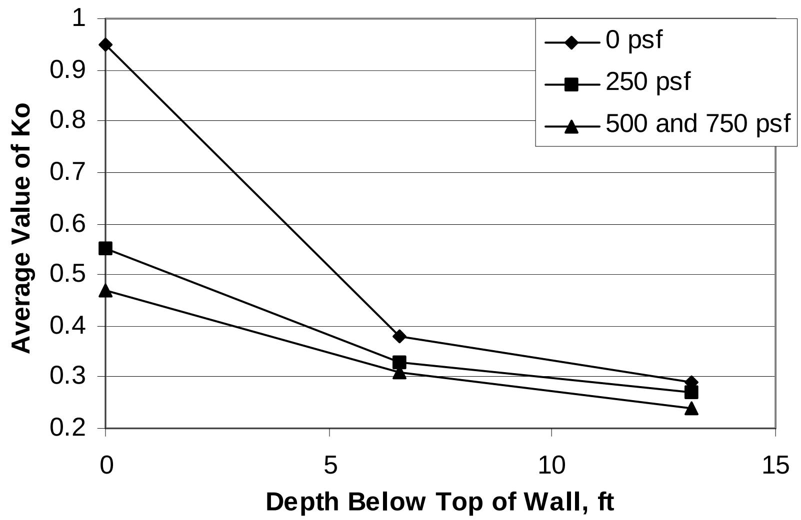

Figure 6. Average Values of K_o (adapted from Tweedie, Humphrey and Sanford, 1998b)

Values of the coefficient of lateral earth pressure for scrap tire backfills are similar to those for soils. However, due to the lighter unit weight of the scrap tire fills (Sec. 4.3.1.2) compared to conventional backfill materials, the resulting lateral earth pressure on retaining structures is reduced.

2.8 Other Uses for Scrap Tires

There are numerous other applications for scrap tires that have been demonstrated or proposed. Interest in these applications is not as high from neither an environmental nor a market perspective because the potential for disposing of large quantities of scrap tires is much smaller, and many of the applications would be considered episodic, hence there would not be continuous demand for tires for these uses. The literature review has been summarized in Table 10. The cited references can be consulted for details, as well as for further information regarding alternative uses for scrap tires.

Table 10. Alternative Uses for Scrap Tires not Addressed by SHB 2308

State or Country	Project or Application Name	Project Description and Comments	Year Built	Reference
CA	Tire anchors	Tire anchors use on tiebacks for a 12 ft. timber walls. Cost was $22/ft^2, many "conventional" walls today fall into this category, likely making this use not economically desirable	1981	Richman, and Jackura, 1984
CA	California-236, near Santa Cruz	This project used whole scrap tires, clipped together, as reinforcement for a 46 ft high embankment constructed as part of a landslide remediation. The project was scheduled for construction in the fall of 1976.	1976 (?)	Forsyth and Egan, 1976
CA	Alternative daily cover (ADC) at landfills	California Integrated Waste Management Board produced a guide for landfill owners	1997	GeoSyntec, 1997
---	Foamed concrete reinforcement	Reinforcement in foamed concrete used for crash attenuators in front of piers.	---	Tom, et al., 2001
Indonesia	Landslide stabilization at a microwave tower facility Bukit Batu Tujoh, Batam Is.	Facing for 7 ft. height geotextile wall for protection from vandalism and ultraviolet radiation. Tires were filled with granite aggregate	1992	Poh and Broms, 1995
IA	Horizontal drains	Tire shreds of 0.33 – 06 ft width and 0.6 – 1.3 ft length were used to construct horizontal drains; the drains were more like what WDOT would consider a "trench drain"	---	Kjartanson, Lohnes and Zimmerman, 2001
ME	Subgrade insulation	Various layer thickness of tire shreds of 2 in maximum size, to 4.75 mm, were placed below an unpaved road. Frost penetration depths were reduced 22 to 37 percent.	1992	Humphrey and Eaton, 1995
NJ(?)	Scour protection at bridge abutments and piers.	Flume tests showed reductions in scour of up to 60%. A demonstration project at two parallel bridges on Rt46 over the Passaic River is currently under design. For control, half of the project will use gabions (Kaufman, 2003).	??	Capers, Kaufman and Bilanin, 2001

3. PAVEMENT USES FOR SCRAP TIRES

3.1 Fundamental Hot-Mix Asphalt Concepts

Prior to discussing how recycled tires can be incorporated into pavements, it is important to first describe the various aspects of pavement types, mix types and asphalt binder characterization.

Pavement Types

Basically, all hard surfaced pavement types can be categorized into two groups, flexible and rigid. Flexible pavements are those that are surfaced with asphalt materials in the surface (or wearing) course. These can be either in the form of pavement surfaces such as a chip seal, which is generally found on lower volume (or lower traffic) roads. A chip seal consists of one or more applications of sprayed-on liquid asphalt followed by a layer of suitable aggregate to protect and preserve the surface, maintain the structural integrity, or restore the surface texture and skid resistance of the roadway. The material is rolled so that the aggregate layer is embedded into the asphalt layer. On the other hand, Hot Mix Asphalt (HMA) surface courses are generally used on higher volume roads such as the Interstate highway network. HMA is a high quality, thoroughly controlled hot-mixture of asphalt binder and aggregate that can be compacted into a uniform dense mass. These types of pavements are called "flexible" since the total pavement structure "bends" or "deflects" due to traffic loads. Further, the flexible pavement structure is generally composed of several layers of materials that can accommodate this "flexing"

Rigid pavements are composed of a portland cement concrete (PCC) surface course. Such pavements are substantially "stiffer" than flexible pavements due to the high modulus of elasticity of the PCC material. Further, these pavements can have reinforcing steel, which is generally used to reduce or eliminate "joints". PCC joints are a design detail, which can vary greatly between the various State Highway Agencies. Some states use joints (transverse across the lane) which are closely spaced (say every 12 to 15 feet) and others use reinforcing steel to increase the allowable distance between joints to 40 feet or more or to eliminate them completely.

HMA Mix Types

The objective of HMA mix design is to ascertain the combination of asphalt binder and aggregate that will give long-lasting pavement performance while minimizing life cycle costs.

In hot-mix, the component materials – aggregate, asphalt binder, and other additives – must be heated prior to mixing to obtain sufficient fluidity for mixing and workability. Mix design involves laboratory procedures developed to establish the necessary proportion of materials for use in the HMA. A sample paving mixture is prepared in the laboratory and can be analyzed to determine its probable performance in a pavement structure. Several characteristics of the mix influence mix behavior: mix density, air voids, voids in the mineral aggregate, and asphalt content.

There are three primary HMA mix types (see Figure 7): dense-graded, open-graded, and gap-graded.

Dense-Graded Mix

A dense-graded mix is a well-graded (even distribution of aggregate particles from coarse to fine), dense HMA mixture consisting of aggregates and asphalt binder. Properly designed and constructed mixtures are relatively impermeable. Dense-graded mixes are considered the workhorse of HMA since they may be used effectively in all pavement layers, for all traffic conditions (Garcia and Hanson, 2001). This mixture provides a nearly impermeable surface to minimize the potential of surface moisture from entering the underlying pavement layers, which if allowed, weakens (lowers ability to carry the required traffic loading) the pavement structure.

Open-Graded Mix

This is a type of asphalt mixture that has a special aggregate size, which creates a very open texture in the final pavement surface. The open surface texture characteristic of this type of pavement provides benefits in the form of decreased spray from vehicles under wet conditions. In addition, the open surface texture characteristics results in lower tire noise levels.

Gap-Graded Mix

A gap-graded mix contains aggregate that is not continuously graded for all size fractions, typically missing one or two of the fines sizes.

Dense-Graded Open-Graded Gap Graded

Figure 7. HMA Mix Types

Strategic Highway Research Program

In 1987, the U.S. Congress established a five-year, $150 million applied research program aimed at improving the performance, durability, safety, and efficiency of the nation's highway system. Called the Strategic Highway Research Program, this program was officially authorized by the Surface Transportation and Uniform Relocation Act of 1987 and consisted of research concentrated in four key areas (FHWA, 1998):

- Asphalt – research to develop a completely new approach to HMA mix design.
  - Investigate why some pavements perform well, while others do not.
  - Develop tests and specifications for materials that will out-perform and outlast the pavement being constructed today.

- Work with highway agencies and industry to have the new specifications put to use.
- Concrete and structures - research in the areas of mix design and assessing, protecting and rehabilitating concrete pavements and structures.
- Highway operations - pavement preservation, work zone safety and snow and ice control research.
- Pavement performance - Long Term Pavement Performance Program (LTPP), a 20-year study of over 2,000 test sections of in-service U.S. and Canadian pavements to improve guidelines for building and maintaining pavements.

Asphalt Binder Grading

Ideally, any pavement mix/binder must be capable of placement and compaction to provide an even and strong riding surface and appropriate mix density (air voids). An asphalt binder, together with the mix design, must be able to withstand loading to prevent pavement deformation (wheel path rutting). A binder must be able to withstand low temperatures and the resulting thermal stresses that develop as the pavement contracts. A binder must be able to withstand repeated loading and unloading without exhibiting fatigue failure (cracking). Finally, an ideal asphalt binder will be able to sustain these performance criteria over an extended period of time.

Prior to the 1990, there were essentially two primary asphalt binders grading systems used in the United States: the viscosity grading system and the aged residue viscosity grading system.

The viscosity grading system is based on the viscosity of the original (as supplied) asphalt binder. The requirements for the viscosity grading system are in accordance with ASTM and AASHTO testing procedures and include tests for viscosity, penetration, flash point, solubility, and the thin film oven test. These tests essentially measure the asphalt binder consistency and temperature susceptibility during handling and placement. Several critical temperatures are evaluated to quantify the asphalt binder performance as it relates to in-service pavements on hot summer days. However, there is no quantification of the asphalt binder performance at average or low pavement temperatures (mild and cold environments).

The aged residue grading system is based on the viscosity of the aged residue (the asphalt binder is heated to simulate in-service aging prior to testing). The requirements for the aged residue viscosity grading system are also in accordance with ASTM and AASHTO test procedures and include tests for viscosity, penetration, ductility, flashpoint, and solubility. This testing system represents the asphalt binder properties after the HMA is manufactured and in the HMA contractor's production facility. As with the viscosity grading system, this system does not quantify asphalt binder performance at average or low pavement temperatures.

The Pacific Coast Conference on Asphalt developed a third system, the PBA grading system, in 1990. The PBA grading concept uses conventional test methods (same tests as used in the viscosity grading systems) for classifying asphalt binder selection based on climatic conditions.

Although in common use throughout the United States, the previous three grading systems are somewhat limited in their ability to fully characterize asphalt binder for use in HMA pavement. Therefore, as part of the Strategic Highway Research Program, new asphalt binder tests and specifications were developed to more accurately and fully characterize asphalt binders for use in

HMA pavements. The performance grade (PG) tests and specifications are specifically designed to address HMA pavement performance parameters such as rutting and thermal cracking. The PG specification allows for the selection of an asphalt binder to meet the low temperature (for minimizing thermal/transverse cracking), high temperature (for minimizing rutting) and the truck traffic volumes (for minimizing rutting) for a specific pavement section.

The PG system is based on the idea that an HMA asphalt binder's properties should be related to the conditions under which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration and viscosity grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures that are dependant upon the specific climatic conditions in the area of use. Therefore, a binder used in the desert would have different properties than one used in the mountains. This concept is not new – selection of penetration or viscosity graded asphalt binders follows the same logic – but the relationships between asphalt binder properties and conditions of use are more complete and more precise with the PG system. Table 11 shows how the PG system addresses specific penetration, viscosity and aged residue grading system general limitations.

The PG system uses two numbers – the first being the average seven-day maximum pavement temperature (°C) and the second being the minimum pavement design temperature likely to be experienced (°C). Thus, a PG 58-22 is intended for use where the average seven-day maximum pavement temperature is 58°C (136°F) and the expected minimum pavement temperature is –22°C (-8°F).

The Superpave binder specification is based on the simplification of assumptions, which might not be valid for all asphalt binders, particularly modified asphalt containing crumb rubber. Tests have shown that the PG binder grading system has some limitations in grading CRM binders (Troy et al, 1996; Loh et al, 2000).

The Federal Highway Administration (FHWA) is coordinating its crumb rubber modifier research with the National Cooperative Highway Research Program (NCHRP). NCHRP 9-10 is a research project entitled "Superpave Protocols for Modified Binders." FHWA is currently reviewing a proposal submitted by the NCHRP 9-10 researchers to establish Superpave asphalt binder protocols for CRM asphalt. It is anticipated that this proposal will be approved, and the current NCHRP 9-10 research on modified binders will be expanded to specifically include CRM binders (U.S. Department of Transportation[2])

As of January 1999, WSDOT specification requires that all asphalt binder must conform to the specification requirements of AASHTO MP 1 Standard Specification for Performance Graded Asphalt Binder (see Appendix D). These specifications do not limit the type or amount of modifier that can be added to the asphalt binder. The only requirement is that the binder performs within the given specifications for each test procedure.

[2] http://www.fhwa.dot.gov//pavement/CrmbRubr.htm

Table 11: Prior Grading System Limitations vs. Superpave Testing and Specification Features (after Roberts et al., 1996)

Limitations of Penetration, Viscosity and Aged Residue Grading Systems	Superpave Binder Testing and Specification Features that Address Prior Limitations
Penetration and ductility tests are empirical and not directly related to HMA pavement performance.	The physical properties measured are directly related to field performance by engineering principles.
Tests are conducted at one standard temperature without regard to the climate in which the asphalt binder will be used.	Test criteria remain constant, however, the temperature at which the criteria must be met changes in consideration of the binder grade selected for the prevalent climatic conditions.
The range of pavement temperatures at any one site is not adequately covered. For example, there is no test method for asphalt binder stiffness at low temperatures to control thermal cracking.	The entire range of pavement temperatures experienced at a particular site is covered.
Test methods only consider short-term asphalt binder aging (thin film oven test) although long-term aging is a significant factor in fatigue cracking and low temperature cracking.	Three critical binder ages are simulated and tested: 1. Original asphalt binder prior to mixing with aggregate. 2. Aged asphalt binder after HMA production and construction. 3. Long-term aged binder.
Asphalt binders can have significantly different characteristics within the same grading category.	Grading is more precise and there is less overlap between grades.
Modified asphalt binders are not suited for these grading systems.	Tests and specifications are intended for asphalt "binders" to include both modified and unmodified asphalt cements.

Figure 8 illustrates the U.S. status on implementation of AASHTO MP 1. From this figure, all but three states have implemented AASHTO MP 1.

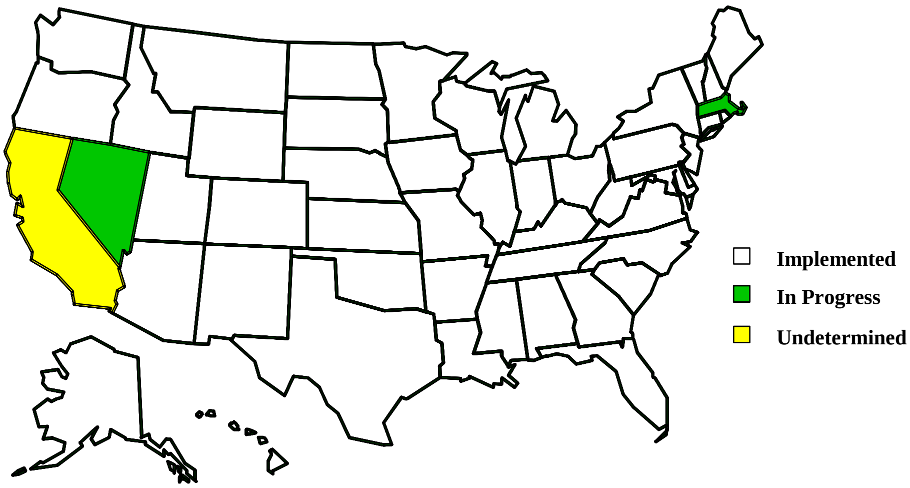

Figure 8. State Implementation of Performance Graded Binders

The following map (Figure 9) illustrates the base grade binders used in Washington State. In general, the binders used on the east side of the state will contain modifiers to meet the PG grading system.

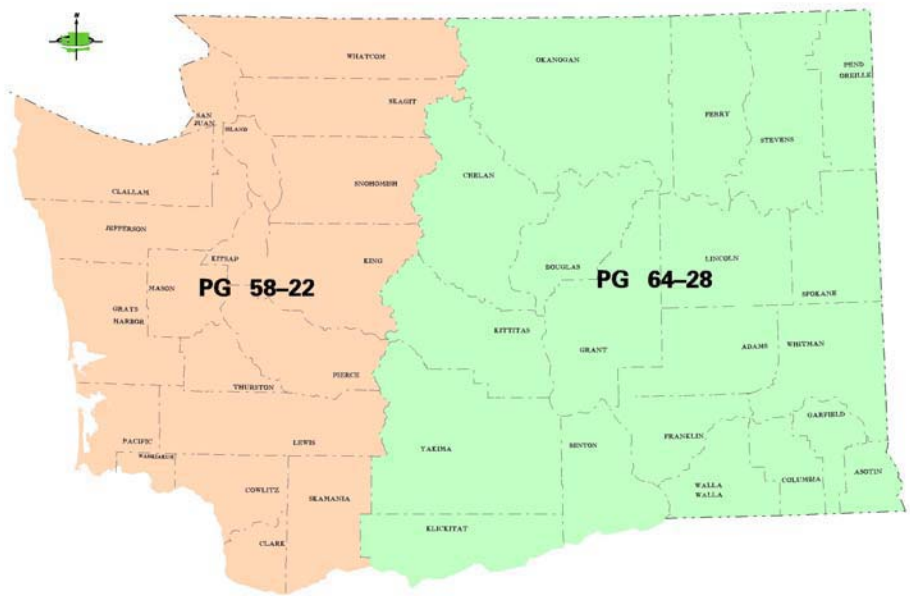

Figure 9. Washington State PG Binders

Considering the effects of traffic volumes and traffic speeds, both of which impact binder performance, the following table lists all of the PG binder grades that are used in Washington State.

Superpave Mix Design Method

Superpave stands for <u>SU</u>perior <u>PER</u>forming Asphalt <u>PAVE</u>ments and consists of three interrelated elements: asphalt binder specification; volumetric mix design and analysis system;

and mix analysis tests and a performance prediction system that includes computer software, weather database, and environmental and performance models.

Table 12. PG Binder Grades for Washington State.

Location	Base Grade	Slow moving vehicles and/or medium traffic volumes	Stopped vehicles and/or heavy traffic volumes
Western Washington	PG 58-22	PG 64-22	PG 70-22
Eastern Washington	PG 64-28	PG 70-28	PG 76-28
Mountain Passes	PG 58-34	PG 64-34	PG 70-34

The volumetric mix design and analysis system allow for the selection of a sound aggregate structure to support the anticipated truck traffic and minimize the potential of rutting.

The mix analysis test and performance prediction system allow for a procedure to predict how a specified mix design (according to rutting and low temperature cracking) will perform in a specified climatic location under specified truck volume.

The Superpave system primarily addresses two pavement distresses: permanent deformation (rutting) and low temperature cracking. The unique feature of the Superpave system is that it is a performance-based specification system – the tests and analyses have direct relationships to field performance (AI).

Photo 1. Rutting

Photo 2. Low Temperature Cracking

Superpave represents an improved system for specifying asphalt binders and mineral aggregates, developing asphalt mixture design, and analyzing and establishing pavement performance prediction (AI).

The following illustrates the benefits of the Superpave mix design procedure over the current Hveem method used by WSDOT.

Superpave
- Considers environmental effects
- Considers traffic levels (heavy truck volumes, slow moving or stopped traffic)
- Ability to predict pavement performance

Hveem
- Developed in the 1950's
- Measures mixture stability (which is closely related to rutting potential)
- Does not consider climate or traffic

There are not, nor will there be, any local, regional or national improvements to the Hveem (or Marshall) mix design procedure. The United States as a whole is moving towards the acceptance and implementation of the Superpave technology. Since pavement performance is dependent on material properties, it is essential to realize that the Superpave technology provides the ability to analyze mix properties and their affect on HMA pavement performance.

Figure 10 illustrates the number of states that have implemented the Superpave mix design. Washington State is currently in the process of fully implementing (by 2004) the Superpave mix design process.

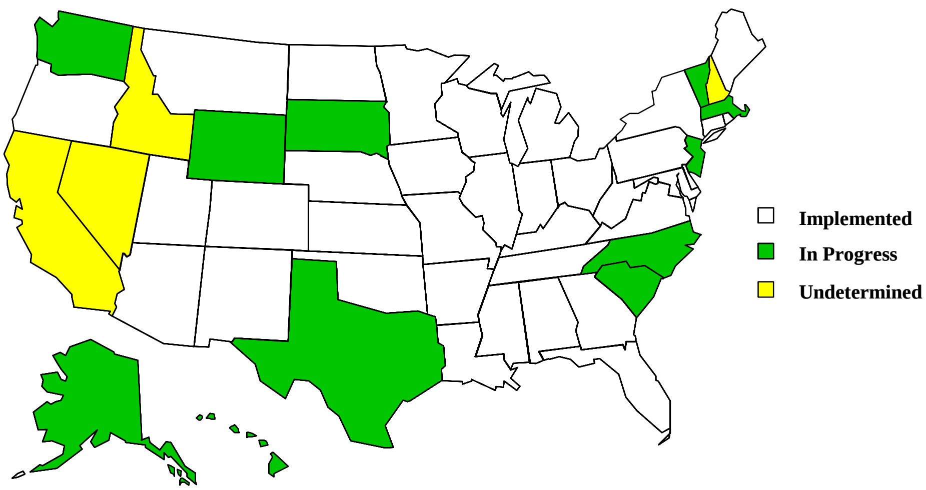

Figure 10. State Implementation of Superpave Mix Design

3.2 Recycled Tires in Hot-Mix Asphalt Pavements

The history of adding recycled tire rubber to HMA material can be traced back to the 1940s, when the U.S. Rubber Reclaiming Company of Vicksburg, Mississippi began marketing a devulcanized, recycled rubber product as a dry particle additive to HMA mixtures. In the mid-1960s, Charles McDonald, a materials engineer for the City of Phoenix, Arizona, began developing a modified asphalt binder using crumb rubber. The Arizona Refining Company, Inc. (also of Phoenix) created a second modified binder in the mid-1970s, replacing a portion of the crumb rubber with devulcanized recycled rubber. The companies marketing these products founded a trade association, the Asphalt Rubber Producers Group, in the mid-1980s.

Another part of the history originates in Sweden. In the 1960s, two Swedish companies began developing an asphalt paving surface mixture that would resist studded tire and chain wear. The mixture included a small amount of crumb rubber as an aggregate and was called by the trade name Rubit. In the late 1970s, this product was introduced and patented in the United States as PlusRide.

Arizona, California, Florida and Texas have led the way in evaluating asphalt rubber pavements. In the late 1980s, Arizona began using gap-graded mixes (described in Section 3.1). California followed with the creation of an asphalt rubber hot-mix gap-graded specification. Today, this Caltrans specification (see Appendix C) is the most popular asphalt rubber mix used by agencies in the United States.

In December 1991, the U.S. Congress enacted the Intermodal Surface Transportation Efficiency Act (ISTEA), which mandated the use of recycled ground scrap tire rubber in prescribed percentages of highways receiving federal aid. However, in 1993, language relating to rubber-modified asphalt in the Act was repealed, and no federal mandate on the use of rubber-modified asphalt exists in the United States today.

Nationally, hot-mix asphalt (HMA) pavement is the most recycled material, more than the total of glass, paper, plastic, and aluminum combined (see Figure 11). Within Washington State, 100 percent of the HMA that is removed is recycled. The use of RAP results in lower costs, due to the use of less virgin material. Therefore, the ability to recycle CRM asphalt pavements is of great concern to both WSDOT and its contracting partners.

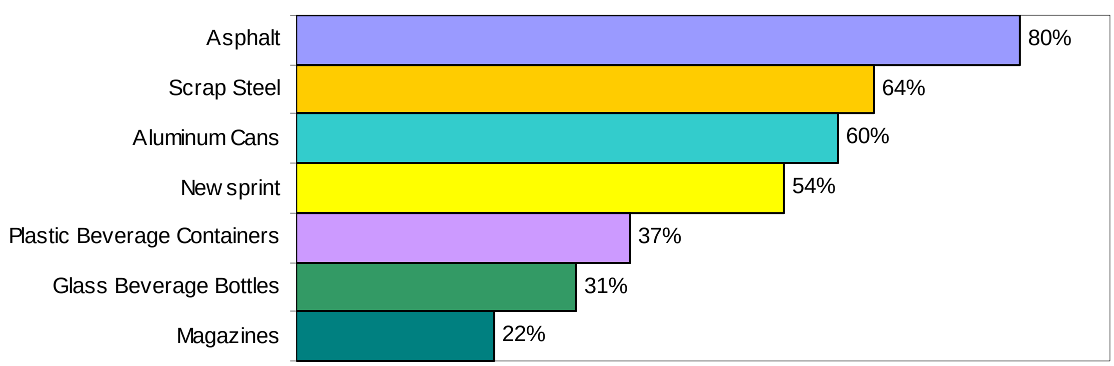

Figure 11. How Much is Recycled?[3]

<u>The Manufacture of Crumb Rubber</u>

Turning whole scrap tires into ground rubber — and turning profits on recycled rubber — is a difficult, detailed, and complex process. Scrap tire rubber is delivered to the processing plant either as whole tires, cut tires (treads or sidewalls), shredded tires, or retread buffing waste. Shredded tires are the preferred alternative (Heitzman, 1992) for CRM. The recycler mechanically removes the steel bead surrounding the inner core of the tire and then shreds the whole tire, typically into chips measuring three inches or less, which can be sold as is (with contaminants included) or processed further. Chips may then be ground to typical particle sizes from 0.08 to ⅜ inch, at which point the recycler removes the non-rubber portions of the tires, including the remaining pieces of steel belt and fibers.

[3] http://www.hotmix.org/recycling.php

Processing contaminated scrap material into clean ground rubber is a capital-intensive business. Rubber recyclers report that $2.00 to $3.00 of capital investment is required for every whole tire processed per year to produce quality ground rubber material (Institute of Scrap Recycling Industries[4]).

Crumb or ground rubbers differ vastly in their types and properties. The Inter-Continental Tire Exchange Granulated Rubber (Tire Crumb) Index identifies 25 different grades of granulated rubber (tire crumb); each grade varies in content and mesh size. Ground rubber may be sized from particles as large as ¾ inch to as fine as 0.006 inch, depending on the type of size reduction equipment and the intended application. Crumb rubber usually consists of particles ranging in size from 3/16 inch to less than 0.003 inches. Most processes that incorporate crumb rubber as an asphalt modifier use particles ranging in size from 1/16 to 0.006 inches.

The differences in crumb rubbers are critical variables in the success or failure of asphalt-rubber binders. Asphalt-rubber binders produced with rubber from the different grinding processes have measurable differences in properties and storage characteristics; these differences are critical to the performance of the binder in open-graded mixtures. The wet-ground rubber material has substantially lower bulk densities and larger surface areas than rubber resulting from other grinding methods. Ground tire rubber materials with greater specific surface areas and more irregular-shaped particles produced asphalt-rubber binders having higher viscosities.

Crumb rubber is the name given to material derived by reducing scrap tire or other rubber into uniform granules, with the reinforcing materials such as steel, fiber, and inert contaminants (dust, glass, rock) removed. Processing scrap tires into crumb rubber modifier (CRM) can be accomplished by several technologies: ambient grinding/granulating, cryogenic grinding, and the micro-mill process. Ground and very fine crumb rubber modifier are typically used for crumb rubber asphalt.

Ambient Grinding/Granulating Process

In ambient ground-rubber processing, scrap tire rubber is ground or processed at or above ordinary room temperature. The temperature of the rubber rises significantly during the process due to the friction generated as the material is torn apart. According to the North American Recycled Rubber Association, the advantages of mechanical grinding are several: the system is well developed, with a variety of components available to reduce the tire into crumb at relatively low cost. The system is comparatively easy to maintain and requires few people to operate and service, and replacement parts are generally easy to obtain and install. There are two disadvantages: first, the considerable added cost and energy required to produce the extremely fine mesh sizes, such as 0.0098 inches and higher. Second, the operation can become very dirty internally, which so far has not become a health issue, but in some regions government health and fire officials could be concerned. It is therefore very important that the factory space be kept thoroughly cleaned on a regular basis to prevent the build up of fine black powder (Coulter, 2003). Both the crackermill and granulator methods of size reduction are ambient grinding processes.

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[4] http://www.isri.org/industryinfo/rubber.htm

Crackermill Process: Ground CRM

The crackermill process, the most commonly used ambient process, produces irregularly shaped torn particles sized from 0.016 to 3/16 inch. Crackermills can be primary, secondary, or finishing mills. They use two large rotating rollers with serrations cut in one or both of them. The product size is controlled by the clearance between the rollers. Crackermills are low-speed machines and the rubber is usually passed through two to three mills to achieve various particle size reductions and further liberate the steel and fiber components. The crumb rubber particles produced by the crackermill are typically long and narrow in shape and have a high surface area.

Granulator Process: Granulated CRM

Granulators reduce the rubber by means of a cutting and shearing action. Screening within the machine controls product size. Screens can be changed to vary the size of the end product. The rubber particles generally have a cut surface shape, are rough in texture, and have similar dimensions on the cut edges. The granulator process produces cubical, uniformly shaped particles with a low surface area, ranging in size from 3/16 inch down to 0.016 inch.

Cryogenic Grinding

Cryogenic processing uses liquid nitrogen or other materials/methods to freeze (-125°F to -325°F) tire chips or rubber particles prior to size reduction. The surface is glasslike, and thus has a much lower surface area than ambiently ground CRM of similar gradation. Cryogenic grinding is a cleaner, slightly faster operation resulting in the production of fine mesh sizes. A disadvantage is the slightly higher production cost due to the added cost of liquid nitrogen.

Binders with the cryogenic ground rubber have the greatest amount of settlement and the least resistance to draindown (West et al, 1996). Draindown is the process by which a portion of the material separates itself from the mix as a whole.

Micro-Mill Process

Micro-milling, also called wet-grinding, is a patented grinding process in which tiny rubber particles are further size-reduced by grinding in a liquid medium, usually water. Grinding is performed between two closely spaced grinding wheels. This process yields finely ground particles ranging in size from 0.003 to 0.016 inch.

<u>Particle Size and Mix Variables</u>

When asphalt and CRM are blended together to create a modified binder. This interaction is affected by a number of variables. The reaction is influenced by the temperature at which the blending reaction occurs, the length of time the temperature remains elevated, the type and amount of mechanical mixing energy, the size and texture of the CRM, and the aromatic content of the asphalt binder. The reaction itself is the absorption of aromatic oils from the asphalt binder into the polymer chains that are the key component of the natural and synthetic rubber in CRM.

Asphalt Type and Concentration

Research has shown that increasing the amount of crumb rubber content increases the viscosity of the modified asphalt binder at pumping and mixing temperatures. The benefit of increased viscosity of asphalt-rubber binder is that additional binder can be used in the asphalt mix to reduce reflective cracking, stripping, and rutting, while improving the binder's response to temperature change and long-term durability, as well as its ability to adhere to the aggregate particles in the mix and to resist aging (Loh et al, 2000). However, this effect is not always favorable, since it makes the pumping of the binders, mixing, and compacting of HMA produced with these modified binders more difficult (Loh et al, 2000; Bahia and Davies, 1994).

CRM asphalt has significantly higher binder contents than unmodified binder; typically, 20 percent higher in dense-graded mixes, 40 – 50 percent higher in gap-graded mixes, and 50 – 60 percent higher in open-graded mixes.

Asphalt Binder Storage Stability

The disadvantage of rubber-modified asphalt is associated with the preparation process during heated storage. The crumb rubber and asphalt separate into two or more phases, because of the weak interaction between the rubber particle surface and the asphalt. Normal asphalt shows a separation of between two to four percent during heated storage. Rubber-modified asphalt yields a non-homogeneous blend with up to 25 percent separation. This non-homogeneity reduces the reliability of the product properties. Separation decreases the expected life of the rubber-modified asphalt.[5]

Climatic Considerations

Environmental factors affecting pavement are temperature and water. Differences in air temperature and rainfall can have a profound effect upon pavement distress mechanisms and pavement performance in different climate regions. A recent California study (Harvey et al, 2000b) stresses the importance of climate region in determining design features for new pavements, rehabilitation, and reconstruction.

Research reported by the Institute of Transportation Studies (University of California at Berkeley) states that due to the stiffness of asphalt rubber, the breakdown rolling must be carried out at 300°F to 325°F to achieve the desired compaction. Breakdown rolling is the initial compaction performed directly behind the paver (no more than 200 feet behind the screed). The goal of the breakdown roller is to obtain the initial lock-up of the aggregate particles at a high mat temperature. The best paving results are achieved when the surface temperature is greater than 85°F. The pavement thickness should also be 0.15 feet (1.8 inch) or greater.

A California study showed that rubber asphalt concrete – gap graded (RAC-G) cools very quickly after placement. Extra attention must be placed on temperature control of this material during compaction (Harvey and Popescu, 2000a, p. 16).

[5] http://www.p2pays.org/ref/11/10504/html/usa/asphalt.htm

Evidence suggests that states with successful crumb rubber paving operations are states with climates that are warm and/or dry for extended periods of time.

Florida's specification (see Appendix F) states, "Apply the asphalt rubber binder only under the following conditions: (1) the air temperature is above 50ºF and rising, (2) the pavement is absolutely dry, and (3) the wind conditions are such that cooling of the asphalt rubber binder will not be so rapid as to prevent good bonding of the aggregate". In addition, Florida has a special temperature requirement for friction courses, which states, "The mixture shall be spread only when the air temperature (the temperature in the shade away from artificial heat) is at or above 60°F".

The Caltrans *Asphalt Rubber Usage Guide* (see Appendix G) stresses that the key to quality in producing asphalt rubber materials and constructing asphalt rubber pavements is temperature control in all aspects of the work. Asphalt rubber materials need to be produced and handled at somewhat higher temperatures than conventional asphalt materials and mixtures because they are stiffer than these conventional materials at the typical mixing and compaction temperatures. Temperature is critical to asphalt rubber binder manufacture, rubber asphalt concrete (RAC) hot-mix production, RAC delivery, RAC placement, and RAC compaction. California's use of asphalt rubber in HMA is limited to gap- and open-gradations. Caltrans special provisions for RAC-G specify minimum atmospheric and pavement surface temperatures of 55°F for mixture placement. When atmospheric and pavement surface temperatures are less than 64°F, spread (lay down) temperature for RAC-G is specified as 290°F to 325°F. Because of the importance of temperature in achieving adequate RAC compaction, operating in the upper half of the temperature range is strongly recommended.

Texas' Special Specification for (see Appendix H) CRM Hot-mix Asphaltic Concrete Pavement states, "Asphaltic concrete shall be placed only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 80°F." Arizona Department of Transportation Specification (see Appendix I) states that asphaltic concrete shall be placed only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 85°F. When a state specifies an air or pavement temperature, they are trying to ensure that placement will happen in good, hot weather.

Climatic Conditions for the States of Arizona, California, Florida, Texas, and Washington.

The states of Arizona, California, Florida, and Texas are the predominant users of CRM in the United States. It is interesting to note that similar climatic conditions exist between these four states, but can significantly differ from the climate conditions in Washington State.

One of the vital elements of HMA performance is adequate compaction. Compaction is primarily a function of mix design, paving equipment (paving machine and rollers), and air temperature. Of these, air temperature is obviously the least controllable. Therefore, Washington State, like all states, specifies the time of year that HMA paving can take place to maximize the potential for adequate air temperatures and therefore maximum possibilities for obtaining the specified compaction level. As stated earlier, CRM construction requires not only higher mat temperatures, but also higher and consistent air temperatures to ensure that adequate compaction is obtained.

In order to illustrate the climatic similarities in states that use CRM, the following climatic analysis was conducted. Table 13 illustrate the average number of days where the average daily temperature is 32°F or less, 75°F to 95°F, and 95°F or more, the average total annual precipitation, and the average freezing index for each state (Appendix E). The climatic data was obtained from the National Oceanic and Atmospheric Administration (NOAA) and includes information that was readily available via the Internet; this comparison does not include all of the state weather stations. This data includes climate data for 20 sites in Arizona, 45 sites in California, 32 sites in Florida, 17 sites in Texas, and 37 sites in Washington State.

Table 13. Summary of Climatic Data for Arizona, California, Florida, Texas, and Washington.

State	Number of Days			Precipitation	Freezing Index
	32°F or less	75°F to 95°F	95°F or more		
Arizona	75	131	46	12	58
California	32	113	32	21	18
Florida	6	253	36	55	1
Texas	37	133	97	30	20
Eastern Washington	124	80	14	16	374
Western Washington	57	45	1	52	41

Figure 12 is a graphical representation of the above table and clearly shows that on average (statewide), eastern Washington has more days below freezing, eastern and western Washington have the fewest days between 75°F and 95°F, and the fewest days of temperatures above 95°F than the other four states.

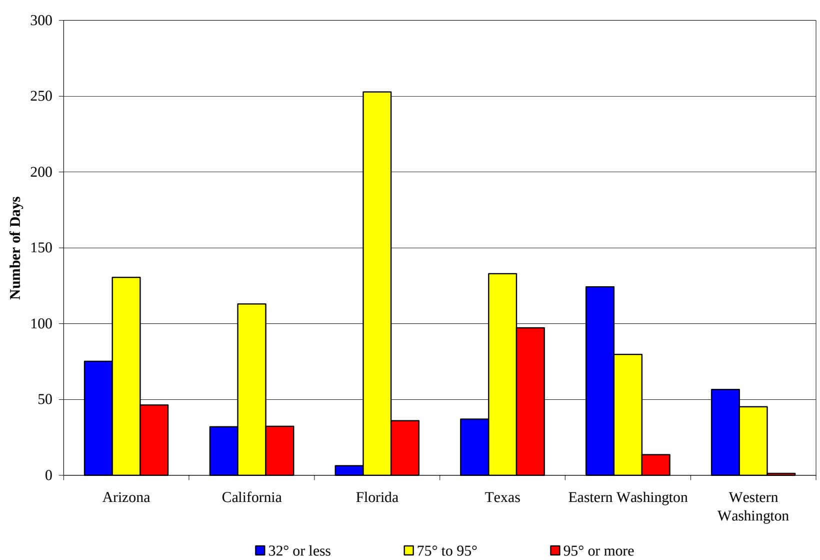

Figure 12. Summary of Climatic Data for Arizona, California, Florida, Texas, and Washington.

Figure 13 summarizes the average statewide precipitation (snow, rain, sleet, etc.) for each of the five states. As shown in the figure, Florida leads the five states in the annual average precipitation with around 55 inches per year, with western Washington having the second most average annual precipitation with approximately 52 inches.

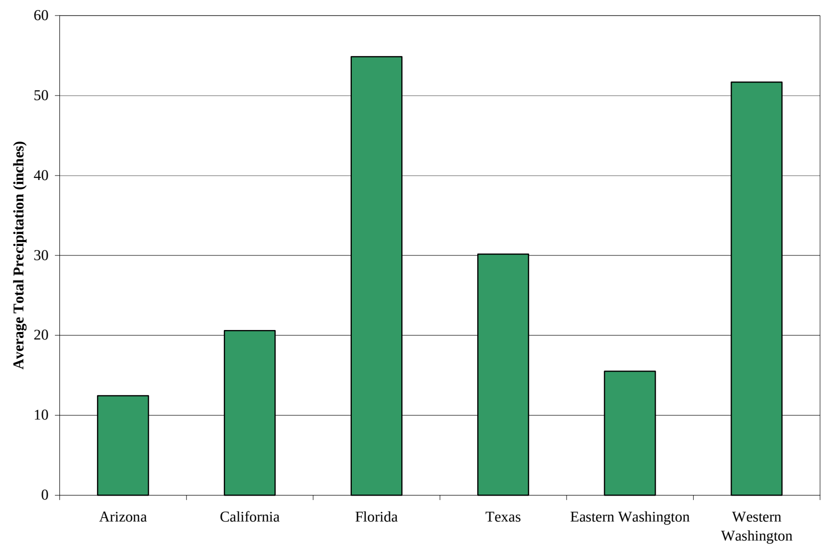

Figure 13. Total Annual Precipitation.

The most distinct difference between the five selected states is the annual freezing index. The annual freezing index is a summation of the number of days below 32°F. For example, if the average temperature was 27°F for five days, than the Freezing Index is simply 32°F - 27°F = 5°F for each day. Therefore, for these five days the Freezing Index would be 25°F-days. Figure 14 summarizes the annual freezing index for the five states.

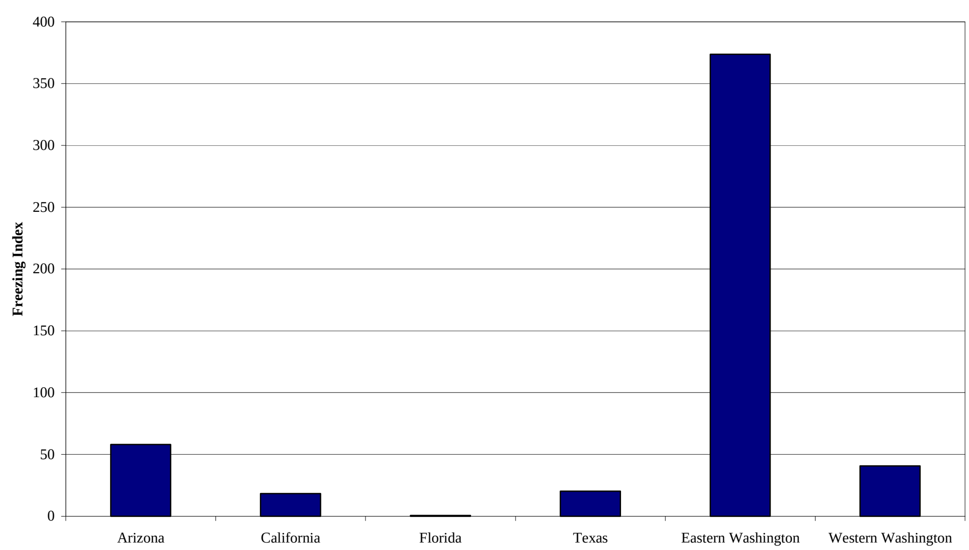

Figure 14. Average Annual Freezing Index.

From this brief overview of climatic conditions, it is clear that the climatic conditions in Washington State are significantly different than in the states of Arizona, California, Florida, and Texas. The major limiting factor in Washington State for the use of CRM-HMA would be the limited number of days for construction.

Future Recyclability

To be considered recyclable, the pavement must perform the same as virgin pavement and meet the Environmental Protection Agency's (EPA) emission standards for the melting and blending of the old pavement into new asphalt. In a Newark, N.J. experiment, a rubber-modified asphalt pavement was successfully recycled, meeting both criteria explained above (Connolly and Sutton, 1992; Baker and Connolly, 1995; Ghaly, 1999).

A Texas study found that it is possible to recycle rubber-modified asphalt pavements. However, some techniques for conventional asphalt mixture design, material processing, and construction must be modified to ensure recycling success, and some techniques may not be appropriate when waste rubber is present in the mixture to be recycled. The authors concluded that if the aggregate and aggregate gradation is good, if the binder can be rejuvenated, and if the RAP is not too wet, it may be possible to recycle 100 percent CRM mixtures (Crockford et al, 1995).

Original arguments that asphalt rubber mixes could not be recycled because of environmental concerns have since been rejected. Another way to overcome such a potential problem would be to place the asphalt rubber mix in a lower lift of the section design that might not be subject to recycling. Indeed, by placing the asphalt rubber in a thicker base lift(s), considerably more rubber would be used, thereby, also achieving the goal of using more discarded tires. In order to accomplish this, though, it would again be necessary to determine the structural contribution of such mixes (King and Abadie, 2000).

HMA Plant Tests (*Asphalt Rubber Usage Guide*)

Plant "stack tests" were performed during asphalt rubber hot mix production in New Jersey (1994), Michigan (1994), Texas (1995), and California (1994 and Bay Area in 2001). The results generally indicate that emissions measured during asphalt rubber production at HMA plants remain about the same as for conventional hot mix and that amounts of any hazardous components and particulates remain below mandated limits. The Bay Area emissions tests showed that measured emissions rates of particulate and toxic compounds were consistently lower than the EPA's AP-42 emission factors for conventional hot mix asphalt plants. However in some cases of RAC production there has been a significant rise in particulates within the vapors that has been tied to use of soft asphalt cements that often include extender oils. Raising HMA plant-operating temperatures typically increases emissions. HMA plant emissions generally appear to be more directly influenced by plant operating temperature, burner fuel and the base asphalt than by CRM.

CRM does not include exotic chemicals that present any new health risks. It consists mostly of various types of rubber and other hydrocarbons, carbon black, oils, and inert fillers. Most of the chemical compounds in CRM are also present in paving grade asphalt, although the proportions are likely to differ.

<u>Exposure of Paving Personnel (*Asphalt Rubber Usage Guide*)</u>

Use of asphalt rubber does not appear to increase health risks to paving personnel, including paver operators, screed person, rakers, roller operators, bootmen on distributor trucks, and other workers. The National Institute for Occupational Safety and Health (NIOSH) in cooperation with FHWA has performed evaluations of possible differences in the occupational exposures and potential health effects of crumb rubber modified hot mixes and conventional HMA mixes. NIOSH Health Hazard Evaluations were performed at seven paving projects located in Michigan, Indiana, Florida, Arizona, Massachusetts, and at two in California from 1994 through 1997. NIOSH has released some preliminary information on individual projects and a report on the Michigan study was presented at an annual meeting of the Transportation Research Board. These reports indicated that increasing operating temperatures of HMA plants seemed to have a greater effect on emissions quantity and content than did adding CRM. However the December 2000 NIOSH report on Health Effects of Occupational Exposure to Asphalt (No. 2001-110) that references these seven projects does not present any of the findings for asphalt mixtures containing CRM. This latest report does not recommend any changes to the 1977 NIOSH criteria for recommended exposure standards.

<u>Environmental Concerns</u>

Based on studies completed to date, the consensus seems to be that rubber-modified asphalts are not any more detrimental to the environment than conventional asphalt. Available asphalt technology, whether conventional HMA, RUMAC, or asphalt rubber, appears capable of meeting environmental regulatory agency criteria provided the process is designed, managed, and operated properly. This applies to air emissions, solid waste, liquid effluents, and occupational health (Emery, 1995).

<u>Lack of National Specifications</u>

One of the main challenges facing highway agencies is the lack of reliable standard protocols to ensure quality of modified asphalts. Existing quality control and quality assurance methods have not been developed enough to ensure that the desired binder properties are obtained in the field. The American Society for Testing and Materials (ASTM) has not established standards for CRM asphalt. There is a lack of data, presented in a comparative and standard form, of long-term tests to demonstrate the efficacy of CRM asphalt as a paving material. As a result, other materials with ASTM standards and long-term performance per test data histories have a competitive and technical advantage over CRM asphalt (Sunthonpagasit and Hickman Jr., 2003).

3.3 Highway Applications for Crumb Rubber

Crumb rubber modifier (CRM), used in asphalt paving materials, consumes one to two million tires/year. Epps (1997) estimates that if ten percent of the approximately 450 million tons of asphalt concrete placed each year are modified with crumb rubber, 75 million scrap tires could be reused. A typical automobile tire weighs 20 pounds and approximately 12 to 13 pounds (about 60 percent) consists of recoverable rubber. A typical truck tire weighs 40 pounds and contains from 60 to 70 percent recoverable rubber (about 24 to 28 pounds). Typically, the recycling process for crumb rubber uses only part of the tire, and most exclusively the tread. The nylon or rayon fibers and steel are separated and must be disposed of either in a landfill or through some other recycling process. Therefore, when recylcing for crumb rubber, eight pounds for each automobile tire and 14 pounds for each truck tire must either be disposed of or recycled in some other medium.

There are four major highway applications for asphalt rubber: (1) chip seal or stress-absorbing membrane (SAM) construction, (2) stress-absorbing membrane interlayer (SAMI) construction, (3) crack or joint sealing, and (4) hot-mixed asphalt concrete pavement construction. In this analysis, we have divided the paving products into sealants, thin surface or interlayer applications, and HMA pavements.

Crumb Rubber Sealants

Size-reduced scrap tire rubber is frequently used in pavement surface treatments such as seal coats, cape seals, or joint and crack sealants.

Seal coat is a collective term for several different kinds of thin surface treatments used to improve the surface texture and protect a HMA surface. Seal coats include fog seals, slurry seals, micro surfacing, and chip seals. A fog seal is a light application of a slow-setting, diluted asphalt emulsion onto an existing pavement surface. A fog seal is used to renew old asphalt surfaces that have become dry and brittle with age, and to seal small cracks and surface voids. A slurry seal is a mixture of graded aggregate and bituminous binder with fillers and additives to make a cold-mixed material that cures quickly to a hardwearing surface. A cape seal is a surface treatment where a chip seal is followed by the application of either slurry seal or micro surfacing.

Micro surfacing is a slurry seal with a polymer-modified binder and higher quality materials. It consists of aggregate, polymer-modified emulsion, water, mineral filler, and field control additives. On HMA pavements, micro surfacing is used for texturing, sealing, and rut filling.

A joint or crack sealant is a compressible material used to prevent the intrusion of water and solid foreign material from joints and cracks.

Crumb Rubber Thin Surface (Interlayer) Applications

Intermediate between sealants and hot-mix paving applications, there are two “interlayer” applications that can utilize crumb rubber: stress-absorbing membranes (SAMs) and stress-absorbing membrane interlayers (SAMIs).

A stress absorbing membrane (SAM) is a surface treatment type pavement similar to a chip seal (see Figure 15). A SAM consists of a layer of rubber-asphalt (produced using the wet process) followed with an aggregate cover. The asphalt-rubber binder is sprayed onto the roadway and the aggregate chips are then spread over the layer of rubber-asphalt and forced into the binder with a roller to form the new pavement surface. A SAM is used to provide a skid resistant surface and to repair minor distress in the underlying pavement.

The amount of CRM in the binder is typically 20 to 30 percent by weight of asphalt binder. A SAM is used primarily to mitigate reflective cracking of an existing distressed asphaltic or rigid pavement.

Figure 15. Chip Seal Construction

A SAM costs two to three times more than a conventional chip seal (Heitzman, 1992; Estakhri et al, 1992). Proponents of SAMs claim they will last twice as long as a conventional chip seal. A Texas study found that a SAM would have to last three times longer than conventional asphalt chip seal to have an equivalent annual cost (Estakhri et al, 1992). In Washington State, the average chip seal life is approximately seven years. Using the Texas results, that would imply that for a SAM to be cost effective, it would require a pavement life of 21 years (which is highly improbable).

A stress-absorbing membrane interlayer (SAMI) is a SAM that is applied beneath an asphalt overlay, which may or may not contain rubber in the mix. The purpose of a SAMI is to extend the serviceable life of an overlay. This is achieved by retarding the rate of reflective crack formation. The use of a SAMI also waterproofs and retards the age hardening of the underlying asphalt pavement.

On the basis of an annualized cost analysis performed by researchers at the Texas Transportation Institute, an overlay with a SAMI would need to last approximately 50 percent longer than an overlay constructed without an interlayer to be cost effective (Estakhri et al, 1992). In Washington State, the average hot-mix pavement life is about 12 years. For an interlayer to be cost effective by this analysis, pavement life would need to average 18 years.

Crumb Rubber Modified Hot Mix Asphalt Pavements

CRM-HMA has been used since the 1960s. They have contained binders prepared from both the wet process (asphalt rubber) and the dry process (rubber-modified hot-mixes). Dense-, open-, and gap-graded HMA have been made using crumb rubber. The following section discusses each of these design methods and mixture properties.

Production of Crumb Rubber in HMA

Conventional HMA paving materials consist of a combination of aggregates that are uniformly mixed and coated with asphalt binder. Several technologies exist to add CRM to HMA: the dry process, the wet process, and the terminal blend process.

The Dry Process

In the dry process, crumb rubber is added to the aggregate in a hot-mix central plant operation before adding the asphalt binder, typically pre-blending the crumb rubber with the heated aggregate before charging the mix with asphalt. Other names for the dry process include rubber-modified hot-mix asphalt (RUMAC) and rubber-modified asphalt binder. A patented form of rubber-modified asphalt binder, PlusRide, is described below.

Crumb rubber is added as a substitute for up to five percent of the aggregate in the asphalt mix. The paving grade asphalt is the same as in conventional mixes. However, higher mixing temperatures (usually between 320°F and 370°F) and higher compaction temperatures (300°F to 320°F) are required. No specialized equipment or significant plant modifications are required for the manufacture or applications of the material. Little, if any, chemical reaction takes place between the rubber and asphalt particles.

The dry process can be used in HMA dense-, open-, and gap-graded mixtures. It does not lend itself to other asphalt paving applications like surface treatments (Heitzman, 1992; Epps, 1994). Pavements produced by the dry process have generally been used as overlays and surface wearing courses.

PlusRide Technology

PlusRide is a proprietary paving system developed in Sweden, in the 1960s, in which a portion of the aggregate in the mix is replaced with particles of granulated tire rubber. The rubber particles are mixed with hot asphalt and aggregate in a conventional asphalt plant (dry process) and laid with a conventional paving machine. The rubber particles, which are up to ¼ inch in size are not melted in this process and can be readily seen in the finished pavement.

The PlusRide mixtures must be gap-graded to allow space for the CRM. Failure to provide a sufficient gap grading would cause the coarse rubber to resist compaction and result in a low-density pavement with high air voids. This mix also contains a higher passing 200 content compared to conventional HMA mixtures to fill air voids.

The rubber used in PlusRide is predominantly a granulated crumb rubber passing the ¼ inch sieve with the fraction passing the 0.08 sieve supplemented with granulated buffings of ground crumb rubber. Like the mineral aggregate, the gradation of the crumb rubber follows a specific gradation band.

Generic Dry Technology

The first generic dry technology system, known as the “TAK” system, uses an equivalent or slightly lower percentage of crumb rubber compared to PlusRide. The crumb rubber is also finer than that used in PlusRide. A conventional dense-graded aggregate is used with only a slight modification. The gradation of the crumb rubber is adjusted to suit the aggregate gradation. It is a two-component system in which the fine crumb rubber interacts with asphalt binder, and the coarse crumb rubber performs as an elastic aggregate in the HMA mixture. The combination of modifying the asphalt binder and increasing the elasticity of the HMA mixture has been claimed to increase the fatigue life, reduce thermal and reflective cracking, and increase the adhesion of the modified binder to the aggregate. Little information is available as to how the amount and the gradation of crumb rubber are determined for a specific mineral aggregate.

Dry process mixes require additional care in material selection; mix design, and material production. Inconsistencies in the dry process mixes appear to be the primary factor leading to construction problems and early failures. Also, cost analyses done for dry process systems indicate increased costs from 50 to 100 percent over conventional mixes (Hunt, 2002). Results from Illinois (Volle, 2000) and other states demonstrate that pavement sections placed using the dry process have reduced pavement performance compared with conventional HMA.

The Wet Process

Charles H. McDonald pioneered the United States' development of the wet process CRM asphalt binders in the 1960s. He, with other associates, patented (which expired in 1992) what is currently described as the MacDonald process or wet process.

The wet process blends and partially reacts crumb rubber with asphalt binder prior to use (1) as a prepackaged joint or crack sealer, (2) in spray applications, or (3) as a binder in a hot-mix central plant process. Typically, asphalt binder and crumb rubber are reacted at higher temperatures than conventional binders, and diluents, aromatic oils, and polymers may be added. The resulting binder is commonly referred to as asphalt rubber (Epps, 1994). Asphalt rubber is also called asphalt-rubber concrete, rubberized asphalt and asphalt-rubber hot-mix. The modified binder has significantly different properties than the original asphalt binder. There are formulation distinctions between various asphalt-rubber blends, depending on application and climatic zones.

Blending methods can generally be divided into three categories: batch blending, continuous blending, and terminal blending. Batch blending is those wet-process technologies that mix batches of crumb rubber and asphalt in production. Continuous blending describes those wet-process technologies that have a continuous production system. Terminal blending is associated with wet-process technologies that have products with extended storage (shelf life) characteristics and are produced at an asphalt binder supply terminal. The terminal blending technologies may use either a batch blending or continuous blending system to actually produce the product at the terminal.

In the wet process, crumb rubber is added to the paving asphalt prior to delivery to the pugmill or drum mixer. The crumb rubber is added to the paving asphalt in a blending tank. After blending is achieved, the mixture is pumped to a reaction tank where it is kept at 375ºF to 400ºF for 35 to 45 minutes before being sent to the pugmill or drum mixer. The use of asphalt rubber mixes will normally tie up the hot plant for the full day's production, so that the hot plant will not be available to produce other mixes during this time. Aggregate and asphalt mixing temperatures must be higher than normal to deliver an asphalt rubber mix at 300ºF to 350ºF (conventional HMA is delivered at 270°F to 320°F) to the project site. Due to the high mix temperature, blue smoke may be a problem, as well as noxious vapors. The vapors are not considered toxic but odor masks should be provided to the paving crews and inspectors (Jorgenson, 2002).

The wet process is the most common method used to add crumb rubber to asphalt concrete.

Continuous Blending Technology

The difference between the McDonald technology and the continuous blending technology is the manner in which the crumb rubber and the asphalt binder are blended. Once blended, the asphalt-rubber is typically pumped to another heated tank, approximately 350°F, where this blend of material is allowed to react for 45 to 90 minutes. Five to 20 percent ground rubber, by weight of binder, is typically blended with conventional asphalt in this technology. The idea is that the use of the fine rubber gradation will shorten the reaction time between the crumb rubber and the asphalt binder.

The Terminal Blend Process

Recent advances in blending polymers and other solid particles in the asphalt binder has made it possible to blend small percentages of crumb rubber during asphalt binder production. The percentage of crumb rubber utilized in terminal blends is significantly lower than the percentage used in traditional asphalt rubber. Used in Texas since 1995, the terminal blend process uses about half the amount of crumb rubber used by either the wet process or the dry process (ten percent of the asphalt binder versus 20 percent). The total binder content is also lower (5.5 percent versus 8.5 percent) (Rubberized Asphalt Concrete Technology Center[6].

3.4 Performance and Cost

The widespread use of crumb rubber in joint and crack sealers, chip seals, interlayers, and HMA has been slow to develop because of (1) high first costs, (2) the lack of conclusive engineering data with which to predict the performance of these asphalt binder systems, and (3) the lack of substantial field performance information to support claims of life-cycle cost advantages (Epps, 1994).

Pavement mixtures containing asphalt rubber binder have been shown to be more ductile and crack resistant. They possess an increased resistance to cracking at low temperatures. In addition, some studies indicate that the use of CRM in asphalt would result in improved resistance to permanent deformation, fatigue failure, and thermal cracking. Although significant research regarding the use of CRM has been performed and some of these CRM modified mixtures indicated outstanding improvement over conventional mixes, the improvement in mechanical properties of CRM modified mixes have not been clearly proven (Loh et al, 2000; Epps, 1997).

[6] http://www.rubberizedasphalt.org/wet.htm

The performance of CRM pavements has had both successes and failures. The successes represent correct project selection, design engineering, and construction decisions. The failures may reflect inexperience with CRM technology in project selection, design engineering, and construction decisions. Reported successes in one region of the country do not immediately substantiate success in other regions, since all the variables do not remain the same.

Costs

Modifying the asphalt binder with CRM will require an increase in binder content. The costs stem from increased binder contents necessary to achieve the desirable performance benefits, increased energy requirements for elevated reaction temperatures and extended mixing time, and high material costs for crumb rubber modifier. In addition, equipment may need modification and personnel may need training. A decade ago, the average cost of CRM from the producer ranged from ten to 15 cents per pound for coarse and medium crumb up to 25 cents per pound for fine ground crumb (Heitzman, 1992). Glover et al (2000) cite a price range of 24 to 40 cents per pound for CRM.

The slower production of asphalt rubber mixes could result in less tonnage per hour delivered to the project—thus increasing costs. Move-in costs for special equipment, higher electrical power costs and the 80 to 90 percent reduced production capacity required for the asphalt rubber blending and reaction process also increases costs. Small projects, such as those under 10,000 tons, will also cost more. Recently the cost of asphalt rubber has been 60 percent to 90 percent more than the cost of standard dense-graded asphalt concrete mix (Jorgenson, 2002). Typical cost increases (without a reduction in thickness) for mixtures containing crumb rubber modifiers are 1.5 to 2.0 times the cost of conventional mixtures. Currently, the price differential between asphalt rubber and conventional hot-mix is about $10.00 per ton (Carlson and Zhu, 1999).

In Arizona, the finished asphalt rubber product is generally from 25 to 75 percent more expensive for the gap-graded asphalt rubber (AR) mix than the typical dense-graded HMA, and 80 to 160 percent more expensive than the typical open-graded friction course.

Caltrans determined that RAC-G costs approximately $15 per ton more (or approximately 46 percent more) than conventional mixes. Thus, the cost per ton of RAC-G is 30 to 80 percent more costly than that of DGAC. Asphalt rubber will generally be cost effective when used in gap- or open-graded surface courses (1.0 to 2.5 inches thick), in chip seals, or as interlayer applications.

Researchers at the Texas Transportation Institute (Glover et al, 2000) found that high asphalt binder mixes (traditional asphalt rubber) require a significantly longer life extension for economic payout. Traditional asphalt rubber is typically cured for one hour at 350°F – 390°F. At 18 percent rubber in the binder and nine percent binder in the mix, a life extension on the order of 60 percent (over a conventional asphalt binder dense-graded mix of the same thickness) is required. With six percent binder in the mix instead of the nine percent, the required life extension is reduced to 33 percent. However, a high-cure crumb rubber binder (cured at a temperature close to 500°F at 16 percent rubber in a dense-graded mix would need to last just 16 percent longer than the comparable conventional mix in order to have an equal capitalized cost, the break-even point.

Other market factors come into play when trying to evaluate the costs of CRM asphalt use in Washington. The Oregon Tire Recycling Task Force (2002) found that transportation economics, combined with a lack of market outlets (i.e., demand), favors landfill disposal for tires generated east of the Cascades (eastern Oregon, eastern Washington, Idaho). In addition, subsidized crumb rubber processed from Canadian scrap tires is often more cost effective for Oregon rubber products manufacturers to purchase, rather than processing all crumb for their products from Oregon tires. At present, Oregon has no monetary incentives to incorporate waste materials in HMA.

Literature Search on Other States' Experiences

An overview of the testing and/or utilization of CRM asphalt by other states (and a few Canadian provinces) are provided below. This summary is based on both print and online literature, with a focus on activities after 1995.

The Rubber Manufacturers Association (2002) states that asphalt rubber remains the largest single market for ground rubber, consuming an estimated 220 million pounds, or approximately 12 million tires. About 180 million pounds of tire rubber is used in the Florida asphalt market. This data supports the belief that the use of asphalt rubber is limited to certain regions of the United States. However, asphalt rubber is being used in greater amounts in Texas and Nebraska, and in 2002/2003 New Mexico will undertake its first large-scale asphalt-rubber project. In addition, the Asphalt Rubber Technology Service is promoting the use of asphalt rubber in South Carolina.

Alaska

In 1997 Alaska evaluated several CRM pavements, including PlusRide projects constructed in 1979 and 1985; an asphalt rubber concrete section constructed in 1988; and a rubberized asphalt rubber concrete (ARC) section (asphalt rubber binder and granulated rubber) placed in 1988. The study focused on fatigue, thermal cracking, and permanent deformation resistance.

Laboratory tests indicated the crumb rubber should increase the fatigue life of the asphalt concrete pavements; however, no differences between control and test sections were noted in the field. Differences in thermal cracking resistance were also measured in the laboratory. The wet process mixes had the best thermal cracking resistance. Laboratory results were mirrored in the field, with the ARC mixes being less temperature susceptible than conventional mixes (Saboundjian and Raad, 1997).

Arizona

Since the late 1960s, the Arizona Department of Transportation (ADOT) has used crumb rubber from ground tires, primarily to reduce reflective cracking. In 1988, ADOT started to use crumb rubber mixed with hot asphalt, commonly referred to as AR as a binder in HMA. Typically, these mixes are either open-graded or gap-graded, and from one-half inch to one inch or one inch to two inches in thickness, respectively. Open-graded mixes generally contain nine to ten percent AR binder, whereas the gap-graded generally contain 7.5 to 8.5 percent AR binder (Way, 1998).

The Arizona Department of Transportation uses AR as a binder in HMA mixes to reduce reflection cracking, improve durability of surface courses, and, in urban areas, to reduce noise when used in open-graded friction courses. By using asphalt rubber as a binder the film thickness is increased to a value of 0.75 – 1.40 mils (one inch equals 1000 mils) compared to the typical dense-graded HMA film thickness of about 0.35 mils. A thicker film thickness reduces the aging effects and therefore improves cracking resistance. The grade of asphalt binder used as a base to make AR is an AC-10, in contrast to typically stiffer grades of AC-20 and AC-30 used in the mountains and AC-30 or AC-40 used in the deserts in dense-graded HMA. The 20 percent ground tire crumb rubber particles change the AR temperature susceptibility such that at high temperatures, the AR is much more viscous (more resistant to rutting) than the neat asphalt. However, at cold temperatures, the AR acts like an AC-10 asphalt (less susceptible to temperature cracking). SHRP asphalt binder tests indicate that AR can be graded from a PG 70-22 to a PG 82-28, which is indicative of a low-temperature susceptible asphalt binder. Typically, the asphalt rubber mixes are one-half inch to one inch thick when open-graded and one inch to two inches thick when gap-graded. For Arizona's climate and materials, AR appears to provide an excellent durable wearing course (Way, 1998).

California

Caltrans began experimenting with rubberized asphalt in the 1980s, and developed design criteria using roadway deflection testing that resulted in thinner overlay courses than conventional asphalt concrete. Research studies over the past 15 years have confirmed the success of the reduced thickness design approach for asphalt rubber hot-mix gap-graded mixes. The Caltrans design method allows for a 50 percent reduction in pavement thickness when this mix is used in lieu of the standard dense-graded asphalt concrete mix. The gap-graded mix allows for higher binder contents, and when combined with the crumb rubber, results in a pavement with much greater flexibility and durability. The RAC-G overlay is performing the same as a DGAC overlay that is 2.1 times thicker. To date, Caltrans has constructed over 750 reduced thickness projects (Jorgenson, 2002).

Temperature is critical for compaction of the RAC-G mixtures, therefore, ambient temperature, pavement surface temperature and wind have considerable impacts on mat temperature during compaction. Caltrans recommends that asphalt rubber mixtures only be used where and when weather conditions are favorable for placement. This does not prevent their use at high elevations, but means that paving in such locations should be performed only in good weather, dry conditions, and not in early spring or late fall (*Asphalt Rubber Usage Guide*). Asphalt rubber paving materials should also not be placed in the following conditions (*Asphalt Rubber Usage Guide*):

- During cold or rainy weather with ambient or surface temperatures < 55°F.
- Over pavements with severe cracks more than ½ inch wide where traffic and deflection data are not available.
- Areas where considerable handwork is required.
- Where haul distances between the HMA plant and the job site are too long to maintain mixture temperatures as required for placement and compaction.

The relatively small proportion of RAC-G overlays compared to dense-graded asphalt concrete (DGAC) overlays is likely due to the following considerations: (1) uncertainty about the relative life-cycle costs of RAC-G versus DGAC because of the lack of good comparative performance data from typical Caltrans applications, and because the cost per ton including construction of RAC-G in place is greater than the cost of DGAC (although cost data from 1993 indicate that the differential is more than offset by use of reduced thicknesses), and (2) uncertainty about the ability of the Caltrans mix design criteria to prevent rutting failures, in part because RAC-G does not meet the criteria for Hveem Stabilometer values used for DGAC, despite the performance history which suggests that RAC-G typically has adequate rutting performance as used by Caltrans. Also, RAC-G is assumed to be as recyclable as DGAC, although this assumption remains to be proven (Harvey et al, 2000a).

Colorado

Colorado investigated two dry processes – the PlusRide process and a process, which involved just adding rubber to the mix. Three PlusRide projects showed early distress in the form of raveling; one PlusRide project performed well. The process that involved the addition of small amounts of crumb rubber to asphalt concrete pavement tested the effects of adding one pound per ton, three pounds per ton, and one percent, i.e., 20 pounds per ton. After five years, the control and test sections performed equally. The mix cost per ton with one percent crumb rubber added was increased by 21 percent (Harmelink, 1999). The study recommends that until the addition of large quantities of crumb rubber in hot bituminous pavement is shown to be cost effective, in addition to enhancing the long-term performance of the pavement, that crumb rubber usage be limited to research applications.

Connecticut

The State of Connecticut tested the use of reclaimed tire rubber in five applications: thick overlays (1-½ inch), thin overlays (½ inch), chip seals, crack and joint sealing, and stress relieving interlayers. The combination of rubber and asphalt as carried out in the study did not prove greatly effective except in the case of seal coats (Stephens, 1989).

Florida

Ground tire rubber has been successfully incorporated in dense-graded friction course mixtures, open-graded friction course mixtures and stress-relief membrane interlayers in Florida (Tia et al, 1994). Since 1994, over 2.6 million tons of rubberized asphalt surface mixtures have been placed throughout the state of Florida.

A ten-year performance evaluation of CRM test sites showed that the wet process addition of crumb rubber improved the crack resistance of surface mixtures. Performance was judged on the basis of various levels and amounts of specific distresses: rideability, rutting, cracking and patching, and skid resistance. The long-term performance data obtained from these test projects provided the Florida Department of Transportation with the necessary information to outline the use of ground tire rubber in all asphalt surface mixtures (Choubane et al 1998; Choubane et al, 1999).

According to Choubane et al (1999), it is estimated that the use of ground tire rubber increases HMA production costs by ten to 15 percent.

Georgia

In 1991, the Georgia Department of Transportation undertook an evaluation of crumb rubber HMA in dense-graded asphalt mixes. The wet-process CRM mix properties were found to be comparable to conventional mixes in terms of stability, flow, and tensile strength. The researchers concluded that terminal blending would have been more successful than on-site blending, since on-site blending does not allow time for checking binder properties prior to being used in the mix. Also, the CRM asphalt concrete became much stiffer over time than the conventional mix, with viscosity increasing by a factor of ten after four years. Costs ran 50 to 100 percent more than the cost of conventional mix (Brown et al, 1997).

Illinois

Between 1991 and 1995, the Illinois Department of Transportation constructed 11 crumb rubber projects. On average, the HMA mix containing CRM for all of the rubberized asphalt projects was 30 percent higher in cost than conventional HMA. The one project in which the CRM and HMA were mixed by the wet process was 101 percent higher in cost than conventional HMA (Volle, 2000).

Iowa

Five projects were constructed by the Iowa Department of Transportation in 1991 and 1992, and were evaluated for five years. The pavements with tire rubber performed essentially the same as those constructed with conventional asphalt concrete. The cost of the pavement with rubber additive was significantly higher, and the researchers concluded that the benefits did not outweigh the costs (Engle et al, 2002).

Kansas

From 1990 to 1995, the Kansas Department of Transportation constructed 13 paving projects incorporating crumb tire rubber. Projects included both wet- and dry-process high-density mixes and open-graded mixes. The study concluded that the use of crumb rubber in HMA was possible but not economically feasible (Fager, 2001).

Louisiana

Three test lanes were constructed at the Louisiana Pavement Research Facility to compare the performance of asphalt rubber HMA with conventional HMA. The AR-HMA consisted of a wet process with ten percent pre-blended 0.0070-inch rubber and AC-30 asphalt binder (King and Abadie, 2000). The Louisiana study proposed to answer whether California's reduced overlay design procedure effectively reduced surface lift thickness when asphalt rubber was used. California's empirical field results, combined with laboratory fatigue test results, indicate that such practice is warranted. However, strength parameters do not reflect the validity of this reduction in thickness design. A determination of structural strength appears to be needed for these AR mixes. Additional field evaluation is needed.

In another study, eight CRM pavement test sections were evaluated. The eight sections included gap-graded mixtures, dense-graded mixtures, an open-graded friction course, a SAMI, and two dry-process applications (PlusRide and generic). After five to seven years of traffic, the pavement sections constructed with CRM asphalt mixtures showed overall better performance indices (rut depth, fatigue cracks, roughness) than the corresponding control sections. Generally, the use of CRM in asphalt pavement significantly increased the construction cost of HMA mixtures (Huang et al, 2002).

Minnesota

The Minnesota Department of Transportation constructed an asphalt-rubber dense-graded asphalt concrete field trial in 1984. The project required specialized equipment to maintain adequate mixing and placing temperatures. The formulation was found to provide little or no perceived benefit to the roadway at much higher costs (Turgeon, 1991).

Mississippi

The Mississippi Department of Transportation constructed a wet-process CRM-HMA pavement in 1991. The amount of CRM was five percent of the total weight of the asphalt binder. The conclusion after 24 months of traffic was that the amount of rutting in the CRM and control sections was insignificant. However, shortly after the 24-month monitoring period, the CRM pavement began to develop significant cracking (Albritton and Gatlin, 1996). The authors recommend further monitoring of pavement performance.

New York

The New York Department of Transportation constructed two dry-process test roads in 1989. Over the five-year evaluation period, the RUMAC did not perform as well as conventional mixes. Service life was not extended sufficiently to offset the higher costs associated with the RUMAC mixes tested in the study (Van Bramer, 1997).

Ohio

Research done in Ohio concluded that rubber-modified asphalt mixtures, produced by the wet process, can be a viable asphalt paving material due to superior resistance to fatigue, low-temperature thermal cracking, and rutting. Best results were obtained with a dense-graded asphalt-rubber mixture. However, the durability of the rubber-modified asphalt concrete in terms of the tensile strength ratio (TSR) had potential problems, and needs further investigation (Liang, 1998).

Oregon

Over a nine-year period (1993-2002), the Oregon Department of Transportation monitored the performance of 17 rubber-modified asphalt and asphalt concrete sections on Oregon highways. They found that the rubber-modified sections that performed the worst were those constructed using the dry process. The best pavement performance was found in open-graded mixes constructed using the binder PBA-6GR, a rubber modified asphalt.

After five years, the PBA-6GR pavements were performing as well or better than the control sections. The cost of the mixes constructed in 1993 and 1994 with PBA-6GR was about 12 percent more than the control sections. Hunt (2002) concluded that over the life of the pavement, terminal-blend asphalt rubber (PBA-6GR) may be cost effective.

Pennsylvania

The Pennsylvania Department of Transportation evaluated a wet-process, rubber-modified asphaltic concrete mix. The control mix (conventional HMA) and the rubber-modified asphalt mix were compared over a performance period of five years. The rubber-modified asphaltic mix showed enhanced signs of wear and cracking. The report concluded that the performance was unsatisfactory and the cost was higher, and that the use of rubber-modified asphalt concrete by the Department was not recommended (Lucas & Brehm, 1998).

Rhode Island

The Rhode Island Department of Transportation has been testing chemically modified crumb rubber asphalt, called a hot-mix maintenance membrane (HM^3), for several years. They found that the HM^3 could be used successfully for thin overlay of less than one inch (Memon et al, 2001).

South Carolina

As of 2001, South Carolina had five rubberized asphalt projects: one dry process, three wet process, and one trickle method. The dry process test section, placed in 1992, has performed well, although there are rubber crumbs on the pavement surface. Two of the wet process projects, placed in 1993 and 1994, also appear to be performing successfully. The Asphalt Rubber Technology Service has paved several new projects that are being monitored for performance (Amirkhanian, 2001; Amirkhanian and Franzese, 2003).

Tennessee

Tennessee presently has two stretches of highway paved with rubber-modified asphalt. In 1998, the Tennessee Department of Transportation placed two projects using CRM-HMA. Each 100 pounds of hot-mix contained two pounds of recycled rubber. The test projects are both on Highway 70 and each section is about seven miles long. TDOT is continuing to evaluate the performance of these projects (Ball, 2001).

Texas

Texas has a long history of utilizing asphalt rubber in the construction and rehabilitation of pavements. Asphalt rubber is used in four applications: as a chip seal coat (SAM), underseal (SAMI), hot-mix, and as the binder for open-graded porous friction course.

Texas Government Code (Title 10, Subtitle D, Section 2155.443) mandates that a preference shall be given to rubberized asphalt paving material made from scrap tires by a facility in this state if the cost, as determined by life-cycle cost benefit analysis, does not exceed the bid cost of alternative paving materials by more than 15 percent.

Tahmoressi (2001) evaluated the performance of ten asphalt-rubber hot-mix pavement projects in Texas, placed from 1992 to 1999. The asphalt-rubber hot-mix projects with gap-graded mixtures appeared to be performing successfully. In several projects, premature failure was attributed to the shrinkage or movement in the base layer, not to the rubber asphalt.

In Texas, an evaluation of five-asphalt rubber open-graded friction courses (OGFC) revealed excellent performance properties. Tahmoressi (2001) concluded that from a cost and benefits standpoint, OGFC represents the best application for asphalt rubber in Texas. The high amount of binder used in CRM OGFC tends to make it more resistant to cracking.

Virginia

Four test sections using asphalt rubber hot-mix were placed in Virginia from 1990 to 1993. Crumb rubber modifier contents carried from eight percent to 20 percent and asphalt grades were AC-10, AC-20, and AC-30. The continuous blending process was used to prepare the asphalt rubber binders. Based on the limited evaluation time, the asphalt rubber mixes performed at least as well as regular mixes. The mixes containing rubber had less rutting. More evaluation time is needed to determine if the long-term performance of the asphalt rubber mixes is superior to conventional mixes.

The use of rubber increased the costs by 64 to 102 percent (Maupin, 1996).

Wisconsin

In 1987, the Wisconsin Department of Transportation constructed two experimental pavements that included test sections incorporating ground tire rubber in asphalt binder. The recycled asphalt rubber mix, compared to a standard recycled mix, developed five more times transverse cracking during the first two years of service (Solberg and Lyford, 1988).

Canada – British Columbia

According to Rustam Jeraj (City of Vancouver, personal communication, 4/2/03), Vancouver placed two test sections of asphalt rubber, both on an arterial street (Kingsway). The first project was completed in September 1994 and the second was completed in June 1995. Most of their arterial streets fail due to rutting and they were interested in finding a paving material that would withstand the heavy pavement loading conditions in Vancouver.

For both projects, the thickness of the surface lift of asphalt was reduced from the normal two inches to 1.5 inches, in accordance with the recommendations of the supplier and based upon California's experience.

The first project on Kingsway/Nanaimo, subject to regular light vehicle arterial traffic, held up nicely with little cracking and light rutting at stop bars. At the second project, Kingsway and Knight streets, a stop light controlled intersection, there was severe rutting. Knight Street has the highest traffic loading of commercial vehicles in the city. Even with a one-inch nominal base paved as lower coarse pavement, ruts of up to two inches appeared at the junction. Furthermore, there were a number of cracks in the test sections.

After eight years of service, the Kingsway and Knight Street section (four city street blocks) paved with rubberized asphalt has ruts greater than one inch over 20 to 50 percent of the roadway and 20 percent of the roadway is cracked with ¼ inch wide or less cracks. There is also cracking of less than ¼ inch with an extent less than 20 percent. The City of Vancouver has not used rubberized HMA pavement concrete on city streets due to this performance.

Canada – Ontario

Ontario evaluated 11 rubber-modified asphalt demonstration projects between 1990 and 1993. Eight projects were dry-process RUMAC; one project was rubber-modified asphalt binder. Short-term performance evaluation showed enhanced performance with the wet-process section and poor performance for the RUMAC sections (Emery, 1995).

3.5 Pavement Applications in Washington State

WSDOT has constructed experimental projects using recycled tire rubber in asphalt applications for over 25 years, with totals close to 275 lane miles of various rubber modified asphalt pavements. The performance histories of these projects were derived from reports and other monitoring activities conducted by the Pavements Branch of the State Materials Laboratory. The following summarizes WSDOT's construction experience with rubber-asphalt paving systems (see Appendix J).

<u>Washington State Pavement Management System</u>

WSDOT manages the route system by monitoring all pavements, annually, to estimate when rehabilitation activities are required. This activity is a key element of the Highway System Plan Pavement Preservation Program. The data and analysis required to do this is termed the Washington State Pavement Management System (WSPMS). The WSPMS has evolved over a period of about 30 years. Initially, WSPMS was simply a listing of the condition of pavement segments on the WSDOT route system, but has become a process which uses the pavement condition information along with historical contract records, traffic counts, and information from other WSDOT data bases to predict the where, when, and what is needed for pavement rehabilitation. The current condition measures include pavement distress, wheel path rutting, roughness, and surface friction. Most often pavement distress such as cracking triggers pavements rehabilitation; however, excessive roughness, rutting, or low surface friction can also trigger pavement rehabilitation.

<u>Stress Absorbing Membrane</u>

The initial use of rubber was with the wet process or "Arizona Process". Two SAM projects were constructed in 1978 and two in 1980 to assess the performance of these rubberized chip seals as a wearing surface. The two projects constructed in 1978 experienced problems almost immediately after construction. The aggregate chips became embedded in the rubber-asphalt binder to such a depth that the surface of the roadway took on the appearance of a sheet of asphalt with no rock. These two applications were termed failures for this reason. The two subsequent projects built in 1980 experienced no problems and performed acceptably until they were overlaid with another standard chip seal. The service life for these four trial sections ranged from a low of three years to a high of seven years, with an average of 5.75 years. The normal life span for chip seals is 6.5 years (average life determined using data from the WSDOT Pavement Management System). The rubber-asphalt SAM's ranged from 2.5 to three times more costly to construct than the standard (non modified) chip seal.

The experimentation with SAM applications ended in approximately 1987 when it was concluded that the performance of the pavement constructed with rubber-asphalt did not justify the added expense of their construction.

Stress Absorbing Membrane Interlayer

A total of six projects were constructed with rubber-asphalt binders used as SAMI's in the 1977 and 1978. The success of these applications was mixed. In general, the SAMI's were successful in retarding the reflection of alligator cracking, but were not successful in retarding reflection of longitudinal and transverse cracking.

One trial use is particularly important. The section from Wheeler Road to Adams County Line, Interstate 90 in Grant County, was designed as a rigorous experiment to determine the performance of the rubber-asphalt interlayers compared with the performance of standard asphalt interlayers. The project included sections of each type of interlayer and a section with no interlayer to serve as a control. The control section experienced the reflection of all the underlying cracking very early in its life. The SAMI and the conventional asphalt interlayers were successful in retarding the reflection of alligator cracking, but were unsuccessful in retarding longitudinal or transverse cracking. The SAMI was fractionally better at retarding the reflection of alligator cracking. The SAMI was 3.7 times as costly as the normal asphalt interlayer.

WSDOT has not constructed a SAMI since 1978 due to the much higher cost of the rubber-asphalt binder. The performance history has indicated that the SAMI is not a cure for the prevention of all types of reflection cracking, although it was successful in retarding the reflection of alligator type cracking. The Wheeler Road to Adams County Line study showed that an interlayer constructed using normal asphalt binders was only slightly less effective than the more expensive SAMI'. The SAMI, at a cost 3.7 times more than a normal asphalt binder interlayer, was not cost effective when the life of the overlay placed on top of it was not increased over overlays constructed without interlayers.

Open-Graded Friction Course

Eight open-graded friction course overlays have been constructed between 1982 and 1993 using the wet process to add the rubber to the pavement. The life of these projects has ranged from five to 15 years. Though the performance, in general, has been good to very good, the primary distress occurring on these roadways has been in the form of raveling (gradual loss of the aggregate from the pavement surface). The raveling is concentrated in the wheel path and is the result of studded tire wear (see Figure 16). The cost of rubber modified open-graded friction course is approximately 1.1 to 3.7 times more than conventional mixes.

Figure 16. Raveling Distress due to Studded Tire Wear

Studded Tire Pavement Damage

According to WSDOT estimates, studded tire pavement damage decreases the life of the pavement surface by about four to six years. This results in increased annual pavement rehabilitation costs that are estimated at $10 million dollars per year. The legislature has had a long and difficult debate over the use of studded tires in our state. Decision makers find it difficult to determine a statewide standard for studded tire use since weather conditions, travel patterns, and consumer trends, vary between motorists in different regions of the state. A survey conducted by WSDOT during the winter of 1996-1997 revealed that, on average, ten percent of passenger vehicles use studded tires in Western Washington and 32 percent of the vehicles use them in Eastern Washington. Of these locations, the survey indicated highest studded tire usage in Spokane (56 percent) and the lowest in Puyallup (six percent). Even though the number of studded tire users in Western Washington is approximately one third that of Eastern Washington, the higher traffic volumes create a much greater raveling problem on major western Washington routes.

Much of the research on studded tires comes from Finland and Sweden where studded tire use is heavy in the winter months. U.S. studies concentrate on states like Alaska, where lightweight studded tires have been advocated, and Minnesota and Michigan where all studded tires have been banned since the early 1970's. These studies all agree on one finding: pavement wear due to studded tire use is substantial and costly. Nationwide, twenty-four states allow studded tire use for at least part of the year. Other states, most notably the snowy climate states of Minnesota and Michigan, have banned studded tires since 1972 and 1974 respectively. Both states banned studded tires due to pavement wear. Neither state has allowed the reintroduction of studded tires.

PlusRide

WSDOT's initial experimentation with PlusRide (dry process) began in 1982 with the paving of a very short section of SR-97 in Yakima. Many problems were encountered in the construction of this section with the result being that WSDOT did not continue a rigorous monitoring of the project beyond the initial construction phase. One additional project was paved in 1982 on a bridge deck located just north of Yakima on I-82. An adjacent bridge deck was also paved with an open-graded rubberized friction course mix to serve as a control section. The PlusRide lasted 8.5 years as compared to the open-graded friction course mix that lasted seven years. PlusRide was also used on a ramp leading to SR-18 near Auburn. This was a successful installation but not a good choice for a test application, due to the low traffic volumes on the ramp. In 1985 the ramp was overlaid with conventional HMA as part of a project, which added additional lanes to SR-18.

In 1984, a southbound bridge deck, I-405 in Renton, was overlaid with PlusRide. Difficulties were encountered in achieving the required compaction of the PlusRide mix, but representatives of PlusRide made the decision to leave it in place rather than replace it with new material, indicting that it would be satisfactory. The PlusRide section experienced ravelling and debonding of the pavement from the bridge deck after two years of service. The PlusRide was 2.3 times more costly than conventional pavements constructed in the same year in the Seattle area.

Two projects were constructed in 1985, one is a disaster and one is reasonably successful.. The WSDOT Ferry Division chose PlusRide for a ferry dock at the Fauntleroy terminal on the Vashon Island route. The PlusRide pavement proved to be unstable with large ruts developing almost immediately under traffic loading. The cause of this failure is unknown; WSDOT removed this mix and replaced with the conventional paving mix. The other project was constructed on near the town of Stanwood and as of 1992 was performing adequately after six years of service. Unfortunately, this roadway is no longer under the jurisdiction of WSDOT and final conclusions cannot be made.

The final PlusRide project was constructed in 1986 on SR-513 between 35th Avenue and I-5. This was the largest project built by WSDOT with 8.0 lane miles of PlusRide. The PlusRide was placed over a concrete pavement and a badly cracked HMA pavement. This project exhibited transverse and longitudinal reflection cracking very soon after installation. This project was overlaid in 1992.

Dense-Graded Mixes

In 1993 WSDOT constructed one project using rubber-asphalt pavement in a dense-graded aggregate structure. Currently, this pavement is performing very similar to the WSDOT's conventional dense grade HMA. Construction related difficulties have hampered the performance of this mixture (and that of the conventional HMA pavement placed under the same contract). It is envisioned that the performance life of the crumb rubber section will equal, but not exceed, the pavement life of conventional HMA. The CRM-HMA on this project cost 33 percent more than a conventional HMA.

Class G Mixes

From 1989 to 1990, WSDOT constructed four projects utilizing asphalt-rubber in WSDOT Class G pavements. A Class G pavement is considered to be a thin overlay and is typically used as a wearing surface through small towns and cities. These projects have ranged in age from seven to 12 years, while the typical pavement life for Class G pavements is six to eight years. The average cost increase to utilize rubber-modified asphalt is approximately ten percent higher than conventional Class G mix. Therefore, for asphalt-rubber to be cost effective in Class G pavements, a pavement life of eight to 11 years would be required. For this application, asphalt-rubber has shown to be cost effective. Due to increased traffic levels and climatic restrictions for placement, the current use of this class of mix is very limited. However, the inclusion of crumb rubber modifier into Class G mix would be appropriate, given that there would be a sufficient market for production (see Market Analysis discussion).

3.6 Summary of WSDOT's Experience

WSDOT has paved a total of 273 lane miles with the various wet and dry processes of rubber-asphalt pavements. The following conclusions are drawn on WSDOT's experience to date:

- The SAM and SAMI processes are not cost effective. Currently, more economical asphalt binders give equal performance at about ⅓ of the cost.
- The open-graded rubberized friction courses process looked very promising, unfortunately, due to the severe ravelling that occurs due to studded tires, this mix is currently not recommended for state highway use.
- PlusRide performance ranges from poor to average. Construction problems, which may relate to the design of the mix, plagued several of the installations. Per ton costs on the projects averaged almost twice that of conventional mixes. Due this experience, and that of other transportation agencies, this mix is no longer marketed or available for use.

Table 14 summarizes the performance of all asphalt-rubber projects constructed to date in Washington State.

Table 14. Actual Life, Expected Life, and Life to be Cost Effective for WSDOT Asphalt-Rubber Projects

Mix Type	Life	Expected Life	Life to be Cost Effective
Dense Graded	11	15	20
SAM	7	7	18
SAMI	15	15	54
OGFC	11	8	15
Class G	10	7	8
PlusRide	5	15	25

4. SCRAP TIRE USE SURVEY

The survey consisted of three separate questionnaires: *General Questions*, *Geotechnical Questions* and *Pavement Questions*. Each portion was constructed using software available through WSDOT's Information Technology Division. The constructed surveys were then stored on a WSDOT server. An e-mail announcing the survey and containing the URL address for each portion of the survey was sent to the State Materials Engineer, or equivalent, in the other 49 states, the District of Columbia, Puerto Rico and Ontario, Canada. The complete questionnaire is contained in Appendix K. The intent of the *General Questions* was to allow the State Materials Engineer either to answer that the state does not use scrap tires for any purpose, thereby negating the pavements and geotechnical portions, or, where appropriate, to send the survey to personnel within his department that could more accurately answer the geotechnical and/or pavements usage questions. The completed surveys are contained in Appendix L.

The e-mail announcing the surveys was initially sent on March 3, 2003. On April 10, 2003 another e-mail was sent to urge those states that had not replied to the first mailing to do so. It was decided to begin analyzing the survey based on those results that had been received by April 30, 2003. At that time, 38 states had responded to the general questions, 33 to the geotechnical and 27 to the pavement questions; as of August 5, 2003, no additional responses had been received. Two states responded to the survey via e-mails.

Objectives of Survey

The primary objective of the survey was to determine how many states are actively using scrap tires, obtain a general understanding of their perspectives toward incorporating scrap tires into their designs and contrast those with the experiences in Washington. If a state was not currently using scrap tires, it was desired to determine the reasons cited for not using them.

4.1 General Questions

This portion of the report will discuss the results from the questionnaire titled General Questions. It is based on questions related to the national use of scrap tires in geotechnical and pavement applications.

A total of 34 responses to the general questions survey were received, with 19 states indicating that they have used recycled tires in transportation projects. The most common uses of recycled tires are in lightweight fills (seven responses) and pavement applications (12 responses).

Of the 15 states that indicated they did not use recycled tires, they listed the following reasons: use of recycled tires is not cost effective (12 responses), state moratorium (one response), environmental concerns (one response), insufficient design guidelines (two responses), and no existing need (three responses).

Only six states currently have subsidy programs.

4.2 Geotechnical Questions

In order to evaluate how the various states are using scrap tires in geotechnical applications, the responses to a selected number of questions from both the *General* and *Geotechnical Questions* were considered. This section presents a summary analysis of those questions. Complete responses to all questions and statistics compiled by the survey software are contained in Appendix **L**.

Summary of Geotechnical Related Information Obtained from the *General Questions*

Of the 38 responses received to the *General Questions*, there were three for which the state of origin could not be determined, one from Ontario, Canada and two responses from one state. The response from Canada was not included in the summary of information regarding geotechnical applications of scrap tires. Therefore, there were 33 usable responses made to the online version of the *General Questions*. Additionally, two states responded via e-mail but did not answer the survey questions. One of those states mentioned limited use of scrap tires in asphalt for overlays; the response of both was negative with respect to geotechnical uses of scrap tires. It was decided to consider the two e-mail responses as valid responses to the *General Questions*. Consequently, including the two email responses, there were 35 usable responses to the *General Questions*. It should be noted that not all states responding to the survey answered all three portions. For instance, five states that responded to the *Geotechnical Questions*, did not respond to the *General Questions*.

- Response to the question: "*Does your State use scrap tires in transportation (geotechnical or pavement applications) related projects?*"

This was question eight from the *General Questions*. A negative response to this answer indicates that the state does not use scrap tires for any geotechnical or pavement application. Of the 35 responding states 16 answered "No". This represents 46 percent of the respondents but only 32 percent of all states. If scrap tires were not being used, the respondent was queried in the following question for reasons why. Responses to this question are summarized below.

- Response to the question: "*Please indicate why scrap tires are not used.?*"

This was question nine from the *General Questions*. The available answers were: (1) departmental moratorium (2) moratorium by another state agency (3) existing federal, state or other guidelines are not sufficient to allow for confidence in design (4) costs are not competitive relative to conventional materials (5) environmental concerns and (6) no need exists.

Amongst the states responding, the most widely cited reason for not using scrap tires was that they are not economical relative to conventionally available materials. This conclusion applies to both pavement and geotechnical applications, since the question was not specific to the application. Other reasons for not using scrap tires are summarized in Figure 17 below. "Design" refers to response number three above, "Costs" to number four, "Environmental Concerns" to number five and "No Need" to number six. Environmental concerns was interpreted to mean that the responding agency was reluctant to use scrap tires because they were unsure of the combustion and/or leaching characteristics of scrap tire fills. No need was interpreted to mean that the responding agency was of the opinion that no technical need existed for the use of scrap tires. Since the choices in the survey were limited to six reasons, there may be others that were not reported.

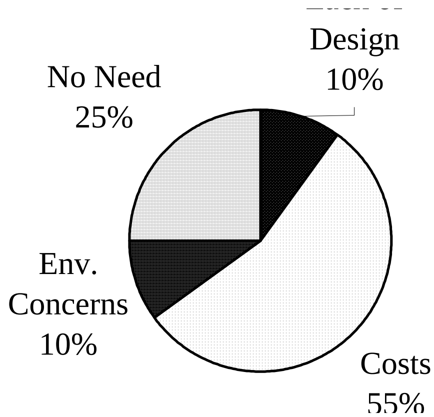

Figure 17. Reasons for not Utilizing Scrap Tires

<u>Summary of Results from *Geotechnical Questions*</u>

There were a total of 33 responses to the on-line version of the *Geotechnical Questions*. Three states submitted answers twice, there was a response submitted from Ontario, Canada and, as previously mentioned, two states submitted responses via-email. Similar to the *General Questions*, it was decided to include the e-mail responses as valid responses to the *Geotechnical Questions*. Consequently, there were 31 usable responses to the *Geotechnical Questions*. The statistics given in this section are based upon the corrected number of survey responses. Uncorrected response statistics to all questions are contained in Appendix L. The statistics contained in Appendix L were automatically compiled by the survey software.

- <u>Response to the question</u>: "*How many years has your State been using scrap tires in* <u>geotechnical</u> *related projects?*"

This was question number eight from the Geotechnical portion of the survey. The available answers were, 0, 1 – 5, 5 – 10 and >10 years. An answer of "0" was interpreted to mean that the answering state does not currently use scrap tires in geotechnical applications for highway work. Of the 31 respondents to the *Geotechnical Questions*, 19, or 61 percent (38 percent of all states), answered "0". Twelve or 39 percent of the respondents (24 percent of all states) indicated that their state had been using scrap tires for greater than one year.

The authors have knowledge of two other surveys, with which the 2003 WSDOT Survey responses can be compared. The first survey was reported by Ahmed and Lovell (1992). Two of the objectives of their survey were to determine what types of waste materials were being used in transportation projects and in what types of applications they were being used. They distributed 52 surveys (presumably the 50 states plus Puerto Rico and the District of Columbia) and received 44 responses. Although 30 respondents (68 percent) stated they had used scrap tires, only three (six percent of all states, including PR and DC) indicated that they had used tires in embankments.

The second survey, an NCHRP survey, was conducted in 1991 and reported by Epps (1994). The 1991 NCHRP Survey specifically addressed the use of scrap tires in both pavement and geotechnical applications. In the 1991 NCHRP Survey, ten states (20 percent of all states) reported they had used scrap tires in embankments and three had pending projects. The three states with pending projects were New Jersey, Ohio and Pennsylvania; Ohio and Pennsylvania did not respond to the 2003 WSDOT Survey, and New Jersey reported in the 2003 WSDOT Survey that they were not currently using scrap tires.

Results regarding the use of scrap tires in geotechnical applications from the 1991 NCHRP and 2003 (WSDOT) Surveys are compared in Table 15. Since 1991, six additional states reported the use of scrap tires. Indiana and Wisconsin reported use in 1991, but they did not respond to the WSDOT Survey. Although California did not answer the *Geotechnical Questions* in the WSDOT Survey, CalTrans' use of scrap tires in embankments is evidenced by the completion in 2001 of the Dixon Landing Road on-ramp on I-880 using nearly one million scrap tires. It is not known by the authors whether California has other pending projects that utilize scrap tires.

When making conclusions based on the above information, there are limitations that should be recognized. Except for Maine and Minnesota, the numbers of project reported is quite low. The numbers reported certainly do not indicate widespread usage of scrap tires in geotechnical applications. Instead, the reported numbers may be more indicative of limited use of scrap tires by the various states on either research and/or trial projects.

Consider the states of Kentucky and New York. The Kentucky embankment was constructed for research purposes, and neither the literature review (see above) nor the responses to the 2003 WSDOT Survey indicate that the use of scrap tires for geotechnical applications has become widespread in Kentucky. The embankment constructed in New York, reported by Dickson, Dwyer and Humphrey (2001), was built partially in response to pending legislation that was to mandate the wider use of recycled materials in highway projects. A 2001 survey by the Rubber Manufacturers Association (RMA) of state legislation pertaining to scrap tires indicated that use of scrap tires in "civil engineering" projects was not encouraged in Kentucky, Louisiana, New York, North Carolina, Oregon, South Dakota and Vermont.

However, legislation recently passed in New York (Dwyer, 2003, personal communication) establishes a fund for the use of scrap tires. Beginning in September of 2003 a $2.50 fee will be collected with each new tire sold. The retailer keeps $0.25, $1.00 goes to the NY State Department of Conservation, and the remaining $1.25 goes into the General Fund. The legislation did not specify how the Department of Conservation was to utilize the funds collected. The NYSDOT does not receive any money from the fund; although the legislation does list NYSDOT as a user of tires for civil engineering purposes.

- There are also gaps in the data that may have resulted in scrap tire usage that was not reported. For instance, Ohio and Pennsylvania had pending projects according to the 1991 NCHRP Survey, but those states did not respond to the 2003 WSDOT Survey.

Table 15: Comparison of 1991 NCHRP and 2003 WSDOT Surveys

States Reporting Scrap Tire Use		Number of Successful Projects Reported in 2003[1]	Comments Relating to 2003 WSDOT Survey
1991 NCHRP Survey	**2003 WSDOT Survey**		
CA			Did not respond to the geotechnical portion of the WSDOT Survey. Completed Dixon Landing Rd. On-ramp in 2001 using nearly 1 million scrap tires.
CO	CO	0	
IN			Did not respond to 2003 WSDOT Survey
ME	ME	5 – 10	Reported 1-5 projects each for lightweight fill, common embankment and retaining wall applications. Noted use as drainage media in cut-off trench.
MN	MN	>10	Reported no use in common embankments. Noted use as “drain tile” and as “basement wall fill” in private applications.
NC	NC	1 – 5	Reported 1-5 projects each for lightweight fill and common embankment applications.
OR	OR	1 – 5	Apparently ceased scrap tire use following the fires in Washington State.
VT	VT	1 – 5	Reported 1-5 projects each for lightweight fill, common embankment and retaining wall applications.
WA		Not reporting	Washington has had two successful projects (see discussion of US101 Contracts in Section 2.3).
WI			Did not respond to 2003 WSDOT Survey
	Additional States Reporting Scrap Tire Use Since 1991 NCHRP Survey		
	KY	1 – 5	One project for research purposes.
	LA	1 – 5	
	NM	1 – 5	
	NY	1 – 5	Reported 1-5 projects each for lightweight fill and common embankment applications. Also reported use as drainage media
	SD	1 – 5	
	VA	1 – 5	Reported in 2003 WSDOT Survey that VDOT had constructed only one major project that incorporated scrap tires. See Table 2 for details.
Percent of Respondents	**Percent of Respondents**		
---	39		
Percent of All States	**Percent of All States**		
20	24		

Notes: 1. Includes any geotechnical application. Data reported is from Question nine of the *Geotechnical Questions*.

A landslide repair that utilized 500,000 tires in Wyoming was well documented in the literature, but Wyoming did not respond to the 2003 WSDOT Survey. Oregon reported that scrap tires were being used in their state, however, they later stated in the survey that usage had stopped subsequent to the fires in Washington State. Other states may have made a similar decision. Therefore to what extent scrap tires are being used in these states cannot be accurately ascertained.

If those states actively using scrap tires are defined as those that reported at least 1 – 5 projects in two or more geotechnical applications, then from Table 15, there are only five active users of scrap tires: Maine, Minnesota, New York, North Carolina and Vermont. This is only ten percent of all states, which is slightly higher than the level of use indicated by Ahmed and Lovell (1992). This definition may be overly optimistic, based on the above discussion and the lack of published information indicating that multiple projects have been completed in those states that reported use in the 2003 WSDOT Survey. At best, it appears that about 20 – 24 percent of the states are willing to use scrap tires in geotechnical applications.

- Response to the question: "*What design guidelines for scrap tire embankments are currently in use in your State?*"

This was question number 16 from the Geotechnical portion of the survey. The available answers were: a) the FHWA 1997 Interim Guidelines for Shredded Tire Embankments (ASTM D 6270-98) b) Your own State's Guidelines c) Other and d) None. Although 55 percent responded "None", this reflects the fact that many states are not *currently* using scrap tires hence no design procedure is being employed.

Of the 12 states that indicated they were using scrap tires, 33 percent were using the FHWA Interim Guidelines for Shredded Tire Embankments (ASTM D 6270-98); 33 percent said "None", and 25 percent said they were using design guidelines they had developed themselves. The states using their own guidelines were Minnesota, North Carolina and Virginia; copies of their material specifications are included in Appendices M – O.

- Response to the question: "*How many successful projects has your State completed using scrap tires where a lightweight fill was required, e.g., embankments over soft ground, landslide repairs?*"

This was question number ten from the *Geotechnical Questions*. The available answers were, 0, 1 – 5, 5 – 10 and >10 projects. Of the 31 respondents to the geotechnical questions, eight States stated that they had had at least one successful project that utilized scrap tires in a lightweight fill application. This represents 67 percent of the states that said they used tires in geotechnical applications, but only 16 percent of all the states. The response indicates that the most widespread use of scrap tires in geotechnical applications is for situations where a lightweight fill is required.

- Response to the question: *"How many successful projects has your State completed using scrap tires as a structural fill in common embankments?"*

This was question number 11 from the *Geotechnical Questions*. The available answers were, 0, 1 – 5, 5 – 10 and >10 projects. Of the 31 respondents to the geotechnical questions, six States (Kentucky, Maine, New York, North Carolina, Vermont and Virginia) indicated that they had successfully used scrap tires in common embankments. This represents 50 percent of the states that said they used tires in geotechnical applications, but only 12 percent of all the states.

- Response to the question: "*How many successful projects has your State completed using scrap tires as a lightweight fill behind retaining structures?*"

This was question number 12 from the *Geotechnical Questions*. The available answers were, 0, 1 – 5, 5 – 10 and >10 projects. Of the 31 respondents to the geotechnical questions, only three States indicated that they had successfully used scrap tires as backfill for retaining walls. While this represents 25 percent of the states that said they used tires in geotechnical applications, it represents only six percent of all states.

- *Response* to the question: "*Based on costs associated with scrap tire use in your State, which statement best characterizes your agency's perspective regarding the economics of using scrap tires in embankment fills?*"

This was question 14 from the *Geotechnical Questions*. The available answers were: a) Only competitive for all uses when a subsidy is in place and b) Unsubsidized scrap tires are only competitive with other types of lightweight fill, e.g., foam. This question was designed to provide some insight into what the perspective of other state departments of transportation are regarding the economics of using scrap tires for geotechnical applications. Recall from the *General Questions* that 55 percent of the respondents stated that unfavorable economics were the main reason for not using scrap tires.

Unfortunately only 15, or 48 percent, of the 31 responding states answered question 14 in the geotechnical section of the survey. Two speculative reasons for the limited response to the question regarding the economics of scrap tire usage are that the respondent did not feel comfortable summarizing his agency's attitude toward the economics of scrap tire usage and/or the selection of responses in the survey was not representative enough. However with regard to the latter reason, the following question was open-ended and asked the respondent to provide any additional comments regarding their State's attitude toward the economics of using scrap tires.

There was a limited response to the open-ended question as well. Only ten states provided additional comments. Three of those comments essentially stated their state did not use scrap tires. Only four of the comments pertained directly to the economics of using scrap tires. Vermont indicated a potential problem in that no producer was located within the state and therefore transportation costs would be high. Virginia stated that in their one major project, scrap tires were allowed as an alternative to conventional materials and were provided free of charge. Therefore the contractor only had to account for transportation costs. Louisiana indicated that a subsidy, from another agency, is in place hence contractors can bid accordingly to attempt to "…undercut alternate methods of construction". A single state, Minnesota, stated "They [scrap tires] are very cost effective". The complete comments can be found in Appendix L.

The use of scrap tires in common embankment applications, i.e., a lightweight fill is not required, appears to be considered uneconomical without a subsidy. Of the six states reporting that they had used scrap tires in common embankment fill applications (See above discussion regarding Question Number 11), Kentucky, Maine, New York and North Carolina all responded that scrap tires were not cost competitive without a subsidy in place. The remaining two states, indicated that scrap tires were only competitive with other types of lightweight fill. This would imply that scrap tires are not economical except as an alternative to other possible types of lightweight fill.

Given the limitations discussed above, it is difficult to make a definitive conclusion regarding the economics of scrap tire usage among the states. Summarizing the available information from the responding states, 35 percent (22 percent of all states) selected response A. Response A was selected by Minnesota and Maine, which are probably the states with the most experience using scrap tires. Response B was selected by 13 percent (eight percent of all states).

The above discussion, together with the responses to *General Question* number nine, indicate that there is little economic advantage to the use of scrap tires, especially without a subsidy in place. The Washington experience (Sec. 2.2) is that the cost of the scrap tires, even with a subsidy, was generally about equal to or greater than the cost of conventional borrow. In this situation, for projects not requiring a lightweight fill, other factors, such as the ability to maintain an adequate delivery rate to the site and constructability issues, may dictate whether or not using scrap tires is desirable.

4.3 Pavement Questions

This portion of the report will discuss findings from the questionnaire titled Pavement Questions.

Survey Results

A total of 26 responses were received for the pavement portion of the survey. A total of 21 states indicated that asphalt binders must be in accordance with AASHTO MP-1. Even though AASHTO specifications do not prohibit the use of CRM, 19 states indicated that they do not use CRM asphalt binders in HMA pavements, primarily, because CRM is not cost competitive (16 responses).

The costs associated with the use of CRM binders are more than doubled for the majority of states (14 responses) that have used them in paving applications. When asked if the use of CRM asphalt has been cost effective, 17 states responded that CRM is not cost effective.

Additional noteworthy comments are that Arizona specifications require that the minimum pavement temperature be 85°F prior to placing CRM-HMA and that Texas has found the use of CRM in OGFC to be cost effective.

Nearly half of the responses indicated that the pavement life of CRM asphalt was ten years or less. Figure 18 illustrates the comparison in pavement life using conventional hot-mix asphalt pavement and CRM asphalt pavements.

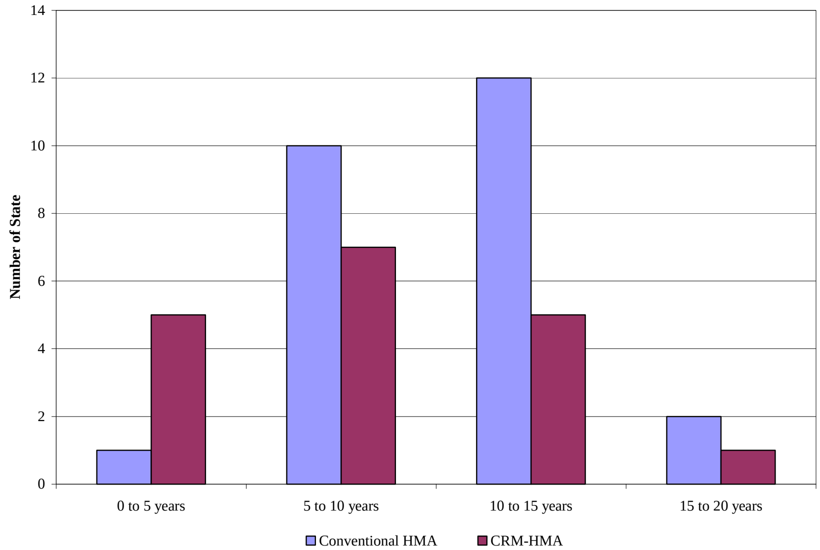

Figure 18. Service Life of Conventional HMA and CRM-HMA.

Arizona specifies that CRM asphalt should be placed when the pavement temperature has a minimum temperature of 85°F. Despite the required minimum surface temperature and surface condition, the Engineer, at any time, may require that work cease or that the work day be reduced in the event of existing or expected weather conditions which would have an adverse effect upon the CRM asphalt.

Connecticut commented that it placed virgin rubber into pavements on what was then Route 9 (now Route 99) as an experiment in 1950. Later rubber-pavement installations were placed in various locations during the 1950’s and 1960’s. In 1977, the University of Connecticut, in cooperation with the Connecticut DOT, undertook a major research project to evaluate the use of recycled rubber in various construction and maintenance activities. Full-scale field tests were carried out with rubber-modified thin and thick overlays, stress-relieving interlayers, joint and crack sealing, and surface chip seals. Approximately 50 test sections were placed on Connecticut highways. Follow-up performance observations and measurements were obtained nine years after placement of the pavements. Because of the mediocre performance, in combination with increased costs due to the addition of recycled rubber, (which were substantial, on the order of 50 – 100 percent) it was demonstrated that the asphalt rubber pavements were not cost effective in Connecticut. Rubberized chip seals and crack filler materials showed promise. The last asphalt rubber pavement placed by the Connecticut DOT was in 1982 and although this project indicated some improvement in retarding (delay) reflection cracking, it was felt that the extremely high cost was not justifiable. A few proprietary rubberized chip seals were placed for evaluation in the mid 1990's that performed fairly well. Other uses of rubber tires, such as in utilizing chipped tires as roadbed insulation in areas with extreme frost penetration, have produced better results. In addition, the tire-to-energy plant in Sterling, Connecticut (Exeter Project) utilizes 9.5 million tires annually (more than three times Connecticut's annual production rate of used tires) to produce electricity. In summary, Connecticut DOT, in conjunction with the FHWA, has expended considerable effort and money over the past 50 years in trying to verify claims of cost savings or benefits from rubber in roads. Unfortunately, to date, unlike in some other states such as California, Arizona and Florida, the results have not provided a sound reason to use asphalt rubber in Connecticut pavements.

Colorado mentioned their experience with crumb rubber was based on one overlay project completed in the 1980's. This project was constructed on an experimental basis using the wet process, the cost per ton was doubled and performance was the same as conventional mix. Crumb rubber asphalt pavements were determined to not be cost effective and when its use was no longer mandated, its use was no longer pursued. However, they commonly use rubberized material in crack filling operations.

Florida utilizes asphalt rubber in some of their applications and has current specifications available online (see Appendix F)**.** These specifications cover ground tire rubber, asphalt rubber binder, friction course mixes, and interlayer construction.

Idaho used crumb rubber in one project that utilized the wet process in 1993, however because of a striping failure, future use has not occurred.

In Georgia, there has not been enough interest by the HMA industry and state environmental protection division; therefore, the use of CRM asphalt has not been pursued.

Nebraska has placed it first two CRM projects in 2000 - 2001, and commented that it is currently difficult to quantify performance due to short evaluation period. However, they have seen that the cost of the binder can be competitive with conventional PG binders. However, the CRM mixes use eight percent binder compared to a standard Superpave mix that uses 5.5 percent binder, which would increase the cost of the CRM mix by 31 percent for the binder alone.

New Jersey and Maine have experienced results comparable to Colorado and Minnesota where cost was greatly increased and performance was the same, or worse, than conventional HMA.

Minnesota had similar comments to that of Colorado where the use of CRM was emphasized during the time of the Federal Mandate. It was discontinued because of equal to poorer performance at a greatly increased cost.

Mississippi currently permits the use of CRM asphalt, however, due to the higher costs of CRM asphalt, as compared to other asphalt modifiers (SBS and SB), it is rarely used by contractors.

Oregon does not currently use CRM asphalt, however, current specifications do not prohibit their use. The asphalt suppliers do not recommend its use due to higher cost as compared to conventional asphalt binder. This outlook is similar to that of Washington, where crumb rubber isn't disallowed, but asphalt suppliers must meet the specification requirements of AASHTO MP-1.

Within Texas, CRM asphalt generally costs thirty percent more and has not performed well when compared to conventional dense-graded mixes. Premature failures were experienced in the early 1990's due to mix design procedures, but have had outstanding performance since learning how to properly design the mixes. CRM asphalt is primarily used as an OGFC. Texas is very pleased with the results of a recently constructed OGFC overlay on top of an existing continuously reinforced concrete pavement. Their oldest pavement has been in place for nearly ten years with no maintenance. One comment was that CRM asphalt is expensive, but performs well when used in the right application.

5. MARKET ANALYSIS FOR SCRAP TIRE USAGE ON WSDOT PROJECTS

5.1 Geotechnical

The **Unstable Slope Management System (USMS)** managed and administered by the WSDOT contains information about the department's unstable slopes statewide. The USMS database is used to evaluate, recommend mitigation, perform cost-benefit analysis and determine priority for the Preservation (P3) Unstable Slope Program. Through a series of data collection and rating calculations, including cost-benefit analysis, a statewide priority list of unstable slopes is developed for the Highway Construction Program.

A recent survey of this system has identified four potential lightweight fill projects that may be constructed in the 2003-2005 and 2005-2007 bienniums. The four lightweight fill projects are required to mitigate unstable slopes and settlement problems. Generally, a lightweight fill will be used to reduce the driving forces causing landslide movement or causing excessive settlements. Preliminary estimates by the WSDOT geotechnical division predict less than 1000 cubic yards of lightweight material would be necessary on these projects.

5.2 Pavements

As indicated earlier, WSDOT does not place open-graded mixes and to date has not placed a considerably large quantity of gap-graded mixes. The following market analysis accounts for the limitation that the only mix WSDOT, at this time, would consider placing are gap-graded mixes.

Caltrans reports (*Asphalt Rubber Usage Guide*) the use 385 tires per lane mile per inch depth of gap graded HMA and an associated cost increase of 46 percent over conventional dense-graded HMA.

Due to climatic conditions, the use of CRM-HMA would be limited to locations in Eastern Washington, south of Interstate 90 and east of the Cascade Range. On average, WSDOT places approximately 350,000 tons of mix each year in this area. The average cost of conventional HMA, in this area, is approximately $31.00 per ton (or a total cost of HMA of approximately $11 million). Using the expected cost increase provided by Caltrans, the additional cost to WSDOT for placing all HMA tonnage using gap-graded CRM-HMA, would result in an additional cost of $4.9 million per year (or placing 158,000 fewer tons, which is approximately 200 fewer lane miles), without any noticeable increase in performance. If the Caltrans design procedure that claims the same performance at ½ the depth when utilizing CRM-HMA can be validated in Washington State, then the added cost would be $2.5 million (or placing 80,000 tons less, which is approximately 100 fewer lane miles), once again without any noticeable increase in performance.

Note that placement of 350,000 tons of gap-graded CRM-HMA would consume approximately 275,000 tires per year, at an increased cost of $4.9 million annually (using the tires per lane mile from the *Asphalt Rubber Usage Guide*.) Thus, if subsidized to make this substitution economically feasible, the cost per recycled tire would be $17.81 ($4.9 million divided by 250,000 tires = $17.81/tire).

WSDOT has shown successful use of CRM in Class G HMA pavements. Over the last three years, WSDOT has placed, on average, approximately 14,000 tons per year of Class G HMA, statewide. Using the tires per lane mile from the *Asphalt Rubber Usage Guide* this would imply that approximately 11,000 tires could be incorporated annually. However, the 14,000 tons of Class G HMA placed annually is a very small portion of the total HMA placed. Production of Class G is approximately one to two percent of the total HMA produced in the state, this small percentage may cause the production of CRM Class G to be cost prohibitive.

6. CONCLUSIONS

While WSDOT supports reducing the waste stream, it is concerned, along with many other State Transportation agencies, about the potential risks and increased costs resulting from the use of waste tires in highway construction.

In considering the incorporation of waste tires in highway construction, there are clearly additional cost savings to the State-at-large in avoided public costs such as existing tire pile risk costs, solid waste tipping fees, reduced landfill demand, etc. that, under current legislation, are not reflected in WSDOT's utilization of these materials.

6.1 Geotechnical

There is still no definitive mechanism for the process of scrap tire fills undergoing an exothermic reaction followed by combustion. Several mechanisms for producing exothermic reactions have been proposed. Design guidelines provided by the FHWA, and standardized as ASTM D 6270-98, that attempt to control those variables thought to contribute to initial exothermic reactions appear to have been successful at preventing the combustion of shredded tire fills. Limited research appears to be occurring at the current time to determine the exact process, or processes, that determine whether an exothermic reaction will occur and then whether or not it will lead to the subsequent combustion of a shredded tire fills.

Projects designed following the FHWA guidelines and those that incorporate mechanisms to prevent the intrusion of water, air, and organics into the tire fill portion appear to have successfully prevented combustion of scrap tire fills. The FHWA stated in their 1997 memorandum that issued the guidelines that the guidelines were conservative. This is supported by the number of successful projects that do not meet the FHWA guidelines in one or more respects. It should be noted that the height of the Cosmopolis, Washington scrap tire fill was approximately two feet in excess of that recommended by the FHWA and that the fill did apparently experience an exothermic reaction, however it did not combust. At the time of this report, the Cosmopolis, Washington scrap tire fill was still performing satisfactorily.

Environmental studies indicate that scrap tires do not leach significant quantities of regulated substances.

Excessive compression of scrap tire fills can be accommodated by the use of surcharges, which is a common practice for embankments constructed on soft ground. Therefore, no "new" technique is required to build a scrap tire embankment in soft ground conditions.

Most states indicated that scrap tire usage was only economical when a subsidy was in place.

The limited use of scrap tires by the states in common embankment situations indicated that this usage is either not economic or not practical. The limited information pertaining to the practicality of using scrap tires indicated that supply and delivery problems were the primary deterrents, rather than difficulties in overcoming technical problems associated with the material properties of scrap tires.

Except for Maine and Minnesota, the numbers of successfully completed projects by individual states is quite low. The low number of projects reported by the respondents to the 2003 WSDOT Survey are more indicative of limited use of scrap tires by the various states on either research and/or trial projects rather than routine, widespread usage. Therefore, there may not be enough case histories to adequately support the success of the guidelines provided by the FHWA. These case histories can only provide an indication that the FHWA's guidelines will result in successful scrap tire use in embankments.

Some states that may be currently using scrap tires, or have in the past, did not respond to the 2003 WSDOT Survey. Therefore the extent of scrap tire usage by these states could not be fully ascertained.

At best, there appears to be about 20-24 percent of the states that are currently willing to use scrap tires in geotechnical applications. The number may be as low as ten percent.

6.2 Pavements

All construction costs increases adversely impact WSDOT's construction and preservation program. For many years WSDOT has been directed to maintain current pavement conditions. This has been accomplished by emphasizing the preservation program. This program has maintained the fairly fine balance between normal pavement deterioration and needed pavement sealing, resurfacing and reconstruction through one of the first and most fully utilized pavement management system in the country. This program is very tenuous balance between preservation costs and pavement performance.

For WSDOT's preservation program to not be impacted by an increase use of rubber-asphalt requires that the added cost of rubber-asphalt (60 to 90 percent higher) must be accompanied by added service life (an additional nine to 14 years). There are many claims regarding improved performance from suppliers of this material, however, the performance experience documented in this state, and many other states, over the last 25 years has not substantiated performance over standard paving materials. The most likely net result of using all current forms of rubber-asphalt materials and technology in the preservation program as currently funded would be higher construction costs with overall performance life similar to the existing trends. The consequence of this action would be fewer miles paved per year with commensurate deterioration of the highway system.

Since 1999, WSDOT has joined the national effort to specify binder type selection according to the performance grading system. It has been discovered that the testing procedures for short and long-term aging are not appropriate for modified binders. Therefore, a nationally funded research project is underway (NCHRP 9-36) to modify/validate the aging procedures to incorporate modified binders. This research should be completed by late 2005.

Evidence suggests that states with successful crumb rubber paving operations are states with climates that are warm and/or dry for extended periods of time. Though there are some locations in Washington State that have similar climatic conditions as those in Arizona, California, Florida, and Texas, Washington state on average has fewer days above 75°F, more rainfall (except for Florida), and has significantly more days of freezing (as noted by the freezing index).

Arizona and Texas have found the use of CRM in OGFC to be cost effective. Caltrans states that asphalt rubber hot mixes are typically most effective as thin overlays (OGFC and gap-graded mixes). In Washington State, the performance of OGFC's, in general, has been good to very good, but with short life cycles. The primary distress occurring on these roadways has been in the form of raveling (gradual loss of the aggregate from the pavement surface). The raveling is concentrated in the wheel path and is the result of studded tire wear. The OGFC's in Washington State should be lasting six to eight years, however, due to studded tire damage, this life is reduced to four to six years. With the added cost of rubber-asphalt and the shortened performance life, WSDOT has determined that the use of OGFC's are not cost effective. The use of gap-graded mixes may be appropriate, however, at this time, the added costs for these mixes is not accompanied by increased pavement life.

7. RECOMMENDATIONS

7.1 Geotechnical

The FHWA Guidelines (ASTM D 6270-98) need to be more fully verified and updated as needed. This will require additional research, which should include field scale trials of scrap tire embankments.

Due to the existence of primarily anecdotal evidence of the causes of scrap tire fires there remains a significant amount of risk in the future use of scrap tires in civil engineering applications. Therefore, it is imperative that all regulatory agencies and stakeholders are aware of these risks and are willing to assume the consequences of failures.

Further research into the possible impacts on future construction/maintenance of scrap tire fills should be completed prior to the adoption of a scrap tire standard specification allowing tires to be considered as a fill material. The decision to use tires in a embankment would be market driven, i.e., can scrap tires be obtained for less cost than common borrow?

If a primary goal in using scrap tires is to reduce current stockpiles, a temporary subsidy to provide incentive to clean up specific problem tire stockpile sites should be considered. This could be based on the New York State experience. Use of scrap tires in common embankments must have subsidies in order to be economical, and we must limit the size of fills to meet FHWA guidelines. Furthermore, there must be a partnership between WSDOT and the resource agencies that recognizes there will be some risk of future environmental problems should we proceed with widespread use of this material even if FHWA guidelines are followed.

7.2 Pavements

Allow the incorporation of CRM into HMA to be market driven. Since the state specification does not disallow the use of crumb rubber as a modifier, the utilization of this material should be based on providing either reduced material cost or improved pavement performance. At this time, it has not been shown that CRM pavements provide either reduced cost or increased performance benefits.

On a national basis, continue to pursue, validate, and implement as appropriate, guidelines and procedures for the recyclability of CRM, CRM binder testing and acceptance, and modifications to mix design procedures for incorporating CRM.

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GLOSSARY OF TERMS

Aggregate: A collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium (such as water, bitumen, portland cement, lime, etc.) to form compound materials (such as asphalt concrete, portland cement concrete, etc.).

Aggregate blending: Combining multiple aggregate sources to produce a desired set of properties. Usually aggregate blending is done to improve or change gradation.

Air voids: Empty spaces in a compacted mix surrounded by asphalt-coated particles, expressed as a percentage by volume of the total compacted mix.

Alligator cracks: Interconnected cracks forming a series of small blocks resembling an alligator's skin. Caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading.

Analysis period: The period of time over which a life cycle cost analysis is performed.

Asphalt: A dark brown to black cementitious material in which the predominating constituents are bitumen's, which occur in nature or are obtained in petroleum processing.

Asphalt binder: The principal asphaltic binding agent in HMA. Asphalt binder includes asphalt cement as well as any material added to modify the original asphalt cement properties. Also referred to as asphalt cement.

Asphalt cement: The principal asphaltic binding agent in HMA. Asphalt binder includes asphalt cement as well as any material added to modify the original asphalt cement properties. Also referred to as asphalt cement. Also referred to as asphalt binder.

Asphalt concrete: A high quality, thoroughly controlled hot-mixture of asphalt binder and aggregate that can be compacted into a uniform dense mass. Also referred to as HMA.

Asphalt rubber: Asphalt binder modified with crumb rubber modifier.

Asphalt-rubber blend: A blend of ground tire rubber and asphalt binder, which is used as the binder in various types of pavement construction. It generally consists of 18 to 26 percent ground tire rubber by total weight of the blend. The blend is formulated at elevated temperatures to promote the chemical and physical bonding of the two constituents. Various petroleum distillates or extender oils may be added to the blend to reduce viscosity, increase spray ability, and promote workability. The blend can be used as the binder in chip seals, seal-slurry coats, and dense- or open-graded asphalt hot-mix construction.

Asphalt-rubber concrete: Implies the use of an asphalt-rubber blend (binder) with dense-graded aggregates in a hot-mix application.

Asphalt-rubber friction course: Implies the use of an asphalt-rubber blend (binder) with open-graded aggregates in a hot-mix application.

Backfill: Material placed to raise the elevation of the original ground or to fill the volume behind a newly constructed retaining wall.

Base course: The portion of a pavement structure immediately beneath the surface course. Its major function is structural support and usually consists of aggregate.

Batch plant: A manufacturing facility for producing asphalt-paving mixtures that proportions the aggregate constituents into the mix by weighed batches and adds asphalt material by either weight or volume.

Binder: A material used to bind aggregates. Usually bitumen and bitumen blends.

Bitumen: A class of black or dark-colored (solid, semi-solid or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, pitches, and asphaltenes are typical.

Bleeding: A film of asphalt binder on the pavement surface caused by the upward migration of asphalt binder in an HMA pavement resulting in the formation of asphalt film on the surface. It is also called flushing.

Block cracking: In flexible pavements, interconnected cracks that divide the pavement up into rectangular pieces.

Breakdown rolling: The initial compaction performed directly behind the paver (no more than 200 feet behind the screed). The goal of the breakdown roller is to obtain the initial lock-up of the aggregate particles at a high mat temperature.

Cape seal: A surface treatment where a chip seal is followed by the application of either slurry seal or micro-surfacing.

Chip seal coat: See Stress Absorbing Membrane (SAM).

Coefficient of Lateral Earth Pressure: See Lateral Earth Pressure.

Common Embankment: A roadway embankment that requires neither special foundation treatment nor construction with lightweight fill material to ensure its stability and long term performance. A common embankment also would be an embankment that does not serve as a bridge approach, which is defined by WSDOT as the last 100 feet of roadway prior to the bridge.

Compaction: The act of compressing a given volume of material into a smaller volume. Insufficient compaction of the asphalt pavement courses may accelerate the onset of pavement distresses of various types.

Consistency: The degree of fluidity of asphalt binder at any particular temperature. The consistency of asphalt binder varies with its temperature: therefore, it is necessary to use a common or standard temperature when comparing the consistency of one asphalt binder with another.

Crack initiation: A mechanism of flexible pavement fatigue, which occurs at the bottom of the asphalt concrete layer and is the result of damage throughout the asphalt concrete from repeated loads.

Crack propagation: A mechanism of flexible pavement fatigue. At cold temperatures, asphalt becomes stiffer and more brittle and the asphalt concrete mix contracts, increasing tensile strains and accelerating cracking.

Crackermill: A process that tears the scrap tire rubber by passing the material between rotating corrugated steel drums, reducing the size of the rubber to a crumb particle.

Cracks: Breaks in the surface of an asphalt pavement. Common types include the following: alligator cracks, edge joint cracks, lane joint cracks, reflection cracks, shrinkage cracks, and slippage cracks.

Crumb rubber modifier: A general term for scrap tire rubber that is reduced in size and is used as modifier in asphalt paving materials.

Cryogenically ground rubber: A process that freezes the scrap tire rubber and crushes the rubber to the particle size desired.

Dense-graded mix: Refers to an HMA mix design using an aggregate gradation that is near the FHWA's 0.45 power curve for maximum density. These are the most common HMA mix designs in the U.S. Also referred to as dense-graded friction course, or DGAC.

Densification: The act of increasing the density of a mixture during the compaction process.

Density: The degree of solidity that can be achieved in a given mixture. This will be limited only by the total elimination of voids between particles in the mass.

Diluent: A lighter petroleum product (typically kerosene) added to asphalt-rubber binder just before the binder is sprayed on the pavement surface.

Draindown: The process by which a portion of the material separates itself from the mix as a whole. The portion that "drains down" is typically asphalt binder, but can includes additives and/or fine aggregate.

Drum plant: A manufacturing facility for producing HMA continuously rather than in batches.

Dry process: Any method that mixes the crumb rubber modifier with the aggregate before the mixture is charged with asphalt binder. This method applies only to hot-mix asphalt production.

Edge Joint Cracks: The separation of the joint between the pavement and the shoulder, commonly caused by the alternate wetting and drying beneath the shoulder surface. Other causes include shoulder settling, mix shrinkage, and traffic straddling the joint.

Extender oil: An aromatic oil used to supplement the reaction of the asphalt and the crumb rubber modifier.

Fatigue cracking: Cracks caused by fatigue failure of an HMA surface (or stabilized base) under repeated traffic loading.

Fatigue resistance: The ability of asphalt to pavement to withstand slight repeated flexing caused by the passage of wheel loads.

Flexible pavement: Pavements surfaced with bituminous (or asphalt) materials in the surface course. These can be either in the form of pavement surfaces such as a bituminous surface course generally found on lower volume (or lower traffic) roads, or HMA surfaces generally used on higher volume roads. These types of pavements are called flexible since the total pavement structure bends or deflects due to traffic loads.

Flushing: A film of asphalt binder on the pavement surface caused by the upward migration of asphalt binder in an HMA pavement resulting in the formation of asphalt film on the surface. Same as bleeding.

Fog seal: A light application of a slow-setting asphalt emulsion to the surface of an aged (oxidized) pavement surface.

Friction course: A specialized wearing course constructed of open-graded asphalt.

Gap-graded aggregate: A graded aggregate in which one or more of the intermediate sizes are absent.

Geotechnical Applications: In general, this report refers to geotechnical applications as being those that involve *scrap tires* in large volume fills. For these applications the tires have undergone minimal pre-processing, usually involving comminution of the tires to sizes ranging up to two feet in length and having no more that one sidewall still attached to the tire. The tires may also have been washed to remove any contaminates adhering to the outside of the tires.

Gradation: The description given to the proportions of aggregate on a series of sieves. Usually defined in terms of the percent passing successive sieve sizes.

Granulated crumb rubber modifier: Cubical, uniformly shaped, cut crumb rubber particle with a low surface area, which is generally produced by a granulator.

Granulator: A process that shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance, reducing the rubber to particles generally ⅜ inch to 0.08 inch in size.

Ground crumb rubber modifier: Irregularly shaped, torn crumb rubber particles with a large surface area, generally produced by a crackermill.

High-cure asphalt rubber: Asphalt rubber cured at conditions of temperature and shear that will significantly reduce the particle size and digest the rubber into the asphalt to a significant degree.

HMA: Hot-mix Asphalt. A high quality, thoroughly controlled hot-mixture of asphalt binder and aggregate that can be compacted into a uniform dense mass. Also referred to as asphalt concrete.

Intermediate course: An HMA pavement course between a base course and a surface course.

Lane Joint Cracks: Longitudinal separations between two paving lanes caused by a weak seam between adjoining pavement courses.

Lateral Earth Pressure: The horizontal pressure exerted by soil on a retaining structure. It is proportional to the vertical pressure; the constant of proportionality (K) is termed the *coefficient of lateral earth pressure*.

Lift: A layer or course of paving material applied to a base or previous layer.

Load transfer: The transfer or distribution of load across pavement discontinuities such as joints or cracks.

Longitudinal cracking: In flexible pavements, cracks parallel to the pavement's centerline or laydown direction. This is the early stage of fatigue cracking when located in the wheel path.

Macadam: Type of early bituminous pavement named after its inventor, a Scotsman named John McAdam (1756 – 1836). McAdam (sometimes spelled "Macadam") pavements used smaller angular aggregate over larger angular aggregate over a well-compacted, sloped subgrade.

Mat: A term used to describe the fresh asphalt surface behind the paving machine. Most commonly used to refer to the asphalt during the laydown and compaction phase of construction.

Mat tearing: A term used to describe the pulling of the HMA under the screed of the paver. Generally results in coarse-textured streaks behind the paver.

Micro-mill: A process that further reduces a crumb rubber to a very fine ground particle, reducing the size of the crumb rubber below the No. 40 sieve.

Microsurfacing: An advanced form of slurry seal that uses the same basic ingredients (emulsified asphalt, water, fine aggregate and mineral filler) and combines them with advanced polymer additives to produce a more capable end product.

Modified asphalt: An asphalt where a binder has been modified by the addition of rubber, polymer, fibers, etc. for specific applications.

Open-graded friction course (OGFC): A pavement surface course that consists of a high-void, asphalt plant mix that permits rapid drainage of rainwater. The mix is characterized by a large percentage of one-sized coarse aggregate.

Open-graded aggregate: A blend of aggregate particles containing little or no fine aggregate and mineral filler; the void spaces in the compacted aggregate are relatively large.

PAV (pressure aging vessel): A Superpave test procedure to simulate in the laboratory the long-term aging that will occur in the field. The results reveal how the binder will perform after years of exposure to traffic and weather.

Pavement distress: The deterioration of the pavement evidenced by visible surface defects.

Pavement structure: A pavement, including all of its courses of asphalt-aggregate mixtures, or a combination of asphalt courses and untreated aggregate courses, placed above subgrade.

PBA-6GR: Performance-based asphalt with ground rubber. A wet-process powdered rubber modified asphalt containing 10 – 12 percent rubber.

Penetration: The consistency of a bituminous material expressed as the distance that a standard needle penetrates a sample vertically under specified conditions of loading, time and temperature.

Penetration grading: A classification system of asphalt binders based on penetration.

Performance grading (PG): Asphalt binder grade designation used in Superpave, based on the binder's mechanical performance at critical temperatures and aging conditions.

Permeability: The resistance that an asphalt pavement has to the passage of air and water into or through the pavement.

Pickup: Pickup occurs when a pneumatic (rubber-tired) roller is being used. The asphalt sticks to the rubber tires and causes the asphalt to "pickup."

Poise: A centimeter-gram-second unit of absolute viscosity, equal to the viscosity of a fluid in which a stress of one dyne per square centimeter is required to maintain a difference of velocity of one centimeter per second between two parallel planes in the fluid that lie in the direction of flow and are separated by a distance of one centimeter.

Polymer-modified asphalt binder: Conventional asphalt binder to which a styrene block copolymer or styrene butadiene rubber (SBR) latex or neoprene latex has been added to improve performance.

PlusRide: A patented form of a rubber-modified asphaltic mix. The product was developed in 1960 in Sweden and patented under the name PlusRide in the United States and Rubit in Sweden. It uses coarse rubber particles (¼ inch to 1/16 inch) as rubber-filled aggregates, generally about three percent weight of mix. The rubber is added directly to a gap-graded aggregate so that a relatively dense-grading between the aggregate and rubber is obtained.

Pugmill: A device for mixing aggregate, sand, and binder.

Pumping: Pavement deflection (usually repeated) under traffic that sometimes results in the discharge of water and subgrade soils along joints, cracks and pavement edges.

RAP: Reclaimed Asphalt Pavement. RAP is typically generated by (1) milling machines in rehabilitation projects or (2) a special crushing plant used to break down large pieces of discarded HMA pavement.

Raveling: In flexible pavements, the progressive disintegration of an HMA layer from the surface downward as a result of the dislodgement of aggregate particles.

Reaction: The interaction between asphalt binder and crumb rubber modifier when blended together. The reaction, more appropriately defined as polymer swell, is the absorption of aromatic oils from the asphalt binder into the polymer chains of the crumb rubber.

Recycled tire rubber: Rubber obtained by processing used automobile, truck, or bus tires. (Note: solid tires; tires from forklifts, aircraft, and earthmoving equipment; other nonautomotive tires; and non-tire rubber sources are excluded).

Reflection Cracks: Cracks in asphalt overlays that reflect the crack pattern in the underlying pavement structure. Caused by vertical and/or horizontal movement in the pavement underneath the overlay.

Rigid pavement: A pavement designed with minimum deflection, such as portland cement concrete pavement (PCCP).

Rubber aggregate: Crumb rubber modifier added to hot-mix asphalt mixture using the dry process, which retains its physical shape and rigidity.

Rubber-modified asphalt concrete (RUMAC): Referred to as the dry process. Process where the crumb rubber is added to the aggregate and not to the asphalt binder. Marketed in the U.S. as PlusRide

Rubber-modified friction course: A hot-mix asphalt mixture with open-graded aggregates using a rubber-modified asphalt.

Rubber-modified hot-mix asphalt: Hot-mix asphalt mixture that incorporates crumb rubber modifier primarily as rubber aggregate.

Rutting: Surface depression in the wheel path of a pavement.

Scrap Tires: a tire that can no longer be used for its original purpose due to wear or damage (ASTM, 1998); in the portions of this report related to geotechnical applications, the term “scrap tires” refers to tires that have been processed for use in the various applications without reference to a particular particle size.

Screed: The part of a paving machine that spreads, smoothes, and provides initial compaction.

Seal coat: A collective term for several different kinds of thin surface treatments used to improve the surface texture and protect an HMA surface. Seal coats include fog seals, slurry seals, micro-surfacing, and bituminous surface treatments.

Shredded Tire: a size reduced scrap tire where the reduction in size was accomplished by a mechanical processing device, commonly referred to as a shredder (ASTM, 1998).

Shredding: A process that reduces scrap tires to small pieces.

Shrinkage cracks: Interconnected cracks forming a series of large blocks, usually with sharp corners of angles. Typically caused by a change in volume of asphalt mix or in the base or subgrade.

Skid resistance: The ability of an asphalt paving surface to offer resistance to slipping or skidding, particularly when wet.

Slippage cracks: Crescent-shaped cracks open in the direction of the thrust of wheels on the pavement surface. Results when severe or repeated shear stresses are applied to pavements that lack a good bond between the surface layer and the underlying course.

Slurry seal: A mixture of an asphaltic oil and water (emulsion) and crushed rock aggregate that is spread over the street at about ¼" thickness. The slurry "cures" when the water evaporates, leaving only the asphalt to coat the crushed rock. The asphalt acts as a binder to hold the slurry together and bond to the existing pavement. Slurry seal is strictly a preventative maintenance operation.

Soft Ground: Any type of soil foundation that when loaded by an embankment, or structure, would either undergo a shearing failure or incur settlements not tolerable by the overlying embankment or structure.

Solubility: A measure of the purity of an asphalt binder. The ability of the portion of asphalt binder that is soluble to be dissolved in a specified solvent.

Stability: The ability of an asphalt paving mixture to resist deformation from imposed loads. Stability is dependent upon both internal friction and cohesion.

Steel Belt: rubber coated steel cords that run diagonally under the tread of steel radial tires and extend across the tire approximately the width of the tread (ASTM, 1998).

Stress-absorbing membrane (SAM): A SAM is used primarily to mitigate reflective cracking of an existing distressed asphaltic or rigid pavement. It comprises an asphalt-rubber blend sprayed on the existing pavement surface followed immediately by an application of a uniform aggregate which is then rolled and embedded into the binder layer. Its nominal thickness generally ranges between ¼ and ⅜ inch. Also known as a chip seal coat.

Stress-absorbing membrane interlayer (SAMI): A membrane beneath an overlay designed to resist the stress and strain of reflective cracks and delay the propagation of the cracks through the new overlay. The membrane is often a spray application of asphalt-rubber binder and cover aggregate. Also known as an underseal.

Stripping: In flexible pavements, the loss of bond between aggregates and asphalt binder that typically begins at the bottom of the HMA layer and progresses upward. When stripping begins at the surface and progresses downward it is usually called raveling.

Subgrade: The soil prepared to support a pavement structure or a pavement system. It is the foundation of the pavement structure.

Superpave: Superior Performing Asphalt Pavements. An overarching term for the results of the asphalt research portion of the 1987 – 1993 Strategic Highway Research Program (SHRP). Superpave consists of (1) an asphalt binder specification, (2) an HMA mix design method and (3) HMA tests and performance prediction models. Each one of these components is referred to by the term "Superpave".

Superpave gyratory compactor (SGC): A device use during Superpave mix design, or field-testing activities, for compacting samples of hot-mix asphalt into specimens used for volumetric analysis. Continuous densification of the specimen can be measured during the compaction process.

Superpave mix design: A mixture design system that integrates the selection of materials (asphalt and aggregate) and volumetric proportioning with the project's climate and design traffic.

Surface course or surface layer: The top wearing course of a roadway. Sometimes called asphalt wearing course.

Terminal blend: A process developed and patented by Texas-based Wright Industries. For terminal blend asphalt rubber, the rubber is blended into the asphalt at the refinery. In practice, the asphalt rubber is then shipped directly to the asphalt plant, just like regular asphalt or other raw materials used in pavement mixes. Highway departments or contractors then buy the asphalt rubber pre-mixed.

Tire Chips: Pieces of scrap tires that have a basic geometrical shape and are generally between ½ inch and two inches in size and have most of the wire removed (ASTM, 1998).

Tire Shreds: Pieces of scrap tires that have a basic geometrical shape and are generally between two and 12 inches in size (ASTM, 1998).

Transverse cracking: Transverse cracking is an asphaltic concrete pavement distress type in which cracks or breaks run approximately perpendicular to the pavement centerline.

Tread rubber: Rubber that consists primarily of tread rubber with less than approximately 5 percent sidewall rubber.

Underseal: See Stress Absorbing Membrane Interlayer (SAMI).

Viscosity: A measure of a liquid's resistance to flow. It is one method of measuring the consistency of asphalt. Absolute viscosity is a measure of the viscosity of asphalt with respect to time, measured in poises, conducted at 140°F. Kinematic viscosity is a measure of the viscosity of asphalt, measured in centistokes, conducted at a temperature of 275°F.

Viscosity grading: A classification system of asphalt binders based on viscosity ranges at 140°F. A minimum viscosity at 275°F is also usually specified. The purpose is to prescribe limiting values of consistency at these two temperatures. 140°F approximates the maximum in service temperature of an asphalt. 275°F approximates the mixing and laydown temperatures for hot-mix asphalt pavements.

VMA: Voids in the Mineral Aggregate. The volume of inter-granular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the specimen.

Waste Tire: a tire which is no longer capable of being used for its original purpose but which has been disposed of in such a manner that it cannot be used for any other purpose (ASTM, 1998).

Wet process: Any method that blends crumb rubber modifier with the asphalt binder before incorporating the binder in the asphalt-paving project.

Whole tire rubber: Rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.

Workability: The ease with which paving mixtures may be placed and compacted.

APPENDIX A – SUBSTITUTE HOUSE BILL 2308

CERTIFICATION OF ENROLLMENT

SUBSTITUTE HOUSE BILL 2308

Chapter 299, Laws of 2002

57th Legislature
2002 Regular Session

RECYCLING

EFFECTIVE DATE: 6/13/02

Passed by the House February 15, 2002
Yeas 98 Nays 0

FRANK CHOPP

Speaker of the House of Representatives

Passed by the Senate March 6, 2002
Yeas 46 Nays 0

BRAD OWEN

President of the Senate

Approved April 2, 2002

GARY LOCKE

Governor of the State of Washington

CERTIFICATE

I, Cynthia Zehnder, Chief Clerk of the House of Representatives of the State of Washington, do hereby certify that the attached is **SUBSTITUTE HOUSE BILL 2308** as passed by the House of Representatives and the Senate on the dates hereon set forth.

CYNTHIA ZEHNDER

Chief Clerk

FILED
April 2, 2002 - 10:21 a.m.

Secretary of State
State of Washington

SUBSTITUTE HOUSE BILL 2308

Passed Legislature - 2002 Regular Session

State of Washington 57th Legislature 2002 Regular Session

By House Committee on Agriculture & Ecology (originally sponsored by Representatives Linville, Schoesler, Anderson, Dunshee, Lovick, Lantz, Santos, Rockefeller, Berkey, Conway, Wood, Edwards, Cooper, Hunt, Fromhold, Dickerson, Cody, Simpson, Upthegrove, Kagi and McIntire)

Read first time 01/22/2002. Referred to Committee on .

AN ACT Relating to recycling and waste reduction; amending RCW 39.04.133, 70.95.010, 70.95.030, and 43.19.1905; adding a new section to chapter 81.77 RCW; adding a new section to chapter 70.95 RCW; and creating new sections.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF WASHINGTON:

NEW SECTION. **Sec. 1.** (1) The department of general administration shall work with commercial and industrial construction industry organizations to develop guidelines for implementing on-site construction waste management planning. The topics addressed in the guidelines shall include, but shall not be limited to:

(a) Standards for identifying the type of wastes generated during construction;

(b) Methods for analyzing the availability and cost-effectiveness of recycling services for each type of waste;

(c) Methods for evaluating construction waste management alternatives given limited recycling services in rural areas of the state;

(d) Strategies to maximize reuse and recycling of wastes and minimize landfill disposal;

(e) Standardized formats for on-site construction waste management planning and reporting documents; and

(f) A training and technical assistance plan for public and private building owners and construction industry members, in order to facilitate incorporation of waste management planning and recycling into standard construction industry practice.

(2) By December 15, 2002, the department of general administration shall provide a report to the legislature on the development of the guidelines required by subsection (1) of this section. The report shall include recommendations for incorporating job-site waste management planning and recycling into standard construction industry practice.

Sec. 2. RCW 39.04.133 and 1996 c 198 s 5 are each amended to read as follows:

(1) The state’s preferences for the purchase and use of recycled content products shall be included as a factor in the design and development of state capital improvement projects.

(2) If a construction project receives state public funding, the product standards, as provided in RCW 21 43.19A.020, shall apply to the materials used in the project, whenever the administering agency and project owner determine that such products would be cost-effective and are readily available.

(3) This section does not apply to contracts entered into by a municipality.

Sec. 3. RCW 70.95.010 and 1989 c 431 s 1 are each amended to read as follows:

The legislature finds:

(1) Continuing technological changes in methods of manufacture, packaging, and marketing of consumer products, together with the economic and population growth of this state, the rising affluence of its citizens, and its expanding industrial activity have created new and ever-mounting problems involving disposal of garbage, refuse, and solid waste materials resulting from domestic, agricultural, and industrial activities.

(2) Traditional methods of disposing of solid wastes in this state are no longer adequate to meet the ever-increasing problem. Improper methods and practices of handling and disposal of solid wastes pollute our land, air and water resources, blight our countryside, adversely affect land values, and damage the overall quality of our environment.

(3) Considerations of natural resource limitations, energy shortages, economics and the environment make necessary the development and implementation of solid waste recovery and/or recycling plans and programs.

(4) Waste reduction must become a fundamental strategy of solid waste management. It is therefore necessary to change manufacturing and purchasing practices and waste generation behaviors to reduce the amount of waste that becomes a governmental responsibility.

(5) Source separation of waste must become a fundamental strategy of solid waste management. Collection and handling strategies should have, as an ultimate goal, the source separation of all materials with resource value or environmental hazard.

(6)(a) It should be the goal of every person and business to minimize their production of wastes and to separate recyclable or hazardous materials from mixed waste.

(b) It is the responsibility of state, county, and city governments to provide for a waste management infrastructure to fully implement waste reduction and source separation strategies and to process and dispose of remaining wastes in a manner that is environmentally safe and economically sound. It is further the responsibility of state, county, and city governments to monitor the cost-effectiveness and environmental safety of combusting separated waste, processing mixed municipal solid waste, and recycling programs.

(c) It is the responsibility of county and city governments to assume primary responsibility for solid waste management and to develop and implement aggressive and effective waste reduction and source separation strategies.

(d) It is the responsibility of state government to ensure that local governments are providing adequate source reduction and separation opportunities and incentives to all, including persons in both rural and urban areas, and nonresidential waste generators such as commercial, industrial, and institutional entities, recognizing the need to provide flexibility to accommodate differing population densities, distances to and availability of recycling markets, and collection and disposal costs in each community; and to provide county and city governments with adequate technical resources to accomplish this responsibility.

(7) Environmental and economic considerations in solving the state's solid waste management problems requires strong consideration by local governments of regional solutions and intergovernmental cooperation.

(8) The following priorities for the collection, handling, and management of solid waste are necessary and should be followed in descending order as applicable:

(a) Waste reduction;

(b) Recycling, with source separation of recyclable materials as the preferred method;

(c) Energy recovery, incineration, or landfill of separated waste;

(d) Energy recovery, incineration, or landfill of mixed municipal solid wastes.

(9) It is the state's goal to achieve a fifty percent recycling rate by 2007.

(10) It is the state's goal that programs be established to eliminate residential or commercial yard debris in landfills by 2012 in those areas where alternatives to disposal are readily available and effective.

(11) Steps should be taken to make recycling at least as affordable and convenient to the ratepayer as mixed waste disposal.

(12) It is necessary to compile and maintain adequate data on the types and quantities of solid waste that are being generated and to monitor how the various types of solid waste are being managed.

(13) Vehicle batteries should be recycled and the disposal of vehicle batteries into landfills or incinerators should be discontinued.

(14) Excessive and nonrecyclable packaging of products should be avoided.

(15) Comprehensive education should be conducted throughout the state so that people are informed of the need to reduce, source separate, and recycle solid waste.

(16) All governmental entities in the state should set an example by implementing aggressive waste reduction and recycling programs at their workplaces and by purchasing products that are made from recycled materials and are recyclable.

(17) To ensure the safe and efficient operations of solid waste disposal facilities, it is necessary for operators and regulators of landfills and incinerators to receive training and certification.

(18) It is necessary to provide adequate funding to all levels of government so that successful waste reduction and recycling programs can be implemented.

(19) The development of stable and expanding markets for recyclable materials is critical to the long-term success of the state's recycling goals. Market development must be encouraged on a state, regional, and national basis to maximize its effectiveness. The state shall assume primary responsibility for the development of a multifaceted market development program to carry out the purposes of this act.

(20) There is an imperative need to anticipate, plan for, and accomplish effective storage, control, recovery, and recycling of discarded tires and other problem wastes with the subsequent conservation of resources and energy.

Sec. 4. RCW 70.95.030 and 1998 c 36 s 17 are each amended to read as follows:

As used in this chapter, unless the context indicates otherwise:

(1) "City" means every incorporated city and town.

(2) "Commission" means the utilities and transportation commission.

(3) "Committee" means the state solid waste advisory committee.

(4) "Composted material" means organic solid waste that has been subjected to controlled aerobic degradation at a solid waste facility in compliance with the requirements of this chapter. Natural decay of organic solid waste under uncontrolled conditions does not result in composted material.

(5) "Department" means the department of ecology.

(6) "Director" means the director of the department of ecology.

(7) "Disposal site" means the location where any final treatment, utilization, processing, or deposit of solid waste occurs.

(8) "Energy recovery" means a process operating under federal and state environmental laws and regulations for converting solid waste into usable energy and for reducing the volume of solid waste.

(9) "Functional standards" means criteria for solid waste handling expressed in terms of expected performance or solid waste handling functions.

(10) "Incineration" means a process of reducing the volume of solid waste operating under federal and state environmental laws and regulations by use of an enclosed device using controlled flame combustion.

(11) "Jurisdictional health department" means city, county, city-county, or district public health department.

(12) "Landfill" means a disposal facility or part of a facility at which solid waste is placed in or on land and which is not a land treatment facility.

(13) "Local government" means a city, town, or county.

(14) "Modify" means to substantially change the design or operational plans including, but not limited to, removal of a design element previously set forth in a permit application or the addition of a disposal or processing activity that is not approved in the permit.

(15) "Multiple family residence" means any structure housing two or more dwelling units.

(16) "Person" means individual, firm, association, copartnership, political subdivision, government agency, municipality, industry, public or private corporation, or any other entity whatsoever.

(17) "Recyclable materials" means those solid wastes that are separated for recycling or reuse, such as papers, metals, and glass, that are identified as recyclable material pursuant to a local comprehensive solid waste plan. Prior to the adoption of the local comprehensive solid waste plan, adopted pursuant to RCW 70.95.110(2), local governments may identify recyclable materials by ordinance from July 23, 1989.

(18) "Recycling" means transforming or remanufacturing waste materials into usable or marketable materials for use other than landfill disposal or incineration.

(19) "Residence" means the regular dwelling place of an individual or individuals.

(20) "Sewage sludge" means a semisolid substance consisting of settled sewage solids combined with varying amounts of water and dissolved materials, generated from a wastewater treatment system, that does not meet the requirements of chapter 70.95J RCW.

(21) "Soil amendment" means any substance that is intended to improve the physical characteristics of the soil, except composted material, commercial fertilizers, agricultural liming agents, unmanipulated animal manures, unmanipulated vegetable manures, food wastes, food processing wastes, and materials exempted by rule of the department, such as biosolids as defined in chapter 70.95J RCW and wastewater as regulated in chapter 90.48 RCW.

(22) "Solid waste" or "wastes" means all putrescible and nonputrescible solid and semisolid wastes including, but not limited to, garbage, rubbish, ashes, industrial wastes, swill, sewage sludge, demolition and construction wastes, abandoned vehicles or parts thereof, and recyclable materials.

(23) "Solid waste handling" means the management, storage, collection, transportation, treatment, utilization, processing, and final disposal of solid wastes, including the recovery and recycling of materials from solid wastes, the recovery of energy resources from solid wastes or the conversion of the energy in solid wastes to more useful forms or combinations thereof.

(24) "Source separation" means the separation of different kinds of solid waste at the place where the waste originates.

(25) "Vehicle" includes every device physically capable of being moved upon a public or private highway, road, street, or watercourse and in, upon, or by which any person or property is or may be transported or drawn upon a public or private highway, road, street, or watercourse, except devices moved by human or animal power or used exclusively upon stationary rails or tracks.

(26) "Waste-derived soil amendment" means any soil amendment as defined in this chapter that is derived from solid waste as defined in RCW 70.95.030, but does not include biosolids or biosolids products regulated under chapter 70.95J RCW or wastewaters regulated under chapter 90.48 RCW.

(27) "Waste reduction" means reducing the amount or toxicity of waste generated or reusing materials.

(28) "Yard debris" means plant material commonly created in the course of maintaining yards and gardens, and through horticulture, gardening, landscaping, or similar activities. Yard debris includes but is not limited to grass clippings, leaves, branches, brush, weeds, flowers, roots, windfall fruit, vegetable garden debris, holiday trees, and tree prunings four inches or less in diameter.

Sec. 5. RCW 43.19.1905 and 1995 c 269 s 1402 are each amended to read as follows:

The director of general administration shall establish overall state policy for compliance by all state agencies, including educational institutions, regarding the following purchasing and material control functions:

(1) Development of a state commodity coding system, including common stock numbers for items maintained in stores for reissue;

(2) Determination where consolidations, closures, or additions of stores operated by state agencies and educational institutions should be initiated;

(3) Institution of standard criteria for determination of when and where an item in the state supply system should be stocked;

(4) Establishment of stock levels to be maintained in state stores, and formulation of standards for replenishment of stock;

(5) Formulation of an overall distribution and redistribution system for stock items which establishes sources of supply support for all agencies, including interagency supply support;

(6) Determination of what function data processing equipment, including remote terminals, shall perform in statewide purchasing and material control for improvement of service and promotion of economy;

(7) Standardization of records and forms used statewide for supply system activities involving purchasing, receiving, inspecting, storing, requisitioning, and issuing functions, including a standard notification form for state agencies to report cost-effective direct purchases, which shall at least identify the price of the goods as available through the division of purchasing, the price of the goods as available from the alternative source, the total savings, and the signature of the notifying agency’s director or the director’s designee;

(8) Screening of supplies, material, and equipment excess to the requirements of one agency for overall state need before sale as surplus;

(9) Establishment of warehouse operation and storage standards to achieve uniform, effective, and economical stores operations;

(10) Establishment of time limit standards for the issuing of material in store and for processing requisitions requiring purchase;

(11) Formulation of criteria for determining when centralized rather than decentralized purchasing shall be used to obtain maximum benefit of volume buying of identical or similar items, including procurement from federal supply sources;

(12) Development of criteria for use of leased, rather than state owned, warehouse space based on relative cost and accessibility;

(13) Institution of standard criteria for purchase and placement of state furnished materials, carpeting, furniture, fixtures, and nonfixed equipment, in newly constructed or renovated state buildings;

(14) Determination of how transportation costs incurred by the state for materials, supplies, services, and equipment can be reduced by improved freight and traffic coordination and control;

(15) Establishment of a formal certification program for state employees who are authorized to perform purchasing functions as agents for the state under the provisions of chapter 43.19 RCW;

(16) Development of performance measures for the reduction of total overall expense for material, supplies, equipment, and services used each biennium by the state;

(17) Establishment of a standard system for all state organizations to record and report dollar savings and cost avoidance which are attributable to the establishment and implementation of improved purchasing and material control procedures;

(18) Development of procedures for mutual and voluntary cooperation between state agencies, including educational institutions, and political subdivisions for exchange of purchasing and material control services;

(19) Resolution of all other purchasing and material matters which require the establishment of overall statewide policy for effective and economical supply management;

(20) Development of guidelines and criteria for the purchase of vehicles, alternate vehicle fuels and systems, equipment, and materials that reduce overall energy-related costs and energy use by the state, including the requirement that new passenger vehicles purchased by the state meet the minimum standards for passenger automobile fuel economy established by the United States secretary of transportation pursuant to the energy policy and conservation act (15 U.S.C. Sec. 2002);

(21) Development of goals for state use of recycled or environmentally preferable products through specifications for products and services, processes for requests for proposals and

requests for qualifications, contractor selection, and contract negotiations.

NEW SECTION. **Sec. 6.** A new section is added to chapter 81.77 RCW to read as follows:

(1) The commission shall allow solid waste collection companies collecting recyclable materials to retain up to thirty percent of the revenue paid to the companies for the material if the companies submit a plan to the commission that is certified by the appropriate local government authority as being consistent with the local government solid waste plan and that demonstrates how the revenues will be used to increase recycling. The remaining revenue shall be passed to residential customers.

(2) By December 2, 2005, the commission shall provide a report to the legislature that evaluates:

(a) The effectiveness of revenue sharing as an incentive to increase recycling in the state; and

(b) The effect of revenue sharing on costs to customers.

NEW SECTION. **Sec. 7.** The department of ecology shall designate a portion of the responsibilities of existing staff to investigate and draw conclusions by December 31, 2002, on the following:

(1) The use of scrap tires as alternative daily cover for landfills. This shall include, but not be limited to, a review of alternative daily cover specifications that have been developed by other states, and either an analysis of those specifications' applicability to Washington or recommendations for developing alternative daily cover specifications that are unique to Washington;

(2) The feasibility of establishing and maintaining an incentive program for market development for scrap tires. This shall include, but not be limited to, the results of research into the availability of funding for such a program and proposed criteria for the program that favors projects utilizing higher end value uses of scrap tires.

NEW SECTION. **Sec. 8.** The department of transportation, in consultation with the office of general administration when needed, shall designate a portion of the responsibilities of existing staff to evaluate scrap tire use for civil engineering and highway construction applications by November 30, 2003. The evaluation shall include:

(1) An analysis of the feasibility of using scrap tires in lightweight fills given the standards and specifications adopted by the federal highway administration and other states; and

(2) An analysis of the feasibility of using rubber-modified asphalt in highway projects, including any changes in the cost of such procedures from the costs reported in the department of transportation's 1992 report to the legislature on the use of recycled materials in highway construction.

NEW SECTION. **Sec. 9.** A new section is added to chapter 70.95 RCW to read as follows:

The department of ecology, in conjunction with the appropriate private sector stakeholders, shall track and report annually to the legislature the total increase or reduction of tire recycling or reuse rates in the state for each calendar year and for the cumulative calendar years from the effective date of this act.

Passed the House February 15, 2002.

Passed the Senate March 6, 2002.

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APPENDIX B – REPORT TO LEGISLATURE

Use of Recycled Materials in Highway Construction

Report to Legislature

January 27, 1992

Washington State Department of Transportation

USE OF RECYCLED MATERIALS IN HIGHWAY CONSTRUCTION

EXECUTIVE SUMMARY

INTRODUCTION

In Second Substitute Senate Bill 5153, the state Legislature directed the Washington State Department of Transportation (WSDOT) to conduct a research study on the use of recycled materials in the transportation sector. The major objectives of this study were to examine: (1) the types of recycled materials that are appropriate and feasible as alternative paving materials, such as mixed plastics and compost, that can be utilized in all types of transportation applications other than pavements.

This executive summary highlights the key findings and conclusion of this report, which responds to the aforementioned directive. The technical report presents a more in-depth discussion of recycled product applications and includes a total of nine appendices, which contain much of the support materials gathered in the course of this effort.

The study was carried out in consultation with the Clean Washington Center (CWC) of the Department of Trade and Economic Development (DTED).

OVERVIEW

The WSDOT has been testing, evaluating and using recycled materials in roadway construction and other highway related applications for over 20 years. Since 1970, WSDOT has experimented with and/or developed applications for a wide variety of recycled products, including scrap tires, glass, asphalt, and concrete pavement, plastics, compost, and aluminum sign stock. This in-state, first hand experience provides the basis for many of the findings and conclusions presented in our report. As a supplement to the in-house experience, a literature search was conducted and a questionnaire was sent to 49 states to survey their experience. Thirty-seven states responded to the survey and over 50 publications were reviewed in the literature search. The information form this search and the experience of other states provided the basis for broader conclusions on recycled product potential and corroborated many of the in-house findings.

Three key factors influenced the content of this report:

1) The supply of, potential uses for, and quality of recycled materials is changing rapidly. This state of constant change makes it difficult and costly to systematically test and apply recycled products in the transportation sector.

2) A considerable amount of time is required for new products or materials to go from development and testing to widespread usage. New applications must be **tested and** evaluated over time. This can take up to 15 years, to determine durability and life

cycle costs in comparison to virgin alternatives for some products. Thus, it may take years before some recycled materials prove their value and result in high volume usage.

3) The mission of WSDOT is to design, build and maintain quality highway system in the most efficient and cost effective manner. This may conflict with the goal of rapidly expanding the use of recycled materials in roadway construction. As a matter of policy and operating procedure, WSDOT is continually examining, testing, and adopting new materials, providing they are cost effective and provide good service.

There are many other recycled materials and application in the transportation section which warrant considerations. Given the limited time and budget for this project only those items having the highest consumption potential have been included. The recycled products reviewed in the study were:

TIRES

The use of scrap tires as an additive for asphalt pavements have been developing for over 25 years. WSDOT has been experimenting with several types of rubber-asphalt pavement applications since 1977. A total of 237 lane miles have been paved with various rubber-asphalt mixtures. Added costs ranging from 1.1 to 4.4 times that of regular hot mix asphalt were documented in the experimental applications conducted since 1977. The approximately 200,00 tires used in these experimental applications were disposed of at cost of about $12 per tire.

The performance of these pavements has been continually monitored and compared to the performance of conventional asphalt pavements. Though there were some dramatic failures of rubber asphalt pavements constructed by WSDOT, there were enough success stories to conclude that rubberized asphalt can improve performance over conventional hot mix asphalt when properly designed and constructed.

WSDOT will continue to construct experimental sections of rubber-asphalt pavement to determine its best use and evaluate ongoing changes in materials and technology. Two such sections were constructed in the last two years; one new Pullman in 1990, and one near Aberdeen in 1991.

At least 29 states have evaluated the performance of rubber-asphalt mixes. Some tests in California, Arizona, and Alaska have proven positive. Most others have been negative. WSDOT expects to continue to monitor the performance of these positive tests to learn about possible breakthroughs in both he materials and the application technologies that will decease costs and improve performance.

National concerns regarding rubber-asphalt mixes centers on the higher costs and inconsistent performance of these pavements. Some additional points are: (1) can pavements containing rubber be recycled in the same manner as conventional hot mix asphalt pavements; (2) if they are recycled, can they meet current or future emission standards, are recycling large quantities of asphalt pavements. The inability to recycle pavements containing rubber would substantially reduce their benefit and also create a new waste problem.

The federal government is promoting recycling of tires into pavements in response to the growing waste disposal problem nationwide. The 1991 Intermodal Transportation Bill requires that states use at least five percent rubberized asphalt in federally funded pavement projects beginning in 1994 with this percentage rising to 20 percent by 1997. The intent of Congress is clear. The legislation, however, recognizes the concerns of the states regarding costs, performance, and the recyclability issue by mandating a study to evaluate these items. If these concerns are not mitigated by the study the mandate can be delayed for three years or more.

WSDOT will be responsive to this new requirement. A rough calculation indicates that Washington would use about 25,000 tons of rubber-asphalt mix in 1994 to meet the mandate. The most promising technology currently available uses approximately three tires per ton of rubber asphalt mix. The cost of that mix in 1991 was $39.50 higher per ton than conventional hot mix asphalt. This will result in approximately $1 million in additional cost to dispose of 75,000 tires at 1991 prices. The recycling industry believes that these prices will come down if greater quantities are utilized. The ongoing testing programs being carried out by this state and others will permit an assessment before 1994 of the feasibility of meeting this mandate within the cost constraints of current funding.

WSDOT has successfully used recycled tires in our asphalt crack filling operations and this material is now included in our Standard Specifications.

Other states and private companies report successful uses of waste tires for energy generation, retreading, artificial reefs, ferry bumpers, sludge composting, safety barriers, erosion control barriers, soil reinforcement, and lightweight backfill. Of these applications, lightweight backfill seems to hold the most promise for the consumption of large quantities of tires at minimal handling cost. WSDOT is aggressively seeking a project suitable for the construction of lightweight fill using scrap tire rubber.

GLASS

There have been sporadic attempts to use waste glass in asphalt concrete pavement since the late 1960’s. With the large increase in waste glass from various recycling programs implemented across the nation, there has been a clear increase in interest and activity in the incorporation of glass into asphalt pavement. New York City has used a considerable amount of waste glass in this manner over the past four yeas. Connecticut, New Jersey, Virginia, and Florida are also active in constructing experimental sections of “glasphalt”. This experience has in general demonstrated the potential for and limitations of this application as summarized below:

1) Glass can be used as an aggregate in asphalt mixes provided it is less that 15 percent of the total volume of the aggregates. Due to concerns with its strength and durability it should only be used for paving low speed, lower volume roadways as well as parking lots and non-vehicle pathways (bike and pedestrian paths). To meet engineering standards in these applications the waste glass must be reasonably clean, be crushed to a specific size, and include an anti-stripping additive such as hydrated lime. These standards are applied due to the inherent nature of the glass which is not as strong as natural aggregates and has such smooth surfaces that asphalt does not stick to it.

2) WSDOT continues to treat “glasphalt” as an experimental material. Any application will require extensive laboratory testing of the glass-asphalt mixtures to assure that the performance of the pavement will meet acceptable standards.

3) Waste glass can also be used as a base material for roadways. WSDOT has already adopted specifications for the use of crushed glass in a wide range of unbound base materials. There is the potential for a large volume of waste glass to be used in base materials provided costs are competitive with natural aggregates.

ASPHALT CONCRETE PAVEMENT

WSDOT has aggressively developed specifications and processes for the recycling of its asphalt concrete pavements. The first recycling project was completed in 1977 on a section of I-90 near Ellensburg. This project was monitored thorough the experimental projects process for over nine years to determine its long-term performance. Continued experimental use of asphalt concrete recycling led to the adoption of specifications to allow the inclusion of recycled asphalt concrete as a standard process in the production of new asphalt concrete. WSDOT presently processes over 100,000 to 200,000 tons of asphalt concrete per year.

FLY ASH

Fly ash can readily be recycled into portland cement concrete applications. As a result of laboratory and field research studies, fly ash is accepted for use in bridges and highways. The fly ash acts as a cement in concrete to replace portland cement with the added bonus that it increases the workability of the fresh mix. Fly ash has been used by WSDOT in bridge projects and will be used in the reconstruction of the Lacey V. Murrow floating bridge in Seattle.

COMPOST

Compost derived from yard waste has considerable potential for applications in the transportation sector. WSDOT has considerable experience with related materials such as sawdust and bark, which may technically meet the legal definition of compost. WSDOT has been meeting with the Washington Organic Recycling Council to establish specification for compost and to develop strategies for testing these new products in the transportation sector. Active contracts in the Seattle area have been recently modified to include yard waste compost products as a substitute for sawdust and bark.

MIXED PLASTICS

Products made from recycled mixed plastics have potential in the transportation sector. The state has conducted tests on several different types of products including roadside delineator posts, dimensional lumber, and polystyrene blocks used for temporary bridge abutments. Transportation agencies in other states are testing safety barriers, barricades and highway drainage pipes. Some of these products may be ready at this time for commercial applications. For other uses of mixed plastics, further testing and experimentation is required. The WSDOT is currently reviewing mixed plastic products through its New Products Evaluation Committee and will continue to monitor developments and breakthroughs in this area.

ALUMINUM SIGN STOCK

WSDOT has pioneered the recycling of aluminum sign stock. Old or defaced aluminum signs are regularly being reprocessed at the Walla Walla prison facility. In 1990, 180,000 square feet of sign stock was recycled saving the state approximately $200,000. Many cities and counties in the state are also using this facility and neighboring states have expressed an interest in doing the same.

WSDOT PROPOSED RECYCLING PROGRAMS AND STRATEGIES

This executive summary highlights the potential uses for recycled materials in the transportation sector. Clearly there is a substantial need for more testing and product development before scale, cost-effective applications of most of these materials can begin. WSDOT has an established program and a proven track record in the testing and evaluation of new products and processes. These programs consist of the New Products Evaluation Committee and the federally sponsored Experimental Features program. This committee and the Experimental Features program have been used in the past to test recycled materials and will continue to be relied on in the future.

In addition, to encourage the use of recycled materials, WSDOT proposes the following:

1) Establishment of a full time position within the agency as a recycling coordinator.

   This person will work as a liaison between the recycling industry and WSDOT to facilitate the use of more recycled materials.

2) Establishment of a special monitoring and reporting process to deal exclusively with recycled content products in the New Products Evaluation Committee.

   The committee's documentation process will be reformatted to track more closely the recycled content products. In addition, an annual report will be prepared summarizing the year's experience with recycled products. This will be made available to the legislature and other interested parties.

It is estimated that approximately $150,000 per biennium for one to two FTE's will be required to support this recycling effort through the New Products Evaluation Committee. These resources have not yet been appropriated. Without this additional funding, recycled materials will compete for consideration on an equal basis with all other existing programs or, in the case of the New Products Evaluation Committee, with all other new products.

Because of the severe time constraints placed upon this project, WSDOT was not able to develop specific programs to demonstrate the feasibility of using recycled materials in roadway construction. WSDOT will work with the various recycling industries to develop programs where the use of such materials are cost effective and provide acceptable performance.

WSDOT does recommend that a focused program be implemented to test and expand the use of recycled materials in non-paving applications. The department's experience and research indicates that in these instances recycled products can perform well and be cost effective. This condition applies to reprocessed asphalt and portland cement concrete, recycled materials in unbound bases such as glass and concrete, compost, and scrap tires for lightweight fills. WSDOT has or will be using most of these materials and plans to expand their use in the future.

APPENDIX C – CALTRANS SPECIFICATION FOR ASPHALT-RUBBER HOT MIX ASPHALT

CRUMB RUBBER MODIFIER (CRM)

Crumb rubber modifier (CRM) shall consist of a combination of scrap tire CRM and high natural CRM. The scrap tire CRM shall consist of ground or granulated rubber derived from any combination of automobile tires, truck tires or tire buffings. The high natural CRM shall consist of ground or granulated rubber derived from materials that utilize high natural rubber sources.

Steel and fiber separation shall be accomplished by any method. Cryogenic separation, if utilized, shall be performed separately from and prior to grinding or granulating.

CRM shall be ground or granulated at ambient temperature. Cryogenically produced CRM particles that pass through the grinder or granulator without being ground or granulated, respectively, shall not be used.

CRM shall not contain more than 0.01-percent wire (by mass of CRM) and shall be free of other contaminants, except fabric. Fabric shall not exceed 0.05-percent by mass of CRM. The test and method for determining the percent by mass of wire and fabric is available at the Transportation Laboratory, Office of Pavement Consulting Services, Sacramento, California, Telephone (916) 227-7300, and will be furnished to interested persons upon request. A certificate of compliance certifying these percentages shall be furnished to the Engineer in conformance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

The length of an individual CRM particle shall not exceed 4.75 mm.

The CRM shall be sufficiently dry so that the CRM will be free flowing and will not produce foaming when combined with the blended paving asphalt and asphalt modifier mixture. Calcium carbonate or talc may be added at a maximum amount of 3 percent by mass of CRM to prevent CRM particles from sticking together. The CRM shall have a specific gravity of between 1.1 and 1.2 as determined by California Test 208. Scrap tire CRM and high natural CRM shall be delivered to the production site in separate bags and shall be sampled and tested separately. CRM material shall conform to the following requirements as determined by ASTM Designation: D 297:

Test Parameter	SCRAP TIRE CRM Percent		HIGH NATURAL CRM Percent	
	Minimum	Maximum	Minimum	Maximum
Acetone Extract	6.0	16.0	4.0	16.0
Rubber Hydrocarbon	42.0	65.0	50.0	—
Natural Rubber content	22.0	39.0	40.0	48.0
Carbon Black Content	28.0	38.0	—	—
Ash Content	—	8.0	—	—

The CRM for asphalt-rubber binder shall conform to the gradations specified below when tested in conformance with the requirements in ASTM Designation: C 136, except as follows:

A. Split or quarter 100 g ± 5 g from the CRM sample and dry to a constant mass at a temperature of not less than 57°C nor more than 63°C and record the dry sample mass. Place the CRM sample and 5.0 g of talc in a 0.5-L jar. Seal the jar, then shake the jar by hand for a minimum of one minute to mix the CRM and the talc. Continue shaking or open the jar and stir until particle agglomerates and clumps are broken and the talc is uniformly mixed.

B. Place one rubber ball on each sieve. Each ball shall have a mass of 8.5 g ± 0.5 g, have a diameter of 24.5 mm ± 0.5 mm, and shall have a Shore Durometer "A" hardness of 50 ± 5 in conformance with the requirements in ASTM Designation: D 2240. After sieving the combined material for 10 minutes ±1 minute, disassemble the sieves. Material adhering to the bottom of a sieve shall be brushed into the next finer sieve. Weigh and record the mass of the material retained on the 2.36-mm sieve and leave this material (do not discard) on the scale or balance. Observed fabric balls shall remain on the scale or balance and shall be placed together on the side of the scale or balance to prevent the fabric balls from being covered or disturbed when placing the material from finer sieves onto the scale or balance. The material retained on the next finer sieve (2.00-mm sieve) shall be added to the scale or balance. Weigh and record that mass as the accumulative mass retained on that sieve (2.00-mm sieve). Continue weighing and recording the accumulated masses retained on the remaining sieves until the accumulated mass retained in the pan has been determined. Prior to discarding the CRM sample, separately weigh and record the total mass of fabric balls in the sample.

C. Determine the mass of material passing the 75-µm sieve (or mass retained in the pan) by subtracting the accumulated mass retained on the 75-µm sieve from the accumulated mass retained in the pan. If the material passing the 75-µm sieve (or mass retained in the pan) has a mass of 5 g or less, cross out the recorded number for the accumulated mass retained in the pan and copy the number recorded for the accumulated mass retained on the 75-µm sieve and record that number (next to the crossed out number) as the accumulated mass retained in the pan. If the material passing the 75-µm sieve (or mass retained in the pan) has a mass greater than 5 g, cross out the recorded number for the accumulated mass retained in the pan, subtract 5 g from that number and record the difference next to the crossed out number. The adjustment to the accumulated mass retained in the pan is made to account for the 5 g of talc added to the sample. For calculation purposes, the adjusted total sample mass is the same as the adjusted accumulated mass retained in the pan. Determine the percent passing based on the adjusted total sample mass and record to the nearest 0.1 percent:

CRM GRADATIONS

	SCRAP TIRE CRM	HIGH NATURAL CRM
Sieve Sizes	Percent Passing	Percent Passing
2.36- mm	100	100
2.00- mm	98-100	100
1.18- mm	45-75	95-100
600- µm	2-20	35-85
300- µm	0-6	10-30
150- µm	0-2	0-4
75- µm	0	0-1

ASPHALT-RUBBER BINDER

Asphalt-rubber binder shall consist of a mixture of paving asphalt, asphalt modifier, and crumb rubber modifier.

At least 2 weeks before its intended use, the Contractor shall furnish the Engineer 4 one liter cans filled with the asphalt-rubber binder proposed for use on the project. The Contractor shall supply the Engineer, for approval, a binder formulation and samples of all materials to be used in the asphalt-rubber binder, at least 2 weeks before construction is scheduled to begin. The binder formulations shall consist of the following information:

A. Paving Asphalt and Modifiers

1. Source and grade of paving asphalt.
2. Source and identification (or type) of modifiers used.
3. Percentage of asphalt modifier by mass of paving asphalt.
4. Percentage of the combined blend of paving asphalt and asphalt modifier by total mass of asphalt-rubber binder to be used.
5. Laboratory test results for test parameters shown in these special provisions.

B. Crumb Rubber Modifier (CRM)

1. Source and identification (or type) of scrap tire and high natural CRM.
2. Percentage of scrap tire and high natural CRM by total mass of the asphalt-rubber blend.
3. If CRM from more than one source is used, the above information will be required for each CRM source used.
4. Laboratory test results for test parameters shown in these special provisions.

C. Asphalt-Rubber Binder

1. Laboratory test results of the proposed blend for test parameters shown in these special provisions.
2. The minimum reaction time and temperature.

The method and equipment for combining the paving asphalt, asphalt modifier, and CRM shall be so designed and accessible that the Engineer can readily determine the percentages by mass for each material being incorporated into the mixture.

The proportions of the materials, by total mass of asphalt-rubber binder, shall be 80 percent ± 2 percent combined paving asphalt and asphalt modifier and 20 percent ± 2 percent CRM. However, the minimum amount of

CRM shall not be less than 18.0 percent. Lower values shall not be rounded up. The CRM shall be combined at the production site and shall contain 75 percent ± 2 percent scrap tire CRM and 25 percent ± 2 percent high natural CRM, by mass.

The paving asphalt and asphalt modifier shall be combined into a blended mixture that is chemically compatible with the crumb rubber modifier to be used. The blended mixture shall be considered to be chemically compatible when the mixture meets the requirements for asphalt-rubber binder (after reacting) found in these special provisions.

The blended paving asphalt and asphalt modifier mixture and the CRM shall be combined and mixed together at the production site in a blender unit to produce a homogeneous mixture.

The temperature of the blended paving asphalt and asphalt modifier mixture shall not be less than 190°C nor more than 226°C when the CRM is added. The combined materials shall be reacted for a minimum of 45 minutes after incorporation of the CRM at a temperature of not less than 190°C nor more than 218°C. The temperature shall not be higher than 6°C below the actual flash point of the asphalt-rubber binder.

After reacting, the blended asphalt-rubber binder shall conform to the following requirements:

BLENDED ASPHALT-RUBBER BINDER

Test Parameter	ASTM Test Method	Requirement	
		Minimum	Maximum
Cone Penetration @ 25°C, 1/10 mm	D 217	25	70
Resilience @ 25°C, Percent rebound	D 3407	18	—
Field Softening Point, °C	D 36	52	74
Viscosity @190°C, Pa • s (x10-3)	See Note	1500	3000

NOTE: The viscosity test shall be conducted using a hand held Haake Viscometer Model VT-02 with Rotor 1, 24 mm depth x 53 mm height, or equivalent, as determined by the Engineer. The accuracy of the viscometer shall be verified by comparing the viscosity results obtained with the hand held viscometer to 3 separate calibration fluids of known viscosities ranging from 1000 Pa to 5000 Pa • s (x10-3). The viscometer will be considered accurate if the values obtained are within 300 Pa • s (x10-3) of the known viscosity. The known viscosity value shall be based on the fluid manufacturer's standard test temperature or the test temperature versus viscosity correlation table provided by the fluid manufacturer. All viscometers used on the project shall be verified to be accurate. The test method for determining the viscosity of asphalt-rubber binder using a hand held viscometer is available at the Transportation Laboratory, Office of Pavement Consulting Services, Sacramento, California, Telephone (916) 227-7300. The accuracy verification results shall be provided to the Engineer and shall be certified by a Certificate of Compliance. The Certificate of Compliance shall be furnished to the Engineer in conformance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

The Contractor shall provide a Haake Viscometer, or equivalent, at the production site during the combining of asphalt-rubber binder materials. The Contractor shall take viscosity readings of asphalt-rubber binder from samples taken from the distributor truck a minimum of 45 minutes after incorporation of the CRM. Readings shall be taken at least every hour with not less than one reading for each batch of asphalt-rubber binder. The Contractor shall log these results, including time and asphalt-rubber temperature. A copy of the log shall be submitted to the Engineer on a daily basis. As determined by the Engineer, the Contractor shall either notify the Engineer at least 15 minutes prior to each test or provide the Engineer a schedule of testing times.

The reacted asphalt-rubber binder shall be maintained at a temperature of not less than 190°C nor more than 218°C.

If any of the material in a batch of asphalt-rubber binder is not used within 4 hours after the 45-minute reaction period, heating of the material shall be discontinued. If the asphalt-rubber binder cools below 190°C and is then reheated, it shall be considered a reheat cycle. The total number of reheat cycles shall not exceed 2. The material shall be uniformly reheated to a temperature of not less than 190°C nor more than 218°C prior to use. Additional scrap tire CRM may be added to the reheated binder and reacted for a minimum of 45 minutes. The cumulative amount of additional scrap tire CRM shall not exceed 10 percent of the total binder mass. Reheated asphalt-rubber binder shall conform to the requirements for blended asphalt-rubber binder.

SCREENINGS

Screenings shall conform to the provisions in these special provisions and in Section 37-1.02, "Materials," of the Standard Specifications, except that the third, fourth, eighth, and ninth paragraphs of Section 37-1.02 shall not apply.

Stockpiling of screenings after preheating and precoating with paving asphalt will not be permitted.

Canvas or similar covers that completely cover each load of precoated screenings shall be used during hauling to minimize temperature drop of the precoated screenings.

Screenings shall conform to the following grading requirements prior to precoating with paving asphalt:

SCREENINGS GRADING REQUIREMENTS 9.5-mm Maximum	
Sieve Sizes	Percentage Passing
12.5- mm	100
9.5- mm	70-85
4.75- mm	0-15
2.36- mm	0-5
75- µm	0-1

Screenings shall conform to the following quality requirements immediately prior to precoating:

SCREENINGS QUALITY REQUIREMENTS

Test Parameters	California Test	Requirements
Los Angeles Rattler Loss (100 Revolutions)	211	10 Max.
Los Angeles Rattler Loss (500 Revolutions)	211	40 Max.
Film Stripping	302	25 Max.
Cleanness Value	227	80 Min.
Durability	229	52 Min.

Screenings for asphalt-rubber seal coat shall be preheated to between 127°C and 163°C and uniformly coated at a rate of 0.7 percent to one percent of grade AR-4000 paving asphalt by mass of dry aggregate at a central mixing asphalt concrete plant which has been approved in conformance with the requirements in California Test 109. The exact rate will be determined by the Engineer.

EQUIPMENT

The Contractor shall utilize the following equipment for asphalt-rubber seal coat operations:

A. Self-propelled power brooms that clean the existing pavement and remove loose screenings without dislodging screenings set in the asphalt-rubber binder. Gutter brooms or steel-tinned brooms shall not be used;

B. Pneumatic tired rollers conforming to the provisions in Section 39-5.02, "Compacting Equipment," of the Standard Specifications, except that the rollers shall have an air pressure of 690 KPa and maintained so that the air pressure will not vary more than ±35 KPa in each tire. A sufficient number of rollers shall be used so that one complete coverage will be provided in one pass;

C. A self-propelled screenings spreader, equipped with a screenings hopper in the rear, belt conveyors to carry the screenings to the front, and a spreading hopper equipped with full-width distribution auger and spread roll. The screenings spreader shall be capable of providing a uniform screening spread rate over the entire width of the traffic lane in one application;

D. D. An asphalt heating tank equipped to heat and maintain the blended paving asphalt and asphalt modifier mixture at the necessary temperature before blending with the CRM. This unit shall be equipped with a thermostatic heat control device and a temperature reading device and shall be accurate to within ±3°C and shall be of the recording type;

E. E. A mechanical mixer for the complete, homogeneous blending of paving asphalt, asphalt modifier, and CRM. Paving asphalt and asphalt modifier shall be introduced into the mixer through meters conforming to the provisions in Section 9-1.01, "Measurement of Quantities," of the Standard Specifications. The blending system shall vary the rate of delivery of paving asphalt and asphalt modifier proportionate with the delivery of CRM. During the proportioning and blending of the liquid ingredients, the temperature of paving asphalt and the asphalt modifier shall not vary more than ±14°C. The paving asphalt feed, the asphalt modifier feed, and CRM feed shall be equipped with devices by which the rate of feed can be determined during the proportioning operation. Meters used for proportioning individual ingredients shall be equipped with rate-of-flow indicators to show the rates of delivery and resettable totalizers so that the total amounts of liquid ingredients introduced into the mixture can be determined. The liquid and dry ingredients shall be fed directly into the mixer at a uniform and controlled rate. The rate of feed to the mixer shall not exceed that which will permit complete mixing of the materials. Dead areas in the mixer, in which the material does not move or is not sufficiently agitated, shall be corrected by a reduction in the volume of material or by other adjustments. Mixing shall continue until a homogeneous mixture of uniformly distributed and properly blended asphalt-rubber binder of unchanging appearance and consistency is produced. The Contractor shall provide a safe sampling device that delivers a representative sample of the completed asphalt-rubber binder of sufficient size to permit the required tests;

F. F. An asphalt-rubber binder storage tank equipped with a heating system to maintain the proper temperature of the asphalt-rubber binder and an internal mixing unit that maintains a homogeneous mixture of blended paving asphalt, asphalt modifier, and CRM;

G. G. A self-propelled truck or trailer mounted distributor, equipped with an internal mixing unit that maintains a homogeneous mixture of blended paving asphalt, asphalt modifier and CRM. The distributor shall have a pump or pumps that sprays asphalt-rubber binder within ±0.25 L/m2 of the specified rate. The distributor shall have a fully circulating spray bar that applies the asphalt-rubber binder without a streaked or otherwise irregular pattern. The distributor shall be equipped with a tachometer, pressure gages, volume measuring devices, and thermometer. The distributor shall have a platform on the rear of the vehicle and an observer shall accompany the distributor. The observer shall ride in such a position that all spray nozzles are in full view and readily accessible for unplugging plugged nozzles, should plugging occur; and

H. H. Tailgate discharge trucks for hauling screenings shall be equipped with a device to lock onto the hitch at the rear of the screenings spreader. Haul trucks shall be compatible with the screenings spreader so that the dump bed will not push down on the spreader when fully raised or have too short a bed which results in screenings spilling while dumping into the receiving hopper.

Equipment shall be approved by the Engineer prior to use.

APPLYING ASPHALT-RUBBER BINDER

Asphalt-rubber binder shall be applied in conformance with the provisions specified for applying asphaltic emulsion in these special provisions and in Section 37-1.05, "Applying Asphaltic Emulsion," of the Standard Specifications, except that the second, third, fourth, fifth, ninth, and twelfth paragraphs of Section 37-1.05 shall not apply.

Asphalt-rubber binder for asphalt-rubber seal coat shall be applied where shown on the plans at a rate of 2.5 L/m2 to 3.0 L/m^2. The exact rate will be determined by the Engineer.

Attention is directed to Section 7-1.11, "Preservation Of Property," of the Standard Specifications and "Existing Highway Facilities" of these special provisions regarding protecting highway facilities from seal coat.

Asphalt-rubber binder shall be placed upon a clean, dry surface. The pavement surface temperature shall be a minimum of 13°C where asphalt-rubber binder is to be applied. The atmospheric temperature shall be a minimum of 16°C.

Distributor bar height, distribution speed, and shielding materials shall be utilized to reduce the effects of wind upon spray distribution as directed by the Engineer. The Engineer will delay or reschedule work when high, gusting or dirty winds prevent or adversely affect binder or screening application operations. Necessary equipment shall be in position and ready to commence placement operations before starting.

The Contractor shall comply with Federal, State, and Local environmental laws, rules, regulations, and ordinances including, but not limited to, air quality requirements.

The asphalt-rubber binder shall be applied to the roadway immediately following mixing and reacting and shall be applied at a temperature not less than 196°C nor more than 213°C. Asphalt-rubber binder application shall not be in excess of that which can be covered with screenings within 2 minutes.

When placing asphalt-rubber seal coat at intersections, left turn lanes, gore points, and other irregular areas, asphalt-rubber application shall not be in excess of that which can be covered with screenings within 15 minutes.

When joining edges against areas with screenings, the joint shall be swept clean of excess screenings prior to the adjacent application of asphalt-rubber binder. Transverse joints of this type shall be constructed by placing roofing paper across and over the end of the previous asphalt-rubber seal coat application. Once the spraying has progressed beyond the paper, the paper shall be removed immediately.

The longitudinal joint between adjacent applications of screenings shall coincide with the line between designated traffic lanes. Longitudinal joints shall be overlapped for complete coverage. The overlap shall not exceed 100 mm.

At longitudinal joints with screenings, the edge shall be broomed back and blended to eliminate differences in elevation. The joints shall be free from ridges and depressions and shall have a uniform appearance consistent with the adjacent sealed surface. Defects shall be corrected at the Contractor's expense.

Joints between areas of asphalt-rubber binder without screenings shall be made by overlapping asphalt-rubber binder distributions. The excess material shall be properly dispersed by spreading with a squeegee or rake over a larger area of freshly applied asphalt-rubber binder.

The application of asphalt-rubber binder to areas not accessible with the distributor bar on the distributor truck shall be accomplished by using pressurized hand wands or other means approved by the Engineer.

SPREADING SCREENINGS

Screenings for asphalt-rubber seal coat shall be spread in conformance with the provisions specified for spreading screenings on asphaltic emulsion in these special provisions and in Section 37-1.06, "Spreading Screenings," of the Standard Specifications, except that the first, fifth, sixth, and seventh paragraphs of Section 37-1.06 shall not apply.

Following the application of the asphalt-rubber binder, screenings shall be placed over areas receiving asphalt-rubber binder.

Screenings for asphalt-rubber seal coat shall be applied at a temperature not less than 107°C and not more than 163°C after applying asphalt-rubber binder.

The Contractor shall prevent any vehicle, including construction equipment, from driving on the asphalt-rubber binder prior to application of screenings.

Screenings shall be applied at a rate of 15 kg/m^2 to 22 kg/m^2. The exact rate will be determined by the Engineer. The completed spread rate shall be within 10 percent of the rate determined by the Engineer. The completed surface shall be free of gaps, ridges, depressions or other irregularities caused by the application of the asphalt-rubber seal coat.

FINISHING

Asphalt-rubber seal coat shall be finished in conformance with the provisions for finishing screenings spread on asphaltic emulsion in these special provisions and in Section 37-1.07, "Finishing," of the Standard Specifications, except that the second, third, seventh, eighth, and ninth paragraphs of Section 37-1.07 shall not apply.

Initial rolling of the asphalt-rubber seal coat shall consist of a minimum of one complete coverage with one or more pneumatic-tired rollers and shall begin within 90 seconds following the placement of the screenings.

The distance between the rollers and the screenings spreader shall not exceed 60 m at any time during the spreading of the screenings operations.

A minimum of 3 complete coverages as defined in Section 39-6.03, "Compacting," of the Standard Specifications with pneumatic tired rollers, after the initial coverage, shall be made on the asphalt-rubber seal coat. When permitted by the Engineer, the final roller coverage may be made with one steel wheel roller weighing 7.25 tonnes minimum and 9 tonnes maximum. If a steel wheel roller is used, the roller shall be operated in the static mode only.

Sweeping shall be a multi-step operation following final rolling of the screenings. Loose screenings shall be removed from the roadway surface and abutting adjacent areas. Loose screenings shall be disposed of at least 46 m from the nearest waterway.

At location 3 and 4 on the plans, sweeping shall be accomplished with pickup brooms and the material removed shall become the property of the Contractor and shall be disposed of as provided in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way."

Initial sweeping shall be completed before controlled traffic is permitted on the asphalt-rubber seal coat. Removal of excess screenings shall be completed before uncontrolled traffic is permitted on the completed asphalt-rubber seal coat. Final sweeping shall be done and loose screenings shall be removed without dislodging the screenings set in the asphalt-rubber binder prior to acceptance.

Sufficient pilot cars shall be available to continuously convoy and control public traffic. Pilot cars used to convoy or otherwise control public traffic shall have radio contact with each other and other personnel in the work area. Pilot cars shall use only traffic lanes open to public traffic.

MEASUREMENT AND PAYMENT

Quantities of asphalt-rubber binder for asphalt-rubber seal coat will be measured in the same manner specified for asphalt in Section 92-1.05, "Measurement," of the Standard Specifications.

Quantities of screenings for asphalt-rubber seal coat to be paid for by the tonne will be determined after preheating and precoating with paving asphalt in the same manner specified for asphalt concrete in Section 39-8.01, "Measurement," of the Standard Specifications.

The contract price paid per tonne for asphalt-rubber binder shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all the work involved in furnishing and applying asphalt-rubber binder, complete in place, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

The contract price paid per tonne for screenings (hot-applied) shall include full compensation for furnishing all labor, materials (including paving asphalt for precoating screenings), tools, equipment, and incidentals and for doing all the work involved in furnishing and applying screenings, complete in place, including preparation for seal coat and preheating and precoating screenings, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

APPENDIX D – PERFORMANCE GRADE ASPHALT BINDER SPECIFICATIONS (AASHTO MP 1)

Table D-1: Performance Graded Asphalt Binder Specifications (AASHTO, 2003)

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day maximum pavement design temperature, °C[a]	<46			<52							<58					<64					
Minimum pavement design temperature, °C[a]	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash point temp, T 48, Minimum °C	230																				
Viscosity, T316:[b] Maximum 3 Pa-s, Test Temp °C	135																				
Dynamic shear, T 315:[c] G*/sinδ[d], minimum 1.00 kPa Test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change,[ε] maximum, percent	1.00																				
Dynamic shear, T 315:[c] G*/sindδ, minimum 2.20 kPa Test temp @ 10 rad/s, °C	46			52							58					64					
Pressure Aging Vessel Residue (R 28)																					
PAV aging temperature, °C[f]	90			90							100					100					
Dynamic shear, T 315:[c] G*sindδ, maximum 5000 kPa Test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Critical low cracking temp, PP42:[g] Determine critical cracking temp as described in PP 42, Test Temp, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in MP 2 and PP 28.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt cement may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[d] G*/sinδ = high temperature stiffness and G*/sinδ = intermediate stiffness.

[e] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) mass change.

[f] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

g

Table D-1: Performance Graded Asphalt Binder Specifications (from AASHTO, 2003) continued…

Performance Grade	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day maximum pavement design temperature, °C[a]	<70						<76					<82				
Minimum pavement design temperature, °C[a]	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-10	>-16	>-22	>-28	>-34
Original Binder																
Flash point temp, T 48, Minimum °C	230															
Viscosity, T316:[b] Maximum 3 Pa-s, Test Temp °C	135															
Dynamic shear, T 315:[c] G*/sinδ[d], minimum 1.00 kPa Test temp @ 10 rad/s, °C	70						76					82				
Rolling Thin-Film Oven Residue (T 240)																
Mass change,[e] maximum, percent	1.00															
Dynamic shear, T 315:[c] G*/sinδ[d], minimum 2.20 kPa Test temp @ 10 rad/s, °C	70						76					82				
Pressure Aging Vessel Residue (R 28)																
PAV aging temperature, °C[f]	100 (110)						100 (110)					100 (110)				
Dynamic shear, T 315:[c] G*sinδ[d], maximum 5000 kPa Test temp @ 10 rad/s, °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Critical low cracking temp, PP42:[g] Determine critical cracking temp as described in PP 42, Test Temp, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24

APPENDIX E – CLIMATE CONDITIONS

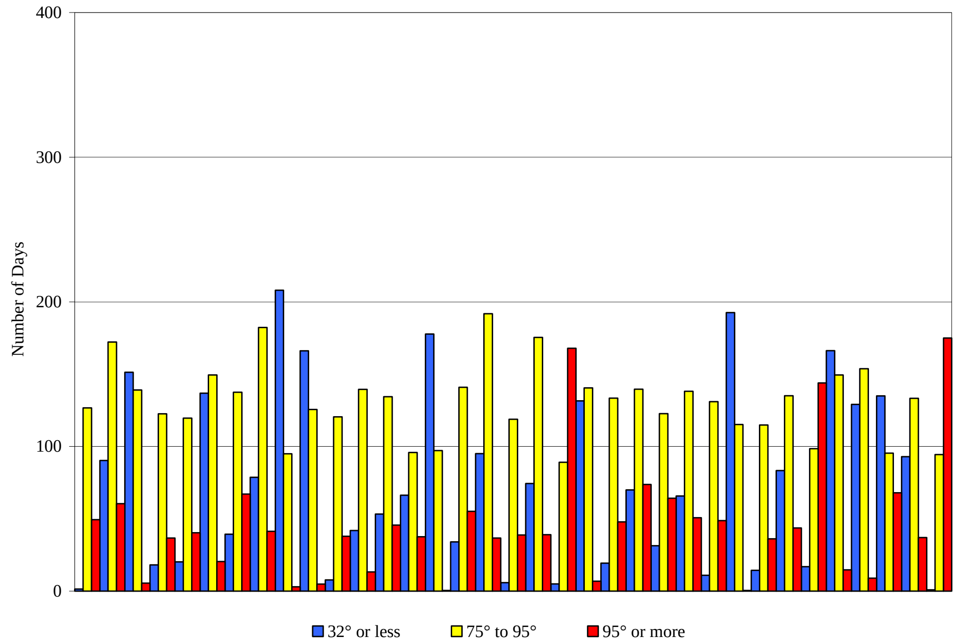

Figure E-1. Arizona Temperature Extremes.

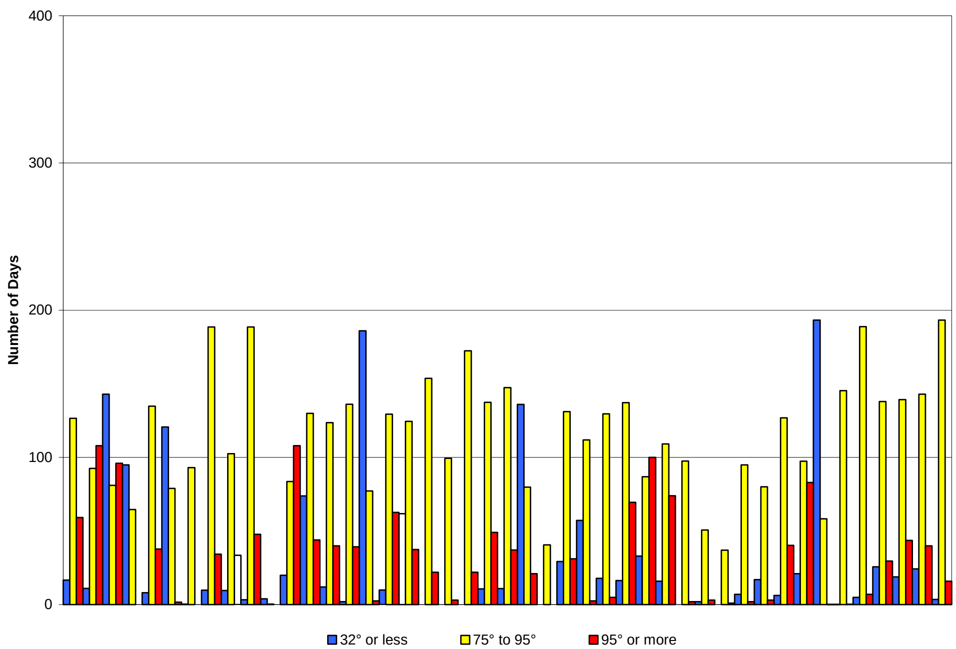

Figure E-2. California Temperature Extremes

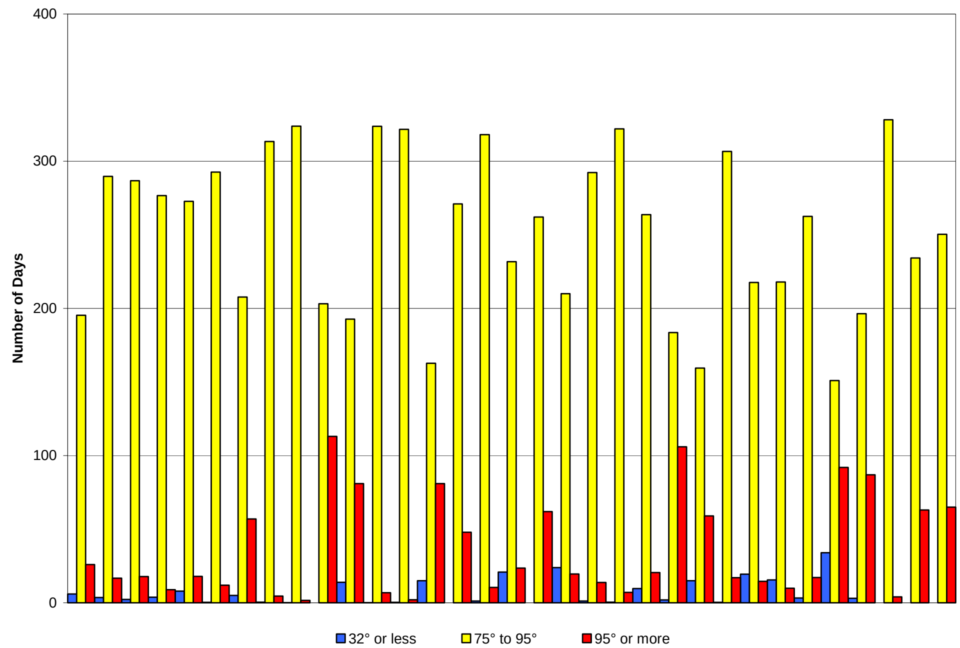

Figure E-3. Florida Temperature Extremes

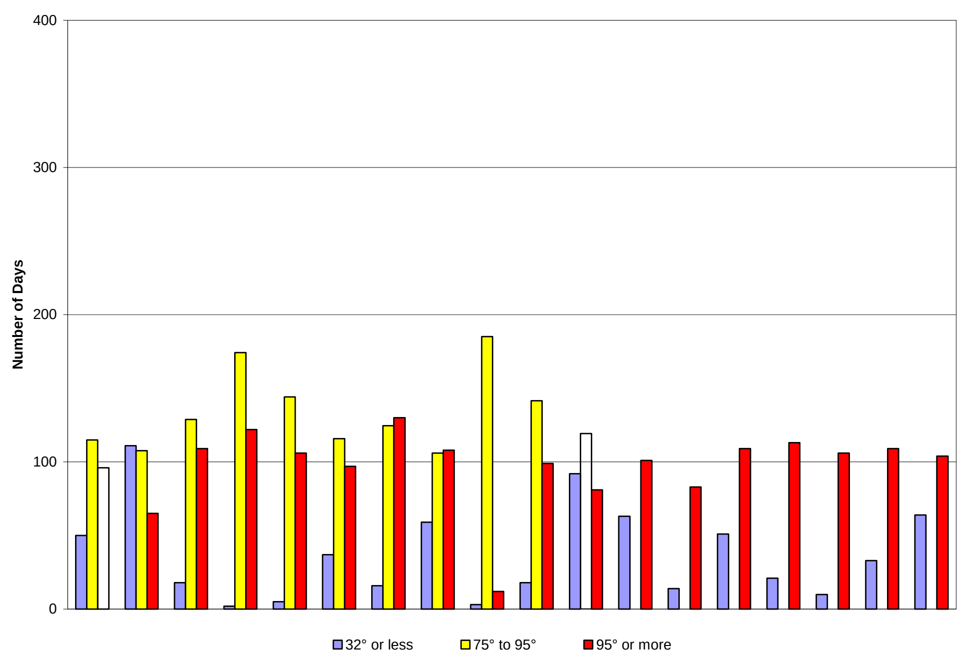

Figure E-4. Texas Temperature Extremes

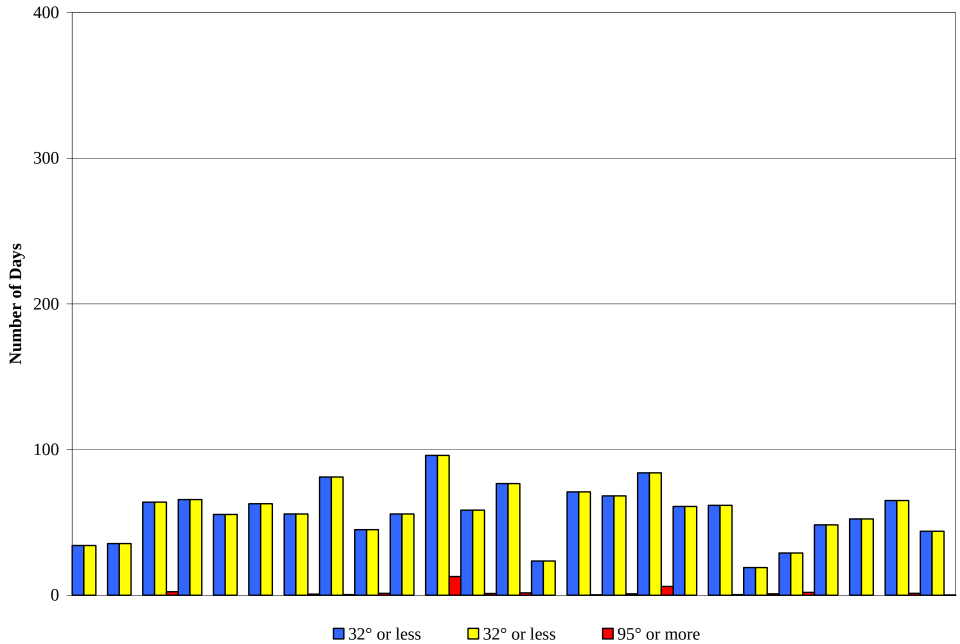

Figure E-5. Eastern Washington Temperature Extremes

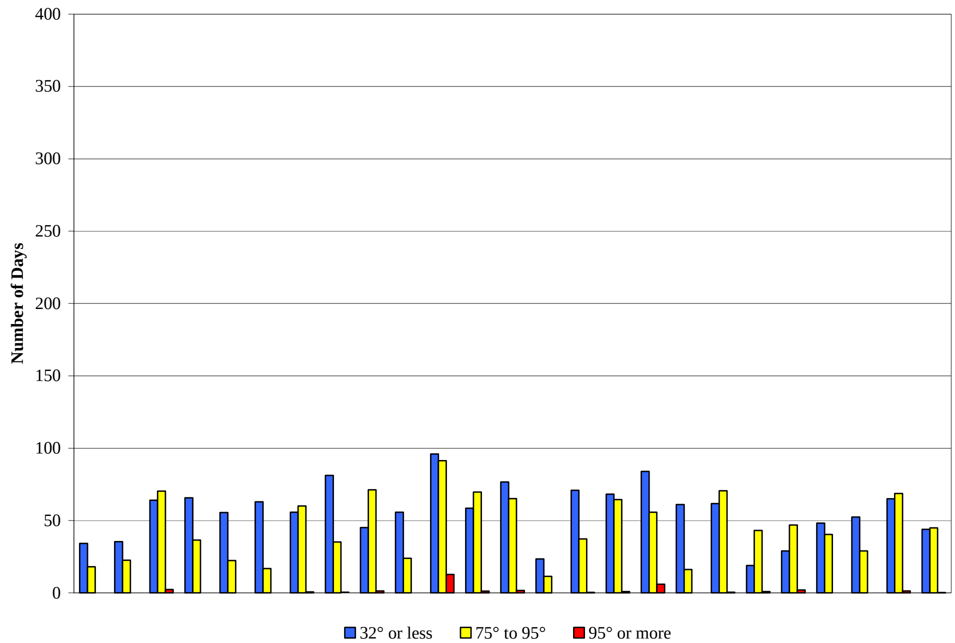

Figure E-6. Western Washington Temperature Extremes

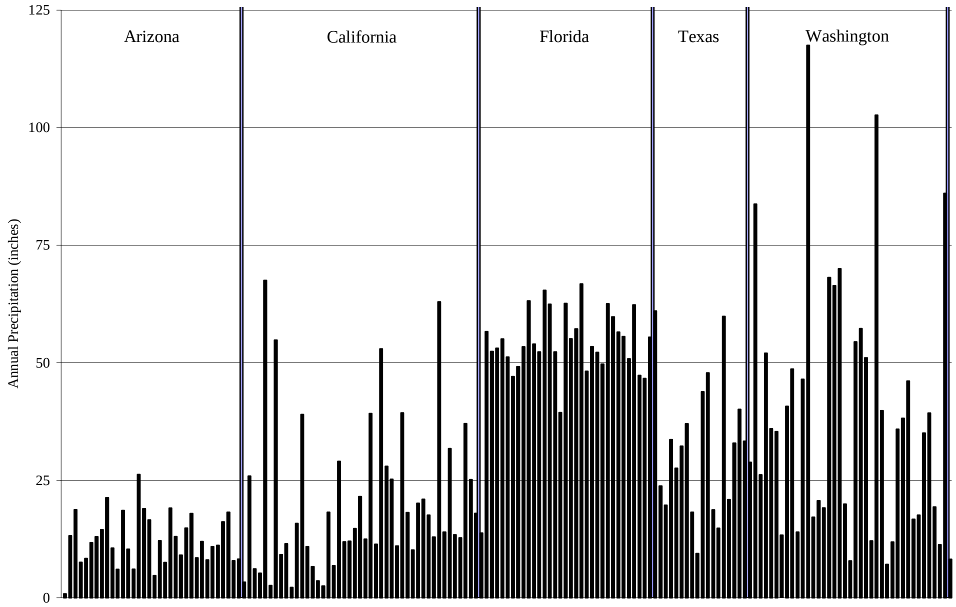

Figure E-7. Total Annual Precipitation by State.

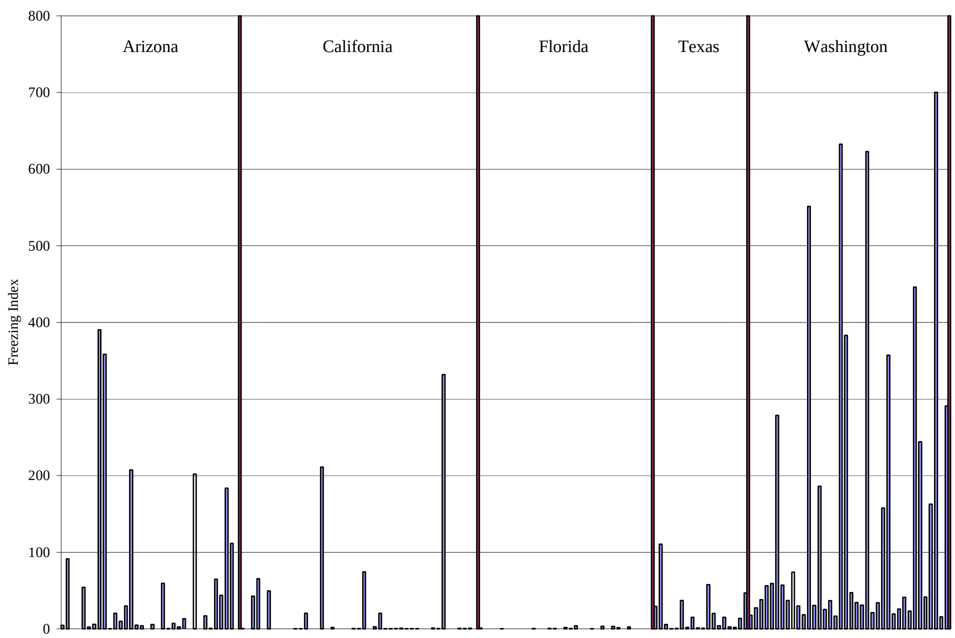

Figure E-8. Annual Freezing Index by State.

City	Mean Number of days with the following Temperature Characteristics				Annual Inches of Precipitation		Freezing Index
	32°F or less	75°F or more	75°F to 95°F	95°F or more	Total Precipitation	Snow	
AJO, AZ	1	176	127	49	0.84	0.1	0
APACHE POWDER COMPANY, AZ	90	233	172	61	13.20	1.2	5
BLACK RIVER PUMPS, AZ	151	145	139	6	18.74	11.4	91
BUCKEYE, AZ	18	159	123	37	7.58	0.0	0
CASA GRANDE. AZ	20	160	120	40	8.38	0.1	0
CHINO VALLEY, AZ	137	170	150	21	11.76	7.4	54
CLIFTON, AZ	39	205	138	67	13.01	1.1	2
DOUGLAS, AZ	79	224	182	41	14.50	0.0	6
FLAGSTAFF, AZ	208	98	95	3	21.33	99.2	390
GANADO, AZ	166	130	126	5	10.58	21.6	358
GILA BEND, AZ	8	158	121	38	6.08	0.0	0
JEROME, AZ	42	153	140	13	18.59	18.0	20
KINGMAN, AZ	53	180	134	46	10.36	3.7	10
LEES FERRY,AZ	66	133	96	38	6.11	2.3	30
MC NARY, AZ	178	98	97	0	26.25	90.0	207
MIAMI, AZ	34	196	141	55	18.96	0.8	5
NOGALES, AZ	95	229	192	37	16.57	2.9	4
PARKER, AZ	6	158	119	39	4.75	0.0	0
PEARCE, AZ	74	215	175	39	12.18	1.1	6
PHOENIX, AZ	5	257	89	168	7.54	0.0	0
PRESCOTT, AZ	132	147	141	7	19.12	25.2	59
SABINO CANYON, AZ	19	181	133	48	13.04	0.3	0
SAFFORD EXPERIMENT FRM, AZ	70	213	140	74	9.07	1.0	7
SAN CARLOS RESERVOIR, AZ	31	187	123	64	14.86	0.2	3
SEDONA RANGER STATION, AZ	66	189	138	51	17.94	3.7	13
SOUTH PHOENIX, AZ	11	180	131	49	8.51	0.0	0
SPRINGERVILLE, AZ	192	116	115	0	12.00	20.1	202
TEMPE CITRUS EXP STA, AZ	14	151	115	36	8.08	0.1	0
TRUXTON CANYON, AZ	83	179	135	44	10.87	2.4	17
TUCSON, AZ	17	243	99	144	11.18	0.7	1
WALNUT CREEK, AZ	166	164	149	15	16.18	11.9	65
WHITERIVER, AZ	129	163	154	9	18.23	17.4	44
WINSLOW, AZ	135	163	95	68	7.89	11.4	184
WUPATKI NAT MON, AZ	93	170	133	37	8.23	6.8	112
YUMA, AZ	1	269	94	175	3.33	0.0	0

City	Mean Number of days with the following Temperature Characteristics				Annual Inches of Precipitation		Freezing Index
	32°F or less	75°F or more	75°F to 95°F	95°F or more	Total Precipitation	Snow	
ASH MOUNTAIN, CA	17	186	127	59	25.91	1.8	1
BAKERSFIELD, CA	11	201	93	108	6.19	0.1	0
BISHOP, CA	143	177	81	96	5.25	8.1	43
BLUE CANYON, CA	95	65	65	0	67.52	251.8	65
BRAWLEY 2 SW, CA	8	173	135	38	2.62	0.0	0
CALAVERAS BIG TREES, CA	121	81	79	2	54.83	129.8	50
CHULA VISTA, CA	0	93	93	0	9.18	0.1	0
CORONA, CA	10	223	189	34	11.49	0.1	0
DEATH VALLEY, CA	10	136	103	34	2.21	0.0	0
EL CAPITAN DAM, CA	3	236	189	48	15.85	0.0	0
EUREKA, CA	4	0	0	0	38.99	0.3	0
FRESNO, CA	20	192	84	108	10.89	0.1	0
HAIWEE, CA	74	174	130	44	6.66	3.6	20
HAYFIELD PUMPING PLANT, CA	12	163	124	40	3.61	0.1	0
IMPERIAL, CA	2	176	136	39	2.54	0.0	0
JESS VALLEY, CA	186	80	77	3	18.24	70.1	211
KETTLEMAN STATION, CA	10	192	129	63	6.82	0.0	0
LAKEPORT, CA	62	162	125	37	29.03	0.4	2
LONG BEACH, CA	0	176	154	22	11.92	0.0	0
LOS ANGELES AP, CA	0	102	99	3	12.06	0.0	0
LOS ANGELES C.O., CA	0	194	172	22	14.73	0.0	0
MARYSVILLE, CA	11	186	137	49	21.52	0.0	0
MODESTO, CA	11	184	147	37	12.48	0.1	0
MOUNT SHASTA, CA	136	101	80	21	39.23	104.7	75
NEWPORT BEACH HARBOR, CA	0	41	41	0	11.39	0.0	0
ORLEANS, CA	29	162	131	31	52.96	4.4	3
PALOMAR MT OBSERVATORY, CA	57	114	112	3	27.97	35.9	20
PETALUMA FIRE STA 2, CA	18	134	130	5	25.20	0.0	0
PORTERVILLE, CA	16	207	137	69	11.03	0.0	0
REDDING, CA	33	187	87	100	39.37	4.8	1
SACRAMENTO, CA	16	183	109	74	18.15	0.0	1
SAN DIEGO, CA	0	100	98	2	10.17	0.0	0
SAN FRANCISCO AP, CA	2	54	51	3	20.11	0.0	0
SAN FRANCISCO C.O., CA	0	38	37	1	20.99	0.0	0
SANTA BARBARA, CA	7	97	95	2	17.60	0.0	0
SANTA MARIA, CA	17	83	80	3	12.92	0.0	0

City	Mean Number of days with the following Temperature Characteristics				Annual Inches of Precipitation		Freezing Index
	32°F or less	75°F or more	75°F to 95°F	95°F or more	Total Precipitation	Snow	
SHASTA DAM, CA	6	167	127	40	62.97	4.8	1
STOCKTON, CA	21	180	97	83	14.01	0.0	0
TAHOE CITY, CA	193	58	58	0	31.75	188.6	332
TORRANCE, CA	0	146	145	0	13.43	0.0	0
TUSTIN IRVINE RANCH, CA	5	196	189	7	12.75	0.0	0
UKIAH, CA	26	167	138	30	37.09	0.2	1
VACAVILLE, CA	19	183	139	44	25.13	0.1	0
WILLOWS, CA	24	183	143	40	17.98	0.6	1
YORBA LINDA, CA	3	209	193	16	13.80	0.0	0
APALACHICOLA, FL	6	221	195	26	56.65	0.0	1
ARCADIA, FL	4	306	290	17	52.40	0.0	0
BARTOW, FL	2	305	287	18	53.11	0.0	0
BROOKSVILLE CHIN HILL, FL	4	286	277	9	55.05	0.0	0
BUSHNELL 2 E, FL	8	291	273	18	51.24	0.0	0
CLEWISTON U S ENG, FL	0	305	293	12	47.10	0.0	0
DAYTONA BEACH, FL	5	265	208	57	49.18	0.0	0
EVERGLADES, FL	0	318	313	5	53.39	0.0	0
FORT LAUDERDALE, FL	0	325	324	2	63.19	0.0	0
FORT MYERS, FL	0	316	203	113	53.99	0.0	0
GAINESVILLE, FL	14	274	193	81	52.31	0.0	0
HIALEAH, FL	0	331	324	7	65.41	0.0	0
HOMESTEAD EXP STA, FL	0	324	322	2	62.45	0.0	0
JACKSONVILLE, FL	15	244	163	81	52.31	0.1	1
KEY WEST, FL	0	319	271	48	39.40	0.0	0
LOXAHATCHEE, FL	1	329	318	10	62.64	0.0	0
MAYO, FL	21	255	232	24	55.10	0.0	2
MIAMI, FL	0	324	262	62	57.23	0.0	0
MILTON EXP STATION, FL	24	230	210	20	66.79	0.3	4
MOORE HAVEN LOCK 1, FL	1	306	292	14	48.18	0.0	0
NAPLES 2 NE, FL	1	329	322	7	53.44	0.0	0
OCALA, FL	10	284	264	21	52.22	0.0	0
ORLANDO, FL	2	290	184	106	49.72	0.0	0
PENSACOLA, FL	15	219	160	59	62.55	0.1	3
POMPANO BEACH, FL	0	324	307	17	59.76	0.0	0
QUINCY 3 SSW, FL	20	232	218	15	56.51	0.1	3
SAINT MARKS 6 SE, FL	16	228	218	10	55.58	0.1	1

City	Mean Number of days with the following Temperature Characteristics				Annual Inches of Precipitation		Freezing Index
	32°F or less	75°F or more	75°F to 95°F	95°F or more	Total Precipitation	Snow	
SANFORD EXP STATION, FL	3	280	263	17	50.88	0.0	0
TALLAHASSEE, FL	34	243	151	92	62.34	0.1	3
TAMPA, FL	3	283	196	87	47.32	0.0	0
TAVERNIER, FL	0	332	328	4	46.68	0.0	0
VERO BEACH, FL	0	297	234	63	55.46	0.0	0
WEST PALM BEACH, FL	0	315	250	65	61.02	0.0	0
ABILENE, TX	50	211	115	96	23.78	4.6	29
AMARILLO, TX	111	173	108	65	19.71	16.4	110
AUSTIN, TX	18	238	129	109	33.65	0.9	6
BROWNSVILLE, TX	2	296	174	122	27.55	T	0
CORPUS CHRISTI, TX	5	250	144	106	32.26	T	1
DALLAS-FORT WORTH, TX	37	213	116	97	37.05	2.6	37
DEL RIO, TX	16	255	125	130	18.23	0.9	2
EL PASO, TX	59	214	106	108	9.43	5.3	15
GALVESTON, TX	3	197	185	12	43.84	0.2	1
HOUSTON, TX	18	241	142	99	47.84	0.4	1
LUBBOCK, TX	92	200	119	81	18.69	10.2	58
MIDLAND-ODESSA, TX	63			101	14.80	4.6	20
PORT ARTHUR, TX	14			83	59.89	0.3	4
SAN ANGELO, TX	51			109	20.91	3.1	15
SAN ANTONIO, TX	21			113	32.92	0.7	2
VICTORIA, TX	10			106	40.10	0.1	2
WACO, TX	33			109	33.34	1.4	14
WICHITA FALLS, TX	64			104	28.83	5.8	47
ABERDEEN, WA	34	18	18	0	83.76	6.1	18
ANACORTES, WA	35	23	23	0	26.16	4.6	27
BATTLE GROUND, WA	64	73	70	2	52.04	5.9	38
BELLINGHAM, WA	66	37	37	0	35.99	11.6	56
BELLINGHAM FAA, WA	56	22	22	0	35.36	13.7	59
BICKLETON, WA	135	74	71	3	13.34	29.8	279
BLAINE, WA	63	17	17	0	40.76	14.2	57
BUCKLEY, WA	56	61	60	1	48.65	11.3	37
CEDAR LAKE, WA	81	36	35	0	14.02	13.4	74
CENTRAILIA, WA	45	73	71	1	46.51	6.2	30
CLEARWATER, WA	56	24	24	0	117.54	6.6	18
COLVILLE, WA	131	104	91	12	17.17	41.4	551

City	Mean Number of days with the following Temperature Characteristics				Annual Inches of Precipitation		Freezing Index
	32°F or less	75°F or more	75°F to 95°F	95°F or more	Total Precipitation	Snow	
COUPEVILLE 1 S, WA	42	20	20	0	20.65	6.6	30
DAYTON 1 WSW, WA	96	104	91	13	19.15	18.0	186
ELMA, WA	58	71	70	1	68.16	6.9	25
GLENOMA 1 W, WA	77	67	65	2	66.41	17.0	37
HOQUIAM FAA AIRPORT, WA	24	11	11	0	70.00	4.8	17
LAURIER, WA	165	97	88	9	19.97	51.9	632
MOSES LAKE 3 E, WA	139	108	96	12	7.87	13.0	383
MUD MOUNTAIN DAM, WA	71	38	37	0	54.47	14.0	47
OAKVILLE, WA	68	65	64	1	57.31	6.3	34
OLYMPIA, WA	84	62	56	6	51.06	18.1	31
OMAK, WA	143	104	95	8	12.14	25.2	623
QUILLAYUTE, WA	61	16	16	0	102.69	13.3	21
PUYALLUP 2 W EXP STA, WA	62	71	71	0	39.84	6.3	34
RICHLAND, WA	85	126	110	15	7.12	8.3	158
RITZVILLE, WA	140	98	88	10	11.88	19.2	357
SEATTLE C.O., WA	19	44	43	1	35.86	4.9	19
SEATTLE SEA-TAC AP, WA	29	49	47	2	38.18	11.7	26
SEDRO WOOLEY, WA	48	40	40	0	46.13	8.6	41
SEQUIM, WA	52	29	29	0	16.74	4.9	23
SPOKANE, WA	139	82	63	19	17.62	10.7	446
STEHEKIN 3 NW, WA	124	89	82	7	35.06	129.1	244
VANCOUVER 4 NNE, WA	65	70	69	1	39.34	6.8	42
WALLA WALLA, WA	73	115	71	44	19.34	17.2	163
WATERVILLE, WA	153	86	80	5	11.31	42.5	700
WILLAPA HARBOR, WA	44	45	45	0	86.05	5.2	16
YAKIMA, WA	149	114	81	33	8.19	24.0	291

APPENDIX F – FLORIDA STANDARD SPECIFICATIONS FOR ASPHALT RUBBER HOT MIX ASPHALT

SECTION 919 GROUND TIRE RUBBER FOR USE IN ASPHALT RUBBER BINDER

919-1 Description.

This specification governs ground tire rubber for use in asphalt rubber binders for use in a variety of paving applications.

919-2 General Requirements.

The ground tire rubber shall be produced from tires by an ambient grinding method. The entire process or a final separate grinding process shall be at or above ordinary room temperature. The rubber shall be sufficiently dry so as to be free flowing and to prevent foaming when mixed with asphalt cement. The rubber shall be substantially free from contaminants including fabric, metal, mineral, and other non rubber substances. Up to four percent (by weight of rubber) of talc or other inert dusting agent, may be added to prevent sticking and caking of the particles.

Ground tire rubber used for any of the applications described herein shall be a product included on the Qualified Products List (QPL).

919-3 Physical Requirements.

The physical properties of the ground tire rubber shall be determined in accordance with FM 5-559, and shall meet the following requirements:

Specific Gravity .... 1.10 ± 0.06
Moisture Content ....Maximum 0.75%
Metal Contaminants..........................Maximum 0.01%
Gradation - The gradation shall meet the limits shown in Table 919-1 for the type of rubber specified.

TABLE 919-1
Gradations of Ground Tire Rubber

Sieve Size % Passing	Type A	Type B	Type C
No. 10 [2.00 mm]	---	---	100
No. 20 [850 µm]	---	100	85-100
No. 40 [425 µm]	100	85-100	20-60
No. 80 [180 µm]	90-100	10-50	5-20
No. 100 [150 µm]	70-90	5-30	---
No. 200 [75 µm]	35-60	---	---

919-4 Chemical Requirements.

The chemical composition of the ground tire rubber shall be determined in accordance with ASTM D 297 and shall meet the following requirements:

Acetone Extract...Maximum 25 percent
Rubber Hydrocarbon Content..............................0 to 55 percent
Ash Content ....Maximum 8 percent*

Carbon Black Content..20 to 40 percent
Natural Rubber...16 to 45 percent
* 10 percent for Type A rubber

919-5 Packaging and Identification Requirements.

The ground tire rubber shall be supplied in moisture resistant packaging such as either disposable bags or other appropriate bulk containers. Each container or bag of ground tire rubber shall be labeled with the manufacturer's designation for the rubber and the specific type, maximum nominal size, weight and manufacturer's batch or LOT designation.

919-6 Certification Requirements.

For initial product approval, the manufacturer of the ground rubber shall furnish the State Materials Office a certified test report from an independent testing laboratory that affirms the material meets all the requirements specified. After initial approval, the producer shall submit copies of this certified test report that are relative to ongoing Contracts. They shall also include a certification that the material conforms with all requirements of this Specification, and shall be identified by manufacturer's batch or LOT number.

APPENDIX G – CALTRANS ASPHALT RUBBER USAGE GUIDE

ASPHALT RUBBER USAGE GUIDE

Caltrans Flexible Pavement Materials Program

State of California Department of Transportation

Office of Flexible Pavement Materials

Division of Engineering Services

Materials Engineering and Testing Services-MS #5

5900 Folsom Boulevard

Sacramento, CA 95819-4612

November 1, 2002

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ABSTRACT

This Asphalt Rubber Usage Guide is intended for use by Caltrans design, construction, and maintenance managers and engineers, as well as by field personnel involved in placement of asphalt rubber paving materials including hot mixes and surface treatments. The purpose of this Guide is to provide state-of-the-practice information regarding product selection and use, design, production, construction, and quality control and assurance of the asphalt-rubber binder, paving materials and spray applications. The intent is to enable Caltrans to optimize the use of asphalt-rubber materials to obtain the advertised benefits. This Guide provides an overview of asphalt rubber (AR) materials, components and binder design, and of the benefits and limitations of these materials. This Guide describes the various types of asphalt rubber products available for use in hot mixes and spray (membrane) applications, and presents criteria for selection and use. It also presents information on:

- Mix design criteria,
- Similarities and differences between asphalt rubber and corresponding conventional bituminous applications,
- Cost and environmental considerations related to asphalt rubber materials, and
- Guidelines for construction and inspection considerations for asphalt rubber pavements and surface treatments.

This Guide does not address maintenance, repair, or rehabilitation of asphalt rubber products. Such information will be added to the Flexible Pavement Rehabilitation Manual in the future and to the Maintenance Technical Advisory Guide currently in development, as appropriate.

DISCLAIMER

Development of this Guide was sponsored by Caltrans Materials Engineering and Testing Service (METS). The contents of this Guide reflect the views and experience of the authors, who are responsible for the facts and accuracy of the information presented herein. This Guide does not constitute a standard, specification or a regulation.

GLOSSARY OF TERMS

Asphalt rubber – is used as a binder in various types of flexible pavement construction including surface treatments and hot mixes. According to the ASTM definition (ASTM D 8, Vol. 4.03, "Road and Paving Materials" of the Annual Book of ASTM Standards 2001) asphalt-rubber is "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles". By definition, asphalt-rubber is prepared using the "wet process". Caltrans specifications for asphalt-rubber physical properties fall within the ranges listed in ASTM D 6114, "Standard Specification for Asphalt-Rubber Binder," also located in Vol. 4.03. Recycled tire rubber is used for the reclaimed rubber and is currently referred to as crumb rubber modifier (CRM). The asphalt-rubber is formulated at elevated temperatures and under high agitation to promote the physical interaction of the asphalt cement and CRM constituents, and to keep the CRM particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability.

Automobile tires – tires with an outside diameter less than 660 mm (26 in.) used on automobiles, pickups, and light trucks.

Crumb rubber modifier (CRM) – general term for scrap tire rubber that is reduced in size for use as modifier in asphalt paving materials. Several types are defined herein. A variety of processes and equipment may be used to accomplish the size reduction as follows.

TYPES OF CRM

Ground crumb rubber modifier – irregularly shaped, torn scrap rubber particles with a large surface area, generally produced by a crackermill.

High natural rubber (Hi Nat) – scrap rubber product that includes 40-48 percent natural rubber or isoprene and a minimum of 50 percent rubber hydrocarbon according to Caltrans requirements. Sources of high natural rubber include scrap tire rubber from some types of heavy truck tires, but are not limited to scrap tires. Other sources of high natural rubber include scrap from tennis balls and mat rubber.

Buffing waste – high quality scrap tire rubber that is a byproduct from the conditioning of tire carcasses in preparation for re-treading. Buffings contain essentially no metal or fiber.

Tread rubber – scrap tire rubber that consists primarily of tread rubber with less than approximately 5 percent sidewall rubber.

Tread peel – pieces of scrap tire tread rubber that are also a by-product of tire re-treading operations, that contain little if any tire cord.

Whole tire rubber – scrap tire rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.

CRM PREPARATION METHODS

Ambient grinding - method of processing where scrap tire rubber is ground or processed at or above ordinary room temperature. Ambient processing is typically required to provide irregularly shaped, torn particles with relatively large surface areas to promote interaction with the paving asphalt.

Cryogenic grinding – process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles with relatively small surface area. This method is used to reduce particle size prior to grinding at ambient temperatures.

Granulation – produces cubical, uniformly shaped, cut crumb rubber particles with a low surface area.

Shredding – process that reduces scrap tires to pieces 0.023 m^2 (6 $in.^2$) and smaller prior to granulation or ambient grinding.

CRM PROCESSING EQUIPMENT

Cracker mill – apparatus typically used for ambient grinding, that tears apart scrap tire rubber by passing the material between rotating corrugated steel drums, reducing the size of the rubber to a crumb particle (generally 4.75 mm to 425 μm [No. 4 to No. 40 sieve]).

Granulator – apparatus that shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance, reducing the rubber to cubicle particles generally 9.5 mm to 2.0 mm (⅜ in. to No. 10 sieve) in size.

Micro-mill – process that further grinds crumb rubber particles to sizes below 425 μm (No. 40 sieve).

Dense-graded – refers to a continuously graded aggregate blend typically used to make hot-mix asphalt concrete pavements with conventional or modified binders.

Devulcanized rubber – rubber that has been subjected to treatment by heat, pressure, or the addition of softening agents after grinding to alter physical and chemical properties of the recycled material.

Diluent – a lighter petroleum product (typically kerosene or similar product with solvent-like characteristics) added to asphalt rubber binder just before the binder is sprayed on the pavement surface for chip seal applications. The diluent thins the binder to promote fanning and uniform spray application, and then evaporates over time without causing major changes to the asphalt rubber properties. Diluent is not used in asphalt rubber binders that are used to make asphalt concrete, and is not recommended for use in interlayers that will be overlaid with asphalt concrete (AC) in less than 90 days due to on-going evaporation of volatile components.

Dry process – any method that mixes the crumb rubber modifier dry with the aggregate before the mixture is charged with asphalt binder. The CRM acts as a rubber aggregate in the paving mixture. This method applies only to hot-mix asphalt production.

Extender oil – aromatic oil used to promote the reaction of the asphalt binder and the crumb rubber modifier.

Flush coat – application of diluted emulsified asphalt onto a pavement surface to extend pavement life, that may also be used to prevent rock loss in chip seals or raveling in AC.

Gap-graded – aggregate that is not continuously graded for all size fractions, typically missing or low on one or two of the finer sizes. Gap grading is used to promote stone-to-stone contact in hot-mix asphalt concrete. This type of gradation is most frequently used to make rubberized asphalt concrete-gap graded (RAC-G) paving mixtures.

Lightweight aggregate – porous aggregate with very low density such as expanded shale, which is typically manufactured. It has been used in chip seals to reduce windshield damage.

Open-graded – aggregate gradation that is intended to be free draining and consists mostly of 2 or 3 nominal sizes of aggregate particles with few fines and 0 to 4 percent by mass passing the 0.075 mm (No. 200 sieve). Open grading is used in hot-mix applications to provide relatively thin surface or wearing courses with good frictional characteristics that quickly drain surface water to reduce hydroplaning, splash and spray.

Reaction – commonly used term for the interaction between asphalt binder and crumb rubber modifier when blended together at elevated temperatures. The reaction is more appropriately defined as polymer swell. It is not a chemical reaction. It is a physical interaction in which the crumb rubber absorbs aromatic oils and light fractions (small volatile or active molecules) from the asphalt binder, and releases some of the similar oils used in rubber production into the asphalt binder.

Recycled tire rubber – rubber obtained by processing used automobile, truck, or bus tires (essentially highway or "over the road" tires). The Caltrans chemical requirements for scrap tire rubber are intended to eliminate unsuitable sources of scrap tire rubber such as solid tires; tires from forklifts, aircraft, and earthmoving equipment; and other non-automotive tires that do not provide the appropriate components for asphalt rubber interaction. Non-tire rubber sources may be used only to provide High Natural Rubber to supplement the recycled tire rubber.

Rubberized asphalt - asphalt binder modified with CRM that may include less than 15 percent CRM by mass and thus may not comply with the ASTM definition of asphalt rubber (ASTM D 8, Vol. 4.03). In the past, terminal blends (Rubber Modified Binder, RMB) have typically fallen in this category.

Rubberized asphalt concrete (RAC) – material produced for hot mix applications by mixing asphalt rubber or rubberized asphalt binder with graded aggregate. RAC may be dense-, gap-, or open-graded.

Stress-absorbing membrane (SAM) – a chip seal that consists of a hot asphalt-rubber binder sprayed on the existing pavement surface followed immediately by an application of a uniform sized cover aggregate which is then rolled and embedded into the binder membrane. Its nominal thickness generally ranges between ⅜ and ½ inch depending on the size of the cover aggregate. A SAM is a surface treatment that is used primarily to restore surface frictional characteristics, seal cracks and provide a waterproof membrane to minimize the intrusion of surface water into the pavement structure. SAMs are used for pavement preservation, maintenance, and limited repairs. Asphalt-rubber SAMs minimize reflective cracking from an underlying distressed asphalt or rigid pavement, and can help maintain serviceability of the pavement pending rehabilitation or reconstruction operations.

Stress-absorbing membrane interlayer-Rubber (SAMI-R) – SAMI-R is an asphalt-rubber SAM that is overlaid with an asphalt paving mix that may or may not include CRM. The SAMI-R delays the propagation of the cracks (reflective cracking) through the new overlay.

Stress-absorbing membrane interlayer (SAMI) - originally defined as a spray application of asphalt-rubber binder and cover aggregate. However, interlayers now may include asphalt-rubber chip seal (SAMI-R), fabric (SAMI-F), or fine unbound aggregate.

Terminal blend – a form of the wet process where CRM is blended with hot asphalt binder at the refinery or at an asphalt binder storage and distribution terminal and transported to the AC mixing plant or job site for use. This type of rubberized binder (Rubber Modified Binder, RMB) reportedly does not require subsequent agitation to keep the CRM particles evenly dispersed in the modified binder. In the past, such blends normally contained 10 percent or less finely ground CRM by mass (which does not satisfy the ASTM D 8 definition of asphalt-rubber) and other additives to eliminate the need for agitation. However, new formulations have reportedly been developed that contain 15 percent CRM by total binder mass.

Truck tires – tires with an outside diameter greater than 660 mm (26 in.) and less than 1520 mm (60 in.); used on commercial trucks and buses.

Viscosity – is the property of resistance to flow (shearing force) in a fluid or semi-fluid. Thick stiff fluids such as asphalt rubber have high viscosity; water has low viscosity. Viscosity is specified as a measure of field quality control for asphalt-rubber production and its use in RAC mixtures.

Vulcanized rubber – crude or synthetic rubber that has been subjected to treatment by chemicals, heat and/or pressure to improve strength, stability, durability, etc. Tire rubber is vulcanized.

Wet process – any method that blends CRM with the asphalt cement before incorporating the binder into the asphalt paving materials. Although most wet process asphalt rubber binders require agitation to keep the CRM evenly distributed throughout the binder, terminal blends or RMB binders may be formulated so as not to require agitation.

1.0 INTRODUCTION AND OVERVIEW

The purpose of this Usage Guide is to provide the California Department of Transportation (Caltrans) state-of-the-practice information regarding product selection and use, design, production, construction, and quality control and assurance of asphalt rubber binder, paving materials and spray applications. It also contains some generally accepted best practices for asphalt rubber binder preparation and mixture placement The intent is to enable Caltrans to optimize the use and handling of asphalt rubber materials in order to obtain the many advertised benefits including increased durability and reduced maintenance.

1.1 WHAT IS ASPHALT RUBBER?

According to the ASTM definition, asphalt rubber (AR) is "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles." By definition, asphalt rubber is prepared using the "wet process." Physical property requirements are listed in ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," located in Vol. 4.03 of the Annual Book of ASTM Standards 2001, and in Caltrans Standard Special Provisions for Asphalt Rubber Binder. The asphalt rubber is produced at elevated temperatures (≥177°C, 350°F) and under high agitation to promote the physical interaction of the asphalt binder and rubber constituents, and to keep the rubber particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability.

Recycled tire rubber is used for the reclaimed rubber and is called crumb rubber modifier (CRM). Tire rubber is a blend of synthetic rubber, natural rubber, carbon black, anti-oxidants, fillers, and extender type oils that is soluble in hot paving grade asphalt.

In California, asphalt rubber is specified to include 18 to 22 percent CRM by total mass of the asphalt rubber blend. The CRM must also include 25 ± 2 percent by mass of high natural rubber content scrap rubber that may come from scrap tires or other sources. Caltrans specifications for asphalt rubber physical properties fall within the ranges listed in ASTM D 6114. Caltrans requires use of extender oil as an asphalt modifier in asphalt-rubber.

Asphalt-rubber should not be confused with other rubberized asphalt products such as the "dry process" in which crumb rubber is substituted for a small proportion of the aggregate and is not reacted with the asphalt binder prior to mixing, or with "terminal blends." Terminal blends are made by the wet process, but historically have included no more than 10 percent ground tire rubber along with other additives. Such low CRM content blends do not achieve sufficient viscosity to perform in AC mixtures in the same manner as the original types of asphalt rubber binders. However, new terminal blends with up to 15 percent CRM have reportedly been developed that might perform more like asphalt rubber. Terminal blends must meet the Caltrans requirements for Rubber Modified Binder (RMB).

Rubberized asphalt concrete (RAC) may be produced using a variety of rubber-modified binders, including asphalt rubber, rubberized terminal blends, RMB materials, or by the dry process.

Both RMB and dry process rubberized AC mixes have had limited usage by Caltrans. Anecdotal reports indicate their performance ranges from very good to poor, but relatively little conclusive data is available about their performance on rehabilitation projects in the California State Highway System. *Consequently, the information presented in this Usage Guide is limited to asphalt rubber-paving materials and may not be appropriate for other modified binder or dry process materials.*

1.2 BRIEF HISTORY OF ASPHALT RUBBER

Development of asphalt rubber materials for use as joint sealers, patches, and membranes began in the late 1930s**.** In the early 1950s, Lewis and Welborn of the Bureau of Public Roads (BPR) conducted an extensive laboratory study to evaluate "The Effect of Various Rubbers on the Properties of Petroleum Asphalts." They used 14 types of rubber powders and three asphalts, including "a California asphalt of low-gravity, low-sulfur, low-asphaltenes type." The results were published in the October 1954 issue of *Public Roads* along with results of a companion "Laboratory Study of Rubber-Asphalt Paving Mixtures," conducted by Rex and Peck at BPR. The mixtures study looked at a wide range of vulcanized and unvulcanized rubber materials including tread from scrap tires, styrene-butadiene rubber (SBR), natural rubber, polybutadiene, and reclaimed (devulcanized) rubber and at both wet and dry methods of adding them to AC mixtures. Interest and work in this area continued to grow, as did the number of patent applications. In March 1960, the Asphalt Institute held the first Symposium on Rubber in Asphalt in Chicago, IL. It consisted of five paper presentations and discussion.

Charles H. McDonald of the City of Phoenix Arizona worked extensively with asphalt and rubber materials in the 1960s and 1970s and was instrumental in development of the "wet process" (also called the McDonald process) of producing asphalt rubber. He was the first to routinely use asphalt rubber in hot mix patching and surface treatments for repair and maintenance. Asphalt rubber chip seals served effectively as the City's primary pavement maintenance and preservation strategy for arterial roadways for nearly twenty years, until traffic volumes forced a change to thin AC overlays. Gap-graded asphalt rubber concrete mixtures were developed as a successful substitute.

In 1975, Caltrans began experimenting with asphalt rubber chip seals in the laboratory and small test patches located at 03-Yol-84-PM 16+ and 03-Sac-99-PM 20+, with generally favorable results. In 1978, the first Caltrans dry process rubber-modified AC pavement was constructed on SR 50 at Meyers Flat. It included one percent ground rubber by mass added to the dry aggregate prior to mixing with the paving asphalt. Performance was rated good. The first Caltrans rubberized asphalt concrete (RAC) pavements made with early versions of "wet-process" asphalt rubber binder and dense-graded aggregate were constructed in 1980 at Strawberry (SR 50) and at Donner Summit (I-80). The Strawberry project was an emergency repair to a dramatically failed pavement. The repair included pavement reinforcing fabric (PRF), and a 60 mm (0.2 ft, 2.4 inches) layer of DGAC to restore structural capacity, under the thin (30 mm, 0.1 ft, 1.2 inches) RAC wearing course. The first three projects are all located in "snow country" at high elevations where tire chains are used in winter. The RAC pavements reportedly performed well in resisting chain abrasion and reflective cracking.

The Ravendale project (02-Las-395) constructed in 1983 significantly changed Caltrans' approach to the use of asphalt rubber. This project presented a typical dilemma. The cost of rehabilitation by overlaying with DGAC was prohibitive, so less costly alternatives were considered, including thinner sections of RAC. The project was designed as a series of 13 test sections that included two different thicknesses each of wet process (dense-graded) and dry process (gap-graded) RAC with SAMI (4 sections), wet and dry RAC at 46 mm

(0.15 ft, 1.8 inches) thick without SAMI (2 sections), four control sections with different thicknesses of DGAC from 46 to 152 mm (1.8 to 6 inches), two sections surfaced only by double asphalt rubber chip seals, and one section surfaced with a single asphalt rubber chip. The test sections were monitored over time. The dry process section at this site lasted over 19 years before it was overlaid in 2002, but performance of such pavements elsewhere has varied. By 1987, it was clear that the thin RAC pavements were performing better than thicker conventional DGAC. Caltrans built more RAC projects and continued to study the performance of RAC constructed at reduced thickness relative to DGAC structural requirements.

Through 1987, Caltrans constructed one or two RAC projects a year. Dense- or open-graded RAC mixes were placed as surface courses at compacted thicknesses ranging from 24 mm for open-graded to 76 mm for RAC-D (0.08 to 0.25 ft). Some projects included pavement reinforcing fabric (PRF) and/or a leveling course, and some others included asphalt rubber stress absorbing membrane interlayer (SAMI) under the asphalt rubber mixes.

In March 1992 Caltrans published a "Design Guide for Asphalt Rubber Hot Mix-Gap Graded (ARHM-GG)" based on these studies and project reviews. The Guide presents structural and reflection crack retardation equivalencies for gap-graded asphalt rubber mixtures (now designated RAC-G) with respect to DGAC, and with and without SAMI. These equivalencies have since been validated and incorporated in Chapter 6, Tables 3 and 4 of the Caltrans Flexible Pavement Rehabilitation Manual (June 2001). RAC-G can generally be substituted for DGAC at about one-half the DGAC thickness.

By 1995, over 100 Caltrans RAC projects had been constructed. Cities and counties in California had by then constructed more than 400 asphalt rubber projects, including asphalt rubber chip seals. However some problems occurred, including some cases of premature distress. Caltrans engineers reviewed RAC performance on the Caltrans projects, selected California city and county projects, and 41 Arizona DOT projects. Some of the problems observed were clearly construction related; many of the contractors involved in those projects had little if any experience working with the RAC mixtures.

The Caltrans review indicated that asphalt rubber materials can perform very well when properly designed and constructed, and that Caltrans should continue using and studying asphalt rubber. A very important finding was that the distresses observed in RAC pavements generally appeared to progress at a much slower rate than would be expected in a structurally equivalent conventional DGAC pavement. In many of the cases where premature RAC distress (particularly cracking) had occurred, relatively little maintenance was required to achieve adequate pavement service life because the subsequent distress developed slowly. One-third of the Strawberry RAC was reportedly still exposed and performing after 15 years, with less maintenance resources and time expended than for all pavements in that district with the exception of another RAC section.

By mid-2001, over 210 Caltrans RAC projects had been constructed throughout California. Municipalities and counties also continued to use asphalt rubber for hot mixes and surface treatments with generally good performance. However some of the old problems with product selection, design, and construction continue to arise. Districts 7 and 8 reportedly experienced several major RAC failures.

The purpose of this Guide is to resolve such problems and enhance the performance of asphalt rubber pavements that will be constructed in California in the future.

The Modified Binder (MB) specification was developed in the early 1990s as part of a continuing movement towards performance-based specifications from method type or "recipe" specifications. It has been suggested that the specification be renamed as "RMB," Rubber Modified Binder. Based on analysis of rheological measurements of samples of asphalt rubber binders and limited evaluations of their field performance, Caltrans researchers developed two new parameters for specifying rubberized binders, using residues aged in the Pressure Aging Vessel (PAV).

- Shear susceptibility of the phase angle delta, SSD, which is related to elastic properties, and
- Shear susceptibility of viscosity, SSV, which is related to stiffness.

Ten pilot projects were constructed between December 1997 and November 1999 to evaluate the performance of materials meeting the MB specification. The MB pilots are located mostly in the coastal regions of California and include both dense-graded and gap-graded mixtures placed over a range of structural sections. These projects were reviewed by a joint Caltrans-Industry group: eight were rated as "good," one as fair, and one that exhibited base failure and pumping as poor. Caltrans has prepared a report on these MB pilot projects. However findings to date are limited and additional pilot RMB projects are being planned for construction in 2003-2004, after completion of heavy vehicle simulator trials being conducted at the University of California Berkeley.

1.3 HOW IS ASPHALT RUBBER USED?

Asphalt rubber is used as a binder in various types of asphalt pavement construction including surface treatments and hot mixes (asphalt concrete). It is also used in crack sealants, which are not a subject of this Guide. For hot mixes, asphalt rubber has been found to be most effective and is most commonly used in gap-graded and open-graded mixes, particularly for surface courses and for thin overlays ≤ 60 mm (2.4 inches) thick. Terminal blends and MB have been used in dense- and gap-graded mixes. The most common spray application is a chip seal, also called a stress absorbing membrane (SAM). Chip seals are primarily used for maintenance and pavement preservation. Asphalt rubber chip seals may also be overlaid with hot mix, making them interlayers, typically called SAMI-R. SAMIs are used primarily for pavement rehabilitation. Chapter 2 provides more detailed information on product selection, usage, and design.

1.4 WHERE SHOULD ASPHALT RUBBER PRODUCTS BE USED?

Asphalt rubber products can be used wherever conventional asphalt concrete or bituminous surface treatments would be used, but provide better resistance to reflective cracking and fatigue than standard dense-graded asphalt concrete (DGAC). Asphalt rubber hot mixes are typically most effective as thin rehabilitative overlays of distressed flexible or rigid pavements. Arizona has had well-documented success with long-term performance of asphalt rubber overlays of rigid pavements (I-17 Durango Curve in Phoenix, I-19 near Tucson, I-40 near Flagstaff), but California's experience with this application appears to be limited.

Caltrans' structural and reflection crack retardation equivalencies for gap-graded asphalt rubber mixes (now called rubberized asphalt concrete, gap-graded, RAC-G) generally allow substitution for DGAC at about one-half the thickness (as referenced in 1.2). The reduced thickness encourages the use of RAC-G mixtures where there are vertical geometric constraints such as curb-and–gutter alignment or underpass clearance.

Temperature is critical for compaction of RAC mixtures. Because asphalt rubber is stiffer than asphalt cement, higher placement and compaction temperatures are usually required. Temperature guidelines for construction operations are presented in Section 4.0. Because RAC-G is placed in thin layers, ambient temperature, pavement surface temperature and wind have considerable impacts on mat temperature during compaction. Asphalt rubber products should thus be used only where and when weather conditions are favorable for placement. This does not prevent their use at high elevations, but means that paving in such locations should be performed only in good weather, dry conditions, and not in early spring or late fall. Asphalt rubber products have been used with success in most of the geographical and climate zones in California, and in Arizona from low desert through the mountain/alpine climate zones. However there are coastal areas in California where favorable conditions for asphalt rubber paving operations may not occur often.

1.5 WHERE SHOULD ASPHALT RUBBER PRODUCTS NOT BE USED?

Problems that have been documented typically have been construction issues related to cold temperature paving or late season construction. This indicates that temperature was a major contributing factor. Temperature also affects placement and compaction of conventional mixtures, but is more critical when working with materials that have been modified to increase high temperature stiffness (such as asphalt rubber and polymer modified performance based asphalt, PBA) and are typically being placed in thin lifts. Asphalt rubber paving materials should not be placed in the following conditions:

- During cold or rainy weather with ambient or surface temperatures <13°C (55°F).
- Over pavements with severe cracks more than 12.5 mm (0.5 inch) wide where traffic and deflection data are not available. *NOTE: Traffic and deflection data are basic requirements for Caltrans structural pavement design and rehabilitation. In some cases it may be necessary to add a layer of DGAC and/or SAMI-R before overlaying with RAC to provide sufficient pavement structure.*
- Areas where considerable handwork is required.
- Where haul distances between AC plant and job site are too long to maintain mixture temperature as required for placement and compaction.

1.6 BENEFITS OF ASPHALT RUBBER

The primary reason for using asphalt rubber is that it provides significantly improved engineering properties over conventional paving grade asphalt. Asphalt rubber binders (ARBs) can be engineered to perform in any type of climate. Although current Caltrans Special Provisions for asphalt rubber do not recommend climate-related binder design, as does ASTM D 6114, they do not prevent it. Responsible asphalt rubber binder designers usually consider climate conditions and available traffic data in their design to provide a suitable asphalt rubber product. More information on asphalt rubber binder design is presented in Chapter 2.

At intermediate and high temperatures, ARB physical properties are significantly different than those of neat paving grade asphalts such as AR-4000. The rubber stiffens the binder and increases elasticity (proportion of deformation that is recoverable) over these pavement operating temperature ranges, which decreases pavement temperature susceptibility and improves resistance to permanent deformation (rutting) and fatigue with little effect on cold temperature properties. Asphalt rubber also provides the benefit of value-added use of waste tires. The benefits of asphalt rubber are summarized in Table 1-1.

Table 1-1: Summary of Benefits of Asphalt Rubber

RAC contains binders that have: • Increased viscosity that allows greater film thickness in paving mixes without excessive drain down or bleeding. • Increased elasticity and resilience at high temperatures. RAC results in pavements that have: • Improved durability. • Improved resistance to surface initiated and fatigue/reflection cracking due to higher binder contents and elasticity. • Reduced temperature susceptibility. • Improved aging and oxidation resistance due to higher binder contents, thicker binder films, and anti-oxidants in the tire rubber. • Improved resistance to rutting (permanent deformation) due to higher viscosity, softening points and resilience (stiffer, more elastic binder at high temperatures). • Lower pavement maintenance costs due to improved pavement durability and performance. In addition, RAC and asphalt rubber binders can result in: • Reduced construction times due to thinner lifts. • Better chip retention in chip seals due to thick films of asphalt. • Savings in energy and natural resources by using waste products. • Improved safety due to better long-term color contrast for pavement markings because carbon black in the rubber acts as a pigment that keeps the pavement blacker longer.

1.7 Limitations Of Asphalt Rubber

Asphalt rubber materials are useful, but they are not the solution to all pavement problems. The asphalt rubber materials must be properly selected, designed, produced, and constructed to provide the desired improvements to pavement performance. Pavement structure and drainage must also be adequate. Limitations on use of asphalt rubber include:

- Higher unit costs due to mobilization of asphalt rubber production equipment. For large projects, these unit costs can be spread over enough tonnage so that they can generally be offset by increased service life, lower maintenance costs, and reduced lift thickness. For small projects, mobilization cost is the same, resulting in greater increase in unit price that may not be fully offset.
- Asphalt rubber is not best suited for use in DGAC. The aggregate gradation does not allow sufficient increase in binder content to enhance performance of dense-graded mixes enough to justify the added cost of the asphalt rubber binder.
- Construction may be more challenging, as temperature requirements are more critical. Asphalt rubber materials must be compacted at higher temperatures than DGAC because, like polymers, rubber stiffens the binders at high temperatures. Also, coarse gap-graded mixtures may be more resistant to compaction due to the stone-on-stone nature of the aggregate structure.
- Asphalt rubber materials are often difficult to hand work because of stiffer binder and coarser mixture gradations.
- Potential odor and air quality problems (see 1.9 for further information).
- If work is delayed more than 48 hours after blending the asphalt rubber, some binders may not be usable. The reason is that the CRM has been digested to such an extent that it is not possible to achieve the minimum specified viscosity even if more CRM is added in accordance with specified limits.
- For chip seals in remote locations, hot and/or pre-coated aggregate may not be available because there may not be a hot-mix plant within reasonable haul distance of the job site.

1.8 Cost Considerations

The unit costs of asphalt rubber products are higher than those of conventional or polymer modified products. The initial cost is one of the reasons that usage of asphalt rubber hot mixes is limited to thin lifts.

Asphalt rubber is generally cost effective when used as thin gap- or open-graded surface courses or overlays of 30-60 mm (1.2-2.4 inches) compacted thickness, chip seals and interlayer applications.

Asphalt rubber products have been proven to be very useful tools to rehabilitate severely deteriorated pavements with some remaining structural integrity that experience heavy traffic loadings. In many cases, the reduced thickness of RAC overlays (half of

DGAC thickness, with 30 mm (1.2 inch) minimum) offsets much of the increase in initial cost. The added benefits of reduced maintenance demand and longer service life provided by asphalt rubber materials generally offset any remaining cost difference. Cost effectiveness can be evaluated using Life Cycle Cost Analysis (LCCA).

Using a SAMI-R in place of a layer of AC saves money and speeds construction, providing additional savings. It is not clear whether SAMI-R can be placed more quickly than SAMI-F (PRF), but SAMI-R provides the benefit of reduced overlay thickness for structural adequacy that the fabric does not.

Typical year 2000 in-place costs for both hot mix and chip seals are as follows.

	Hot Mix	**Chip Seal**
	$/tonne	**$/m^2**
Conventional	33-38	1.20-1.50
Polymer Modified	38-44	1.50-1.80
RAC-G	49-55	3.00-3.60

Generally RAC-G hot mixes cost about $16/tonne ($15/ton) more than conventional mixes, although this may vary with job size. Mobilization and set up of the asphalt rubber binder production equipment costs as much for small jobs as for big ones. Large projects may thus allow some reduction in unit costs because mobilization costs can be spread over a greater RAC tonnage.

In 1998 Caltrans conducted an analysis of RAC and DGAC unit prices versus mix quantity based on data from 1996 and 1997 Caltrans projects. The results were reported in a July 7 memorandum that indicated that unit costs escalate considerably for jobs with less than 2250 tonnes (2,500 tons) of RAC. The memo suggests that smaller RAC projects may not be cost effective with respect to initial cost. The break point for project size may have changed since then but it is reasonable to assume that if paving can be completed in three days or less, the unit costs are likely to be significantly higher than for larger RAC projects.

The costs of RAC-O and RAC-O (HB) overlays are not listed. These are higher than conventional OGAC because of the higher binder content (1.2 to 1.6 times more for HB (High Binder) than the conventional AR-4000 content). Since OGAC is not considered a structural element, there is no reduction in thickness compared to conventional open-graded mixtures. However, improved durability, particularly resistance to reflective cracking and related reduced maintenance needs, should substantially reduce the overall life cycle costs and help offset the difference in initial cost.

1.9 ENVIRONMENTAL CONSIDERATIONS

There are clearly environmental benefits to using asphalt rubber materials, but there are also some issues and concerns regarding emissions from asphalt rubber and hot-mix production and paving operations.

1.9.1 *Benefits*

There are a number of social benefits of using rubber that is ground from recycled scrap tires to build pavements.

1.9.1.1 *Not Contributing to Tire Stockpiles.* The primary benefit is putting newly generated waste tires into a secondary use instead of contributing to tire stockpiles. The Department's most recent annual report to the Legislature and the California Integrated Waste Management Board (CIWMB) states that over 30 million waste tires are generated in California and over 3 million more waste tires are imported into the State each year, of which about 19 million are recycled yearly. This does not account for tires that have been stockpiled legally or otherwise in the past, although CIWMB reports that stockpiles have been substantially reduced.

1.9.1.2 *Value-Added Use Of Waste Tires.* Burning waste tires for fuel is an effective method of disposal that helps to conserve other energy resources, but the value of the rubber is consumed and disposal of incinerator ash and residues remains an issue. Asphalt rubber paving products provide a "value-added" means of reutilizing the waste rubber material. The rubber enhances the physical properties of the resulting paving materials over the life of the pavement, and thus provides a long-term benefit to tax payers and the motoring public. Estimates indicate that RAC-G uses about 620 tires/lane kilometer/25 mm (1,000 tires/lane mile/1-inch) of thickness.

1.9.1.3 *Noise Abatement.* Reduced traffic noise (primarily tire noise) is another important benefit of using asphalt rubber materials that has been documented in Europe (Belgium, France, Germany, Austria, the Netherlands), Canada, Arizona and

California (Orange and LA counties). Significant reductions in traffic noise, ranging from 40 to 88 percent, have been measured not only for open-graded but also for gap-graded RAC. However there were unanswered questions regarding how long the noise would remain abated. The Sacramento County Department of Environmental Review and Assessment and a consultant specializing in acoustics and noise control conducted a six-year study on RAC pavements that was finished in 1999. Their results supported the findings of other similar studies referenced within their report. The Sacramento study showed that the RAC continued to keep the traffic noise level down after six years, while noise measured on the conventional DGAC was back up to pre-paving levels within four years.

1.9.2 *Issues and Concerns*

The high temperatures and the highly aromatic extender oils involved in asphalt rubber binder and mixture production would be expected to increase the amount of emissions (fumes and smoke) generated by production and construction of asphalt products. This is not necessarily true. A number of emissions studies have been performed during the last 10-15 years, although reports are not currently available for all of them.

The distinctive odor of asphalt rubber continues to trigger concerns about emissions, because people have a natural tendency to think that strong odors indicate a hazard.

1.9.2.1 *Hot Plant Tests.* Plant "stack tests" were performed during asphalt rubber hot mix production in New Jersey (1994), Michigan (1994), Texas (1995), and California (1994 and Bay Area in 2001). The results generally indicate that emissions measured during asphalt rubber production at AC plants remain about the same as for conventional hot mix and that amounts of any hazardous components and particulates remain below mandated limits. The Bay Area emissions tests showed that measured emissions rates of particulate and toxic compounds were consistently lower than the EPA's AP-42 emission factors for conventional hot mix asphalt plants. However in some cases of RAC production there has been a significant rise in particulates within the vapors that has been tied to use of soft asphalt cements that often include extender oils. Raising AC plant operating temperatures typically increases emissions. AC plant emissions generally appear to be more directly influenced by plant operating temperature, burner fuel and the base asphalt than by CRM.

CRM does not include exotic chemicals that present any new health risks. It consists mostly of various types of rubber and other hydrocarbons, carbon black, oils, and inert fillers. Most of the chemical compounds in CRM are also present in paving grade asphalt, although the proportions are likely to differ.

The asphalt rubber binder manufacturing plant does require an air quality permit, but emissions levels are low due to the essentially sealed nature of the process. Only some minimal filtered venting is required.

1.9.2.2 *Exposure of Paving Personnel.* Use of asphalt rubber does not appear to increase health risks to paving personnel, including paver operators, screed person, rakers, roller operators, bootmen on distributor trucks, and other workers. A 2-1/2 year study was performed in Southern California to assess the effects of "Exposure of Paving Workers to Asphalt Emissions (When Using Asphalt Rubber Mixes)". The study began in 1989 and results were published in 1991, before fume exhaust ventilation and capture devices were implemented on paving equipment. The study monitored a number of individual paving workers in direct contact with fumes during hot mix paving operations as well as spray applications. The researchers found that the results "clearly demonstrated that risks associated with the use of Asphalt-Rubber products was negligible". "Emission exposures in asphalt rubber operations did not differ from those of conventional asphalt operations".

The National Institute for Occupational Safety and Health (NIOSH) in cooperation with FHWA has performed evaluations of possible differences in the occupational exposures and potential health effects of crumb rubber modified hot mixes and conventional AC mixes. NIOSH Health Hazard Evaluations were performed at seven paving projects located in Michigan, Indiana, Florida, Arizona, Massachusetts, and at two in California from 1994 through 1997. NIOSH has released some preliminary information on individual projects and a report on the Michigan study was presented at an annual meeting of the Transportation Research Board. These reports indicated that increasing operating temperatures of AC plants seemed to have a greater effect on emissions quantity and content than did adding CRM. However the December 2000 NIOSH report on Health Effects of Occupational Exposure to Asphalt

(No. 2001-110) that references these seven projects does not present any of the findings for asphalt mixtures containing CRM. This latest report does not recommend any changes to the 1977 NIOSH criteria for recommended exposure standards, which can be readily accessed through the NIOSH and OSHA web sites.

2.0 ASPHALT RUBBER PRODUCT DESIGN, SELECTION AND USE

Asphalt rubber binders can be used in hot mixes and for spray applications as surfaces or interlayers. To aid evaluation of project submittals including asphalt rubber binder designs and quality control plans for binder production, this chapter summarizes the state-of–the–practice of asphalt rubber binder design. It also presents guidance to assist project and pavement designers with selecting the appropriate type of asphalt-rubber product for the intended use, for maintenance, rehabilitation, or construction.

2.1 ASPHALT RUBBER BINDER (ARB) DESIGN

Asphalt rubber binders must be properly designed and produced to provide the appropriate level of modification and field performance for the expected climate and traffic conditions. Caltrans Special Provisions for Asphalt-Rubber Binder require that at least 2 weeks prior to start of construction the Contractor must supply to the Engineer, for approval, an asphalt rubber binder formulation (design or "recipe") that includes results of specified physical property tests, along with samples of all of the component materials. Samples of the prepared asphalt rubber binder must be submitted to the Engineer at least 2 weeks before it is scheduled for use on the project.

2.1.1 *Caltrans Specification Requirements*

Current Caltrans Special Provisions for Asphalt Rubber Binder call for 20 ± 2 percent crumb rubber modifier (CRM) content by total binder mass (see SSP 39-400 for RAC-G and SSP 39-480 for RAC-O.) The CRM must include 25 ± 2 percent by mass of high natural rubber CRM and 75 ± 2 percent scrap tire CRM. Both types of rubber must meet specific chemical and physical requirements including gradation and limits on fabric and wire contaminants. The scrap tire CRM consists primarily of 2 mm to 600 μm sized particles (No. 10 to No. 30 sieve sizes). The high natural rubber CRM is somewhat finer, mostly 1.18 mm to 300 μm (No. 16 to No. 50 sieve sizes). An asphalt modifier, of resinous, high flash point aromatic hydrocarbon compounds (extender oils), is added at a rate of 2.5 to 6 percent by mass of the asphalt binder. AR-4000 is typically specified as the base paving asphalt to be used in asphalt rubber binders.

Extender oils and high natural CRM are used to enhance the asphalt rubber interaction. Extender oils act as "compatibilizing" agents for the asphalt rubber interaction by supplying light fractions (aromatics, small molecules) that swell the rubber particles and help disperse them in the asphalt. High natural CRM has also been found to aid chip retention in chip seal applications, even at concentrations as low as 3 percent by asphalt rubber binder mass. Use of high natural CRM appears to improve the bond between cover aggregate and the asphalt rubber membrane.

It is important to understand that just mixing together proportions of arbitrarily selected asphalt, CRM and extender oil components within the specified ranges will not necessarily yield a binder that complies with the physical property requirements in the special provisions. Properties of asphalt rubber binders depend directly on the composition, compatibility and relative proportions of the component asphalt and CRM materials and other additives, as well as on the interaction temperature and duration. There are many combinations of suitable materials within the recipe proportions that simply do not provide an appropriate or even usable asphalt rubber binder. That is why binder design and testing procedures are essential to develop satisfactory asphalt rubber formulations.

2.1.2 *Design Considerations*

Most asphalt rubber binders are produced just prior to use, but may be stored at elevated temperatures for 24 hours or more if weather or other factors delay construction. It is important that the asphalt rubber binder properties, particularly the primary field control of viscosity, remain in compliance with specifications when mixed with aggregate or spray-applied. This means that the asphalt rubber binder properties should remain relatively stable over time. Uniformity of binder properties also facilitates RAC production, placement and compaction operations. For this reason, some contractors prefer that all of the different asphalt rubber binders that they use be formulated to remain within a relatively narrow viscosity range, such as 2,000 to 3,000 cP, so that other critical construction operations can be performed in a consistent manner from job to job.

Established asphalt rubber industry standard procedures for laboratory design profile the asphalt rubber interaction over a period of 24 hours by measuring the physical properties of the asphalt rubber binder sampled at specific time intervals. Table 2-1 presents an example of a state-of–the-practice asphalt rubber binder design, similar to what would be submitted by a contractor that routinely works with asphalt rubber materials.

The special provisions do not require that the interaction be monitored and tested over a 24-hour period; they require only that specification compliance be documented with results of tests performed on samples taken after 45 minutes of interaction. The Engineer may ask if a 24-hour design profile is available for review.

Although AR-4000 is typically specified as the base paving grade asphalt for use in asphalt rubber binders, there are cases where use of a softer grade should be considered in order to provide better long-term performance in resisting low-temperature cracking. The reason is that at cold temperatures of about 5°C (45°F) and below, the physical properties of the base asphalt binder typically govern asphalt rubber binder behavior. There are two ways to enhance resistance to cold temperature cracking in the asphalt rubber binder and the resulting RAC mixture:

- Start with a softer grade of paving asphalt than AR-4000, such as AR-2000 or for severe cold temperature conditions, possibly AR-1000, or

- Increase the percentage of extender oil to soften the binder.

Both of these approaches would also make the asphalt binder softer at intermediate temperatures of 10-40°C (50-104°F) and higher pavement temperatures > 40°C (104°F). However, because the CRM increases binder stiffness (typically up to two grades) and elasticity in these intermediate and high temperature ranges without compromising the cold temperature properties, CRM can significantly extend the performance range of most paving asphalts.

For hot climate locations, it is advisable to reduce extender oil dosage to minimize potential for flushing. The high-temperature stiffening effects of CRM do have limits, and in low desert regions it is not unusual for exposed AC pavement temperatures to reach 82°C (180°F). Extender oil dosage may be increased for low volume roadways, which tend to crack from lack of use.

2.1.3 *Design Procedure and Criteria*

Caltrans has specified ranges of particular physical properties for asphalt rubber binders that are indicators of the relative amount of modification achieved by CRM interaction. The properties are rotational viscosity, resilience, cone penetration and ring-and-ball softening point. The specification limits are also shown in Table 2-1, along with test results from an actual binder design. Resilience has proved to be one of the best indicators of asphalt rubber field performance in terms of resisting fatigue and reflective cracking. Increased resilience typically indicates improved performance.

Table 2-1: Laboratory Asphalt Rubber Binder Design Data

Test Performed	Minutes of Reaction					45 minutes Specification Limits***
	45	90	240	360	1,440	
Viscosity, Haake at 190°C, Pa·s, (10^{-3}), or cP (*See Note)	2400	2800	2800	2800	2100	1500 – 4000
Resilience at 25°C, % Rebound (ASTM D 3407)**	27	--	33	--	23	18 Minimum
Ring & Ball Softening Point, °C (ASTM D 36)	59.0	59.5	59.5	60.0	58.5	52 – 74
Cone Pen. at 25°C, 150g, 5 sec., 1/10 mm (ASTM D217)	39	--	46	--	50	25 – 70

Notes regarding specified test procedures for Asphalt-Rubber Binder

***** *The viscosity test shall be conducted using a hand-held Haake viscometer ….or equivalent.*

*** ASTM D3407was recently replaced by ASTM D 5329 that also includes the referenced test procedure for resilience.*

**** Per Caltrans specifications 7/2002*

The first step an asphalt rubber producer must take in the design process is to obtain samples of the base asphalt binder (usually AR-4000), CRM, and any other additives that will be used for the subject project(s), because asphalt rubber interactions are highly material-specific. Use of extender oil and high natural CRM can help compensate for variability in the other components to some extent, but changes in source or grade of the asphalt cement or CRM can have major impacts on binder properties and would require a new design.

The asphalt rubber binder designer blends trial proportions of the designated components within specification requirements, based on practical

experience. The asphalt rubber interaction is then conducted at the specified temperature. Samples of the asphalt rubber binder are taken after various intervals of interaction time as shown in Table 2-1 and tested for specification compliance. This provides a profile of how the asphalt-rubber properties behave over time and a reasonable indicator of what to expect during field production, though field data may vary from the lab design. If results of the first trial are not adequate, additional interactions are performed as needed.

Best practice indicates that the asphalt rubber interaction properties (particularly softening point and resilience) should be examined to evaluate whether the extender oil content is appropriate for project environmental and traffic conditions. ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," lists three types of asphalt rubber binder with varying limits on softening point and resilience. The Appendix provides corresponding suggested climate guidelines for type selection that may be used as a reference for such evaluation. Hot, moderate, and cold climate ranges are defined in terms of average monthly minimum and maximum temperatures. Some states have specified asphalt rubber properties based on climate and/or traffic considerations.

The proportions of the components and test results for the selected formulation are reported as part of the asphalt rubber binder design and submitted to the Engineer for approval, as required by Caltrans.

2.2 RUBBERIZED ASPHALT CONCRETE (RAC) HOT MIXES

Use of asphalt rubber in hot mixes is typically limited to gap and open gradations because these are most cost-effective. Use of asphalt rubber is not recommended in dense-graded mixtures because there is insufficient void space to accommodate enough of the modified binder to significantly improve performance of the resulting pavement.

Gap and open-graded RAC mixes are most often used as overlays for maintenance and/or rehabilitation of existing asphalt concrete and Portland cement concrete pavements. RAC is also used as surface (wearing) courses for new pavement construction, most often in residential areas where traffic noise is a consideration. Structural design is performed as for conventional DGAC pavements, and thickness reductions may be applied when gap graded asphalt rubber surface courses are substituted for DGAC.

2.2.1 *Gap Graded Hot Mix*

The most commonly used asphalt rubber product in California is gap graded hot mix (RAC-G). RAC-G lift thickness is limited to a minimum of 30 mm (0.1 ft, 1.2 inch) by component aggregate size, and maximum 60 mm (0.2 ft, 2.4 inches) based on limited experience with thicker lifts that is mostly due to economic considerations. Should greater increase in structural capacity be required, a layer of DGAC and/or a SAMI-R may be placed first. The pavement deflection study will determine structural requirements, based upon which the designer may provide such structural section alternatives.

2.2.1.1 *Purpose of RAC-G.* RAC-G mixes provide a durable, flexible pavement surface with increased resistance to reflective cracking, rutting and oxidation, good surface friction characteristics due to the texture provided by the gapped aggregate grading, and often reduced traffic noise. The RAC-G acts as a structural layer in the pavement.

2.2.1.2 *Appropriate Use.* RAC-G can be used for overlay or new construction for a wide range of traffic volumes and loadings. RAC-G can also be used in urban areas where there is considerable stop-and-go traffic for which open-graded mixes would not be suitable. Such areas include numerous signalized intersections and driveways, and parking areas. However, RAC-G mixtures due to their high binder contents may exhibit some flushing at intersections with heavy truck traffic.

2.2.1.3 *RAC-G Overlay Thickness Design.* Current Caltrans rehabilitation policy is to design an overlay so as to extend the service life of the pavement for ten years, although other design periods can be used.

Overlay thickness design is based on the Traffic Index (TI) for the design period and the following three items:

- Structural adequacy upgrade;
- Reflective crack retardation; and
- Ride quality improvement.

Designing a RAC-G overlay involves determining the overlay thickness for a conventional DGAC overlay based on measured pavement deflection, then adjusting the thickness according to structural equivalencies between DGAC and RAC-G. Thickness of DGAC needed to retard reflective cracking and to restore ride are also evaluated. The thickest of these is selected; reductions to RAC thickness are made for structure and cracking, but not for ride quality. The Caltrans Flexible Pavement Rehabilitation Manual provides details for designing a variety of overlay strategies. Figure 2-1 illustrates the half thickness scenario. The RAC tonnage shown is slightly less than half that of the DGAC because unit weights of RAC and DGAC differ as a function of the higher binder content in the RAC. Binder has a much lower specific gravity than aggregate, so RAC has a slightly lower unit weight.

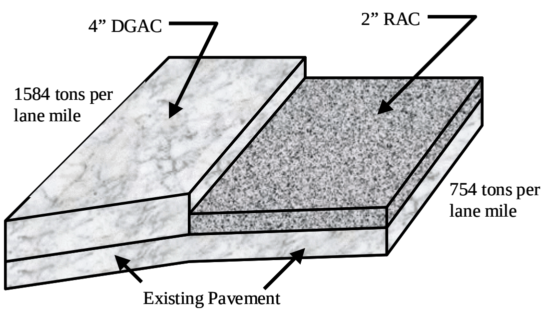

Figure 2-1: Typical RAC-G Overlay

RAC Overlay Systems. RAC overlays may also be placed as two and three layer systems, surfaced with either gap- or open-graded RAC. A two-layer system is typically RAC placed directly on a SAMI-R. SAMI-F (PRF) is not used under RAC because the mix temperature will damage the fabric. When a leveling course is placed prior to application of the SAMI-R, a three-layer system is created as shown in Figure 2-2. SAMI-R provides some limited structural equivalence, of approximately 15 mm (0.05 ft, 0.6 inch) of DGAC according to Table 3 of the Caltrans June 2001 Flexible Pavement Rehabilitation Manual.

RAC-G for New Construction. When used for new construction, RAC-G should be directly substituted (1:1) for the top 25 to 50 mm (1-2 inches) of DGAC (appropriate layer thickness is 2 to 3 times the maximum aggregate size in the RAC-G). Use of the half-thickness equivalence customarily used for Caltrans rehabilitative overlays of distressed pavements is not recommended for new construction due to possible long term effects on the fatigue life of underlying layers of the pavement structure. Caltrans has not yet had enough experience with use of RAC for new construction to evaluate application of equivalency factors that were developed for rehabilitation purposes.

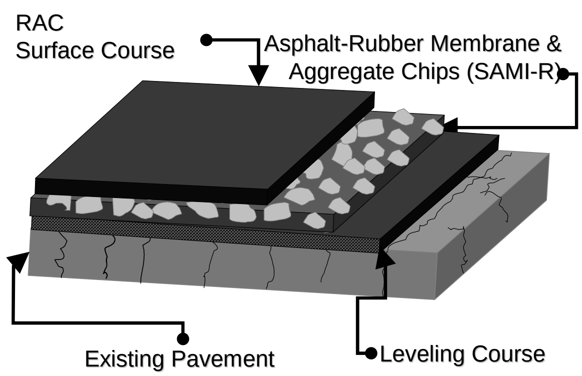

Figure 2-2: Three-Layer System

2.2.1.4 *RAC-G Mixture Design.* Existing California Tests, including CT 367 with Hveem compaction, are used with some modifications as indicated in the Special Provisions for RAC-G. These include allowances for lower Hveem stability, requirements for voids in mineral aggregate (VMA) and significantly higher binder content (7.0 to 9.0 percent by mass of dry aggregate). Air voids contents are similar to dense graded AC and Optimum Bitumen Content (OBC) corresponds to that yielding 4 percent air voids. A finished RAC-G pavement is shown in Figure 2-3.

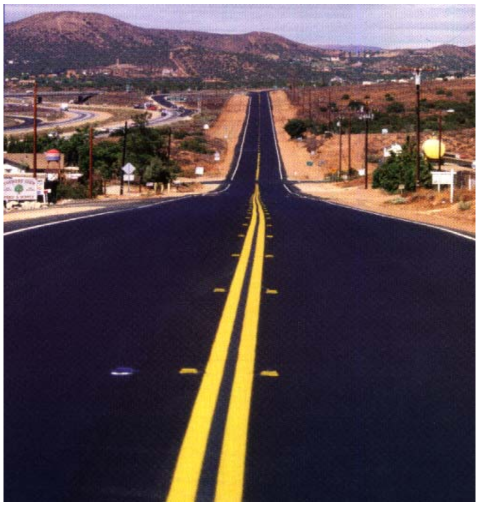

Figure 2-3: Finished RAC-G Pavement

2.2.2 *Open Graded Hot Mix*

Open graded surface mixes (OGAC) provide good surface frictional characteristics. OGAC pavements are intended to be free draining so that surface water can quickly travel through the mat to drain out along the edges of the pavement structure. This reduces splash, spray, and hydroplaning during and immediately after rains and thus improves safety. Conventional OGAC also reduces traffic noise, although reports of long- term effectiveness of such reduction vary. There are advantages to using OGAC and there are additional advantages to using RAC-O.

The thicker film coating of the asphalt rubber binder increases durability of open-graded pavements. One of the reasons that RAC-O mixtures are durable are that these are relatively low modulus materials, which means that they have lower stress to strain ratios than stiffer materials like DGAC. They move more in response to the same level of loading, and function by flexing and recovering (relaxing, creeping, rebounding, etc.) rather than by being stiff. The high asphalt rubber binder contents render these materials very resilient and resistant to fatigue, but they are not stiff layers and are placed as thin lifts, about 24 to 30 mm (0.08 to 0.1 ft, 1 to 1.2 inches) thick. Thus, RAC-O and RAC-O (HB) are not considered to be structural elements and no thickness reduction is applied for these uses of asphalt rubber.

Asphalt rubber open graded mixes (RAC–O and RAC-O (HB)) are primarily used as maintenance blankets, and overlays for rehabilitation, including restoration of surface friction.

2.2.2.1 *Advantages of RAC-O.* These include:

- The thicker asphalt rubber binder film provides improved resistance to stripping and oxidative aging.
- RAC-O mixes are highly resistant to reflection of cracks and joints in PCC pavements, and to reflection of severe cracks from underlying AC pavements.

2.2.2.2 *Purpose.* The primary reasons for using RAC-O include:

- Providing a durable, highly flexible pavement surface with enhanced drainage and frictional characteristics that reduces splash and hydroplaning in wet conditions (see Figure 2-4).
- Providing increased resistance to:
  - Reflective cracking
  - Rutting
  - Oxidation
- Reducing traffic noise.

2.2.2.3 *Appropriate Use.* RAC-O is a surface course (for overlay or new construction) for roadways where traffic flow is essentially uninterrupted by signalization, such as some freeways, rural and secondary highways. It is highly effective as an overlay of PCC and AC pavements in locations where potential for reflective cracking is severe. RAC-O is also used as a maintenance blanket to restore surface frictional characteristics and to help preserve the underlying pavement. District 2 cautions against use of RAC-O in tire chain areas. Tire chains and snowplow use are both factors that should be considered in selecting surface course material. However Arizona DOT reports no major problems with using RAC-O in alpine chain areas.

Open graded mixes should not be used where there is a significant amount of stop and go traffic or turning vehicles, such as city streets or in parking lots, because the porous pavement is susceptible to damage from leaking vehicle fluids.

Figure 2-4: Free-Draining RAC-O Next To DGAC

2.2.2.4 *RAC-O Mixture Design.* Mixture design is performed according to California Test 368, with asphalt rubber binder content set at 1.2 times the optimum bitumen content for AR-4000, and with a check test for drain off. If long hauls are anticipated, drain off should also be checked for the expected haul time. If excessive, adjustments may be required. For long hauls, reducing mixture temperature for hauling may not be appropriate for complying with minimum requirements for placement temperature

Caltrans is evaluating use of higher asphalt rubber binder contents, 8 to 10 percent by mass of dry aggregate, in some open-graded mixtures. These mixtures are called RAC-O(HB), High Binder. Other agencies have shown that asphalt rubber binder contents can be increased to 10 percent or more by mass of dry aggregate without excessive drain-off because of the high viscosity of the asphalt rubber binder. Such open-graded mixtures have generally provided excellent performance.

2.3 ASPHALT-RUBBER SPRAY APPLICATIONS

Asphalt rubber spray applications may be used as surface treatments or interlayers. Such applications are almost always used for maintenance or rehabilitation of existing pavements, and are very effective at resisting reflective cracking (see Figure 2-5).

2.3.1 *Chip Seals (SAMs)*

Chip seals are used by Caltrans for preventative and major maintenance as follows:

- Correct surface deficiencies.
- Seal raveled pavement surfaces.
- Seal off and protect the pavement structure against intrusion of surface water.
- Protect the pavement surface from oxidation.

In many jurisdictions, chip seals are called stress-absorbing membranes (SAMs). Chip seals do not add structural strength or correct ride roughness problems. However, some agencies also use them as an alternate to OGAC to restore surface frictional characteristics where traffic volumes allow.

To construct a chip seal, the hot asphalt rubber binder is sprayed on the roadway surface at a rate determined by the Engineer. The binder is immediately covered with a layer of hot pre-coated chips that must be quickly embedded into the binder by rolling before the membrane cools. Best results are achieved with clean nominal 9.5 to 12.5mm (3/8 to 1/2-inch) single-sized chips. The standard chip size for Caltrans asphalt rubber seals is 9.5 mm; 12.5 mm chips are used by Caltrans only where ADT is less than 5,000/lane. Lightweight aggregates may be substituted to minimize windshield breakage by loose chips in areas where traffic is heavy or fast. Pre-coating the aggregate with asphalt cement improves adhesion by removing surface dust and "wetting" the chips. Caltrans requires that the aggregate chips be delivered to the job site precoated and hot. To further aid chip retention after the chips have been embedded and swept, a fog seal of asphalt emulsion (diluted 1:1 with water) is sprayed over the chips at a typical rate of 0.14 to 0.27 l/m^2 (about 0.05 to 0.1 gal/yd^2). A light dusting of sand, 1 to 2 kg/m^2 (about 2 to 4 lbs/yd^2) is then applied as blotter as directed by the Engineer.

> ***Note:*** *All chip seals are very sensitive to construction operations and site environmental conditions. With hot-applied seals, the thin binder membrane cools very quickly regardless of its composition. Embedment and adhesion must be accomplished while the membrane is still hot.*

2.3.1.1 *Advantages.* Asphalt rubber chip seals provide the same benefits as conventional chip seals, but also provide the following additional advantages:

- Significantly longer service life than conventional chip seals.
- Superior long-term performance in resisting reflective cracking.

Figure 2-5: Chip Seal Train

2.3.1.2 *Purpose*. Asphalt rubber chip seals provide a flexible, waterproof, skid resistant and durable surface that resists oxidation and is highly resistant to reflective cracking. A chip seal is not a structural layer.

2.3.1.3 *Appropriate Uses*. These include:

- Rehabilitation of structurally sound pavements that are cracked or raveled.
- Restoration of surface frictional characteristics (corrective maintenance).
- Routine preventative maintenance to extend the life of AC pavements.

Caltrans Maintenance Manual (Volume 1) includes criteria for use of chip seals and cover aggregate size based on speed limits and average daily traffic. Use of chip seals is not encouraged in areas with heavy trucks or stop-and-go traffic, or at signalized intersections. In locations where speed limits are ≥45 mph (72.4 kph), maximum ADT limit is 30,000.

2.3.1.4 *Asphalt-Rubber Binder Design.* The special provisions for asphalt-rubber binder referenced in 2.1 also apply to asphalt rubber binders for chip seals. The asphalt rubber binder design and materials submittals requirements, including test results that verify compliance with asphalt rubber binder physical property specifications, are the same for chip seals as for hot mixes.

2.3.1.5 *Application Rates.* According to Caltrans standard special provisions for asphalt rubber seal coat, SSP37-030, application rates for asphalt rubber chip seals are:

Chip Size	Asphalt Rubber Binder	Stone
12.5 mm (1/2 in.)	2.5-3 l/m^2 (0.6-0.7 gal/yd^2)	15-22 kg/m^2 (30-44 lbs/yd^2)
9 mm (3/8 in.)	2.5-3 l/m^2 (0.6-0.7 gal/yd^2)	15-22 kg/m^2 (30-44 lbs/yd^2)

However, the exact rate is to be determined by the Engineer. There are a number of factors that can affect the asphalt rubber binder and cover aggregate application rates including:

- Surface texture of the existing pavement: severely aged, oxidized and open-textured surfaces will absorb more binder than newer tighter surfaces.
- Traffic volumes: typically use smaller chips for higher volumes to reduce potential for vehicle damage by loose chips. Binder application rates can be increased for low traffic volume areas.
- Seasonal temperature ranges: thicker membranes may be used in areas with cool climates.
- Aggregate size: large stone requires more asphalt rubber binder (thicker membrane) to achieve 50 to 70 percent embedment.
- Aggregate gradation: single-sized materials require more asphalt rubber binder than do graded aggregates.

There are methods by which the specified aggregate application rate can be evaluated prior to the start of construction. The easiest is to simply lay the aggregate one-stone deep on a measured area, weigh the amount of stone required to cover that area and convert to appropriate units (kg/m^2, lbs/yd^2).

To verify if application rates are appropriate, also check the embedment of the cover stone. The stone should be embedded to a depth of about 50-70 percent after seating in the lab or by rollers and traffic in the field. Excess chip application interferes with embedment and adhesion.

Excess asphalt rubber application can literally submerge or swallow the chips, and results in flushing/bleeding. Loose stones along the roadway edge after sweeping may indicate excessive chip application and wasted stone, that the asphalt rubber application is too light, or that the binder cooled before embedment and adhesion were achieved.

2.3.2 *Asphalt Rubber Stress Absorbing Membrane Interlayers (SAMI-R)*

A SAMI-R is simply an asphalt rubber chip seal that is overlaid with conventional AC or RAC. The SAMI material is very flexible and elastic and has a low modulus; it flexes and creeps to relieve stresses and to heal many of the cracks that do occur. SAMI-R acts to interrupt crack propagation and has been shown to be highly effective in delaying reflective cracking in overlays. The aggregate chips key into the overlay upon compaction to prevent formation of a slippage plane along the relatively thick asphalt rubber membrane.

No fog seal or sand should be applied over a SAMI-R because this could interfere with bonding of the overlay.

SAMIs may be applied to any type of rigid (PCC) or asphalt pavement, and have proved very effective at minimizing reflection of PCC joints. However the Caltrans Maintenance Manual states that if the surface irregularities (rutting in AC or faulting of PCC) exceed 12.5 mm (1/2-inch) then either a leveling course should be placed or grinding and crack filling are required prior to placing SAMI-R.

2.3.2.1 *Advantages.* These include:

- Highly effective in minimizing reflective cracking in overlays of existing distressed asphalt and jointed portland cement concrete pavements.
- Minimize overlay thickness when reflective cracking is expected to be the primary distress mode and structural capacity is deemed sufficient.
- Provides the benefit of reduced structural overlay thickness that fabric does not.

The Caltrans Flexible Pavement Rehabilitation Manual gives SAMI-R credit for a structural contribution ranging from 15 to 30 mm (0.6 to 1.2 inches) of RAC, depending on whether structural strength or reflective cracking governs the design.

2.3.2.2 *Purpose.* SAMI-R is a low modulus (non-structural) layer that is used to retard and minimize reflective cracking in overlays placed on it, and to minimize further infiltration of surface water through the pavement structure.

2.3.2.3 *Use.* SAMIs are used under corrective maintenance overlays and are a pavement rehabilitation tool. A SAMI would not be included as part of new construction.

2.3.2.4 *Design.* Design of the asphalt rubber binder is the same as for chip seal. Determination of appropriate binder and cover aggregate application rates is also the same. SAMIs have been assigned an equivalency factor in rehabilitation projects when reflection cracking is the governing distress mode for overlay design.

3.0 PRODUCTION OF ASPHALT-RUBBER BINDERS AND MIXTURES

This chapter presents information and procedures for production of asphalt-rubber binder and how use of asphalt rubber binder affects AC mixture production.

3.1 ASPHALT RUBBER BINDER PRODUCTION

Asphalt rubber binder production methods are essentially the same for both hot mix and spray applications. The primary difference is the importance of coordination of asphalt rubber and hot mix production to assure that enough asphalt rubber binder is available to provide the desired AC production rate. Figure 3-1 shows a schematic of asphalt rubber blending. Figure 3-2 shows an example of a typical asphalt rubber production set up at an AC plant. Binders for spray applications are typically produced close to the job site, not necessarily at an AC plant, and must also be coordinated with application operations.

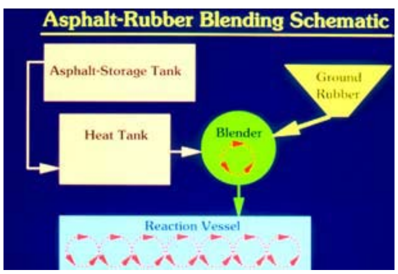

Figure 3-1: Asphalt Rubber Blending Schematic

Equipment for feeding and blending may differ among asphalt rubber types and manufacturers, but the processes are all similar. Temperature is always critical to controlling asphalt rubber manufacture, and temperature gauges or thermometers should be readily visible.

Augers are needed to agitate the asphalt rubber inside the tanks (Figure 3.3) to keep the CRM particles well dispersed; otherwise the particles tend either to settle to the bottom or float near the surface. Agitation can be verified by periodic observation through the hatch where the auger control is inserted.

Figure 3-2: Asphalt Rubber Production Set Up At AC Plant

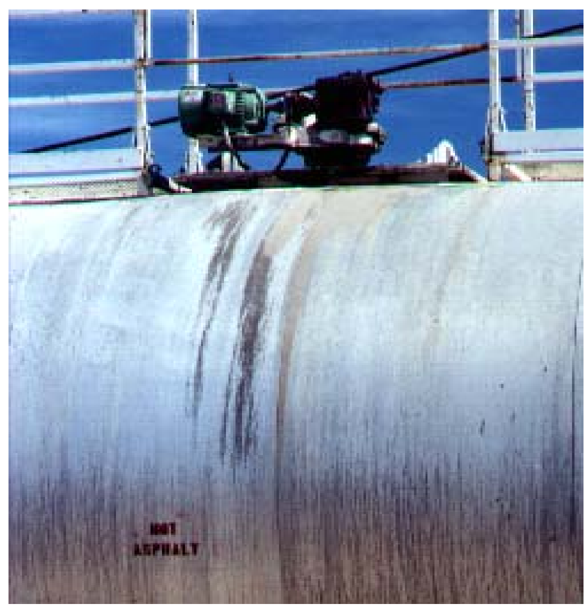

Figure 3-3: Auger For Agitating Asphalt Rubber Storage Tank

CRM may be packaged in 22.7 kg (50-pound) bags that are fed into the blending unit by conveyor (Figure 3-4) or in 0.91 tonne (one ton) super sacks that are fed into a weigh hopper for proportioning (Figure 3-5). The containers should be clearly labeled and stored in an acceptable manner. Caltrans' acceptance sampling should be coordinated with asphalt rubber personnel to assure that all CRM lots can be sampled as appropriate.

The asphalt rubber binder production process depends on temperature, agitation, and time. ***Temperature is critical for process control***. All tanks that store asphalt rubber between initial blending and use must be heated and insulated. Thus, asphalt rubber production equipment and storage tanks should generally be expected to include retort heaters or heat exchangers to heat the asphalt cement and/or asphalt rubber. It is reasonable to assume some heat will be lost in any transfers. Insulated tanks that are heated to elevated temperatures ranging from the specified minimum temperature of 190°C (375° F) to a maximum of 226°C (440° F) are used to hold the blended asphalt rubber binder materials and the base paving grade asphalt cement.

Figure 3-4: Conveyor Blending

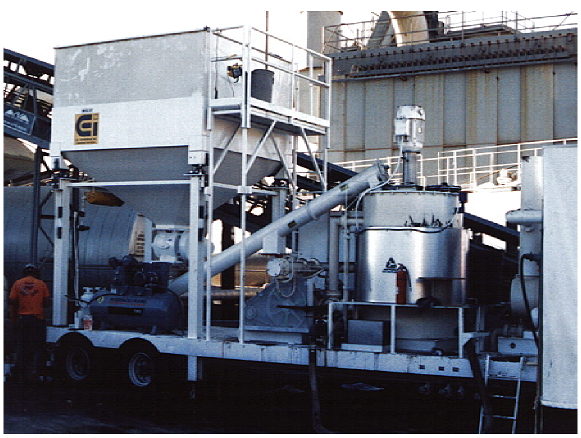

Figure 3-5: Blending From CRM Weigh Hopper

The asphalt rubber binder must be interacted with agitation for a minimum of 45 minutes at temperatures from 190 to 218°C (375 to 425°F) to achieve the desired interaction between asphalt and rubber. In order to maintain the reaction temperature within the specified range of 190 to 218°C (375 to 425°F), the asphalt cement must be hot, 204 to 226°C (400 to 440°F) before the design proportions of scrap tire and high natural CRM are added. This is because the CRM is at ambient temperature (not heated) and when added, it drops the binder temperature by about 4 to 10°C (7 to 18°F).

The component materials are metered into blending units to incorporate the correct proportions of CRM into the paving grade asphalt, and are thoroughly mixed. The asphalt rubber producer is allowed to add the extender oil while adding the rubber, although in some cases the paving asphalt may be supplied with the extender included. If the asphalt rubber producer adds the extender oil, use of a second meter is recommended to best control the proportioning. The meter for the extender oil should be linked to that for the paving grade asphalt.

An asphalt rubber binder processed (interacted) at lower temperatures will never achieve the same physical properties as the laboratory design, although it may achieve the minimum specification values for use. Hand held rotational viscometers (Haake or equivalent as referenced in Table 2-1) are used to monitor the viscosity of the asphalt rubber interaction over time for quality control and assurance. Before any asphalt rubber binder can be used, compliance with the minimum viscosity requirement must be verified using an approved viscometer.

The asphalt rubber binder must achieve the specified minimum viscosity before spray application or AC production can commence. This go/no-go field test governs use of the asphalt rubber binder. The special provisions do not indicate that the production viscosity results must correlate with the submitted asphalt rubber binder design data, only that they remain within specified limits. As long as the viscosity is in compliance, the asphalt rubber may be used.

3.1.1 *Hold-Over and Reheating*

Caltrans requires that heating be discontinued if asphalt rubber material is not used within 4 hours after the 45-minute reaction period. The rate of cooling in an insulated tank varies, but reheating is required if the temperature drops below 190°C (375°F). A reheat cycle is defined as any time an asphalt rubber binder cools below and is reheated to

190 to 218°C (375 to 425°F). Caltrans allows two reheat cycles, but the asphalt rubber binder must continue to meet all requirements, including the minimum viscosity. Sometimes the binder must be held overnight. The asphalt and rubber will continue to interact at least as long as the asphalt rubber remains liquid; rubber breakdown (digestion) continues during this period. To restore the viscosity to specified levels, it is usually necessary to add more CRM (limit 10 percent more by binder mass) and react the resulting asphalt rubber blend at 190 to 218°C (375 to 425°F) for 45 minutes.

3.1.2 *Documentation*

3.1.2.1 *Certificates of Compliance.* According to Caltrans requirements, a certificate of compliance (COC) is required for every binder constituent as well as for the finished asphalt rubber binder. The COCs must include test results that show conformance of all of these materials to the respective special provisions, including chemical composition of the scrap tire and high natural CRM materials and asphalt modifier (extender oil). COCs for all of the component materials delivered to site of the asphalt rubber blending operation should be provided to the Engineer, inspector and/or project staff. It is current policy for Caltrans representatives to sample components and blended asphalt rubber materials at the mixing site for testing and acceptance.

3.1.2.2 *Asphalt Rubber Binder Design.* The asphalt rubber producer should have on site a copy of the approved asphalt rubber binder design that includes results of specified laboratory tests (see Table 2-1) and proportions of each component.

3.1.2.3 *Asphalt Rubber Binder Production Log.* Most asphalt rubber producers maintain a log of asphalt rubber binder production for each project. This practice has proved very useful and is highly recommended. For each batch of asphalt rubber produced, the log should list the weights of each component used, the reaction start time, and results of all viscosity tests performed, including the time and asphalt rubber binder temperature. *The last three items must be reported to Caltrans daily.* Figure 3-6 presents an example of an asphalt rubber Binder Viscosity Log. It is recommended that the logs should also record when each asphalt rubber batch was metered into the AC plant. The production log should also include all holdover and reheat cycle information including the time that heating was discontinued, the time that reheating began and corresponding asphalt rubber binder temperature, amount and time of CRM addition, and subsequent viscosity test data.

3.1.3 *Sampling and Testing Requirements*

For quality control, sampling and testing frequencies for all components of AR binders are listed in Table 3-1. Quality Assurance testing requirements may vary, but sampling requirements typically should not exceed the frequencies shown below.

Tests for CRM gradation and chemical composition may take more time to conduct than for conventional paving materials. Failures to meet these requirements should be evaluated on a case-by-case basis and results of physical property tests of the asphalt rubber binder should also be considered.

Table 3-1: QC Sampling and Testing Frequency

Material	QC Sampling and Testing Frequency*
CRM	Chemical composition Each 225 tonnes (about 250 tons)
CRM	Gradation and physical properties Each truckload: ≈ each 18 tonnes (20 tons)
Asphalt Rubber Binder	Viscosity: Test every hour during AC production. Retain 4 liters (1 gallon) per batch
Paving Asphalt	Each 180 tonnes (about 200 tons) – sample at point of origin or at mixing site.
Asphalt Modifier	Each 23 tonnes (about 25 tons) – sample at point of origin or at mixing site.

**Minimum frequency is once for each project.*

3.1.3.1 *CRM Sampling and Testing.* CRM consists of graded particles of ground rubber that tend to agglomerate (clump) in the presence of moisture and may segregate by size. Although CRM manufacturers certify CRM gradation at the plant, segregation may occur during storage and shipping. Segregation is not an issue when the entire container is added to the asphalt rubber blend, but it can affect small samples (approximately 100 grams) obtained for purposes of gradation testing for acceptance. Tube samplers such as grain probes have been used to obtain representative samples of CRM. Caltrans is currently evaluating CRM sampling methods to address these issues and is working to develop a standard method of sampling CRM from shipping containers.

3.1.3.2 *Asphalt Rubber Sampling and Testing.* Caltrans requires the Contractor (typically the asphalt rubber binder producer) to sample the asphalt rubber from the feed line into the AC plant and measure the viscosity at least every hour during AC production. At least 4 l (1 gallon) of asphalt rubber binder should be wasted to assure that the sampling valve is clear, and the sample to be tested should be poured into a clean, dry container that can be sealed and clearly labeled. At least one viscosity test is required for each asphalt rubber batch, and the Engineer is to be notified when the tests will be performed. Caltrans requires that results of all viscosity tests performed, including the time and asphalt rubber binder temperature, be submitted to the Engineer on a daily basis. Figure 3-6 presents a sample Asphalt Rubber Binder Viscosity Testing Log.

Project Name/No.	
Date	
Binder Producer	
Tested by	

BINDER FORMULATION **Blend Proportions**

Asphalt Cement Source and Grade		
Asphalt Modifier Source & Description		% by AC mass:
Asphalt Cement and Modifier		% by Asphalt Rubber Binder mass:
Scrap Tire CRM Source & Description		% by Asphalt Rubber Binder mass:
High Natural CRM Source & Description		% by Asphalt Rubber Binder mass:

ASPHALT RUBBER BINDER (ARB) MATERIAL MUST BE TESTED BEFORE USE TO VERIFY COMPLIANCE WITH VISCOSITY SPECIFICATION

***Cycle Start Time**	**Batch Number**	**Temp. (°C) ARB Tank**	**Temp. (°C) of Viscosity Test (190 ± 2°C)**	**MEASURED VISCOSITY** Pa•s(x10^{-3})**	**Time Tested**	**Comments**

Viscometer Make, Model and Serial #:____

**The cycle begins when tank is fully loaded and at 190± 2°C (374±4°F)*
*** Measure at 190± 2°C (374±4°F)*
Note: *Viscometer reads in units of cP. To convert to metric notation, cP = Pa•s(x10^{-3})*

Figure 3-6: Asphalt Rubber Binder Viscosity Testing Log

Viscosity depends on temperature. It is essential to have a controllable heat source (hot plate, gas stove/burner, etc.) to maintain asphalt rubber sample temperature at 190°C (375°F) during viscosity measurement.

Because the procedure for testing asphalt rubber binder viscosity in the field is not published on the Internet with the other Caltrans test methods, a description is presented below. The field procedure can be obtained from the Transportation Laboratory, Pavement Branch by request.

The open asphalt rubber binder sample container should be set on or over the heat source as appropriate, and the sample should be stirred to prevent scorching or burning. The No. 1 viscometer spindle should be inserted in the hot binder sample near the edge of the can for about 1 minute to acclimate, without plugging the vent holes. This is longer than the Caltrans test method requires, but 10 seconds is not enough time to raise the spindle temperature by 150°C (300°F). While acclimating, the sample can be thoroughly stirred and the temperature measured. The probe should then be moved to the center of sample to make the viscosity measurement. The hand held viscometers have a level bubble for proper orientation (probe shaft perpendicular to binder surface and viscometer level) and an immersion depth mark on the shaft. Once leveled, begin probe rotation. The peak viscosity value is read from scale labeled with the corresponding spindle number (see Figures. 3.7 and 3.8).

Figure 3-7: Hand Held Viscometer Testing

The peak measurement represents the viscosity of the asphalt rubber binder system and that is the value that should be reported and logged. As the probe continues to turn, it "drills" into the sample, (i.e., spins rubber particles out of its measurement area) and the apparent viscosity drops to reflect only the liquid phase of the asphalt rubber. It is recommended that three measurements be taken and averaged to determine the viscosity. Between measurements, the viscometer probe should be moved away from the center (without removing it from the asphalt rubber binder sample) and the sample should be thoroughly stirred again.

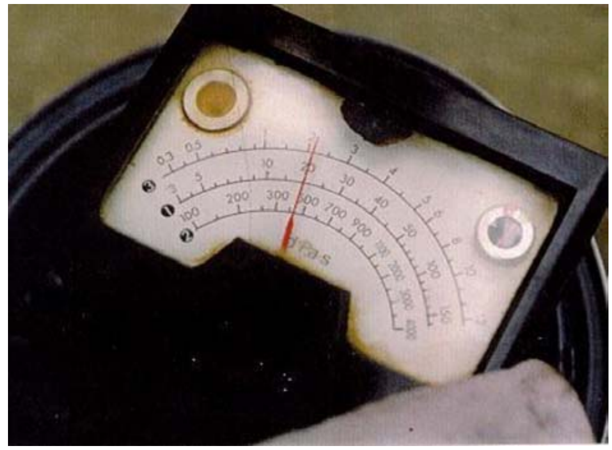

Figure 3-8: Viscometer Reading–Scale No. 1

During asphalt-rubber production, field viscosity measurements may vary from the laboratory design by as much as ± 800 centipoise (cP), but should follow a similar pattern of increase and/or decrease over the duration of the asphalt rubber interaction. Larger differences or different patterns can indicate that a change may have occurred in component materials since the original design and testing was performed. In such cases, samples of the reacted asphalt rubber binder should be obtained and tested immediately for specification compliance. As long as the asphalt rubber binder viscosity complies with specification limits, the Contractor may elect to use that batch of binder. However in such cases, there is a risk that the test results may show that the sample does not comply with other specified physical property requirements and that penalties may be applied. Complete and well-maintained asphalt rubber production logs can help limit areas of removal and replacement by recording when and/or where the reject material was used.

Upon request or as agreed during the pre-paving conference, asphalt rubber producer personnel should provide to the Engineer or Inspector samples of reacted asphalt rubber binder for quality assurance and acceptance testing for compliance with the specified property limits.

3.1.3.3 *Terminal Blend Products.* Terminal blend products may be manufactured by different methods and are governed by different specifications than the asphalt rubber binders described in this Asphalt-Rubber Usage Guide. These items are not within the scope of this Guide.

3.2 ASPHALT-RUBBER HOT MIXES (RAC)

3.2.1 Mix Production

Using asphalt rubber binder has relatively little effect on hot plant operations, for either batch or continuous AC plants, except that it may be necessary to increase the plant operating temperature in order to provide the higher mixing and placement temperatures typically required for RAC mixtures.

The asphalt rubber production equipment is independent of the AC plant, but is usually set up as close to the mixing unit as feasible to minimize the length of the heated and/or jacketed binder feed lines.

The asphalt rubber producer provides special heavy-duty pumps to transfer the asphalt rubber binder, because most AC plant pumps cannot handle such viscous materials without risk of damage. A two- or three-way valve is installed in the asphalt feed line that allows the AC plant to switch between using the asphalt rubber binder or the regular paving asphalt in the AC plant tanks, according to demand for various AC products. For drum plants, the asphalt rubber producer is required to use a flow meter that interlocks the asphalt rubber binder feed with the plant aggregate feeds. Asphalt rubber binder feed rate into the AC plant can be as high as 23 to 27 tonnes (25 to 30 tons) of binder per hour. At a mid-band asphalt rubber binder content of 8.0 percent by weight of aggregate, this will accommodate an RAC-G production rate of about 305 to 368 tonnes (335 to 405) tons per hour, but at no time should the CT 109 limits be exceeded. Terminal blends that meet asphalt rubber requirements will usually have relatively low viscosity, but may still require heavy-duty pumps.

RAC production rates may be reduced from DGAC rates due to higher binder content (increased mixing time) and asphalt rubber binder production rate. Planning and coordination between the asphalt rubber binder producer and the AC plant operator is important to minimize impacts on RAC production. The binder supplier can in many cases arrange to use more or larger storage and reaction tanks, and schedule materials deliveries and asphalt rubber blending operations to expedite asphalt rubber and mix production. Because of the relatively high mixing temperatures, there is potential for increased emissions of smoke and/or fumes. Reducing the mix production rate usually reduces visible emissions.

3.2.1.1 *Inspection and Troubleshooting of the RAC Mixture.* Both the plant and field inspectors should visually inspect the RAC in the haul truck bed for signs of any problems with the mix and check mix temperature. Measure RAC temperature with a thermometer that has a probe at least 152 mm (6 inches) long, by sticking the full depth of the probe into the mix. Surface readings are not an accurate indicator. If only a heat gun is available, it will be necessary to measure temperature of the RAC as it is flows out of the plant discharge chute into the haul truck.

Whenever any type of RAC mixture problem is suspected, the Inspector should obtain samples immediately and have them tested immediately for gradation and asphalt rubber binder content. In some cases, it may be necessary to check voids properties of compacted hot mix specimens. The Inspector should enter a full description of the problem observed and subsequent activities in the project daily log, and immediately report these observations to the Resident Engineer (RE). Test results should be relayed to the RE immediately upon receipt. Some of the potential "trouble" signs to watch for in the mix are as follows.

- Segregation: Particle size segregation may be difficult to identify in some coarse gap-graded mixtures. There are few fines present and that can sometimes make the RAC appear segregated even if it is not. Identify the affected truckloads and corresponding placement areas, take samples and test gradation and binder content to verify. It is also recommended that, if possible, samples of RAC that do not appear segregated should be taken from the same truckload, for comparison. Temperature segregation (hot or cold spots) may be checked with a heat gun or with an infrared camera. The primary concern is differences rather than exact values.
- Blue smoke: Mix is too hot.
- White smoke: Steam – too much moisture. This means that the aggregate was not dried enough prior to mixing with asphalt rubber binder. This may cause the RAC mix to become tender and may contribute to compaction problems.
- Stiff appearance: Mix may be too cool – check temperature.
- Dull, flat appearance: Indicates low asphalt rubber binder content and/or excessive fines (minus 0.075 mm (No. 200 sieve size)). Localized areas of dullness may indicate insufficient mixing of the asphalt rubber binder and aggregates, or mix

segregation. Take samples and test for gradation and binder content.

- Slumped and shiny: High asphalt rubber binder content. RAC-O, and especially RAC-O (HB) mixtures, may look this way and still meet SSP requirements, so this is not always a problem. An old descriptive term for this is “wormy,” because the mix seems to almost crawl when watched. Look in the truck bed for binder drain down, take and test samples for asphalt rubber binder content and gradation.

The only change to the plant Inspector’s normal duties is the addition of monitoring the asphalt rubber production and viscosity results and sampling the asphalt rubber binder and its components. The Asphalt Rubber Binder Production Log and Testing Log should contain all of the pertinent information, and should be available for inspection. The Inspector should obtain at least one 3.8 liter (1-gallon) sample from each batch of asphalt rubber binder produced for the project to test for compliance with specification limits.

All of the regular activities related to plant inspection for AC production remain the same:

- Observing aggregate storage and handling and plant operations
- Basic sampling and testing procedures for checking aggregate and RAC characteristics;
- Verifying that the correct mixture is being produced according to the design and in compliance with specifications, etc.

3.2.2 Importance of Temperature

The key to quality in producing asphalt rubber materials and constructing asphalt rubber pavements is temperature control in all aspects of the work. Asphalt rubber materials need to be produced and handled at somewhat higher temperatures than conventional bituminous materials and mixtures because they are stiffer than these conventional materials at the typical mixing and compaction temperatures. Temperature is critical to:

- Asphalt rubber binder manufacture
- RAC hot mix production
- RAC delivery
- RAC placement
- RAC compaction.

It is therefore important to closely monitor temperature of the materials during all phases of asphalt rubber binder and mixture production and construction. The Inspector should have appropriate equipment for checking temperature of asphalt rubber binder and hot mix, including surface and probe type thermometers that can also measure ambient air temperature, and a heat gun. The asphalt rubber blending and storage tanks should also be equipped with readily visible thermometers.

Safety is always a consideration when working with hot materials. Conventional AC mixtures are hot enough to cause burns, and so are asphalt rubber binders and RAC materials. Personnel should wear appropriate protective gear including but not limited to gloves made for handling hot samples and suitable eye protection.

4.0 CONSTRUCTION AND INSPECTION GUIDELINES

This chapter presents information and procedures for construction and inspection of asphalt rubber pavements, chip seals and interlayers, including placement, compaction and finishing.

4.1 HOT MIX (RAC) PAVING EQUIPMENT

The field inspector should confirm that the necessary paving equipment is on site before any asphalt rubber hot mix is shipped from the AC plant. Any equipment-related questions or issues should have been resolved in the pre-paving conference. Availability and paving capability may be affected by unanticipated mechanical problems or logistics.

4.1.1 *Haul Trucks*

Any type of trucks that are customarily used for transporting AC may be used, including conventional end or bottom dumps, or horizontal discharge (live bottom). However, all trucks hauling RAC mix should be tarped to retain heat during transport.

4.1.2 *Material Transfer Vehicle (MTV)*

Use of this type of equipment is optional. MTVs have been described as "surge bins on wheels" and are most often used when smoothness, segregation, or mixture delivery rate are concerns.

4.1.3 *Pavers*

Conventional mechanical self-propelled pavers are used to place RAC mixes. Pavers should be equipped with vibratory screed and screed heaters, automatic screed controls with skid, and comply with all of the pertinent Caltrans specification requirements.

4.1.4 *Rollers*

Rubber tired rollers are not appropriate for compacting RAC mixes because of excessive pick up of the mixture by the tires. All rollers for RAC must be steel-wheeled (drum), and must be equipped with pads and a watering system to prevent excessive pick-up. It may sometimes be necessary to add a little soap to the watering system.
RAC-G mixtures are likely to require more compaction effort than DGAC. Minimum recommended roller weight is 7.3 tonnes (8 tons) and pup rollers cannot provide sufficient compaction. The types of rollers normally include the following:

- **Breakdown roller with vibratory capability.** It is strongly recommended that two breakdown rollers be used, especially if paving width exceeds 3.65 m (12 feet).
- **Intermediate roller.** These should be of equal or greater width than the breakdown roller(s), or use two intermediate rollers.
- **Finish roller.** These should be a static roller, with a minimum of 7.3 tonnes (8 tons)
- **Standby roller.** One with vibratory capability should be on site and should be required if only one breakdown roller is available.

4.1.5 *Sand Spreader*

Any Caltrans approved spreader with uniform distribution capabilities to provide a sand blotter for opening the RAC surface to traffic.

4.2 FINAL PREPARATIONS FOR PAVING

Surface preparation must be completed prior to RAC production or spray application. This includes standard items such as removal and replacement of failed pavement and pothole repair (patching), milling or grinding for smoothness and matching elevations, crack filling, etc. Immediately prior to mixture delivery, the surface should be swept and tack coat applied.

4.2.1 *Tack Coat (Paint Binder)*

A tack coat should generally be uniformly applied so as to lightly cover the entire pavement surface to be overlaid. Recommended application rate is 0.1 to 0.3 l/m^2 (0.05 to 0.1 gal/yd^2) residual. Area of tack application should be limited to what will be paved over on that day. However, tack coat is not required when a SAMI-R will be placed prior to overlaying, and is not recommended when RAC will be placed directly on a new pavement.

4.2.1.1 *Emulsified Asphalt***.** Caution should be used when ambient and pavement temperatures are marginally cool and emulsion tack coats are to be used. Emulsion must "break" (i.e. turn from dark brown to black as the suspended asphalt droplets separate from the water) and the water must evaporate prior to paving. Otherwise, the remaining water in the emulsion will turn to steam and rise up through the mat. This prevents the tack from establishing the intended bond with the new pavement and the excess moisture may also cause a tender spot in the mix during compaction. Water trapped between pavement layers may cause stripping. Cold or damp conditions and lack of sun all slow evaporation and may delay paving operations.

4.2.1.2 *Paving Grade Asphalt.* Regular paving grade asphalt can also be used as tack (paint binder) and might in some cases be substituted for emulsion due to adverse site conditions. Asphalt tack should be hot enough, about 149 to 176°C (300 to 350°F), to spray an overlapping fan pattern and not to string out in a manner that leaves much of the surface without tack. If the application rate is not properly controlled, bleeding or delamination may result. Any defective or plugged nozzles must be corrected immediately. If using hot paving asphalt for tack, the distributor truck must have a heater to maintain asphalt temperature and consistency for spray application.

4.3 HOT MIX DELIVERY

Although any type of conventional AC haul truck can be used to transport RAC, when air and pavement surface temperatures are near the minimum specified limits use of bottom dumps is not recommended. It is critical that the RAC does not cool below the minimum placement temperature of 143°C (290°F) during transport. Tarps are needed to maintain acceptable temperature. Mixture shipment temperatures may range from 149°C (300°F) on hot days with short hauls up to 174°C (345°F) for cold days with long hauls; typical maximum is about 163°C (320°F).

4.3.1 *Release Agents*

No solvent based release agents or diesel fuel should be used in haul truck beds because of adverse effects on the asphalt rubber binder. Soapy water (dish or laundry soap) is recommended; it is effective and cheap. Dilute silicone emulsions may also be used.

4.3.2 *Coordinating Mix Delivery and Placement*

Coordination is essential to achieving a smooth finished pavement with a pleasing appearance, the two factors that motorists reportedly consider the most important indicators of pavement quality. The paver should never have to stop due to lack of material. If it stops on the new mat, the result is either a bump or depression that is not removable by rolling. A long line of haul trucks waiting to access the paver generally means that some loads will cool enough to be rejected. MTVs can be used to minimize adverse impacts of irregular mix delivery.

4.3.2.1 *Unloading Hot Mix Into a Paver Hopper***.** The haul truck should be centered and backed up to the paver, but should stop just short of contacting the push rollers on the front of the paver (Figure 4-1). After the truck releases its brakes, the paver should move forward to pick up and push the truck forward, instead of the truck bumping the paver. This method helps to minimize screed marks and roughness. End dumps and if used, live bottom trucks, should raise their beds slightly so that the mix slides up against the closed tailgate, then open the gates to discharge the mix in a single mass. This "floods" the paver hopper and helps to minimize potential for mix segregation.

Figure 4-1: Unloading RAC-G Into Paver Hopper

4.3.2.2 *Unloading Hot Mix Into A Material Transfer Vehicle.* This is easier, because MTVs also have a front hopper to receive the mix, but eliminate the problem of bumping the paver. The same method of discharge should be used to flood the MTV hopper as a paver hopper.

4.3.2.3 *Load Tickets. Load tickets should be collected when the mix is discharged from the haul truck.* Yield calculations are typically used to verify overall thickness based on total tonnage and area paved. The standard for DGAC is about 58.6 kg/square meter/25 mm of thickness (12 pounds/square foot/inch). RAC-G is about 5 percent lighter, as the higher binder content reduces the proportion of stone.

Hot Mix Placement

Placement of asphalt rubber materials or any AC materials requires good paving practices. Temperature is critical, for proper placement of all AC materials. Asphalt rubber binders are stiffer than conventional paving asphalt at the customary placement and compaction temperatures, so time available for compaction of modified materials is typically shorter than for conventional DGAC mixtures. How much shorter depends on a number of variables that are discussed in section 4.5 on Compaction.

Caltrans special provisions for RAC-G specify minimum atmospheric and pavement surface temperatures of 13°C (55°F) for mixture placement. When atmospheric and pavement surface temperatures are less than 18°C (64°F), spread (lay down) temperature for RAC-G is specified as 143 to 163°C (290 to 325°F). For site temperatures ≥18°C (64°F), RAC-G is to be spread at temperatures from 138 to 163°C (280 to 325°F). Because of the importance of temperature in achieving adequate RAC compaction, operating in the upper half of these respective temperature ranges is strongly recommended.

Asphalt rubber paving materials should not be placed during rain or when rain is imminent. If site conditions are wet, windy, or too cold, placement should be delayed until environmental conditions improve. Otherwise significant problems in achieving adequate compaction should be expected to occur. Weather conditions may change during the paving operation. If necessary, paving should be stopped until conditions improve.

4.3.3 *Paver Operations*

Paver operations for RAC should not differ from those commonly used for conventional AC, except perhaps for paying closer attention to the temperature of the mix in the hopper. It is important to the quality of the finished product that the paver be operated so as to minimize starting and stopping. The importance of coordinating mix delivery with placement cannot be overemphasized. A consistent paver speed, even if relatively slow, helps maintain a uniform head of material and to control thickness. Care should be taken to dump (fold) the paver wings before mix collected in the corners cools enough to form chunks. However, wings should *never* be dumped into an empty hopper. Slat conveyors should not be allowed to run empty or nearly so.

Examples of Good Paving Practices

Use appropriate and properly maintained equipment operated by responsible, well-trained personnel.

Comply with plans and specifications, and pay attention to details.

Handle the mix so as to minimize segregation by particle size or temperature.

Maintain mix temperature by using tarps and/or insulated beds on haul trucks.

Deliver the mixture as a free flowing, homogeneous mass without segregation, crusts, lumps, or significant binder drain-off.

Coordinate mix production, delivery and paving operations to provide a smooth uninterrupted flow of material to the paver. MTVs may be used to minimize effects of variations in delivery. Ideally, the paver should never stop on the new mat.

Attention to cold and hot, longitudinal and transverse joints during placement and compaction.

Use sufficient rollers to achieve adequate breakdown and intermediate compaction and to complete finish rolling within the temperature limits for these operations.

Raking and Handwork

Asphalt rubber mixtures are not particularly amenable to raking or

handwork. The relatively coarse RAC-G aggregate gradation and stiffer binder make handwork a problem, and may affect the appearance of joints. Handwork and raking of RAC should be minimized, but if required, should be performed immediately before the mix has time to cool. The higher asphalt rubber binder content of RAC-O-HB makes raking and handwork a little easier. Broadcasting of the mix at joints is not considered good practice and should not be done.

The lack of fines in the gap and open graded mixes can create a somewhat rough and open-looking texture, even when placed by machine. RAC placed by hand may not provide a pleasing appearance even if the workmanship is excellent and the best practice is applied.

4.3.4 *Joints*

AC joints are typically defined as longitudinal or transverse, cold or hot. Butt joints are most typical and the practices presented apply to those. Some agencies have adopted wedge joints and/or skewed joints that are not discussed in this Guide.

4.3.4.1 *Longitudinal Joints* are most likely to be cold joints. To provide a good bond with the adjacent pavement, remove any loose material and tack the vertical edge prior to placing hot mix. To minimize need for raking, it is important to set both the screed overlap and height carefully on the adjacent pass. The screed should overlap the cold material by only about 25 to 38 mm (1 to 1.5 inches). The screed should be set above the elevation of the cold side by approximately 6 mm for each 25 mm (1/4 inch for each inch) of compacted pavement thickness being placed. Compacted thickness of RAC is generally 30 to 60 mm (1.2 to 2.4 inches) so the differences in height would range from about 7 to 14.4 mm (0.3 to 0.6 inches). This is relatively small compared to maximum stone size in the mix. Since it is difficult to feather RAC mixtures, some raking may be unavoidable. Extra material should be raked onto the hot side, not the cold.

If the mix is placed by hand rather than machine, the height difference for compaction should be increased to 9.5 mm for each 25 mm (3/8 inch for each inch). The height difference may vary among mixes, so experience and engineering judgment should be used as appropriate.

4.3.4.2 *Transverse Joints.* These may be hot or cold. Hot joints should be treated the same as for conventional DGAC, but the RAC mix will stiffen more quickly. Cold joints should be treated as described for longitudinal joints. Most often, transverse joints are constructed at the end of the paving day or when a lane is finished, using a bulkhead or Kraft paper to provide a vertical butt joint. If the paver runs out the mix, the joint should be constructed where the full compacted thickness is available, and the rest of the mix placed past that point should be removed and wasted. Ideally, transverse joints should be rolled in a transverse direction. This is usually not practical and they are generally rolled longitudinally.

4.4 HOT MIX COMPACTION

Compaction is essential to the performance of any asphalt pavement. Although asphalt rubber mixtures are very forgiving materials, even they require adequate compaction to achieve the desired performance and durability. The best materials, mix designs, and placement techniques cannot compensate for adverse effects resulting from poor compaction during construction.

The coarse aggregate structure and stiff asphalt rubber binders in RAC-G mixes may require increased compaction effort over conventional DGAC. Compaction depends primarily on temperature and compactive effort. Breakdown compaction of RAC-G mixtures should always be performed in the vibratory mode. This is not necessarily true for RAC-O. Open-graded mixtures respond differently to compaction, and are typically only placed in very thin lifts about 24 to 30 mm (0.08 to 0.1 ft) thick, with only a couple of compaction passes by breakdown and static rollers. Vibratory compaction is not typically used for thin lifts of RAC-O.

4.4.1 *Temperature Requirements*

According to the Special Provisions for RAC-G, when atmospheric and pavement surface temperatures are less than 18°C (64°F), breakdown compaction must be completed before the mat temperature drops below 127°C (260°F). For site temperatures ≥18°C (64°F), breakdown compaction must be completed before the mat temperature drops below 121°C (250°F). ***However, it is strongly recommended that breakdown compaction of RAC-G should be completed before the temperature of the RAC mat drops below 143°C (290°F).*** It is also recommended that mat temperature be closely monitored during placement and compaction, and that adjustments be made as needed to speed up the compaction process. It may be necessary to add a second breakdown roller. Inability to perform breakdown rolling within the temperature range specified may be cause to terminate paving operations and reject loads. Also, vibratory rolling below the minimum breakdown rolling temperature should not be allowed, nor should vibratory rolling after static (finish) rolling.

Factors That Affect AC Compaction

Compaction is affected by many factors including:

- Layer thickness,
- Air temperature,
- Pavement/ base temperature,
- Mix temperature,
- Wind velocity, and
- Sunlight or lack thereof.

Thin lifts, cool temperatures and wind reduce the time available for compaction because of temperature loss. Therefore, it is often easier to compact thick lifts (>50 mm (2 inches) thick) than thin ones. The rule of thumb is that the compacted thickness should be at least twice the maximum aggregate size, or three times the nominal maximum aggregate size. Otherwise, there may be problems with compaction due to a tendency for stones to stack and to catch under the screed and be dragged through the mat. When stones stack, they tend to reorient with each paver pass, or to break.

When placing asphalt rubber mixtures, it is important for the breakdown roller to follow immediately behind the paver in order to achieve 95 percent of the required compaction during the vibratory breakdown while the mix is still hot. The number of vibratory coverage required may vary depending on the mix and site conditions during placement. The anticipated roller coverages may need to be adjusted based on temperature and wind conditions. Therefore, it is advisable to use two breakdown rollers to keep up with the paver and to obtain sufficient compaction. Intermediate rolling provides relatively little increase in density of RAC mixes.

4.4.2 *Test Strips and Rolling Patterns*

California Test Method 113 is required for pavements with thickness ≥ 60 mm (2.4 inches) to establish the engineer's approval of equipment and rolling pattern based on achieving a minimum of 95 percent compaction relative to the mix design value. Sixty mm is the upper limit of RAC thickness, so CT 113 may not be required for most RAC pavements although it would be useful. Test strips for thinner RAC lifts are recommended when feasible to indicate what level of compaction effort is needed to achieve adequate in-place density. However, when CT 113 is used, the temperature ranges for the test must be modified for RAC-G. During test strip compaction, both Contractor and agency representatives should correlate their respective nuclear gauge(s) on the test strip according to CT 375.

Gauge data should then be correlated with core results in order for nuclear density to provide accurate data for quality control during paving.

A Paving Check List is included in Appendix A. This handout should be delivered to the contractor for distribution to all members of the construction staff as well as to the Inspector.

4.5 CHIP SEAL CONSTRUCTION

Chip seals are extremely sensitive to construction operations and site conditions, including ambient air temperature and temperatures of the cover aggregate, and underlying pavement. There are only minor practical differences in construction of conventional hot chip seals versus asphalt rubber chip seals. The primary difference is that the asphalt rubber membrane is thicker and chips must be large enough so as not to be "swallowed" by the membrane. The other is that the distributor nozzles may have a greater tendency to clog due to the presence of discrete rubber particles. This is addressed by appropriate nozzle sizing.

Temperature is absolutely critical to successful chip seal construction whether using conventional paving grade asphalt or asphalt rubber as the binder. Clean or precoated (preferably) hot chips are also critical. Embedment and adhesion of the chips must be accomplished while the asphalt rubber membrane is still hot. A reasonable production rate is about 5-7 lane miles per day.

4.5.1 *Chip Seal Equipment*

The equipment required to place a chip seal includes:

- Distributor truck with fume hood to spray apply asphalt rubber membrane
- Chip Spreader
- Haul trucks for chips
- Roller(s): Because the surface of the chip seal is the cover aggregate, rubber tired rollers may be used to embed the aggregate and are recommended for their kneading action.
- Hand tools (broom, shovels, etc.).
- Power broom
- Distributor truck to apply a flush coat (typically diluted emulsion)

4.5.2 *Asphalt Rubber Spray Application*

The distributor must be properly adjusted and operated to apply the proper amount of asphalt rubber binder uniformly over the surface. As for the tack coat, fanning and overlap is necessary to apply the membrane. The nozzle (snivy) size, spacing, and angle in relation to the spray bar help determine the height of the bar. Streaking may occur if the asphalt rubber binder is too cold, when its viscosity is too high, or the spray bar too low. The person who monitors the application for uniformity and nozzle problems is protected from fumes by a pollution hood over the spray bar. Application rate according to Caltrans special provisions is 2.5 to 3.0 l/m^2 and the Resident Engineer determines the exact rate.

Each spray application should start and end on paper (tar paper or roofing felt if possible) to ensure uniformity for the entire application. The application width should be adjusted so that the longitudinal joint (meet-line) is not in the wheel path, but on the centerline or in the center or edge of the driving lanes.

After each application, the distance, the width, and the amount of asphalt rubber should be determined to verify the application rate.

4.5.3 *Chip Application*

The hot pre-coated chips should be applied immediately behind the asphalt rubber binder spray; the chip spreader should follow at a maximum distance of about 20 to 30 meters (65 to 100 feet). The asphalt rubber binder must be fluid so the rock will be embedded by the displacement of the asphalt, preferably to 50 to 70 percent embedment. A chip seal train consisting of binder distributor truck, chip spreader, and roller is shown in Figure 4-2.

Figure 4-2: Chip Seal Train

The standard chip application rate is 15 to 22 kg/m^2, with the exact rate to be determined by the Engineer. Trucks should back into the spreader box and should not cross over any exposed asphalt rubber membrane. This is illustrated in Figure 4-3; the chip spreader is in the foreground of the photo, and the raised bed of the haul truck can be seen behind the spreader. The speeds and loads of the trucks hauling the chips should be regulated to prevent damage to the new seal. They should turn as little as possible on the new seal.

Figure 4-3: Spreading Precoated Aggregates

The chip spreader should be operated at a speed that will prevent the cover aggregate from being rolled as it is being applied. The aggregate supply should be controlled to assure a uniform distribution across the entire box. If an excess of aggregate is spread in some areas, it should be distributed on the adjacent roadway surface or picked up. However, excess application usually interferes with embedment and adhesion and may lead to future problems with chip loss. Areas that do not get enough aggregate cover (about 85 percent of the total membrane area is a reasonable target) should be covered with additional aggregate (normally by hand), but problems with adhesion may occur, because by then the asphalt rubber has cooled.

4.5.4 *Rolling Asphalt Rubber Chip Seals*

Pneumatic rollers are normally used for rolling chip seals because the kneading action of the rubber tires promotes embedment. The tires do not bridge across surface irregularities and depressions, as do steel drums.

Skirts around the tires can help maintain elevated tire temperature to aid compaction. Rolling of a chip seal is done to orient and embed the rock (get the flat sides down). Rollers should be operated at slow speeds of 6 to 10 kph (4 to 6 mph) so that the rock is set, not displaced. The number of rollers required depends on the speed of operation, as it takes 2 to 4 passes of the roller to set the rock (Figure 4-4).

Figure 4-4: Rubber-Tired Rollers With Skirts On Chip Seal

4.5.5 *Sweeping*

Sweeping (brooming) is done at the completion of chip sealing to remove surplus aggregate from the surface of the new chip seal to minimize flying rocks. Sweeping can be done shortly after application, usually within 30 minutes. It is desirable to sweep during the cool period of the day using a rotary power broom (Figure 4-5).

Figure 4-5: Sweeping Chip Seal To Remove Loose Cover Aggregate

Figure 4-6: Finished Chip Seal Before Applying Fog Seal and Sand

4.5.6 *Flush Coat*

The flush coat consists of an application of fog seal over the new asphalt rubber chip seal followed by a sand cover.

4.5.6.1 *Fog seals* are applied over chip seals to help retain the cover aggregate and provide a more uniform appearance. Fog seals are not applied over SAMI-R because it will be covered with an overlay. Fog seals typically consist of grade CSS-1, CSS-1h, or CQS-1 asphalt emulsion diluted with 50 percent added water. The standard application rate over asphalt rubber chip seals is 0.14 to 0.27 l/m^2 or as determined by the Engineer.

4.5.6.2 *Sand cover* is applied immediately after application of the fog seal to prevent pick up and tracking of the chip seal material by vehicle tires. The sand must be clean (free of clay fines or organic material). It is spread in a single application of 1 to 2 kg/m^2, or at a rate determined by the Engineer.

4.5.7 *Traffic Control*

Some form of traffic control is required to keep the initial traffic speed below about 40 kph (25 mph). Flag persons or signs help, but the most positive means is a pilot car. The primary purpose of the pilot car is to control the speed of the traffic through the project. This traffic will also supply some additional pneumatic tire rolling and kneading action.

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APPENDIX A

Checklists

CHECKLIST OF MATERIALS SUBMITTALS

I. BINDER

A. Binder Formulation ❑

1) Paving Asphalt and Modifiers - % of Total Binder
   a) % Asphalt of Paving Asphalt
   b) % Extender Oil of Paving Asphalt
2) Crumb Rubber Modifier (CRM) - % of Total Binder
   a) % Scrap tire rubber of total rubber
   b) % Natural rubber of total rubber, based on
      i) Specification, and
      ii) Chemical Analysis of natural rubber

B. Rubber Test Documentation ❑

1) Chemical analysis of natural rubber
2) Chemical analysis of scrap tire rubber
3) Fiber content for both types
4) Gradations of tire rubber
5) Gradations of natural rubber

C. Certification of Compliance/Specific Product and Project ❑

1) Asphalt Cement incl. Source and Grade
2) Extender Oil incl. Source and Type ID
3) Scrap Tire Rubber including Source and Type ID
4) Natural Rubber including Source and Type ID

D. Rubber Samples (Needed for matching with materials at plant) ❑

1) Scrap Tire rubber
2) Natural rubber

E. Laboratory Tests for Asphalt Rubber Binder ❑

1) Penetration
2) Resilience
3) Softening Point
4) Viscosity

F. Two binder samples ❑

II. AGGREGATE ❑

A. LA Rattler
B. Crushed Faces
C. Sand Equivalent*
D. K_c and K_f *

III. MIX DESIGN ❑

A. Target gradations within specification
B. Binder content vs. air voids plot (Form TL-306)*
D. Selected binder content (corresponding to specified air voids)
E. Show recommended range (+0%/-.3%)*
G. Stabilometer value*
H. VMA*
I. Target Gradations for specified sieves
J. Bin percentages and sieve analyses for each

** Not applicable to chip seals.*

CHECKLIST FOR PAVING AND CHIP SEALS

I. HOT MIX

A. Pre-Spread ❑

1. Functional heater element for hot asphalt tack.
2. Uniform application of tack, at agreed rate of __________.

C. Joints at proper locations (traffic lane lines or clear of wheel paths in center of lane).

D. Proper thickness at 0" grind point (screed break at grade break).

B. Compaction Equipment (Steel drum) ❑

1. Vibratory roller for (breakdown) and another vibratory for backup
2. Intermediate roller of the same or greater width than the breakdown roller
3. Finish roller

C. Compaction Process

4. No vibratory mode when mat temperature is below 121°C (250° F)
5. Intermediate roller operating at all times during paving?

D. Post Compaction ❑

1. Sand cover is required, but cannot be applied until compaction is complete except as authorized by Caltrans in special circumstances.

II. CHIP SEALS

A. Pre-Spread ❑

1. Pavement is clean and dry.
2. Pavement temperature in shade above 13° C (55°)
3. Air temperature above 16°C (60°).
4. Hot asphalt coated rocks on site
5. Nominal size chip size 9.5 mm (3/8") or 12.5 mm (1/2")
6. Trucks lock onto hitch of aggregate spreader
7. 3 rubber tire rollers (two if equivalent coverage), all functional
8. One functional 8-10 ton steel wheel roller
9. Sweeper functional
10. Joints are positioned to avoid wheel paths

B. Spread ❑

1. Binder application temperature
2. Binder application rate
3. Chip spreader following immediately behind (20-30 m) distributor truck
4. Chip application rate
5. Lead roller follows immediately behind (20-30 m) chip spreader
6. Number of coverage's by rubber tire rollers
7. Joints thoroughly swept 150 mm (6") from edge prior to overlapping application
8. Overlapping nozzle angled to cut back application rate at joints
9. Overlap at longitudinal joints, 102 mm (4") maximum

C. Post-Spread ❑

1. Sweep loose aggregate

**Falling out of compliance with these parameters will be cause to halt paving operations until reconciled.*

APPENDIX H – TEXAS SPECIFICATIONS FOR ASPHALT RUBBER HOT MIX ASPHALT

ITEM 318

HOT ASPHALT-RUBBER SURFACE TREATMENTS

318.1. Description. This Item shall govern for the construction of a surface treatment composed of a single or double application of hot asphalt-rubber material, each covered with aggregate, constructed on existing pavements or on the prepared base course or surface in accordance with these specifications.

318.2. Materials. All materials shall conform to the pertinent material requirements of the following Items:

Item 300, "Asphalts, Oils and Emulsions"

Item 302, "Aggregate for Surface Treatments"

Item 303, "Aggregate for Surface Treatments (Lightweight)"

(1) Asphaltic Materials.

(a) Asphalt Cement. The asphalt cement shall be of the type and grade shown on the plans or designated by the Engineer.

(b) Tack Coat. Cut-back asphalt may not be diluted with gasoline and/or kerosene. Emulsions may be diluted with the addition of water, with the approval of the Engineer.

(2) Rubber. The rubber shall be Type I or Type II and shall meet the requirements specified in "Properties of Rubber Used in Sealer" in Section 300.2.(8).(b).

The ground rubber may contain up to four (4) percent by mass of a dusting material such as calcium carbonate to prevent the particles from sticking together. The rubber, irrespective of diameter, shall not be greater than six (6) millimeters in length and shall not have a moisture content in excess of two (2) percent by mass.

(3) Diluent. The diluent shall be a hydrocarbon distillate complying with the following requirements when tested in accordance with ASTM D 86:
Initial Boiling Point, °C, Minimum . . . 170
End Point, °C, Maximum 315

(4) Extender **Oil.** The extender oil shall be a high-flash, resinous aromatic type which, when blended with the asphalt cement, will result in a mixture with an absolute viscosity of 60 - 200 pascal·second at 60 °C. Sampling and testing will be in accordance with Test Method Tex-528-C.

(5) Aggregate**.** The aggregate shall be of the types and grades as shown on the plans.

318.3. Equipment.

(1) Distributor. The distributor shall be a self-propelled pressure type, equipped with an asphaltic material heater and a distributing pump capable of pumping the material at the specified rate through the distributor spray bar. The distributor spray bar shall be capable of fully circulating the asphaltic material. The distributor spray bar shall contain nipples and valves so constructed that the nipples will not become partially plugged with congealing asphaltic material, in order to prevent streaking or irregular distribution of asphaltic material. Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, and a thermometer for reading the temperature of tank contents. The distributor shall be capable of keeping the rubber in uniform suspension and adequately mixing the asphalt, rubber, and diluent or oil.

The distributor may be equipped with an onboard scale system. If this system is used for proportioning and/or measurement and payment, it shall be capable of weighing the load within an accuracy of 0.4 percent and shall meet the requirements of Item 520, "Weighing and Measuring Equipment". The method and equipment for combining the rubber and asphalt shall be so designed and accessible that the Engineer can readily determine the percentages, by mass, of each of the materials being incorporated into the hot asphalt-rubber material.

When a uniform application of asphaltic material is not being achieved, the Engineer may require that the spray bars on the distributor be controlled by an operator riding in such a position at the rear of the distributor that the operation of all sprays is in full view.

(2) Aggregate Spreader. A self-propelled continuous-feed aggregate spreader shall be used which will uniformly spread aggregate at the rate specified by the Engineer.

(3) Rollers. Rolling equipment shall meet the governing specifications for Item 210, "Rolling (Flat Wheel)" and Item 213, "Rolling (Pneumatic Tire)". A minimum of three pneumatic tire rollers shall be required for the hot asphalt-rubber surface treatment unless otherwise directed by the Engineer.

(4) Broom. The broom shall be a rotary, self-propelled power broom for cleaning existing surfaces.

(5) Aggregate. Heating System. The system for heating the aggregate shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the heating operations. The burner, or combination of burners, and type of fuel used shall be such that in the process of heating the aggregate to the specified temperature, no residue from the fuel shall adhere to the heated aggregate. A continuous recording thermometer shall be provided which will indicate the temperature of the aggregate when it leaves the heating system.

(6) Truck Scales. A set of standard platform truck scales, conforming to Item 520, "Weighing and Measuring Equipment", shall be placed at a location approved by the

Engineer. This requirement is waived if the distributor has an adequate calibrated scale system on board.

(7) **Asphalt Storing and Handling Equipment.** All equipment used in storing or handling asphaltic material shall be kept clean and in good operating condition at all times and shall be operated in such a manner that there will be no contamination of the asphaltic material. The Contractor shall provide and maintain a recording thermometer to continuously indicate the temperature of the asphaltic material at the storage heating unit.

(8) Vehicles used for hauling aggregate shall be of uniform capacity unless otherwise authorized by the Engineer.

318.4. Construction Methods.

(1) **General.** Temporary stockpiling of aggregates on the right of way will be permitted, provided that the stockpiles are so placed as to allow for the safety of the traveling public and not obstruct traffic or sight distance, and do not interfere with access from abutting property, nor with roadway drainage.

The aggregate placement sites will be subject to the approval of the Engineer.

Location of stockpiles shall be either a minimum of ten (10) meters from the edge of the travel lanes or shall be signed and barricaded as shown on the plans.

Surface treatments shall not be applied when the air temperature is below 25 °C and is falling, but may be applied when the air temperature is above 20 °C and is rising, the air temperature being taken in the shade and away from artificial heat. Surface treatments shall not be applied when the temperature of the surface on which the surface treatment is to be applied is below 20 °C. Hot asphalt-rubber material shall not be placed when general weather conditions, in the opinion of the Engineer, are not suitable.

The aggregate shall be surface dry before application unless otherwise directed by the Engineer.

When shown on the plans, the cover aggregate shall be preheated to a temperature between 120 °C and 175 °C. Canvas or similar covers that completely cover each load shall be used to minimize the temperature drop of the preheated cover aggregate, if directed by the Engineer.

When directed by the Engineer, a tack coat shall be applied prior to applying the hot asphalt-rubber treatment on an existing wearing surface. Application of tack coat shall be in accordance with Subarticle 340.6.(2).

If a job delay results after the full reaction described below has occurred, the asphalt-rubber mixture may be allowed to cool but shall be slowly reheated to an acceptable spraying temperature just prior to application. If, in the opinion of the Engineer, the asphalt-rubber mixture has been damaged by excessive or prolonged heating, the mixture shall not be used.

The Contractor shall show proof that his equipment is capable of mixing the asphaltic material and rubber to achieve the required consistency, or demonstrate the ability to achieve this consistency by placing a test section at a location acceptable to the Engineer.

The Contractor may use a mixture of asphalt cement, diluent (if needed) and Type I rubber or a mixture of asphalt cement, extender oil (if needed) and Type II rubber.

(2) Mixing.

(a) Mixture of Asphalt Cement, Type I Rubber and Diluent (if needed). The proportions by mass of the asphalt cement and rubber in the mixture shall be 75 percent plus or minus two (2) percent and 25 percent plus or minus two (2) percent, respectively.

The temperature of the asphalt cement shall be between 175 °C and 215 °C during the addition of the rubber. The asphalt cement and rubber shall be carefully combined, mixed and reacted. The reaction period shall be at least 30 minutes after all rubber has been added. At the direction of the Engineer, the reaction period shall be extended to obtain the desired properties in the asphalt-rubber mixture. The temperature of the resulting asphalt-rubber mixture shall not be less than 163 °C during the reaction period.

Just prior to application, diluent up to a maximum amount of 7-1/2 percent by volume of the hot asphalt-rubber mixture may be added as required to obtain optimum viscosity for spray application and better "wetting" of the cover aggregate.

The temperature of the asphalt-rubber mixture and diluent shall be adjusted to obtain the proper application characteristics, but shall not exceed 175 °C.

(b) Mixture of **Asphalt Cement, Extender Oil (if needed) and Type II Rubber.** The proportions by mass of the asphalt cement (including extender oil, if needed) and rubber in the mixture, shall be 78 percent, plus or minus two (2) percent, and 22 percent, plus or minus two (2) percent, respectively. The asphalt cement and extender oil (if needed) shall be combined and heated to a temperature of not less than 200 °C.

After the asphalt cement and extender oil have reached the proper consistency, the rubber shall be added, thoroughly mixed and allowed to react. The reaction period shall be at least 30 minutes after all rubber has been added. Temperature of the material during the reaction period shall be 190 °C to 220 °C.

The temperature of the asphalt-rubber mixture shall be adjusted to obtain the proper application characteristics, but shall not exceed 220 °C.

(3) Application. The mixture shall be applied on the approved, prepared surface with a specified self-propelled **pressure** distributor so operated as to distribute the material at the rate specified, evenly and smoothly, under a pressure necessary for proper distribution. Aggregate shall be immediately and uniformly applied and spread by the specified aggregate spreader, unless otherwise authorized by the Engineer.

The rates shown on the plans for hot asphalt-rubber and aggregate are for estimating purposes only. The rates may be varied as directed by the Engineer.

Hot asphalt-rubber material shall be applied in a width not to exceed four (4) meters, unless otherwise shown on the plans. The width may be reduced if uniformity of distribution is not achieved. The Contractor shall be responsible for uniform application of the hot asphalt-rubber material at the junction of distributor loads. Paper or other suitable material shall be used to prevent overlapping of transverse joints. Longitudinal joints shall match lane lines unless otherwise authorized by the Engineer. Application of hot asphalt-rubber material will be measured as necessary to determine the rate of application. Hot asphalt-rubber material shall not be applied until immediate covering with aggregate at the proper temperature is assured.

After applying the aggregate the entire surface shall be broomed, bladed or raked when required by the Engineer and shall be thoroughly rolled with the type or types of rollers specified herein or as shown on the plans.

The finished surface shall be cleared by the Contractor of any surplus aggregate by sweeping or other approved methods after all rolling is completed.

The Contractor shall be responsible for the maintenance of the surface until the work is accepted by the Engineer.

Prior to final acceptance of the project, aggregate stockpiles deemed undesirable by the Engineer shall be removed by the Contractor. The temporary stockpile areas shall be left in a neat condition satisfactory to the Engineer. Aggregate stockpiles remaining on the State's right of way 30 days after the final acceptance of the project will become the property of the Texas Department of Transportation.

318.5. Measurement. Hot asphalt-rubber mixture will be measured by the megagram including asphalt, rubber, and diluent (or extender oil); weighed upon completion of the mixing and just prior to delivery to the point of application and tared immediately after application. If the distributor is equipped with onboard scales, the weighing will be immediately before and after each application.

Aggregate will be measured by the cubic meter in vehicles, as applied on the road.

318.6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit prices bid for "Hot Asphalt-Rubber" and "Aggregate" of the type and grade specified. These prices shall be full compensation for cleaning the existing surface; for furnishing all materials including tack coat and freight involved; for all heating, mixing, hauling and placing all materials, including tack coat; for rolling, removing excess aggregate and cleaning up stockpile areas; and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work including royalties, permits costs, etc., and test sections.

APPENDIX I – ARIZONA SPECIFICATIONS FOR ASPHALT RUBBER HOT MIX ASPHALT

(1005PG, 03/11/99)

SECTION 1005 - BITUMINOUS MATERIALS FOR SURFACING: of the Standard Specifications is revised to read:

1005-1 General Requirements:

Bituminous materials shall conform, when tested in accordance with the tests hereinafter enumerated, to the following requirements, as applicable, for the types and grades designated and used.

Certificate of Compliance conforming to the requirements of Subsection 106.05 shall be submitted.

1005-2 Sampling of Bituminous Material:

Sampling of bituminous material shall conform to the requirements of AASHTO T 40. Samples shall be taken by the contractor and witnessed by the Engineer. The point of sampling and the number of samples will be specified by the Engineer.

The contractor shall provide convenient facilities for obtaining accurate samples of bituminous material.

1005-3 Bituminous Material Requirements:

1005-3.01 Asphalt Cement:

Asphalt cement shall be a performance grade (PG) asphalt binder conforming to the requirements of AASHTO Provisional Standard MP 1a-03. The pressure aging temperature shall be **XXX** °C.

A minimum of seven working days prior to the start of asphaltic concrete production, the contractor shall provide the Engineer a four-liter sample of the proposed asphalt binder and Certificate of Analysis showing complete AASHTO Provisional Standard MP 1a-03 asphalt binder testing. Laboratory-prepared samples will not be acceptable. Asphaltic concrete production shall not begin until the Engineer determines the acceptability of the proposed asphalt binder.

If, during asphaltic concrete production, it is determined by testing that asphalt cement fails to meet the requirements of AASHTO Provisional Standard MP 1a-03 for the specified grade, the asphaltic concrete represented by the corresponding test results shall be evaluated for acceptance. Should the asphaltic concrete be allowed to remain in place, the contract unit price will be adjusted by the percentage shown in Table 1005-1. Should the asphalt cement be in reject status, the contractor may supply an engineering analysis of the expected performance of the asphaltic concrete in which the asphalt cement is incorporated. The engineering analysis shall detail any proposed corrective action and the anticipated effect of such corrective action on the performance. Within three working days, the Engineer will determine whether or not to accept the contractor's proposal. If the proposal is rejected, the asphaltic concrete shall be removed and replaced with asphaltic concrete meeting the requirements of the applicable specifications at no additional expense to the Department. If the contractor's proposal is accepted, the asphalt concrete shall remain in place at the applicable percent of contract unit price allowed, and any necessary corrective action shall be performed at no additional cost to the Department.

1005-3.02 Liquid Asphalt:

Liquid asphalt shall conform to the requirements of AASHTO M 82, Cut-back Asphalt (Medium Curing Type).

Adjustments in the contract unit price, in accordance with the requirements of Table 1005-2, will be made for quantities of material represented by the corresponding test results.

1005-3.03 Emulsified Asphalt:

Emulsified asphalt shall conform to the requirements of Table 1005-3 for Anionic Rapid Set (RS-1, RS-2), Anionic Slow Set (SS-1), Cationic Rapid Set (CRS-1, CRS-2) and Cationic Slow Set (CSS-1).

Emulsified asphalts shall be homogeneous. If emulsified asphalt has separated, it shall be thoroughly mixed to insure homogeneity. If emulsified asphalt has separated due to freezing, it shall not be used. Emulsified asphalt shall not be used after 30 days from delivery.

1005-3.04 Emulsified Asphalt (Special Type):

Emulsified asphalt (special type) shall consist of Type SS-1 or CSS-1 diluted with water to provide an asphalt content not less than 26 percent. The material may be diluted in the field.

1005-3.05 Recycling Agents:

Recycling agents shall conform to the requirements of Table 1005-4.

1005-3.06 Emulsified Recycling Agents:

Emulsified recycling agents shall conform to the requirements of Table 1005-5.

1005-3.07 Other Requirements:

Other requirements for bituminous materials shall conform to the requirements of Table 1005-6.

TABLE 1005-1
ASPHALT BINDER PAY ADJUSTMENT TABLE

Test Property	Test Value	Percent of Contract Unit Price Allowed
Dynamic Shear of Original Binder, G*/Sin δ, kPa	0.90 - 0.99 0.70 - 0.89 Less than 0.70	95 85 70 †
Dynamic Shear of RTFO Binder, G*/Sin δ, kPa	2.00 - 2.19 1.60 - 1.99 Less than 1.60	95 85 70 †
Dynamic Shear of PAV Binder, G*Sin δ, kPa	5001 - 5500 5501 - 7000 7001 - 8000 More than 8000	95 85 75 65 †
Creep Stiffness of PAV Binder, S, Mpa	301 - 330 331 - 450 451 - 600 More than 600	95 85 75 65 †
m-value at 60 sec.	0.270 - 0.299 0.230 - 0.269 Less than 0.230	95 80 65 †

† Reject Status: The price adjustment applies if the asphaltic concrete is allowed to remain in place.

Notes:

Specified properties in AASHTO Provisional Standard MP1 for flash point, viscosity at 135 °C, and mass loss are not considered performance related. Specification deficiencies for these properties shall be cause for a work stoppage until specification properties are met, but will not be cause for a pay adjustment.

Should the bituminous material be deficient on more than one property, the price adjustment will be the greatest adjustment possible considering individual test results.

The information presented in this table does not apply to asphalt cement used for tack coats.

TABLE 1005-2 **MC LIQUID ASPHALT**		
Grade	Viscosity, mm^2/s, Deviations	Percent of Contract Unit Price Allowed
70	70 – 140 63 - 69 or 141 - 154 52 - 62 or 155 - 175 Less than 52 or greater than 175	100 90 75 60 (1)
250	250 - 500 225 - 249 or 501 - 550 187 - 224 or 551 - 625 Less than 187 or greater than 625	100 90 75 60 (1)
800	800 – 1600 720 - 799 or 1601 - 1760 600 - 719 or 1761 - 2000 Less than 600 or greater than 2000	100 90 75 60 (1)
3000	3000 - 6000 2700 - 2999 or 6001 - 6600 2250 - 2699 or 6601 - 7500 Less than 2250 or greater than 7500	100 90 75 60 (1)

(1) If allowed to remain in place.

Note: Since volatile solvents utilized in the manufacture of MC Liquid Asphalt may volatilize in varying amounts during normal transporting, handling, and storage operations, whenever such Liquid Asphalts are used for prime coats or curing seals, deviations from the maximum specification limits greater than those listed may be permitted when justified. In such cases, when material is allowed to remain in place, 60% of the contract unit price is allowed.

TABLE 1005-3 EMULSIFIED ASPHALTS							
Test On Emulsions	Test Method (1)	Requirement					
		RS-1	CRS-1	RS-2	CRS-2	SS-1	CSS-1
Viscosity, Saybolt Furol, seconds, range:	T 59						
25 °C		20-100				20-100	20-100
50 °C			20-100	50-400	50-400		
Settlement, 5 days, %, maximum	T 59	5	5	5	5	5	5
Sieve, Retained on 850-µm, %, maximum	T 59 (2)	0.10	0.10	0.10		0.10	0.10
Particle Charge	T 59		Pos.		Pos.		Pos. (3)
Demulsiability, 35 mL, 0.02 N calcium chloride, %, minimum	T 59	60		60			
Classification, Uncoated particles, %, min.	Ariz. 502				55		
Residue (4) Residue, %, minimum (5)		55	60	63	65	57	57

(1) T 59 is AASHTO
(2) Distilled water will be used instead of the two percent sodium oleate solution.
(3) If the Particle Charge Test result is inconclusive, material having a maximum pH value of 6.7 will be acceptable.
(4) Residue will be obtained in accordance with the requirements of Arizona Test Method 504 and shall conform to all the requirements of AASHTO Provisional Standard MP1 for PG 64-16, except that for CRS-2, the dynamic shear ($G^*/\sin\delta$) on the original residue shall be a minimum of 1.00 kPa and a maximum of 1.50 kPa.
(5) Residue by evaporation may be determined in accordance with the requirements of Arizona Test Method 512; however, in case of dispute, AASHTO T 59 will be used.

TABLE 1005-4 RECYCLING AGENTS									
Test On Recycling Agent	Test Method	Requirement							
		RA-1		RA-5		RA-25		RA-75	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity, 60°C, mm^2/s	T 201 (1)	100	200	200	800	1000	4000	5000	10 000
Flash Point, Cleveland Open Cup, °C, min.	T 48 (1)	170		190		220		230	
Saturate, by weight, %	D 2007		30		30		30		30
Asphaltenes, % (2)	D 2006-70		1.0		5.0		10.0		17.0
Chemical Composition: $\frac{N+A1}{P+A2}$ (3)	D 2006-70	0.2	1.0	0.2	1.2	0.2	1.4	0.2	1.6
Compatibility: $\frac{N}{P}$ (3)	D 2006-70	0.5		0.5		0.5		0.5	
Test on Residue (4) Weight Change, %			6.5		4		3		2
Viscosity Ratio (5)			3		3		3		3

(1) Are AASHTO; Others are ASTM
(2) Asphaltenes for RA-1 may be determined in accordance with the requirements of Arizona Test Method 505; however, in case of dispute, ASTM D 2006-70 shall be used.
(3) N = nitrogen bases; P = paraffins; A1 = first acidaffins; A2 = second acidaffins.
(4) Residue will be obtained in accordance with the requirements of AASHTO T 240.
(5) Viscosity Ratio:

$$\frac{\text{Viscosity of residue at 60 °C, mm}^2\text{/s}}{\text{Viscosity of recycling agent at 60 °C, mm}^2\text{/s}}$$

TABLE 1005-5 EMULSIFIED RECYCLING AGENTS					
Test on Emulsified Recycling Agent	AASHTO Test Method Except as Shown	Requirement			
		ERA-1	ERA-5	ERA-25	ERA-75
Viscosity, Saybolt Furol, 25 °C, seconds, range	T 59	15 - 40	15 - 100	15 - 100	15 - 100
Miscibility	T 59	Passes	Passes	Passes	Passes
Sieve Test, %, maximum	T 59 (1)	0.10	0.10	0.10	0.10
Particle Charge	T 59	Positive	Positive	Positive	Positive
Residue (2) Residue, %, minimum (3)		60	60	60	60

(1) Distilled water will be used instead of the two percent sodium oleate solution.

(2) Residue will be obtained in accordance with the requirements of Arizona Test Method 504 and shall conform to all requirements specified in Table 1005-4.

(3) Residue by evaporation may be determined in accordance with the requirements of Arizona Test Method 512; however, in case of dispute, AASHTO T 59 will be used.

TABLE 1005-6 OTHER REQUIREMENTS			
Grade of Asphalt Specification Designation	Range of Temperatures for Application by Spraying, °C	Range of and Max. Temperature of Aggregate for Plant Mixing, °C	Basis of Conversion Average Liters Per Metric Ton at 16 °C
Paving Asphalt	135 - 205	------	
PG 76-XX			968
PG 70-XX			972
PG 64-XX			981
PG 58-XX			985
PG 52-XX			993
Liquid Asphalt			
MC-70	40 - 80	30 - 70	1056
MC-250	60 - 110	50 - 90	1039
MC-800	80 - 125	70 - 110	1022
MC-3000	100 - 140	90 - 125	1006
Emulsified Asphalt		-----	1000
RS-1	20 - 60		
CRS-1	50 - 85		
RS-2	50 - 85		
CRS-2	50 - 85		
SS-1	20 - 70		
CSS-1	20 - 70		
Emulsified Asphalt (Special Type)	20 - 70	-----	1000
Recycling Agent (RA-1, RA-5, RA-25, RA-75)	-----	-----	1000
Emulsified Recycling Agent (ERA-1, ERA-5, ERA-25, ERA-75)	20 - 70	-----	1000

SECTION 1009 - ASPHALT-RUBBER MATERIAL:

1009-2.01(A) Asphalt Cement: of the Standard Specifications is revised to read:

Asphalt cement shall be a performance grade (PG) asphalt binder conforming to the requirements of Section 1005.

1009-2.03 Asphalt-Rubber Properties: of the Standard Specifications is revised to read:

Asphalt-rubber shall conform to the following:

Property	Requirement		
	Type 1	Type 2	Type 3
Grade of base asphalt cement	PG 64-16	PG 58-22	PG 52-28
Rotational Viscosity *; 177 °C; pascal seconds	1.5 - 4.0	1.5 - 4.0	1.5 - 4.0
Penetration; 4 °C, 200 g, 60 sec. (ASTM D 5); minimum	10	15	25
Softening Point; (ASTM D 36); °C, minimum	57	54	52
Resilience; 25 °C (ASTM D 5329); %, minimum	30	25	15
* The viscotester used must be correlated to a Rion (formerly Haake) Model VT-04 viscotester, using the No. 1 Rotor. The Rion viscotester rotor, while in the off position, shall be completely immersed in the binder at a temperature from 177 to 179 degrees C for a minimum heat equilibrium period of 60 seconds, and the average viscosity determined from three separate constant readings (± 0.5 pascal seconds) taken within a 30 second time frame with the viscotester level during testing and turned off between readings. Continuous rotation of the rotor may cause thinning of the material immediately in contact with the rotor, resulting in erroneous results.			

1009-3 Construction Requirements: of the Standard Specifications is modified to add:

During production of asphalt-rubber, the contractor shall combine materials in conformance with the asphalt-rubber design unless otherwise approved by the Engineer.

1009-3.01 Mixing of Asphalt-Rubber: the last paragraph of the Standard Specifications is revised to read:

Prior to use, the viscosity of the asphalt-rubber shall be tested by the use of a rotational viscotester, which is to be furnished by the contractor or supplier.

1009-3.02 Handling of Asphalt-Rubber: the first paragraph of the Standard Specifications is revised to read:

Once the asphalt-rubber has been mixed, it shall be kept thoroughly agitated during periods of use to prevent settling of the rubber particles. During the production of asphaltic concrete the temperature of the asphalt-rubber shall be maintained between 163 and 191°C. However, in no case shall the asphalt-rubber be held at a temperature of 163 C or above for more than 10 hours. Asphalt-rubber held for more than 10 hours shall be allowed to cool and gradually reheated to a temperature between 163 and 191°C before use. The cooling and reheating shall not be allowed more than one time. Asphalt-rubber shall not be held at temperatures above 121°C for more than four days.

1009-4 Method of Measurement: the title and text of the Standard Specifications are hereby deleted.

SECTION 414 – ASPHALTIC CONCRETE FRICTION COURSE (ASPHALT-RUBBER):

414-1 Description: the first paragraph of the Standard Specifications is revised to read:

Asphaltic Concrete Friction Course (Asphalt-Rubber), hereinafter asphaltic concrete, shall consist of furnishing all materials, mixing at a plant, hauling, and placing a mixture of aggregate materials, mineral admixture, and bituminous material (asphalt-rubber) to form a pavement course or to be used for other specified purposes, in accordance with the details shown on the project plans and the requirements of these specifications, and as directed by the Engineer.

414-3 Materials: of the Standard Specifications is modified to add:

For comparative purposes, quantities shown in the bidding schedule have been calculated based on the following data:

Spread Rate, kg/m^2	**XXXXX**
Bituminous Material, %	**XXX.X**
Mineral Admixture, %	1.0

The spread rate specified includes **XXX** percent for leveling to provide a minimum **XXXXX**-millimeter thickness above the leveling thickness. The exact spread rate will be determined by the Engineer.

414-3.02 Mineral Aggregate: the first paragraph of the Standard Specifications is revised to read:

Mineral aggregate shall be separated into at least two stockpiles. No individual stockpile usage shall be less than three percent of the total mineral aggregate.

Coarse mineral aggregate shall consist of crushed gravel, crushed rock, or other approved inert materials with similar characteristics, or a combination thereof, conforming to the requirements of these specifications.

414-3.02 Mineral Aggregate: table 414-1 of the Standard Specifications is revised to read:

TABLE 414-1 MIX DESIGN GRADING LIMITS FOR MINERAL AGGREGATE (Without Admixture)	
Sieve Size	**Percent Passing**
9.5 mm	100
4.75 mm	30 - 45
2.36 mm	4 - 8
75 µm	0 - 2.5

414-3.02 Mineral Aggregate: the "Combined Water Absorption", "Sand Equivalent", and "Crushed Faces" data lines in table 414-2 of the Standard Specifications are revised to read:

TABLE 414-2 MINERAL AGGREGATE CHARACTERISTICS		
Characteristic	**Test Method**	**Requirement**
Combined Water Absorption	Arizona Test Method 814	0 – 2.5%
Sand Equivalent	Arizona Test Method 242	Minimum 45
Fractured Coarse Aggregate Particles	Arizona Test Method 212	Minimum 85% (two fractured faces)

414-3.03 Mineral Admixture: of the Standard Specifications is revised to read:

Mineral admixture will be required. The amount shall be 1.0 percent, by weight of the mineral aggregate and shall be either portland cement type II or hydrated lime, conforming to the requirements of Table 414-3.

TABLE 414-3 MINERAL ADMIXTURE	
Material	**Requirement**
Portland Cement, Type II	ASTM C 150
Hydrated Lime	ASTM C 1097

A Certificate of Analysis conforming to the requirements of Subsection 106.05 shall be submitted to the Engineer.

414-3.04 Bituminous Material: the first paragraph of the Standard Specifications is revised to read:

Bituminous material shall be asphalt-rubber conforming to the requirements of Section 1009 of these specifications. The asphalt-rubber shall be Type **XXXXX**. The crumb rubber gradation shall be Type B conforming to the requirements of Section 1009.

414-4 Mix Design: the fourth paragraph of the Standard Specifications is revised to read:

Within 10 working days of receipt of all samples and the contractor's letter in the Central Laboratory, the Department will provide the contractor with the percentage of asphalt-rubber to be used in the mix, the percentage to be used from each of the stockpiles of mineral aggregate, the composite mineral aggregate gradation, the composite mineral aggregate and mineral admixture gradation, and any special or limiting conditions for the use of the mix.

The Department will provide the contractor material to be used for calibration of nuclear asphalt content gauges. The material will be fabricated by the Department utilizing asphalt-rubber submitted by the contractor for mix design purposes.

414-6.02 Mineral Aggregate: of the Standard Specifications is revised to read:

Aggregate shall be free of deleterious materials, clay balls, and adhering films or other material that prevent thorough coating of the aggregate with the bituminous material.

During asphaltic concrete production, the Engineer shall obtain and test samples of mineral aggregate for the determination of the sand equivalent, fractured coarse aggregate particles, and flakiness index. The sample shall be obtained either from the cold feed prior to addition of mineral admixture, or from the stockpiles. Should such testing indicate results not meeting the requirements of Table 414-2 for sand equivalent, fractured coarse aggregate particles, and flakiness index, operations shall cease and the contractor shall have the option of requesting a new mix design or correcting deficiencies in the aggregate stockpiles.

414-6.03 Asphaltic Concrete: of the Standard Specifications is revised to read:

(A) Mineral Aggregate Gradation:

For each approximate 450 metric tons of asphaltic concrete, at least one sample of mineral aggregate will be taken. Samples will be taken in accordance with the requirements of Arizona Test Method 105 on a random basis just prior to the addition of mineral admixture and bituminous material by means of a sampling device which is capable of producing samples which are representative of the mineral aggregate. The device, which shall be approved by the Engineer, shall be furnished by the contractor. In any shift that the production of asphaltic concrete is less than 450 metric tons, at least one sample will be taken.

Samples will be tested for conformance with the mix design gradation without mineral admixture in accordance with the requirements of Arizona Test Method 201.

The gradation of the mineral aggregate will be considered to be acceptable unless the average of any three consecutive tests or the result of any single test varies from the mix design gradation percentages as follows:

Passing Sieve	Number of Tests	
	3 Consecutive	**One**
4.75 mm	± 4	± 6
2.36 mm	± 3	± 4
75 µm	± 1.0	± 1.5

One hundred percent of the material shall pass the largest sieve size shown in Table 414-1.

At any time that test results indicate that the gradation of the mineral aggregate does not fall within all of the limits indicated, the production of asphaltic concrete shall cease immediately and shall not begin again until a calibration test indicates that the gradation is within the 3-consecutive test limits indicated.

(B) Asphalt-Rubber **Content:**

During production of asphaltic concrete, the contractor shall maintain at the plant site a nuclear asphalt content gauge calibrated and operated in accordance with Arizona Test Method 421. The calibration shall be performed using material supplied by the Department as stated in Section 414-4. Under the observation of the Engineer, the contractor shall determine the asphalt-rubber content by means of the nuclear asphalt content gauge a minimum of four times/full shift. The contractor's technicians performing the testing, including the calibration of the nuclear gauge, shall meet the technician requirements given in the Department's System for the Evaluation of Testing Laboratories. The requirements may be obtained from ADOT Materials Group, 1221 North 21st Avenue, Phoenix, AZ 85009. Production of asphaltic concrete shall cease immediately and the plant and/or the nuclear asphalt content gauges re-calibrated if the Engineer determines the percent of asphalt-rubber has varied by an amount greater than ± 0.5 percent from the amount directed by the Engineer.

414-7.01 Quality Control: of the Standard Specifications is revised to read:

Quality control of mineral aggregate production and asphaltic concrete production shall be the responsibility of the contractor. The contractor shall perform sufficient testing to assure that mineral aggregate and asphaltic concrete are produced which meet all specified requirements. The Engineer reserves the right to obtain samples of any portion of any material at any point of the operations for the Engineer's own use.

414-7.03 Proportioning: the second paragraph of the Standard Specifications is revised to read:

Unless approved by the Engineer, no individual stockpile usage shall be less than three percent of the total mineral aggregate.

Changes in stockpile/hot bin use in excess of five percent from the approved mix design will not be permitted without the approval of the Engineer.

414-7.06(A)(1) Dates and Surface Temperature: of the Standard Specifications is revised to read:

Asphaltic concrete shall be placed between the dates of **XXXXX** and **XXXXX** and only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 29 C.

Despite a surface temperature of 29°C, the Engineer at any time may require that the work cease or that the work day be reduced in the event of weather conditions either existing or expected which would have an adverse effect upon the asphaltic concrete.

414-7.08(A) General Requirements: the second paragraph of the Standard Specifications is revised to read:

The wheels of compactors shall be wetted with water, or if necessary soapy water, or a product approved by the Engineer to prevent the asphaltic concrete from sticking to the steel wheels during rolling. The Engineer may change the rolling procedure if in the Engineer's judgment the change is necessary to prevent picking up of the asphaltic concrete.

414-7.08(B) Equipment: the third paragraph of the Standard Specifications is revised to read:

The compactors shall be self-propelled and shall be operated with the drive wheel in the forward position. Vibrator rollers may be used in the static mode only.

414-7.08(C) Rolling Procedure: the third paragraph of the Standard Specifications is revised to read:

Two compactors shall be used for initial breakdown and be maintained no more than 100 meters behind the paving machine. The roller(s) for final compaction shall follow as closely behind the initial breakdown as possible. As many passes as is possible shall be made with the compactors before the temperature of the asphaltic concrete falls below 105 degrees C.

414-7.09 Surface Requirements and Tolerances: the second paragraph of the Standard Specifications is revised to read:

Asphaltic concrete shall not vary more than three millimeters from the lower edge of a three meter straightedge when the straightedge is placed parallel to the center line of the roadway, or six millimeters when placed in the transverse direction across longitudinal joints.

414-8 Method of Measurement: the second paragraph of the Standard Specifications is revised to read:

Asphalt-rubber will be measured by the metric ton.

The weight of the asphalt-rubber material shall either be determined by weighing directly enroute from the reaction vessel to the point of delivery or be determined from the weight of the asphalt cement and the weight of the rubber minus wastage.

414-9 Basis of Payment: the second paragraph of the Standard Specifications is revised to read:

Payment for the asphalt-rubber will be made by the metric ton, including asphalt cement and crumb rubber. The results of a nuclear asphalt content gauge shall not be used to determine the weight of asphalt-rubber material as the basis of payment.

APPENDIX J – WASHINGTON STATE CRUMB RUBBER PROJECTS

SR	Begin Milepost	End Milepost	Project Name	Class of Mix	Unit Cost Rubberized (Ton)	Unit Cost Non-Rubber (Ton)	Cost Multiplier	Year Paved	Year Repaved	Age	Expected Life	Life to be Cost Effective
5	118.77	120.77	Nisqually River to Gravelly Lake	Dense Graded	$36.00	$27.00	1.3	1993	2004	11	15	20
530	30.90	31.50	SR-532, et al - Region Seal	G	unknown	unknown		1989	1996	7	7	
92	5.97	8.26	Granite Falls Vicinity - Region Seal	G	unknown	unknown		1989	1998	9	7	
9	94.58	97.43	SR 546 to Johnson Creek Bridge 9/360	G	$23.00	$21.00	1.1	1990	2002	12	7	8
92	3.37	5.97	Granite Falls Vicinity - Region Seal	G	$29.00	$27.00	1.1	1990	2001	11	7	8
520	3.98	5.87	Evergreen Point Bridge to SR908	OGFC	$27.00	$24.00	1.1	1982	1997	15	8	9
405	3.51	3.81	S-Curve/Cedar River Bridge and RR Bridge	OGFC	$86.85	$23.25	3.7	1984	1989	5	8	30
5	0.28	2.42	Columbia River to 39th Street	OGFC	$55.56	$36.80	1.5	1986	1997	11	8	12
195	25.81	29.14	Armstrong Road to Albion Road	OGFC	$64.10	$35.00	1.8	1990	1999	9	8	15
9	68.00	74.50	Acme Vicinity - Region Thin Overlay	OGFC	$33.50	$24.00	1.4	1990	1999	9	8	11
101	87.40	88.94	22nd St to Little Hoquiam R. Br. and Riverside Br. 101/125	OGFC	$79.50	$35.00	2.3	1991	2007	16	8	18
5	87.14	88.03	Lewis County Line to SR12	OGFC	$51.25	$34.75	1.5	1992	1998	6	8	12
90	121.96	124.11	West Ellensburg I/C to Ryegrass Rest Area	OGFC	unknown	unknown	#VALUE!	1993	2008	15	8	
18	6.20		84th Ave S. I/C and Auburn Ramps	PlusRide	$53.60	$28.50	1.9	1983	1987	4	15	28
405	3.51	3.81	S-Curve/Cedar River Bridge and RR Bridge	PlusRide	$50.00	$21.80	2.3	1984	1989	5	8	18
513	8.55	9.29	35th Avenue NE to SR5	PlusRide	$52.50	$32.95	1.6	1986	1992	6	15	24
No longer a state route			Main Street to South First Street (Union Gap)	PlusRide	$41.00	$27.00	1.5	1982	unknown		15	23
82	30.78	30.82	Bridge No. 82/114N	PlusRide	$75.00	$50.00	1.5	1982	1991	9	12	18

SR	Begin Milepost	End Milepost	Project Name	Class of Mix	Unit Cost Rubberized (Ton)	Unit Cost Non-Rubber (Ton)	Cost Multiplier	Year Paved	Year Repaved	Age7	Expected Life	Life to be Cost Effective
82	30.90	30.96	Bridge No. 82/115N	PlusRide	$75.00	$50.00	1.5	1982	1989	7	12	18
			Fauntleroy Ferry Dock	PlusRide	$68.50	$27.00	2.5	1985	1985	0	15	38
No longer a state route			Skagit Co Line to Dalgren Road	PlusRide	$55.00	$27.00	2.0	1985	unknown		15	31
17	21.80	27.94	Franklin County Line to Jct SR26	SAM	$335.00	$114.00	2.9	1978	1986	8	7	21
No longer a state route			Buena Loop Rd to Roza Drive et al	SAM	$300.00	$114.00	2.6	1978	1980	2	7	18
97	201.23	233.49	37th Street to Rocky Reach Dam	SAM	$470.00	$191.00	2.5	1980	1992	12	7	17
			District 5 Rubberized Seal	SAM	$435.00	$191.00	2.3	1980	unknown		7	16
No longer a state route			SR-5 to Napavine	SAMI	unknown	unknown		1977	unknown		15	
90	182.64	191.89	Wheeler Road to Adams County Line	SAMI	$426.00	$114.00	3.7	1978	1991	13	15	56
12	69.16	80.28	Jackson Highway to Beach Road (see Note 1)	SAMI	$330.00	$114.00	2.9	1978	2002	24	15	43
2	297.46	299.79	Hillyard Junction to MP 300.40	SAMI	$380.00	$114.00	3.3	1978	1987	9	15	50
12	96.91	104.41	Morton to Packwood	SAMI	$415.00	$114.00	3.6	1978	1991	13	15	55
195	86.22	89.80	Paradise Road to Mullen Hill Road	SAMI	$500.00	$114.00	4.4	1978	1993	15	15	66

APPENDIX K – WSDOT SCRAP TIRE USE SURVEY

General Questions

1. Name of person completing the general questions portion of the survey.

2. Title of the person completing the general portion of the survey.

3. Can we contact you regarding your responses to the survey? If no, please skip to question 7.
   a. Yes
   b. No

4. What is your mailing address?

5. What is your phone number? If you would prefer to be contacted solely by e-mail please omit your phone number and only include your e-mail address below.

6. What is your e-mail address?

7. Would you like to have a copy of the final report?
   a. Yes
   b. No

8. Does your State use scrap tires in transportation (geotechnical or pavement applications) related projects? If yes, please skip to question 10. If no, please answer question 9 and submit the survey; thank you.
   a. Yes
   b. No

9. Please indicate why scrap tires are not used (select all that apply)
   a. Departmental moratorium
   b. Moratorium by another state agency
   c. Existing federal, state or other guidelines are not sufficient to allow for confidence in design
   d. Costs are not competitive relative to conventional materials
   e. Environmental concerns
   f. No need exists

10. What are some specific applications that have been made in your State select all that apply)?
    a. Lightweight fill for embankments over soft ground
    b. Fill for common embankments
    c. Lightweight backfill for retaining structures
    d. Lightweight fill for landslide remediation
    e. Pavements
    f. Safety devices
    g. Other

11. Please, list any others not specified in question 10.

12. Is there a program in place in your State that subsidizes the use of scrap tires? If yes, omit questions 17 and 18. If no, skip to question 17 and 18.
    a. Yes
    b. No

13. What agency administers the program?

14. If required by the program, what is the minimum quantity of scrap tires that must be utilized per year?
    a. < 10000 tons
    b. > 10000 tons
    c. No minimum

15. How is this program funded, e.g., fees associated with new tire purchases or vehicle registration, sales tax, etc.?

16. How many years has this program been in place?
    a. 0 - 1
    b. 1 - 5
    c. >5

17. If there is currently neither a program policy requiring the use of scrap tires nor an incentive program for the use of scrap tires in transportation related projects, are you aware of any impending policy changes and/or incentive programs to do so?
    a. Yes
    b. No

18. If there is impending legislation, or other policy, that promotes, or requires, the use of scrap tires, which statement(s) best describe it (select all that apply)?
    a. Legislation sponsored by industry
    b. Legislation sponsored an environmental group(s)
    c. Policy or program initiated by Transportation Department
    d. Policy or program initiated by another state agency
    e. Not aware of any impending law or policy changes

Pavement Questions

1. Name of person completing pavement portion of the survey.

2. What is your title?

3. Can we contact you regarding your responses to this survey? If no, please skip to question 7.
    a. Yes
    b. No

4. Please give your mailing address.

5. What is your phone number? If you would prefer to be contacted solely via e-mail, omit your phone number and include only your e-mail address below.

6. What is your e-mail address?

7. Do you currently use crumb rubber modified asphalt pavements in your state?
   a. Yes
   b. No

8. Do you specify asphalt binders in accordance with AAASHTO MP-1 (PG binders)?
   a. Yes
   b. No

9. Is crumb rubber modified binder cost competitive with other typical asphalt binder modifiers?
   a. Yes
   b. No

10. How much does crumb rubber modified asphalt cost?
    a. Less than half the cost of conventional mix
    b. Half the cost of conventional mix
    c. Same cost as conventional mix
    d. Twice the cost of conventional mix
    e. More than twice the cost of conventional mix

11. How many miles of crumb rubber asphalt pavements are typically placed per year?
    a. Less than 10 lane miles
    b. 10 to 100 lane miles
    c. Greater than 100 lane miles

12. Have you had any failures with crumb rubber modified asphalt?
    a. Yes
    b. No

13. If yes, please explain.

14. Are there any application limitations of crumb rubber modified asphalt?
    a. Yes
    b. No

15. If yes, please explain

16. Can recycled asphalt pavements (RAP) be used in crumb rubber modified asphalt?
    a. Yes
    b. No

17. Can crumb rubber modified asphalt be recycled?
    a. Yes

b. No

18. What is the typical service life of a conventional asphalt concrete overlay in your state?
    a. 0 to 5 years
    b. 5 to 10 years
    c. 10 to 15 years
    d. 15 to 20 years

19. What is the typical service life of a crumb rubber modified asphalt overlay?
    a. 0 to 5 years
    b. 5 to 10 years
    c. 10 to 15 years
    d. 15 to 20 years

20. In your opinion, has the use of crumb rubber modified asphalt been cost effective?
    a. Yes
    b. No

21. Are studded tires allowed in your state?
    a. Yes
    b. No

22. If yes. Is crumb rubber modified asphalt more or less susceptible to studded tire wear?
    a. More
    b. Same
    c. Less
    d. Don't know

23. Any additional comments?

Geotechnical Questions

1. Name of person completing geotechnical portion of the survey.

2. What is your title?

3. Can we contact you regarding your responses to this survey? If no, please skip to question 7.
    a. Yes
    b. No

4. Please give your mailing address.

5. What is your phone number? If you would prefer to be contacted solely via e-mail, omit your phone number and include only your e-mail address below.

6. What is your e-mail address?

7. Would you like to have a copy of the final report?
   a. Yes
   b. No

8. How many years has your State been using scrap tires in geotechnical related projects?
   a. 0
   b. 1 - 5
   c. 5 - 10
   d. > 10

9. How many successful projects has your State completed using scrap tires?
   a. 0
   b. 1 – 5
   c. 5 – 10
   d. > 10

10. How many successful projects has your State completed using scrap tires where a lightweight fill was required, e.g., embankments over soft ground, landslide repairs?
    a. 0
    b. 1 –5
    c. 5 – 10
    d. > 10

11. How many successful projects has your State completed using scrap tires as structural fill in common embankments?
    a. 0
    b. 1 – 5
    c. 5 – 10
    d. >10

12. How many successful projects has your State completed using scrap tires as lightweight fill behind retaining structures?
    a. 0
    b. 1 – 5
    c. 5 – 10
    d. >10

13. What are some other geotechnical uses for which scrap tires have been employed in your State, e.g., as drainage layers, wall facings, insulating layers, etc?

14. Based on costs associated with scrap tire use in your State, which statement best characterizes your agency's perspective regarding the economics of using scrap tires in embankments fills?
    a. Only competitive for all uses when a subsidy is in place
    b. Unsubsidized scrap tires are only competitive with other types of lightweight fill, e.g., foam.

15. If you have additional comments regarding the economics of scrap tire use, please include them below.

16. What design guidelines for scrap tire embankments are currently in use in your State?
    a. FHWA 1997: Interim Guidelines for Shredded Tire Embankments (ASTM D 6370-98)
    b. Your own State's Guidelines
    c. Other
    d. None

17. What is the maximum height of any existing scrap tire embankment in your State?
    a. 3 - 10 ft
    b. 10 - 20 ft
    c. > 20 ft
    d. No existing scrap tire embankment

18. What type(s) of scrap tire embankments are allowed in your State?
    a. Monofills
    b. Alternating layers of pure tires and soil
    c. Tire/Soil Mixtures

19. What statement below best characterizes your design practice with respect to placement of scrap tire fills in relation to the ground water table?
    a. Construction above the ground water table is always required.
    b. Construction below the ground water table is always allowed.
    c. Construction below the ground water table is allowed on a case-by-case basis.

20. What statement below best characterizes your design practice with respect to placement of scrap tire fills in proximity to wetlands or other environmentally sensitive areas? Consider "in proximity" to mean that leached contaminants would immediately impact the sensitive area. In the statements below, "environmentally sensitive areas" include wetlands.
    a. Construction in proximity to environmentally sensitive areas is not allowed.
    b. Construction in proximity to environmentally sensitive areas is allowed on a case-by-case basis.

21. Prior to considering a scrap tire embankment, does your State have any guidelines with regard to the intended use of the highway, e.g., maximum ADT, type of traffic?
    a. Yes
    b. No

22. What is the minimum thickness of pavement and subgrade that is to be placed over scrap tire embankments?
    a. No minimum is specified
    b. < 2 ft
    c. 2 - 4 ft
    d. > 4 ft
    e. Unknown

23. If there have been failures of scrap tire embankments in your State, what have been the reasons for failure?
    a. Combustion
    b. Excessive compression of the scrap tire fill
    c. Excessive settlement of the foundation soil
    d. Slope failures (including reactivation of repaired landslides)
    e. Poor performance of pavements
    f. Environmental reasons, e.g., excessive leaching of hazardous substances

24. If asked, could you provide any case studies of projects completed within your State that employed scrap tires?
    a. Yes
    b. No

25. If asked, could you provide a copy of a typical plan sheet for an embankment or retaining wall project, within your State, in which scrap tires are to be, or have been, utilized?
    a. Yes
    b. No

26. If asked, could you provide a copy of your State's Contract Special Provisions that pertain to the use of scrap tires?
    a. Yes
    b. No

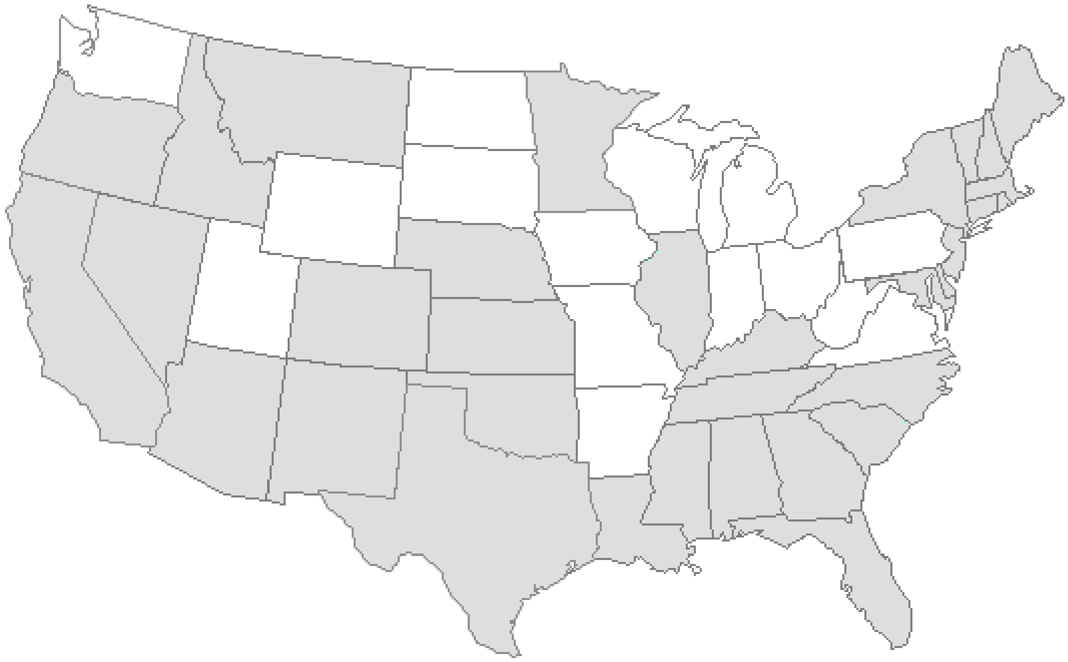
27. If possible, can you elaborate on any failures that you noted above? If desired, extra sheets, copies of published papers, reports, etc. can be mailed to the contact indicated in the footer.

28. Is your Transportation Department, or other state agency, conducting or sponsoring (financially or with in-kind services) any research pertaining to the use of scrap tires in geotechnical engineering applications?
    a. Yes
    b. No
    c. Unknown

APPENDIX L – STATE RESPONSES TO WSDOT SCRAP TIRE USE SURVEY

Responses to General Questions

*Hawaii and Canada are not shown.



Alabama	Georgia	Maryland	New Hampshire	Rhode Island
Arizona	Idaho	Massachusetts	New Jersey	South Carolina
California	Illinois	Minnesota	New Mexico	Tennessee
Colorado	Kansas	Mississippi	New York	Texas
Connecticut	Kentucky	Montana	North Carolina	Vermont
Delaware	Louisiana	Nebraska	Oklahoma	*Canada
Florida	Maine	Nevada	Oregon	

Question 8: Does your State use scrap tires in transportation (geotechnical or pavement applications) related projects? If yes, please skip to question 10. If no, please answer question 9 and submit the survey; thank you.

Yes	19	(55.9%)
No	15	(44.1%)

Question 9: Please indicate why scrap tires are not used.

Departmental moratorium	1	(2.9%)
Moratorium by another state agency	1	(2.9%)
Existing federal, state or other guidelines are not sufficient to allow for confidence in design	2	(5.9%)
Costs are not competitive relative to conventional materials	12	(35.3%)
Environmental concerns	1	(2.9%)
No need exists	3	(8.8%)
No Response	1	(2.9%)

Question 10:	What are some specific applications that have been made in your State?

Lightweight fill for embankments over soft ground	7	(20.6%)
Fill for common embankments	7	(20.6%)
Lightweight backfill for retaining structures	4	(11.8%)
Lightweight fill for landslide remediation	4	(11.8%)
Pavements	12	(35.3%)
Safety devices	4	(11.8%)
Other	5	(14.7%)
No response	4	(11.8%)

Question 11: Please, list any others not specified in question 10.

Open-Graded Friction Course (OGFC)

We have done one project with crumb rubber but that was back in 1993.

Erosion control (experimental)

Did some test sites in 1992, but nothing since that time.

It is allowed as an alternate binder (AC-15-5-TR) for chip seals. So far, not used due to costs.

Special crack sealing products made which include crumb rubber

Constructed one retaining wall using scrap truck tires in lieu of timber/pile, block, or precast panels for a demonstration project.

Hot-pour joint sealants Maintenance chip surface seals

Subsurface drainage in shallow ditch

As a drainage media (partial replacement for stone fill in roadside ditches)

Pavements applications have been used in the past put are in moratorium. Geotechnical applications were proposed but vetoed by environmental agency and fire concerns.

Question 12: Is there a program in place in your State that subsidizes the use of scrap tires? If yes, omit questions 17 and 18. If no, skip to question 17 and 18.

Yes	6	(17.6%)
No	12	(35.3%)
No response	2	(5.9%)

Question 13: What agency administers the program?

Louisiana Department of Environmental Quality

South Carolina Dept of Health and Environmental Control

Mississippi Department of Environmental Quality

No specific program; Experimental use only

Department of Environmental Protection

Illinois Environmental Protection Agency

Colorado Department of Public Affairs

California Environmental Protection Agency - California Integrated Waste Management Board

	Somewhat, we apply for grants to the Nebraska Department of Environmental Equality to offset delta costs.
Question 14:	If required by the program, what is the minimum quantity of scrap tires that must be utilized/year?

< 10000 tons	0	(0.00%)
> 10000 tons	0	(0.00%)
No minimum	6	(17.7%)
No response	13	(38.2%)

Question 15: How is this program funded, e.g., fees associated with new tire purchases or vehicle registration, sales tax, etc.?

Fees associated with tire purchases

Not know by submitter. Contact MS DEQ for information

Unsure

Fees associated with new tire purchases

$0.50 @ charge for discarded (traded-in tires)

Fees collected for tire disposal

$1 tire fee

Question 16: How many years has this program been in place?

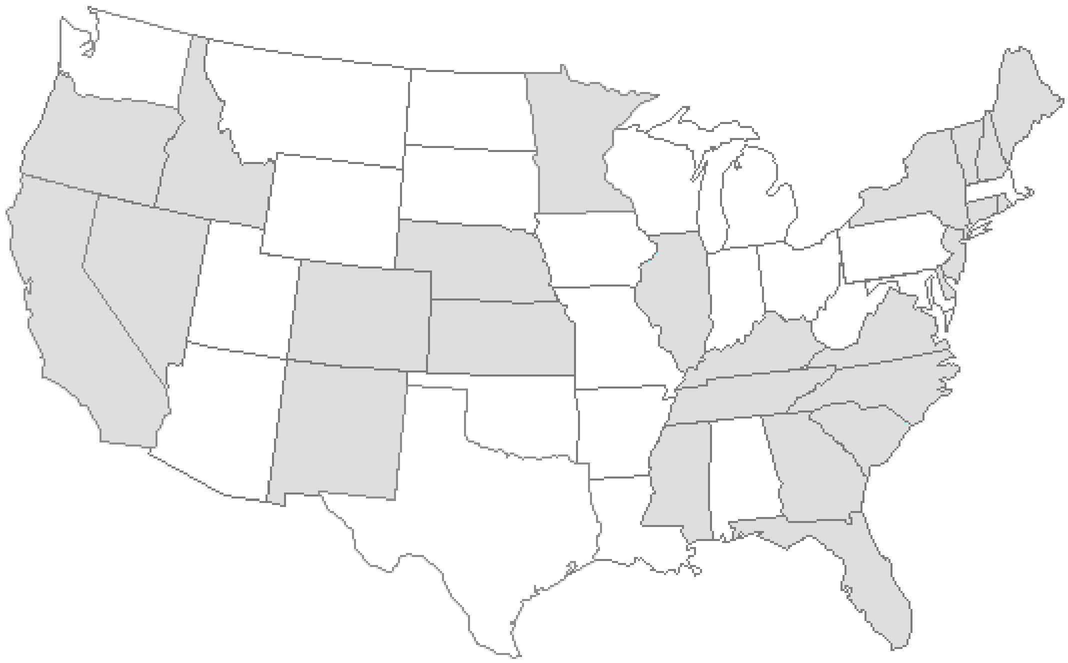
0 - 1	0	(0.00%)
1 - 5	2	(5.9%)
>5	4	(11.8%)
No response	13	(38.2%)

Question 17: If there is currently neither a program policy requiring the use of scrap tires nor an incentive program for the use of scrap tires in transportation related projects, are you aware of any impending policy changes and/or incentive programs to do so?

Yes	0	(0.00%)
No	13	(38.2%)
No response	7	(20.6%)

Question 18: If there is impending legislation, or other policy, that promotes, or requires, the use of scrap tires, which statement(s) best describe it?

Responses to Pavement Questions



California	Idaho	Mississippi	New York	Vermont
Colorado	Illinois	Nebraska	North Carolina	Virginia
Connecticut	Kansas	Nevada	Oregon	
Deleware	Kentucky	New Hampshire	Rhode Island	
Florida	Maine	New Jersey	South Carolina	
Georgia	Minnesota	New Mexico	Tennessee	

Question 7: Do you currently use crumb rubber modified asphalt pavements in your state?

Yes	7	(26.9%)
No	19	(73.1%)
No Response	0	(0.00%)

Question 8: Do you specify asphalt binders in accordance with AASHTO MP-1 (PG binders)?

Yes	21	(80.8%)
No	3	(11.5%)
No Response	2	(7.7%)

Question 9: Is crumb rubber modified binder cost competitive with other typical asphalt binder modifiers?

Yes	6	(23.1%)
No	16	(61.5%)
No Response	4	(15.4%)

Question 10:	How much does crumb rubber modified asphalt cost?

Less than half the cost of conventional mix	0	(0.00%)
Half the cost of conventional mix	0	(0.00%)
Same cost as conventional mix	3	(11.5%)
Twice the cost of conventional mix	14	(53.9%)
More than twice the cost of conventional mix	2	(7.7%)
No Response	7	(26.9%)

Question 11:	How many miles of crumb rubber asphalt pavements are typically placed/year?

Less than 10 lane miles	73	(73.1%)
10 to 100 lane miles	8	(7.7%)
Greater than 100 lane miles	8	(7.7%)
No Response	12	(11.5%)

Question 12:	Have you had any failures with crumb rubber modified asphalt?

Yes	58	(57.7%)
No	38	(38.5%)
No Response	4	(3.9%)

Question 13: If yes, please explain.

In dense graded mixes about 10 years ago.

Please see our research reports.

Typically related to poor construction practices, which led to pre-mature distress.

We had a project using the "PlusRide" system that raveled within 3 months of placement. It was removed and replaced.

We have not used CRM-HMA for several years. Failures were typically ravelling. A couple of sections remain. Have not used CRM mixes for at least 8 years.

Performance was very variable. Some jobs had poorer performance and some same or better. Cost was always higher.

Premature cracking from the CRM absorbing the AC in the mix

Bad raveling. Poor distribution of crumb rubber in the mix.

Crumb rubber asphalt pavements have typically not performed will in Nevada. Failures have occurred due to stripping, and ravelling. These failures occurred after about five years.

Have only used crumb rubber on two projects. Both have shown a lot of early cracking. One project was a PG 58-34. The crumb rubber section has considerably more cracking than the control. We don't understand what has caused this.

Binder not meeting PG grade - Do not have any roadway failures.

Florida's Asphalt Rubber Binder spec requires a minimum of Ground Tire Rubber for the particular application. At least one pavement failure (flushing/bleeding) was probably due to not enough Ground Tire Rubber appropriately blended into the final Asphalt Rubber Binder.

Our only experience with crumb rubber asphalt pavements has been in research projects over 8 years ago. Some projects were OK others did not perform. The cost is prohibitive.

We had problems with a surface treatment job on U.S. 82 in Georgia using lightweight crumb rubber

	modified asphalt.
	One project was constructed on a heavy truck traffic route. The crumb rubber mix stripped in the first year and eventually was recycled then overlaid.
	Crumb rubber has only been used on a limited number of trial projects.
Question 14:	Are there any application limitations of crumb rubber modified asphalt? Yes 9 (34.6%) No 10 (38.5%) No Response 7 (26.9%)
Question 15:	If yes, please explain. We only use it in open-graded friction course mixes. Asphalt rubber is most effective as a thin rehabilitative overlay of distressed flexible or rigid pavement. Can be bid as an alternate (AC-15-5-TR) for chip seal against emulsion. Not using. We are not typically specifying. Must be placed in warm weather. Asphalt rubber binder with 5% ground tire rubber (GTR) is required for Florida's dense graded friction course mixes. Asphalt rubber binder with 12% GTR is required for our open-graded friction course mixes. Asphalt rubber binder with 20% GTR is required for our SAMI type (interlayer) construction to reduce reflective cracking. On the one project we used it (in 1993), we required the plant to store the material in the silo for 1 hour prior to shipment for the asphalt to absorb into the rubber. Current certification process of asphalt products would not allow the "wet" system process due to the testing time required after material is produced. See # 13
Question 16:	Can recycled asphalt pavements (RAP) be used in crumb rubber modified asphalt? Yes 7 (26.9%) No 9 (34.6%) No Response 10 (38.5%)
Question 17:	Can crumb rubber modified asphalt be recycled? Yes 9 (34.6%) No 6 (23.1%) No Response 11 (42.3%)
Question 18:	What is the typical service life of a conventional asphalt concrete overlay in your state? 0 to 5 years 1 (3.9%) 5 to 10 years 10 (38.5%) 10 to 15 years 12 (46.2%) 15 to 20 years 2 (7.7%) No Response 1 (3.9%)

Question 19:	What is the typical service life of a crumb rubber modified asphalt overlay?

0 to 5 years	5	(19.2%)
5 to 10 years	7	(26.9%)
10 to 15 years	5	(19.2%)
15 to 20 years	1	(3.9%)
No Response	8	(30.8%)

Question 20:	In your opinion, has the use of crumb rubber modified asphalt been cost effective?

Yes	5	(19.2%)
No	17	(65.4%)
No Response	4	(15.4%)

Question 21:	Are studded tires allowed in your state?

Yes	10	(38.5%)
No	12	(46.2%)
No Response	4	(15.4%)

Question 22:	If yes. Is crumb rubber modified asphalt more or less susceptible to studded tire wear?

More	0	(0.00%)
Same	0	(0.00%)
Less	0	(0.00%)
Don’t know	15	(57.7%)
No Response	11	(42.3%)

Question 23:	Any additional comments?

In OGFC, we have seen an increase of 15 to 20% in the cost of the binder.

Needed a few more don’t knows in the above questions. We don’t disallow crumb rubber in our asphalts, it just isn’t used by our suppliers because of costs without requiring it. According to Les Jorgenson summer of 2002 Tech Transfer Newsletter - UC Berkley, Institute of Transportation studies, best paving results occur at >85 degrees surface temperature. How often do you get that, especially if you are paving at night. We are about to use CRM ac as rap on a project on U.S.97. We will be keeping an eye on it. A summary of our research is that our results are quite mixed. Feel free to download our report.

We only have experimented with CRM asphalt or Asphalt Rubber Hot-mix (ARHM) in 3 applications, one in the early 1980's, two in 1990;s. We have experimented with tire chips as an embankment fill and a base course on a local road. We can provide you reports on these applications, should you wish them.

The Department Asphalt Rubber Usage Guide can be found at: www.dot.ca.gov/hq/esc/Translab/pubs/Caltrans_Asphalt_Rubber_Usage_Guide.pdf Clarifications to the above questions are as follows: 10. The cost of using crumb rubber asphalt is about 1 1/2 times that of conventional AC. It is still cost effective because we use a thinner overlay and due to it's longevity compared to that of conventional AC. 17. This has not been done to a large extent. A better answer would be "Do not know". 18 & 19. Largely depends on the type of pavement, which is being overlayed. Can last up to 15 years in some cases. 22. Snow areas typically use pcc pavement. A rubber pavement was placed on a portion of Highway in a snow area in the early 1980's. The pavement wore down under chain wear similar to conventional AC. The deterioration rate compared to conventional AC for this project is not known.

We only did about 10 projects with crumb rubber starting in the mid '80's and ending in the mid '90's. We did not see any particular benefit of the crumb rubber and the cost was significantly higher. CRM did seem to perform well in an open-graded application.

Studded tires banned in 1971. Plus ride was tried as a ice control technique, but did not meet expectations. CRM mixes were emphasized during the time of the MANDATE. Discontinued because of equal or poorer performance at greatly increased cost. Note: this survey format is pretty neat.

Studded tires are allowed only in the winter months. They are not used to any extent. Some time ago, we constructed several test sections with asphalt rubber and could not predict performance. Sometimes it was ok, but a lot of time the performance was poorer. Costs were always higher. We are currently allowing (AC-15-5-TR) as an alternate versus emulsion on some chip seal projects. (Has 5% tire rubber, same as Texas and Oklahoma DOT's allows.) So far, they have not been a lower cost. Four or five projects bid as alternates this year, all went emulsion.

Mississippi utilizes a dense graded mix for surface courses, which does not lend itself as well to CRM modification as open or gap graded mix designs. Currently CRM is permitted, but due to the high cost of CRM as opposed to SBS or SB modifiers, contractors rarely choose to use CRM.

RI uses almost all its crumb rubber in a thin overlay (3/4"). Answer to #18 depends on existing surface before overlay.

Some references from Florida that may be of assistance: 1. Journal of the Association of Asphalt Paving Technologists Vol 61, 1992 (pp446-472). 2. Transportation Research Record 1339, 1992 (pp16-22). 2. Transportation Research Record 1638, 1998 (pp134-140). 3. Transportation Research Record 1681, 1999 (pp10-18). Current FDOT specs (Sections 919 Ground Tire Rubber, 336 Asphalt Rubber Binder, 337 Friction Course Mixes and 341 Interlayer Construction) are available on the internet.

Evaluation of the use of rubber (recycled tires) and other additives to improve the performance of asphalt pavement in Connecticut dates back to the 1950's. ConnDOT first placed virgin rubber into pavements on what was then route 9 (now route 99) in Rocky Hill as an experiment in 1950. Later rubber-pavement installations were placed in various locations in 1953, 1954, 1961 and 1966. In 1977, the University of Connecticut in cooperation with ConnDOT undertook a major research project to evaluate the use of recycled rubber in various DOT construction and maintenance activities. Full-scale field tests were carried out with rubber-modified thin and thick overlays, stress-relieving interlayers, joint and crack sealing, and surface chip seals. Approximately 50 test sections were placed on Connecticut highways. Follow-up performance observations and measurements were obtained for nine years after placement of the pavements. The observed performance for the rubber and non-rubber control sections was nearly identical after only 3 years. This was very disappointing, because the mediocre performance in combination with increased costs due to the addition of recycled rubber, (which were substantial, on the order of 50-100% at that time) demonstrated that the asphalt rubber pavements were not cost effective in Connecticut. The rubberized chip seals and crack filler materials showed promise. Many crack sealants used today contain rubber. The last asphalt rubber pavement placed in ConnDOT was in 1982. Although this site on route 79 indicated some improvement (delay) in retarding reflection cracking, again it was felt that the extremely high cost was not justifiable. A few proprietary rubberized chip seals were placed for evaluation in the mid 1990's. These performed fairly well. Other uses of rubber tires have produced more positive results, such as in utilizing chipped tires as roadbed insulation in areas with extreme frost penetration. ConnDOT participated in the New England Transportation Consortium study done in Maine using this procedure. Also the tire-to-energy plant in Sterling CT (Exeter Project) utilizes 9.5 million tires annually (more than 3 times Connecticut's annual production rate of used tires) to produce electricity. In summary, ConnDOT in conjunction with the FHWA has expended considerable effort and money over the past 50 years in trying to verify claims of cost savings or benefits from rubber in roads. Unfortunately, to date, unlike in some other states such as California, Arizona and Florida, the results have not provided a sound reason to use asphalt rubber in Connecticut pavements. Published reports on the various studies covering the period 1977 through 1987 are available upon request.

On the one project we used it on, it was an add-on location so it was not competitively bid. Our normal price of HMA was $30/ton and the crumb rubber modified HMA was $80/ton.

Our experience with crumb rubber is based on one overlay project completed in 80's. The wet process was used and cost/ton of HMA was doubled. Long term performance was same as conventional mix. We would allow crumb rubber on current projects where modified binders are required.

We placed several test sections in 1992, but none since that time. We plan to place another section later this year using a wet-blending process.

We have only one project built in the early-mid 90's. We don't know the long-term life of the project. Due to cost of wet system, we have not pursued.

Crumb rubber pavements have only been used on an experimental basis by Colo DOT. In the experimental phase, the determination was that crumb rubber asphalt was not cost effective. Once the mandate by federal law disappeared, so did the use of crumb rubber asphalt. In pavements, about the only common use now is in crack filler. My answers above are based on a very limited usage.

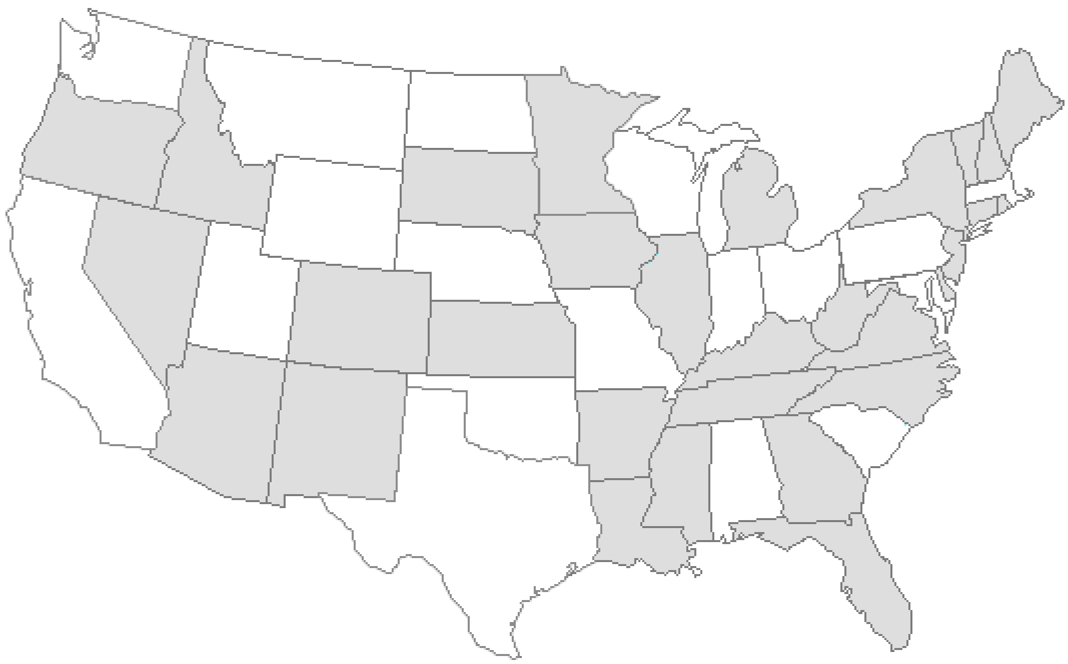
We have not seen enough interest in the industry and state environmental protection division in Georgia on using crumb rubber modified asphalt in pavements.

Because of the failure of the one project using the wet process, No further use of crumb rubber has occurred or was/is planned.

Performance of the crumb rubber modified mixes is difficult to quantify, as we just put down our first two projects in the last two years. The cost of the binder appears to be competitive with conventional PG binders especially when competition increases. However crumb modified mixes use about 8% binder versus 5.5% in standard Superpave.

Responses to Geotechnical Questions

*Hawaii and Canada are not shown.



Arkansas	*Hawaii	Maine	New Mexico	Vermont
Arizona	Idaho	Michigan	New York	Virginia
Colorado	Illinois	Minnesota	North Carolina	West Virginia
Connecticut	Iowa	Mississippi	Oregon	*Canada
Delaware	Kansas	Nevada	Rhode Island	
Florida	Kentucky	New Hampshire	South Dakota	
Georgia	Louisiana	New Jersey	Tennessee	

Question 8:	How many years has your State been using scrap tires in geotechnical related projects?
	0 60.61% 1 - 5 12.12% 5 - 10 21.21% > 10 3.03%
Question 9:	How many successful projects has your State completed using scrap tires?
	0 63.64% 1 - 5 27.27% 5 - 10 3.03% > 10 3.03%

Question 10:	How many successful projects has your State completed using scrap tires where a lightweight fill was required, e.g., embankments over soft ground, landslide repairs?
	0 72.73% 1 - 5 21.21% 5 - 10 0.00% > 10 3.03%
Question 11:	How many successful projects has your State completed using scrap tires as structural fill in common embankments?
	0 75.76% 1 - 5 18.18% 5 - 10 0.00% >10 0.00%
Question 12:	How many successful projects has your State completed using scrap tires as lightweight fill behind retaining structures?
	0 84.85% 1 - 5 9.09% 5 - 10 0.00% >10 0.00%
Question 13:	What are some other geotechnical uses for which scrap tires have been employed in your State, e.g., as drainage layers, wall facings, insulating layers, etc?
	Drainage in shallow trench under ditch for subsurface
	Note the answers to questions 9-12 should have been left blank. we have no projects. by putting a zero it incorrectly implies that we have had some but none successful
	Drain tile and basement wall fill to reduce lateral loads on private applications. Q. 14 below is very bad and cannot be answered either way. Both are untrue.
	Used as wall facing for a demonstration project in place of precast panels, timbers, or concrete block (retaining wall constructed of truck tires bolted together, filled and backfilled with select material).
	NDOT does not use scrap tires for geotechnical uses.
	We have not used scrap tires in geotechnical applications and we have not developed plans and specifications for using them.
	Discussed option of using scrap tires as lightweight fill, but never received approval from state DEP.
	We have one project in which we used scrap tires as a capillary break/drainage layer in an unpaved road. The road was subsequently paved.
	Has not been used to-date in CT
	drainage layer erosion control (experimental)
	Have not used scrap tires in embankments or for other geotechnical uses
	As a drainage media (partial replacement for stone fill in a stile-filled ditch)
	Lightweight fill considered but vetoed by environmental agency and due to fire concerns.
	Several projects have been suggested for scrap tire embankments, but the lack of a sufficient quantity or the economics have prevented their use. The following answers are based on those projects.

Question 14:	Based on costs associated with scrap tire use in your State, which statement best characterizes your agency's perspective regarding the economics of using scrap tires in embankments fills?
	Only competitive for all uses when a subsidy is in place 30.30% Unsubsidized scrap tires are only competitive with other types of lightweight fill, e.g., foam. 18.18%
Question 15:	If you have additional comments regarding the economics of scrap tire use, please include them below.
	Note: we have never had a project
	To my knowledge, we have constructed one scrap tire embankment that was constructed as a research project. Since these embankments are not constructed as standard practice, I did not answer questions 18-22. I requested a copy of the research report from the University of KY, but it cannot be located. If it is located, we could provide you more information (questions 24-26).
	Virginia had 1 major project where shredded scrap tires were used (Rte. 199 in James City/York counties). It was used as an allowable alternative to regular borrow soil. Contractor bid the use of tires at same price as borrow soil even though the tires were given to the contractor, they only had to deal with the transport costs (about 18 miles - one way).
	Not used
	They are very cost effective.
	Never has been used on FDOT project, so do not have a firm idea on economics.
	At one time there was a scrap tire processing facility in VT. It has since gone out of business and all scrap tires are shipped out of state for fuel. On at least one completed project, shredded tires had to be imported from an adjacent state to keep up with the demand. Needless to say, this resulted in excessive trucking costs.
	Considering a subsidy is in-place from an outside agency, the contractor has only bid as necessary to undercut alternate methods of construction.
	No.
	We stopped, based on anecdotal evidence of spontaneous combustion.
Question 16:	What design guidelines for scrap tire embankments are currently in use in your State?
	FHWA 1997: Interim Guidelines for Shredded Tire Embankments (ASTM D 6370-98) 15.15% Your own State's Guidelines 9.09% Other 0.00% None 57.58%
Question 17:	What is the maximum height of any existing scrap tire embankment in your State?
	3 - 10 ft 12.12% 10 - 20 ft 21.21% > 20 ft 3.03% No existing scrap tire embankment 48.48%
Question 18:	What type(s) of scrap tire embankments are allowed in your State?
	Monofills 9 Selections, 27.27% Alternating layers of pure tires and soil 4 Selections, 12.12%

	Tire/Soil Mixtures 6 Selections, 18.18%
Question 19:	What statement below best characterizes your design practice with respect to placement of scrap tire fills in relation to the ground water table?
	Construction above the ground water table is always required. 21.21% Construction below the ground water table is always allowed. 0.00% Construction below the ground water table is allowed on a case-by-case basis. 18.18%
Question 20:	What statement below best characterizes your design practice with respect to placement of scrap tire fills in proximity to wetlands or other environmentally sensitive areas? Consider "in proximity" to mean that leached contaminants would immediately impact the sensitive area. In the statements below, "environmentally sensitive areas" include wetlands.
	Construction in proximity to environmentally sensitive areas is not allowed. 12.12% Construction in proximity to environmentally sensitive areas is allowed on a case-by-case basis. 24.24%
Question 21:	Prior to considering a scrap tire embankment, does your State have any guidelines with regard to the intended use of the highway, e.g., maximum ADT, type of traffic?
	Yes 0.00% No 54.55%
Question 22:	What is the minimum thickness of pavement and subgrade that is to be placed over scrap tire embankments?
	No minimum is specified 9.09% < 2 ft 0.00% 2 - 4 ft 18.18% > 4 ft 6.06% Unknown 15.15%
Question 23:	If there have been failures of scrap tire embankments in your State, what have been the reasons for failure?
	Combustion 0 Selections, 0.00% Excessive compression of the scrap tire fill 1 Selections, 3.03% Excessive settlement of the foundation soil 0 Selections, 0.00% Slope failures (including reactivation of repaired landslides) 0 Selections, 0.00% Poor performance of pavements 1 Selections, 3.03% Environmental reasons, e.g., excessive leaching of hazardous substances 0 Selections, 0.00%
Question 24:	If asked, could you provide any case studies of projects completed within your State that employed scrap tires?
	Yes 27.27% No 36.36%
Question 25:	If asked, could you provide a copy of a typical plan sheet for an embankment or retaining wall project, within your State, in which scrap tires are to be, or have been, utilized?

	Yes 24.24% No 42.42%
Question 26:	If asked, could you provide a copy of your State's Contract Special Provisions that pertain to the use of scrap tires?
	Yes 15.15% No 45.45%
Question 27:	If possible, can you elaborate on any failures that you noted above? If desired, extra sheets, copies of published papers, reports, etc. can be mailed to the contact indicated in the footer.
	This particular site did not fail. In fact, it performed very well.
	Insufficient pavement structure above the shredded tire layer resulted in premature cracking in the pavement.
	1. Excessive compression of the scrap tire fill. 2. Combustion of the scrap tire fill behind retaining structure.
Question 28:	Is your Transportation Department, or other state agency, conducting or sponsoring (financially or with in-kind services) any research pertaining to the use of scrap tires in geotechnical engineering applications?
	Yes 12.12% No 69.70% Unknown 6.06%

APPENDIX M – SHREDDED WASTE TIRE IN EMBANKMENTS (NORTH CAROLINA DOT)

August 5, 2003

Material

The material shall be from waste tires, which shall be shredded into one inch to three inch size strips.

Constructions Methods

Shredded tires shall not be placed within three feet of the outside limits of embankments, within four feet of subgrade, or below the water level of the surrounding area.

Embankments shall be constructed by placing alternate layers of shredded tires and soil and mixing and blending together during compaction. The embankment shall be manipulated sufficiently to minimize voids. The thickness of uncompacted layers of shredded tires and soil shall be as directed by the Engineer.

At locations where shredded tires are to be incorporated into the embankment, shredded tires shall constitute between ten percent and forty percent by volume of that portion of the embankment. An average of twenty-five percent shall be a goal. The actual percentage shall be as directed by the Engineer.

The compaction shall be to the satisfaction of the Engineer.

Method of Measurement

The quantity of shredded tires to be paid for will be the actual number of cubic yards of approved material, measured in trucks, which has been delivered and incorporated in the completed and accepted work. Each truck will be measured by the Engineer and shall bear a legible identification mark indicating its capacity. Each truck shall be loaded to at least its measured capacity at the time it arrives at the point of delivery.

APPENDIX N –SHREDDED SCRAP TIRE LIGHTWEIGHT FILLS (VIRGINIA DOT)

February 3, 1994

DESCRIPTION

These specifications cover the construction of lightweight fills using shredded scrap tires. The placement of shredded scrap tires shall be in areas of embankment as detailed in Section III herein.

MATERIALS

Shredded scrap rubber shall be cut from any type tires and by any method that will meet the following requirements:

A. The average size of shredded scrap rubber shall not exceed 40sq. in. (determined from average of 10 samples).
B. The maximum length of any piece shall be 10 in.
C. All pieces shall have at least one sidewall severed from the face of the tire.
D. No metal particles shall be placed in the fill that are not firmly attached to a rubber segment.

Stockpiling of shredded scrap tires will not be permitted on the project site. Shredded scrap tires shall be transported from the processing site and placed directly in the embankment.

CONSTRUCTION PROCEDURES

The shredded scrap tires shall be blended with soil within the following boundaries in the embankment:

A. Bottom – minimum two feet (2′) above the high water table.
B. Sides – minimum four feet (4′) inside the side slopes.
C. Top – minimum 5 foot (5′) soil embankment “cap.”

The embankment sections shall be constructed with a crown of not less than ¾ inch per foot away from the centerline of the fill. If the soil and tire fill becomes saturated during construction, drainage ditches shall be constructed to dry the material before proceeding.

Embankments shall be constructed by placing alternate layers of shredded tires and soil and mixing and blending during compaction. The thickness of uncompacted layers of shredded tires and soil shall be as directed by the Engineer. For those areas where shredded tires are to be incorporated into the embankment, shredded tires shall constitute approximately fifty percent (50%) by volume of that portion of the embankment. The soil and tire embankment shall be manipulated sufficiently to minimize voids.

Manipulation and compaction of the soil and tire embankment shall be to the satisfaction of the Engineer, and shall be accomplished with a sheepsfoot roller or other approved method.

Soil embankment “cap” shall be compacted in accordance with Section 303 of the Specifications.

A five (5′) minimum uncompacted surcharge shall be placed on top of the "cap" as detailed on the plans. Surcharge shall remain in place for the time period specified on plans or until removal is authorized by the Engineer.

Settlement plates shall be placed as detailed on the plans and according to Section 303.04 of the Specifications.

METHOD OF MEASUREMENT AND BASIS OF PAVEMENT

Shredded scrap tires will be paid for at the contract unit price per ton, which shall be full compensation for furnishing tires and for placing, manipulation and compaction.

Surcharge placement and removal will be measured and paid for in accordance with Section 303.06 of the Specifications.

Payments will be made under:

Pay Item	Pay Unit
Shredded Scrap Tires	Ton
Surcharge Placement and Removal	Cubic Yard
Settlement Plate	Each