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State of the Practice—

Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier

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16. Abstract

This document is a comprehensive overview of the terminology, processes, products, and applications of crumb rubber modifier (CRM) technology. This technology includes any use of scrap tire rubber in asphalt paving materials. In general, CRM technology can be divided into two categories—the wet process and the dry process. When CRM is incorporated into an asphalt paving material, it will modify the properties of the binder (asphalt rubber) and/or act as a rubber aggregate (rubber modified hot mix asphalt). The five concepts for using CRM discussed in the report are McDonald, PlusRide, generic dry, chunk rubber asphalt concrete, and continuous blending asphalt rubber.

There are two principal unresolved engineering issues related to the use of CRM in asphalt paving materials. On the national level, the ability to recycle asphalt paving mixes containing CRM has not been demonstrated. At the State and local levels, these modified asphalt mixes must be field evaluated to establish expected levels of performance.

The appendices provide guidelines for material specifications, mix design, and construction specifications. An experimental work plan for monitoring performance and a stack emission testing program are also included.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2

VOLUME

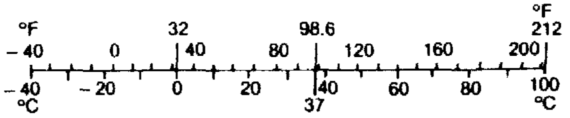
Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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I. PURPOSE

The use of scrap tire rubber as an modifier for asphalt cement has been developing for over 25 years. However, since the late 1980's, the emphasis for this engineering technology began to focus on its potential as a significant alternative use for an environmental solid waste problem - scrap tires. Unlike some "environmental solutions" in highway engineering, the use of scrap tire rubber in asphalt paving applications may have benefits recognized by both the engineer and environmentalist.

The present interest in this technology has national environmental significance. Scrap tires are visually offensive, a health and fire hazard, and a part of the solid waste management problem. Many States have enacted legislation to regulate the scrap tire problem. At the national level, both the House and Senate introduced legislation in 1990 which could consolidate the States' efforts. The legislation would regulate the transportation and storage of scrap tires and encourage the development of alternative uses. Further, Section 1038 of the Intermodal Surface Transportation Efficiency Act of 1991 specifically addresses the study and utilization of scrap tire rubber by the highway industry.

This report provides technical guidance to the asphalt paving community on the use of scrap tires. The report discusses scrap tire rubber as a highway engineering material; the technology presently available to incorporate this material; the engineering products, design considerations, and construction practices; and the additional research needs as they relate to applying this technology. Each highway agency interested in, or required by legislation, to evaluate **Crumb Rubber Modifier** (CRM) technology should become familiar with all the available processes and engineering concepts as a part of developing their evaluation program. There are a number of possible applications, but not all applications are appropriate in every State.

The bottom line of the evaluation program should be the determination of the expected performance of the material/application being studied. The performance data collected can become a part of a national data base provided the experimental project is properly designed, monitored and documented. A few applications have been adequately documented. The largest potential application, projects incorporating scrap tire rubber into hot mix asphalt paving mixes, has an insufficient number of acceptable experimental projects from which to establish the expected performance. This report will not address the issue of expected field performance, but will provide the highway agency the state-of-the-practice on CRM technology. A highway agency can develop an evaluation program to address their particular paving needs and collect performance data using the theory, design, and construction information in this report.

Pavement performance is a key component in determining if the use of scrap tire rubber is cost-effective. To determine if the material is cost-effective involves many variables and may include the environmental benefit of the CRM as an alternative use for scrap tires. However, highway agencies should focus their attention on developing those applications which can demonstrate a reasonable benefit to the highway system. It is probable that some areas of the country will not benefit from this technology.

II. BACKGROUND

A. Environment and Legislation

Each year the United States discards approximately 285 million tires. Of that figure, 33 million tires are retreaded and 22 million tires are reused (resold). Another 42 million are diverted to various other alternative uses. The remaining 188 million tires are added to stockpiles, landfills, or illegal dumps across the country. The Environmental Protection Agency (EPA) estimates that the present size of the scrap tire problem is 2 to 3 billion tires.[1]

Most of the markets which use the 97 million tires that are "recycled" cannot support additional expansion. The supply of retread, reuse, and processed rubber products meets or exceeds the existing demand. These saturated markets represent 70 percent of the present demand for scrap tires. When compared to the annual number of tires discarded, these 65 to 70 million tires used by the saturated markets only absorb 24 percent of the tire waste stream.

Of the available expanding markets for scrap tires, only two have shown the potential to use a significant number of scrap tires. They are fuel for combustion and crumb rubber modifier (CRM) for asphalt paving.[2] Combustion already plays a major role, consuming 26 million tires annually. Many industries benefit from the high energy output supplied from scrap tire rubber. Most of the facilities blend a shredded scrap tire product, known as tire-derived fuel (TDF), with their normal fuel stock in their existing furnaces. Newer, specially designed furnaces accept whole tires. Combustion facilities have the potential to use 0.5 to 10 million scrap tires per facility per year. In comparison, the second potential new market, CRM, presently consumes 1 to 2 million tires per year. The CRM technology can incorporate the rubber from 2 to 6 tires into a metric ton (ton) of hot-mix asphalt (HMA) paving material. To recycle 10 million scrap tires annually as CRM, 2 to 5 million metric tons (2 to 5 million tons) of HMA material would require modification.

There are other alternative highway uses for scrap tires. The Transportation Research Board (TRB) initiated a synthesis in 1989 to document these other alternative uses.[3] Scrap tires, or rubber processed from scrap tires, have been examined by a number of highway agencies for use in light-weight embankments, retaining walls, safety hardware, and pavement subbase. Details on these potential uses will be documented in the TRB synthesis.

The environmental risks linked to the presence of scrap tire stockpiles and a number of recent, well publicized tire stockpile fires initiated legislative action at the State and national level. At the beginning of 1991, 44 States had drafted, introduced, regulated, or enacted laws to control the scrap tire problem.[4] Typical provisions of the States' legislation include: regulations to control the processing, hauling and storage (stockpiles) of scrap tires; restrictions on scrap tires in landfills; provisions for funding, normally a tire disposal fee; and in a number of States, incentives for developing new alternative use markets. The obvious intent of the incentive program is to develop uses for scrap tires in the host State. Unfortunately, this pragmatic approach does not, by the strict letter of the law, encourage the development of CRM technology. In a majority of cases, it is not practical to require that the host State's scrap tires be processed and incorporated into that specific State's paving project. This issue is further addressed in Section III.

As the States began regulating scrap tires, it became apparent that the imbalance in regulations and fees between neighboring States created a shift in the movement of scrap tires. States with little or no regulation became importers, shouldering a portion of their neighbor's problem. Also, the promising alternative use technologies could not be developed without national markets. These problems triggered national legislators to attempt to consolidate the regulations and stimulate alternative use technology. As Congress began to consider the reauthorization of the Solid Waste Disposal Act (RCRA), a number of bills were introduced to address the scrap tire problem. In 1990, the *Tire Recycling Incentives Act* was introduced in both the House (H.R. 4147) and Senate (S.2462). The Act was re-introduced in 1991 (H.R.871 and S.396) and it addressed both the regulation and technology issues. The *Waste Tire Recycling, Abatement and Disposal Act* (S.1038) and the *Tire Recycling and Recovery Act* (H.R.3058/3059) were introduced in 1991 as alternative methods of addressing the problem. Final action on RCRA is not anticipated before 1992.

The unique provisions of these proposed amendments to RCRA are the concepts developed to stimulate alternative use technologies. The Tire Recycling Incentives Act requires the tire manufacturers to recycle tires or use a recycling credit system to purchase credits from scrap tire recycling companies. The Waste Tire Recycling, Abatement and Disposal Act provides for a mandated market for CRM on federally funded asphalt paving projects. And the Tire Recycling and Recovery Act establishes a scrap tire trust fund to assist State developed recycling programs.

More revellent to the highway community is the Intermodal Surface Transportation Efficiency Act of 1991 which was enacted in December of 1991. The Act specifically addresses the use of CRM in Section 1038, "Use of Recycled Paving Material." The three primary requirements of this Section as they relate to CRM are:
(1) relax federal regulations to permit State and local agencies to use CRM,
(2) study the performance, recycling, and environmental aspects of CRM, and
(3) satisfy a minimum CRM utilization requirement beginning in 1994.

B. Hierarchy of Available Technology

Crumb Rubber Modifier (CRM) technology is a general term to identify a group of concepts which incorporate scrap tire rubber into asphalt paving materials. CRM is identified as an modifier because the introduction of the scrap tire rubber modifies conventional asphalt paving products. These modified asphalt paving products generally exhibit enhanced material properties, but unlike the comparison of asphalt cement to Portland Cement, are not considered a separate type of paving product.

Publications during the last 25 years used a variety of terms to define different processes and products as the technology evolved. Conflicting terminology has made it difficult for many user agencies to understand the technology. It is important that this document standardize the terminology, identify the processes and products, and distinguish between the various concepts as they are introduced. A summary of the terms used throughout this document are found in Appendix A.

In general, CRM technology can be divided into two categories. These categories define the basic processes used to add the crumb rubber into an asphalt paving material. They are the wet process and dry process. The ***wet process*** defines any method that blends the crumb rubber with the asphalt cement prior to incorporating the binder into the project. The ***dry process*** defines those methods that mix the crumb rubber with the aggregate before the mixture is charged with asphalt binder. The dry process is limited to hot mix asphalt (HMA) applications, while the wet process has been applied to crack sealants, surface treatments, and HMA mixtures.

There are a number of individual method technologies developing under these two broad categories. The first two technologies applied in the United States were the basis for defining wet process and dry process. The others are relatively new concepts which use the same basic processes, but have had little or no field evaluation. The first technology which applied the wet process is called the **McDonald Process.** The first application of the dry process is called the **PlusRide Process**. The newer concepts include the **Generic Dry Process, Chunk Rubber Asphalt Concrete** and **Continuous Blended Asphalt Rubber**. These newer concepts are described in Section VI. Figure 1 depicts the basic hierarchy of the presently known CRM technology as it has just been defined.

It is also important to distinguish between the processes, as just defined, and the products which can be produced. When CRM is incorporated into an asphalt paving material, the CRM will modify the properties of the binder and/or act as an rubber aggregate. The modified binder is commonly called **asphalt rubber**. When CRM is used as an rubber aggregate, the HMA is called **rubber modified hot mix asphalt.** Each method technology is specifically designed to achieve one or both of these products. Understanding the process/product relationship is key to developing the design for a specific project.

C. History in the United States

The use of CRM in asphalt paving did not develop as a solution to an environmental problem. In fact, the development of natural rubber in bitumen was introduced in the early 1840's.[5] For years, engineers and chemists have worked to blend natural rubber (latex) and synthetic rubber (polymers) in asphalt cements to enhance the elastic properties of the binder. Tire rubber, a compound of natural and synthetic rubber, is an available raw material which has been included in this effort.

In the early 1960's, Charles McDonald, Materials Engineer for the City of Phoenix, began working with a local asphalt company, Sahuaro Petroleum, to develop a highly elastic maintenance surface patch using CRM. This effort successfully blended the CRM with asphalt cement and placed a thin maintenance patch ("band-aid"). Observations of its performance expanded into the placement of surface treatments for entire projects. In 1968, the Arizona Department of Transportation (ADOT) placed its first Stress Absorbing Membrane (SAM), a surface treatment using an asphalt rubber binder. The "wet process," Sahuaro technology, continued to develop in the 1970's. ADOT placed their first Stress Absorbing Membrane Interlayer (SAMI) in 1972 and used asphalt rubber binder in HMA open graded friction course in 1975. During the mid 1970's ADOT placed over 700 miles of SAM and SAMI.[6]

As the Sahuaro technology continued to expand, the Arizona Refinery Company (ARCO) developed a similar "wet process" technology which added a blend of CRM and de-vulcanized CRM to the asphalt cement. The ARCO technology, through the addition of the de-vulcanized CRM, hoped to take advantage of the properties of re-processed rubber to further enhance the modified asphalt binder. Unfortunately, the advantages of using de-vulcanized CRM over standard ambient ground CRM were not significant and could not justify the additional cost of processing to achieve de-vulcanization.

The Sahuaro and Arco technologies merged and are presently controlled by the patents' co-owners. Carl Jacobson, Jr. and E.J. Johnson, the co-owners, retain all patent rights to the Sahuaro and ARCO technology.[7] In this document, the wet process developed in Arizona is referred to as the McDonald technology. A number of companies have licenses with the patents' owners to apply the McDonald process across the country.

The dry process was developed in the late 1960's in Sweden. The European trade name for this hot mix asphalt mixture with CRM as an rubber aggregate was Rubit. The Swedish technology was patented for use in the United States in 1978 under the trade name PlusRide. In the mid 1980's, the mix design was refined and established as the gap-graded mix commonly specified as PLusRide today. The Alaska Department of Transportation and Public Facilities (AKDOT&PF) began working with PlusRide in 1976 and is still the principal State highway agency developing this technology.[8] They placed 19 experimental projects between 1976 and 1983.

Four corporations have marketed the Plusride technology since it was introduced in the United States, originally All Seasons Surfacing Corp., then PlusRide Asphalt Inc., PaveTech Corp., and presently EnvirOtire Inc. All of these companies were based in the Seattle, Washington area. EnvirOtire Inc. retains all patent rights and establishes specific licensing agreements with contractors on a project by project basis.[9]

The Federal Highway Administration (FHWA) has been involved with CRM since the beginning of the 1970's. In 1971, FHWA report FHWA-RD-72-1, *An Annotated Bibliography on Use of Rubber in Asphalt Pavements*, provided a summary of 86 documents discussing the use of rubber in asphalt pavements. Although a majority of these publications are related to natural and synthetic rubber modifiers, some also discuss the use of tire rubber (CRM).

The first formal program to examine CRM was initiated in 1976 as Demonstration Project No. 37 - *The Use of Discarded Tires in Highway Construction*. This program encouraged State highway agencies to examine the field application of SAM's and SAMI's. Forty (40) projects were constructed and evaluated under this program.

In 1983, the Demonstration Projects Division opened Experimental Projects No.3 (EP-3) - *Asphalt Additives*. The EP-3 program examines a broad range of asphalt additives, including CRM. The focus for CRM in EP-3 is toward the development of HMA Paving Materials. This program is ongoing. The title of the program was changed to Test and Evaluation Project No. 3 (TE-3) in late 1990. This program is presently evaluating the field performance of nine CRM experimental projects. See Appendix B.

The most comprehensive review of CRM projects by FHWA was published in 1986 as report FHWA/RD-86/027, *Investigation of Materials and Structural Properties of Asphalt-Rubber Paving Materials*. This pooled-fund research study evaluated more than 200 field test sections constructed between 1977 and 1984 involving many applications of the wet and dry processes.

The FHWA Office of Technology Application, formerly the Demonstration Projects Division, provides the national coordination for the evaluation of new materials and technologies. Experimental projects in addition to those funded through Demo-37 and TE-3, are tabulated in the National Experimental Projects Tabulation (NEPT), which categorically lists all known materials being evaluated by highway agencies. Through Demo-37, TE-3, and NEPT, the State highway agencies have a vehicle to examine the design, construction and field performance of CRM.

The experimental evaluation program for CRM has been divided into two groups, surface treatments and HMA's. While the primary emphasis of Demo-37 was on the application of CRM (wet process) as a surface treatment binder, the primary emphasis of TE-3 is to evaluate the design, construction and performance of CRM (both wet and dry process) as an HMA binder.

III. CRUMB RUBBER MODIFIER AND ITS PAVING PROPERTIES

A. Crumb Rubber Modifier (CRM)

Tire rubber is the principal component in CRM. Tire rubber is primarily a composite of a number of blends of natural rubber, synthetic rubbers, and carbon black. Tire rubber, fiber, and steel belting comprise the key elements of today's tire. Various parts of the tire construction require specific rubber properties, flexible walls, abrasion resistant tread, etc. These various parts of the tire contain rubber with different amounts of natural and various synthetic rubbers. Natural rubber provides elastic properties while synthetic rubbers improve the compound's thermal stability properties. In addition, there are differences between types of tires. The CRM industry has found that earlier passenger tires contained approximately 20 percent natural and 26 percent synthetic rubber, while earlier truck tires contained approximately 33 percent natural and 21 percent synthetic rubber.[10] With the development and improvement of the steel belted tire design, however, the difference in tire rubber composition between passenger and truck tires has reduced.

Although these variations in tire rubber exist, both between tires and within the tire structure, the rubber composition of a bulk sample of CRM is reasonably uniform. A majority of the CRM industry does not routinely produce a crumb rubber based on a specific blend of tires. In general, to achieve a specific or unique set of modified properties, other sources of rubber (scrap, natural, or synthetic) can be added to build a particular chemical composition.

The principal source of raw material for producing CRM is scrap tire rubber. Scrap tire rubber can be delivered to the processing plant as whole tires, cut tires, shredded tires or retread buffing waste. The form of scrap tire rubber delivered will depend greatly on the capabilities of the processing plant. Whole tires require the least amount of pre-processing but are bulky and limit shipping capacity. Cut tire raw material is scrap tires which have been minimally processed, typically split or sectioned, to improve handling and shipping. Both whole and cut tire materials are difficult for many processing plants to reduce to CRM due to limits of the processing equipment.

Shredded tire rubber is the preferred and logical alternative as a raw material for producing CRM. The shredding process is generally a mobile operation, easily taken from one scrap tire stockpile to another to reduce whole scrap tires into a manageable material which is less bulky and easier to transport. The shredding process typically reduces the tire to pieces 0.15 meter (6 inches) square and smaller.

Buffing waste is a high quality scrap tire rubber which is a by-product from the conditioning of tire carcasses in preparation for retreading. The scrap tire rubber generated by the buffing process is very small thread-like shapes. Buffing waste has been marketed since the development of retreading and, because of its size and quality, is an excellent raw material for many existing rubber manufacturing processes. Although buffing waste rubber is available, most of the material is already allocated to the established rubber manufacturing companies and is generally in high demand.

The quality of the raw material, particularly its cleanliness, is a factor in producing a quality CRM. The amount of contaminate, specifically soil, sand, and rocks, included in the raw material delivered to the reprocessing plant will many times follow through the processing and account for a fraction of the delivered CRM product. Whole tires have the highest potential for retaining deleterious material, especially inside the tire. Cut tire sections reduce this retention factor, but still hold deleterious material by nature of their concave shape. Reducing scrap tires to a shredded tire raw material can significantly improve the quality of the material. Most shredding operations will substantially eliminate the concave shape and the processing itself physically loosens soil adhering to the tire, which can be discarded prior to processing the shredded tire into CRM.

The type of scrap tire raw material and the quality of that material are generally the responsibility of the CRM processor. The capabilities of the processing plant and the buyer's specified CRM properties will direct the processor's operation.

There are basically four methods of processing scrap tire rubber into CRM.

> The **crackermill process** is the most common method. The crackermill process tears apart scrap tire rubber, reducing the size of the rubber by

passing the material between rotating corrugated steel drums. The tearing action is achieved by the spacing between the pair of drums and the differential speeds of the drums. The process is performed at ambient temperature and requires that the scrap tire be pre-processed by shredding. The crackermill process is the most common and productive method of producing CRM at the present time.

The **granulator process** shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance. The granulator process is performed at ambient temperatures and can accommodate any form of scrap tire rubber, including whole tires.

The **micro-mill process** further reduces a crumb rubber to a very fine ground particle. One micro-mill process mixes crumb rubber with water to make a rubber slurry. The slurry is forced between rotating abrasive disc which reduce the rubber crumb to a smaller size. The processed slurry is extruded and dried to achieve this crumb rubber product.

The **cryogenic process** is not performed at ambient temperatures. This process reduces the temperature of scrap tire rubber by submersing it in a bath of liquid nitrogen. The brittle rubber is then crushed to the desired particle size. Although this technique has been successfully demonstrated, it is too costly for full scale production at this time. In addition, the surface texture of cryogenically crushed scrap tire rubber may have limited benefit as CRM. This report will not expand on the use of CRM produced by the cryogenic process.

Although there are substantial differences in the methods just described, there are several common aspects to producing CRM. Each process, except for micro-milling, requires one or more series of fiber and steel separators. As the scrap tire rubber is processed, reducing its size, the steel belting and fiber reinforcing is separated from the rubber. The fiber and steel separators in the processing chain remove these materials out of the processed rubber crumb. Depending on the conditions, talc or other inert mineral powder, is added to the CRM to reduce the rubber particles' tendency to stick together. This, in turn, improves the CRM's ability to be handled and flow from its shipping container. Typically, the amount of talc required should not exceed 4 percent by weight of the rubber.

In general, a scrap tire weighing approximately 9 kilograms (20 pounds) will produce 4.5 to 5.5 kilograms (10 to 12 pounds) of CRM. The remainder of the tire is fiber, steel and small amounts of rubber removed with the fiber and steel. These by-products from processing scrap tires can have recycling value depending on the availability of those recycling industries.

In addition to mechanical reduction of scrap tire rubber, it is possible to chemically alter the rubber component. Early work by the Arizona Refinery Company (ARCO) reduced a portion of the crumb rubber to a devulcanized state. This chemical processing breaks the vulcanization (polymer block linking) to attain a softer, more pliable material. ARCO's research and field application of devulcanized CRM showed no significant improvement over CRM which did not receive the additional processing. Therefore, the cost associated with the additional processing could not be justified. This report will not elaborate on devulcanized CRM.

Each method of producing CRM generates a unique particle with specific characteristics. The crackermill process produces an irregularly shaped torn particle with a large surface area. The particles can be produced over a range of sizes from 4.75-millimeter sieve to 425-micron sieve (No. 4 to No. 40 sieve). These particles are commonly described as a **ground** CRM. The granulator produces a cubical, uniformly shaped cut particle with a low surface area. The particles can be produced over a range of sizes, typically from 9.5-millimeter sieve down to 2.00-millimeter sieve (3/8-inch to No.10 sieve). This material is called a **granulated CRM.**

The micro-mill process produces a very fine ground CRM. The particles can be reduced to a range of sizes from 425-micron sieve down to 75-micron sieve (No. 40 to No. 200 sieve).

The desired surface area, size, and shape of the CRM for a particular project will determine which method of processing is required. The project specifications should establish the required gradation of the CRM and the type of particle, ground or granulated. From this specification, the contractor can solicit information and quotes from the CRM producers and/or subcontractors specializing in CRM technology.

Although there are inherent variables in the raw material, scrap tires, some degree of quality control can and should be required for CRM producers. Appendix C provides a basic material specification for the CRM. Every CRM producer should have a quality control program to continually monitor the uniformity of the product, both its chemical composition and gradation. Expected minimal testing is described in the Appendix C specification. Major fluctuations in the chemistry or gradation could alter the properties of the desired paving product. ASTM is also considering a specification for CRM.[11]

Processing scrap tires into CRM is not a mobile operation. A small industrial facility with a $5 to $10 million capital investment in equipment is necessary to produce a quality product. Table 1 provides a list of present known CRM producers. The list is not inclusive of all producers. Most of the producers have established scrap tire sources and already work at peak capacity to fulfill existing contracts. The cost of CRM from the producer ranges from 20 to 35 cents per kilogram (10 to 15 cents per pound) plus shipping for coarse and medium particles (above 425-micron sieve), and above 55 cents per kilogram (25 cents per pound) for fine ground CRM.

Most CRM is shipped in 22- to 27-kilogram (50- to 60-pound) bags, which are paper or plastic. These are stacked on pallets and shipped in trailers. There are also 900 kilogram (2000 pound) containers which are either canvass (reusable) or paper. The 900 kilogram containers are readily handled by conventional forklift equipment and discharge the CRM from the bottom. Other methods of bulk shipment are being examined by the CRM industry. The major problem with bulk shipment is segregation of the smaller particle sizes to the bottom of the container. If blends of CRM specify a broad gradation range (for example:4.75-millimeter sieve to 425-micron sieve, No.4 to No.40), then bulk shipment may not be an appropriate method of transporting the CRM.

The geographic range required by the producers to obtain scrap tires is substantially smaller than their range for shipping the CRM product. As previously noted, many of the established State legislation packages on scrap tires which have an incentive program for alternative uses require that scrap tires from that State be incorporated in the project. This restriction is impractical for asphalt paving projects using CRM. Unless the CRM producer maintains a facility in that State or routinely receives scrap tires from that State, mandatory use of "in-state" scrap tires can reduce or eliminate any benefit from the program. The cost associated with double-shipping the rubber is prohibitive.

The following are two possible alternatives for handling this problem. The first alternative is to have the CRM producer ship processed CRM to the project and return with "in-state" tires to his facility. Even though the CRM used on the project was not produced from "in-state" scrap tires, the equivalent amount of "in-state" scrap tires are removed from the State's inventory. The other alternative is to require the contractor to have "in-state" scrap tires properly recycled by any acceptable method instead of using them for the CRM project. In either situation, the ratio of scrap tires to processed CRM should not be based on an equal weight. Based on the industry rule of thumb, a standard scrap tire weighs 9 kilograms (20 pounds) and the standard ambient CRM processing methods produce 4.5 to 5.5 kilograms (10 to 12 pounds) of CRM per scrap tire. The supply to product ratio of 2 to 1 can be considered reasonable.

B. Paving Properties

There are two basic products which can be achieved by adding CRM to asphalt paving applications. They are modified binder and rubber aggregate. The size, shape, and texture of CRM required to achieve these end-products varies with the proposed application. The remainder of this section discusses how the CRM affects the asphalt cement and aggregate.

Modified Binder

When asphalt cement and CRM are blended together, there is an interaction between the materials. This interaction, defined as asphalt-rubber reaction, is affected by a number of variables. Specifically, 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 component of the asphalt cement. The blending temperature, time, and mechanical energy are parameters of the process used to add the CRM. Depending on the process selected, these parameters can be adjusted (within limits) to achieve the desired product.

The reaction, more appropriately defined as polymer swell, is not a chemical reaction. It is the absorption of aromatic oils from the asphalt cement into the polymer chains which are the key components of the natural and synthetic rubber in CRM.[12] The natural rubber polymers are more reactive with the asphalt cement than the synthetic rubber polymers. Each group of polymer chains imparts particular characteristics into the modified binder.

The reaction does not result in a melting of the CRM into the AC. The reaction is similar to a compressed, hard, dry sponge being placed in a water bath. As the sponge absorbs the water, it swells and softens. CRM behaves in a similar manner. As CRM reacts with the asphalt cement it also swells and softens. And, in addition, the reacted particle becomes tacky and develops an adhesive property. A fully reacted particle can swell 3 to 5 times its original volume.[13]

The viscosity of the asphalt/CRM blend is used to monitor the reaction. As the asphalt and CRM react, absorbing aromatic oil from the asphalt cement, the blend's viscosity increases as the amount of aromatic oils to lubricate the binder reduces. The swelling and adhesive characteristics of the reacted CRM also add to the increased viscosity. An asphalt cement modified with 15 percent CRM can increase the binder's high temperature (135 °C, 275 °F) viscosity by a factor of 10.

The rate of reaction between CRM and the asphalt cement can be increased by increasing the surface area of the CRM. A given weight of ambient ground CRM passing a 850-micron sieve (No. 20 sieve) reacts faster than an equal weight of granulated CRM passing a 4.75-millimeter (No. 4 sieve). The surface area is increased by the reduction in size and the difference in production methods. This concept is used to distinguish between modified binder and rubber aggregate.

The rate of reaction is also influenced by the temperature at which the blend is reacted. If a modified binder is the desired product, then blending temperatures between 150 °C and 200 °C (300 ° and 400 °F) are needed to accelerate the reaction. There are some experts that believe some rate of reaction takes place even at ambient temperatures.[14] It is very probable that the supply of aromatic oils available in the asphalt cement is "shared" with the CRM and that the reaction occurs both ways depending on the balance of aromatic oils available to the system. Also note that the binder viscosity stabilizes as the reaction continues. The specified reaction time should be the minimum time (at a preset temperature) required to stabilize the binder viscosity.

The mechanical mixing energy used to blend and react the modified binder can significantly alter the characteristics of the binder. Due to the particle size typically specified for CRM, only low energy shear mixing has been applied. High shear mixing equipment will not handle the coarse CRM. The use of high-energy shear mixing and fine ground CRM may be an area for further research.

This modified binder, asphalt rubber, exhibits enhanced binder properties when compared to conventional asphalt cement in laboratory tests. Changes in the viscosity of the binder over the normal range of operating and mixing temperatures indicates that the addition of CRM flattens the temperature/viscosity curve, reducing the binder's temperature sensitivity. Most of the modification in the binder's properties, with regard to viscosity, occur at the higher temperatures. Figure 2 illustrates the effect of CRM on the binder's temperature/viscosity curve.[15] By increasing the high temperature viscosity of the binder, the binder can be modified in one of two ways. As already noted, using a standard asphalt cement with CRM will modify the high temperature properties of the binder. The other approach is to lower the viscosity grade of the standard asphalt cement and, through the addition of CRM, retain the standard asphalt cement high-temperature properties while modifying the low temperature properties of the binder. The shift in low temperature properties can also be accomplished through the addition of extender oil with the standard asphalt cement and CRM. Figure 2 illustrates how the binder viscosity can be changed by alternative material selections. Table 2 shows how the binder properties can be altered by the addition of CRM.[16]

A majority of the standard binder tests used to measure the properties of asphalt cement can be applied to asphalt rubber binder. Appendix C provides a basic material specification for asphalt rubber binder. Only the conventional capillary type viscometer tests are known to be ineffective. The physical restrictions of the capillary tube will not accommodate the swollen rubber particles. Research to increase the diameter of the tube was unable to achieve consistent results.[17] The method used to measure the viscosity of these modified binders is rotational shear resistance using the Brookfield Viscometer, ASTM D 2994. Portable versions of this viscometer are commonly used to monitor the binder during the reaction phase and as a production control. Several binder tests may show an increase in standard deviation due to the non-uniformity of the modified binder. Since the crumb rubber does not "dissolve" into the asphalt cement, the swollen rubber particles in the binder can affect the consistency of the binder during a particular test, such as penetration and ductility.

The enhancements in the binder properties measured in the lab can be an indication of better performance of the paving material in the field. However, there are numerous variables, beyond the properties of the binder, which also affect the overall performance of the pavement. Setting these other variables aside, the modified binder properties may influence the following performance characteristics:

1) Thermal cracking.

> The reduced temperature susceptibility will allow the mix designer to choose a softer binder which is more flexible at low temperatures without decreasing the binder's rutting resistance. The elastic properties of the modified binder enhance the mixture's ability to resist tensile stresses.

2) Rutting.

> A primary effect of adding CRM to the binder is its ability to modify the high operating temperature properties of the binder.

3) Reflective Cracking.

A CRM modified binder demonstrates a significant enhancement in laboratory elasticity and resilient modulus testing.

4) Aging.

One of the components of CRM is carbon black. Studies show that the addition of carbon black improves the binder's durability. In addition, these binders are more viscous and typically retain thicker binder films on the aggregate. The thicker film delays the detrimental effect of oxidation.

5) Chip Retention.

The adhesive properties of the natural rubber component increase the binder's ability to hold aggregate in place.

There is also the potential for certain undesirable side effects. To develop enhanced pavement performance characteristics, the mix design will generally require the modified binder to increase its role in the paving material. In simple terms, modifying the asphalt binder with CRM will require an increase in the binder content. This has the following effects on the paving material's characteristics:

1) Cost.

The increase in the binder content and the cost associated with a CRM modified binder substantially increases the cost of the pavement. General costs for different applications are provided in Section V. To justify this cost requires an equally substantial improvement in pavement performance.

2) Bleeding and Flushing.

Higher binder contents increase the potential for bleeding and flushing. These mixes are sensitive to deviations from the established mix design.

Both the mix design procedures and construction control practices must be followed carefully.

3) Tracking.

CRM modified binder readily adheres to rubber. Blotter sand may be required on newly constructed surfaces to reduce tire tracking until the binder has sufficiently cooled and the surface oxidizes.

The ability of CRM to enhance the properties of the binder hinges on the compatibility between the asphalt cement and the CRM. Compatibility is dependent on the composition of both materials. The composition of the CRM is a relatively homogeneous blend of numerous rubber polymers from different types and parts of a tire. For all practical purposes, our ability to change the overall blended composition of CRM is limited. The asphalt is composed of asphaltenes (solids), aromatics (oils), and saturates (gels) which vary with crude source. The type and amount of aromatics in the asphalt cement play a major role in determining the compatibility. There must be sufficient aromatics in the asphalt cement to satisfy the absorption demands of the CRM and retain the needed low temperature flexibility of the binder. If the proposed asphalt cement is from a low aromatic crude, an extender oil will be needed to "sweeten" the asphalt cement or a different asphalt source should be considered. Every asphalt source should be checked for compatibility with CRM before field placement of material. The asphalt cement and CRM are compatible if the reaction time and temperature are reasonable (175 °C (350 °F) for 1 hour) and there is a significant flattening in the temperature viscosity curve. These conditions will vary with the particle size and amount of CRM.

Rubber Aggregate

The other product achieved by adding CRM is rubber aggregate. By limiting the time that the asphalt cement and CRM are maintained at mixing (reaction) temperatures and by specifying a coarse granulated CRM, the CRM can retain its physical shape and rigidity. This rubber aggregate product is only applied to hot-mixed asphalt designs and cannot be applied to non-plant mixed applications (surface treatments).

Generally, a mix design using this concept will include a percentage of finer ground CRM which produces a partially reacted modified binder. Evidence of this reaction has been noted by the "swelling" which occurs in the laboratory mix.

The limited reaction time allows the surface of the rubber particle to react with the asphalt cement, but does not permit sufficient time for the reaction to penetrate the entire rubber mass. This creates an asphalt/rubber interface which bonds the two materials together.

By specifying a granulated CRM, the smooth sheared surfaces of the particle are less reactive (lower surface area than ground CRM) and its cubical shape can be factored into the combined gradation of CRM and aggregate. The design of the combined gradation must take into account the difference in material specific gravities. CRM has a specific gravity of 1.15 and most aggregates have a specific gravity around 2.65. The weight of the CRM particles retained on any given sieve must be adjusted by a factor of 2.3 (2.65 ÷ 1.15) to determine the composite gradation.

Putting aside the effect of any binder modification which may accompany a design with rubber aggregate, how might rubber aggregate affect the performance of the hot mix asphalt mixes?

1) Reflective Cracking.

CRM, as rubber aggregate, may resist the stresses which occur as cracks in the existing pavement propagate upward through the overlay. When the stress at the tip of the crack reaches a rubber particle, the particle absorbs the stress, delaying the advance of the reflective crack.

2) Ice Disbonding

When a rubber modified hot mix asphalt is laid and compacted, some of the rubber particles in the mix are exposed on the surface. These rubber tips compress slightly when subjected to wheel loads. This creates a small area of flexibility that will not retain ice when it begins to crystallize. The benefit of this characteristic may only apply when the surface is continuously loaded and when the ice is relatively thin.

There are potential disadvantages associated with CRM used as a rubber aggregate. Similar to a CRM modified binder, for rubber aggregate to achieve the benefits of delayed reflective cracking and ice disbonding requires a minimum CRM content in the mix. This may have the following effect on the material's characteristics:

1) Cost.

The cost of CRM is significantly higher than the aggregate being displaced. In addition to this increase in cost, the binder content will increase to satisfy the small degree of rubber/asphalt reaction that occurs on the surface of the CRM. The total increase in the cost of the paving material must be balanced by an equal or better increase in the performance.

2) Ravelling.

When a load is placed on a particle of crumb rubber, it will deform and then rebound when the load is removed. If the structural aggregate matrix includes particles of CRM, the surface aggregate will displace when subjected to wheel loading because the CRM deforms as the aggregate transfers the stress into the pavement structure. The strain at the binder/aggregate interface increases with the increase in aggregate displacement. If the amount of strain and repetition of strain exceeds the ability of the binder to retain the surface aggregate, surface ravelling will occur.

Compatibility is not as critical with CRM as an rubber aggregate. The reaction between the CRM and the asphalt cement does not play a significant role in developing the performance enhancements of rubber aggregate. Some reaction is necessary to achieve the bond between the CRM and the asphalt, but a complete reaction (sufficient aromatic in the asphalt) is not desired. As noted previously, however, a mix design incorporating CRM as a rubber aggregate usually includes finer ground rubber which modifies the binder. The degree of binder modification desired will govern the need to consider compatibility between the CRM and asphalt cement.

IV. CONSTRUCTION PROCESS FOR CRUMB RUBBER MODIFIER

Section III defined crumb rubber modifier (CRM) and the two products that can be achieved by adding CRM to asphalt paving materials. The objective of this section is to describe the two processes presently in use to combine the CRM with paving materials. The intent of each process closely parallels the products. For simplicity, the processes are called the "wet process" and the "dry process." The remainder of this section will define each process, identify the equipment needed, and outline each procedure.

A. Wet Process

The ***wet process*** defines any method that adds the CRM to the asphalt cement prior to incorporating the binder in the asphalt paving project. This process is used to produce a modified binder product. There are three elements to the equipment necessary to achieve the wet process. They include blending the CRM and asphalt cement, reacting the two materials, and transferring the modified binder product to the desired project application. Figure 3 provides a simple schematic of the "wet process."

The blending unit must be capable of properly metering the CRM (a dry ground and/or granulated material) into the asphalt cement (a hot viscous liquid) at the required proportion established by the mix design. The blending chamber uses low shear mechanical energy to produce a uniform blend of CRM and asphalt cement. The chamber should be heated to retain the temperature specified for the reaction. Early projects using the process used agitated, heated asphalt tanker trucks to blend the CRM into the asphalt cement. This method was found to be unsatisfactory. It could not produce a uniform blend of modified binder and could not maintain adequate temperature for the reaction. Today's blending units are separate from the reaction tanks and are continuous blending units. The operator's panel controls the feed rate of the CRM and the pump speed for the asphalt cement. The materials are combined in the blending chamber and immediately discharged into the reaction tank.

The reaction tank must be capable of maintaining a uniform blend and maintaining a uniform constant temperature. It should be equipped with a mechanical agitating system that will keep the CRM uniformly dispersed in the asphalt cement and circulate the binder to maintain the reaction temperature uniformly throughout. The heating system must be capable of maintaining the reaction temperature (typically 175 to 200 °C, 350 to 400 °F) without generating hot spots which can "burn" or "coke" the modified binder. Again, conventional agitated tankers are not reliable reaction tanks based on past performance.

Once the reaction holding time has been achieved (typically 45 minutes to 1 hour), the modified binder is ready for use. The particular application will determine what method of transfer is required. Most applications require some method of controlled metering for the modified binder. Past experience in the CRM industry has shown that the asphalt rubber binder is an abrasive fluid and will deteriorate conventional binder pumps rapidly. Special pumps and frequent calibration are essential to ensure that a uniform accurate application of the modified binder is achieved.

The equipment necessary to perform the wet process is easily mounted on truck and trailer frames, making it very portable. The wet process is usually performed at or near the project site or hot mix facility. The equipment is self-contained and does not require any utility hook-ups. Two limiting factors to the process are having sufficient storage area for the shipment of CRM and the manual effort required to add CRM to the blending unit's hopper. The present practice is to manually break 22- to 27-kilogram (50- to 60-pound) bags of CRM and deposit the crumb onto an auger conveyor which feeds the blending hopper.

B. Dry Process

The ***dry process*** defines any method of adding CRM directly into the hot mix asphalt mix process, typically pre-blending the CRM with the heated aggregate prior to charging the mix with asphalt. This process is normally used when a rubber aggregate product is desired. No special equipment is needed for this process; however, a calibrated proportioning feed system is necessary when drum plants are used. The dry process has only been applied to hot mixed paving projects. It does not lend itself to other asphalt paving applications, such as surface treatments.

Incorporating the dry process at a batch mix facility is simple, but labor-intensive. The CRM is delivered to the site in 22- to 27-kilogram (50- to 60-pound) plastic bags. The bags are made of a low melting point material which allow the operator to charge the mixing chamber with the entire bag of CRM. The size of the batch to be mixed determines the number of bags to be added to each batch. The batch size usually corresponds to a whole number of bags per batch. No partial bags are added.

The dry process sequence at a batch mix facility is as follows. The mixing chamber is charged with heated aggregate, immediately followed by manual charging of the CRM bags. The aggregate and CRM are "dry" blended for approximately 15 seconds before the asphalt cement is added to the batch. The entire batch is then mixed to obtain a uniformly coated mixture prior to discharge.

The dry process can be used with drum mix facilities similar to producing mixes with recycled asphalt product (RAP). The process and equipment required for introducing RAP into a drum mixer can also be used to introduce CRM into a drum mixer. It is essential that the CRM feed system is electronically synchronized with the aggregate cold feed system to maintain proper proportioning of the CRM to the aggregate. The method used to meter the CRM must be sensitive enough to handle the small percentage (typically less than 3 percent by mix weight) of low specific gravity (1.15) material. Although there are no additional steps in processing CRM into a drum mix plant, some adjustment in temperatures and mix time will be needed to produce a uniformly blended/coated mixture.

The dry process will generate some reaction between the CRM and asphalt cement. The temperature of the mix and the time the mix is maintained within the mix/compaction temperature band will be sufficient to react a portion of the crumb. The amount of fine CRM introduced into the mix will determine the degree of modification to the asphalt binder.

Similar to batch mixing, the "dry process" at a drum mix facility has been labor intensive. Most projects are supplied with 22- to 27-kilogram (50- to 60-pound) bags which must be manually emptied into the feed system. Receiving bins which would accept the 900 kilogram (2000 pound) containers would greatly improve this condition.

V. DESIGN AND CONSTRUCTION PRACTICES

The use of crumb rubber modifier (CRM) in asphalt paving materials requires an understanding of appropriate design procedures and construction practices for the various paving applications. This section provides an overview of how CRM affects the design and construction of crack and joint sealants, surface treatments, hot mix asphalt, and composite designs.

A. Crack and Joint Sealants

The wet process is used to modify the properties of an asphalt crack/joint (C/J) sealant with CRM. This ensures that the CRM is fully reacted and has the maximum potential to enhance the asphalt. The use of asphalt-rubber C/J sealant is common across the country and is routinely used by many State maintenance crews. The material has an excellent performance record and is generally a cost-effective alternative.[18]

The choice of a sealant for a given location should take into consideration the type of pavement, type of crack or joint, shape/size of the crack or joint, time before next scheduled major rehabilitation, traffic volume, degree of pavement distress, maximum/minimum temperatures, availability of equipment and work crews, and traffic control. Other factors may also be relevant to the selection of the sealant material. The manufacturers of asphalt rubber C/J sealant provide a variety of sealants to meet different climate/pavement conditions. These sealants are normally designed to meet various ASTM specifications (D3405, D3406, D5078). If the manufacturer's standard sealants do not meet a specific requirement, it is possible for them to develop a special asphalt rubber blend to meet the highway agency's needs.

Asphalt rubber C/J sealant is typically preblended and packaged in 22.7 kilogram (50-pound) blocks. These blocks must be remelted and "reacted" before the sealant can be applied. Due to the nature of asphalt rubber, the melting pot should have heating and circulation features similar to those discussed for reacting asphalt rubber. The sealant is generally heated to 175 °C (350 °F) and has a pot life of approximately 12 hours. Even at the application temperature, the asphalt rubber sealant is more viscous and will not self-level after being applied.

With any choice of C/J sealant, it is important to properly prepare the pavement. The crack or joint must be shaped, cleaned, and dried in preparation for the proposed sealant. The optimum shape factor for asphalt rubber is 1 to 1 (width to depth ratio) and should never exceed 2 to 1. A backer rod or other bond breaker may be desirable for some applications. To obtain the best possible adhesion between the pavement and the sealant, the pavement temperature should be above 5 °C (40 °F). Follow the manufacturer's recommended application instructions to achieve the best performance from the asphalt rubber sealant.

The engineering properties characteristic of an asphalt modified with CRM are beneficial for its application as a sealant. Asphalt rubber binder has enhanced temperature susceptibility and aging properties. The polymer (rubber) chains improve the high temperature viscosity without significantly altering the low temperature viscosity. The carbon black component of tire rubber is a known aging inhibitor. These properties enhance the durability of the sealant. The polymer chains also improve the elasticity of the asphalt rubber, which benefits the flexibility of the sealant. Asphalt rubber has improved adhesion properties. This characteristic is important for the sealant to maintain its bond to the pavement surfaces when tensile stress increases during cold weather contraction of the pavement.

Asphalt rubber C/J sealant is available from a number of manufacturers and would not be considered a proprietary product if the specification is not manufacturer specific. This should not be confused with other polymer (rubber) modified asphalt C/J sealants which use virgin polymers as the modifier. McDonald's asphalt rubber C/J sealant is patented. Carl C.Jacobson, Jr. and E. J. Johnson are the patent holders.[7] A number of companies around the country are licensed with the patent holders to manufacture and sell McDonald's asphalt rubber sealant.

Approximately 80 percent of the States use some amount of asphalt rubber C/J sealant. States which apply a large amount of this sealant include: Texas, Nebraska, Georgia, Arizona, Pennsylvania, New York, California, Nevada, New Mexico, and Wisconsin. The cost of the material generally ranges from 45 to 65 cents per kilogram (20 to 30 cents per pound). This is the material cost and does not include shipping or the cost of installation (labor, equipment or traffic control).

B. Surface Treatments (SAM)

A surface treatment using an asphalt rubber spray application and cover aggregate is called a "Stress Absorbing Membrane" (SAM). Because this construction technique requires the spray application of the binder and there is no mechanical mixing with aggregate involved, the use of a SAM is only possible with the CRM wet process.

The results of Demonstration Project No. 37 - *Use of Discarded Tires in Highway* Construction found that SAM's can be a cost-effective surface treatment in certain situations. This conclusion was confirmed in the follow-up pooled-fund study.[19]

The design of a SAM should examine both the binder and cover aggregate. The asphalt rubber binder may be thinned with a diluent to improve distributor/spray flow. The amount of CRM in the binder is typically 20 to 30 percent by weight of asphalt cement. The diluent is normally a lighter petroleum product (typically kerosene) added to the modified binder just before the binder is applied to the pavement surface. The amount of diluent is approximately 5 to 7 percent by weight of the asphalt rubber binder.

The cover aggregate is the other component material of a SAM. Proper selection of the aggregate size (gradation) and shape is important to the performance of the surface treatment. Cover aggregate is generally a uniform size (9.5-millimeter to 6.3-millimeter sieve, 3/8-inch to 1/4-inch sieve size) and preferably hot precoated with 0.3-0.5 percent (by weight) asphalt cement. The aggregate should be relatively clean to insure a bond with the binder. The compatibility of the binder and aggregate is a part of the design process. An appropriate stripping test should be performed to insure compatibility. This applies to the asphalt rubber and aggregate as well as the precoat asphalt cement and aggregate.

Once the materials have been selected, the designer must determine the appropriate spray application rate and aggregate spread rate to achieve proper coverage and embedment. One proposed design procedure is included in Appendix D. Typical values which have been used successfully are 2.7 litre per square meter (0.6 gallons per square yard) of diluted asphalt rubber binder and 19 kilograms per square meter (35 pounds per square yard) of precoated cover aggregate. Improper selection of the spray and spread rate has resulted in flushing and/or aggregate loss. Both failure modes can be safety problems requiring maintenance attention.

The construction of a SAM is similar to any surface treatment. The major difference is the modified binder applicator. The asphalt rubber binder, even diluted, is more viscous and abrasive than conventional asphalt cement binder. The spray applicator truck must be capable of properly holding the binder (temperature and circulation) and uniformly metering and spraying the binder. The pumps are generally heavier and the spray orifice is larger.

The diluent chosen to reduce the asphalt rubber viscosity will affect the cure time. To minimize wheel tracking immediately after construction, a blotter sand can be applied.

The construction of a SAM should include proper inspection of the materials, project site, and application procedures. A guide specification can be found in Appendix E. The asphalt rubber binder should be checked for complete reaction, maintained temperature/circulation, and proper dispersion of the diluent. The reaction and dispersion of diluent are verified by using a portable rotational shear viscometer which can take quick measurements of the binder's viscosity. These measurements can be compared to laboratory mix design values. The aggregate should be examined for moisture and contaminating fines. If the aggregate is precoated, uniform coating of the aggregate should be checked. The existing pavement surface should be properly cleaned before applying the SAM. During the application of the SAM, the rate and uniformity of the distributor spray is very important. Improper application of the binder can cause loss of aggregate (insufficient embedment) or flushing (excessive binder). The cover aggregate must be spread uniformly at the designed rate of spread and then embedded with a roller. Generally, spreading and rolling the cover aggregate follow immediately behind the distributor.

The use of an asphalt rubber binder in a surface treatment may have particular benefits for the performance of the pavement. The addition of CRM to the asphalt cement enhances the temperature susceptibility, aging, elasticity, and adhesion characteristics of the binder. Temperature susceptibility and elasticity influence the binder's ability to resist the stresses induced by climate and traffic, thus the name stress absorbing membrane (SAM). The carbon black content of tire rubber increases the binder's ability to resist aging, a significant factor in the overall life of a surface treatment. Finally, the ability of the binder to retain the cover aggregate is enhanced by the adhesion of asphalt rubber binder.

The engineering properties of a SAM can resist and delay the development of reflective cracks when the cracks are generally inactive, like alligator fatigue cracking and closely spaced random or block cracking. A SAM can not resist the amount of strain that is typical of transverse thermal cracks in asphalt concrete pavements or transverse contraction joints in Portland Cement Concrete pavements. As with any surface treatment, the existing pavement structure must be sound. Placement of a SAM over moisture-related pavement distress without proper consideration for repair and prevention of further moisture distress will not achieve the expected performance and could accelerate additional moisture damage.

The design and construction of a surface treatment is a conventional paving procedure, but the use of an asphalt rubber (McDonald) binder is proprietary. Jacobson and Johnson are the patent holders, and a number of companies around the country are licensed with them to manufacture and sell asphalt rubber binder.[7] These companies are also equipped with special distributor equipment to handle the application of asphalt rubber.

Several States routinely design and apply SAM's to their pavement network. Arizona, California, and Texas are predominant States involved with using this product.[20,21,22] Although most SAM applications are applied at the local level, some primary and interstate routes also receive this pavement surface treatment. The cost of a SAM is significantly higher than conventional surface treatments. The present cost of a SAM in place is generally 100 percent higher than a conventional surface treatment. The cost increase is due principally to the asphalt rubber binder. In Arizona and California during the late 1980's, the in-place cost for a SAM generally ranged from $1.90 to $2.30 per square meter ($1.60 to $1.90 per square yard).[19]

This section has focussed on the application of asphalt rubber as a spray application for surface treatments. Other thin asphalt surfacing techniques may also benefit from CRM technology. Each application should be examined to determine if the properties of the modified binder are needed for the given conditions.

C. Hot Mix Asphalt (HMA)

The use of CRM in hot mix asphalt (HMA) paving materials has much broader variability and potential than the previously discussed applications, crack/joint sealant and surface treatments. Two of the principal variables are the type of CRM process (wet or dry) and the type of HMA (dense, gap, or open graded). For clarity, this section on HMA paving applications is divided into two parts:

(1)HMA applications using the wet process (McDonald), and
(2)HMA applications using the dry process (PlusRide).

Each part will discuss the various types of HMA paving applications using that particular CRM technology. The new CRM technologies and their use for HMA applications are discussed in Section VI.

One common issue related to both of these HMA applications is that they are relatively new with respect to appropriate field evaluation. Many factors regarding mix design, construction, and especially, performance, are still unresolved. Even States that have put substantial research effort into evaluating CRM technology have not resolved all the factors, particularly performance and its relationship to cost-effectiveness for the highway community.[23]

1) HMA - McDonald technology

Conventional Marshall and Hveem mix design procedures have been used successfully for **dense graded mixes** using McDonald's asphalt rubber. The characteristics of the modified binder alter the laboratory measured properties of the mix and should be understood when designing these dense mixes. The mixing and compaction temperatures should be increased to better reflect proposed field conditions. For a Marshall design, the stability of the mix is lower and the flow, VMA, and binder content are higher. For a Hveem design, the stability is lower and VMA and binder content are higher. The higher viscosity of asphalt rubber, even at higher mixing temperatures, creates a thicker binder film on the aggregate. Coupled with the elasticity of the binder, specimens subject to the loading of the Marshall or Hveem stability test absorb some stress in the binder through elastic strain better than conventional asphalt binder. Typically, the slope of the Marshall load (stability) deformation (flow) curve for an asphalt rubber specimen will be flatter than a comparable conventional specimen. To maintain a desired air void content along with the thicker binder film will require an increase in the VMA. As a general rule, the increase in the designed binder content will be proportional to the amount of CRM in the binder. For example, if the conventional dense graded mix requires 5 percent binder, then the modified mix with 20 percent CRM in the binder will require approximately 6 percent binder (5 X 1.20).

Conventional **gap graded mixes** are designed to enhance the stability of the mix through coarse aggregate contact, filling the voids with binder and fine aggregate. The present design concept being developed for modified gap graded mixes is to maximize the asphalt rubber content of the mix. This design is intended to combine the stability of coarse aggregate contact with the elastic properties of asphalt rubber. The mix, as proposed, could replace the application of a SAM in urban areas where damage from loose surface aggregate has been a reported problem. To date, the design of this mix requires field trial and error to establish the binder content and amount of fine aggregate. Flushing is the principal parameter in the design. Typical asphalt rubber binder contents for gap graded mixes developed in Phoenix range from 8 to 9 percent.

The design of **open graded mixes** with asphalt rubber binder requires two revisions to the procedure.[24] A standard Open Graded Friction Course (OGFC) design is divided into five parts: asphalt content, void capacity, fine aggregate content, mixing temperature, and retained strength. To determine the binder content of OGFC with asphalt rubber will require a revision of the formula to account for the thicker binder film associated with asphalt rubber, in essence, compute a higher binder content. One approach would be to compute the conventional asphalt content and increase the value proportional to the CRM content, similar to the general rule for dense graded mixes. The void capacity, fine aggregate content, and retained strength (stripping) procedures remain unchanged. The procedure for establishing the optimum mixing temperature will require a change in the target binder viscosity to better reflect the high viscosity of asphalt rubber. This change in the target viscosity is simply the starting point for determining the optimum mixing temperature. The desired drain-down characteristics do not change. A moderate amount of binder contact with the surface is necessary to adhere the OGFC to the pavement (prevent delamination).

Using the McDonald technology with any of the three HMA applications will have a number of common considerations which must reflect the project conditions. The selection of the asphalt cement must consider its compatibility with CRM and the desired operating temperature characteristics. The design engineer can select the normal grade of asphalt used for the particular project location and add an extender oil to provide the needed aromatic oils required for asphalt/CRM reaction. The amount of extender oil will depend on the desired temperature/viscosity relationship. The other option is to select a softer grade (viscosity) of asphalt. Reacting the lower viscosity asphalt with CRM will increase the binder's viscosity properties to reflect the normally chosen grade. As discussed in Section III(B), the amount of CRM in asphalt rubber binder for HMA applications generally ranges from 15 to 25 percent by weight of asphalt cement.[16]

Since the McDonald technology focuses on a reacted asphalt/CRM binder, the CRM should be ground. The gradation of the CRM should consider the available void space in the aggregate gradation. If the proposed aggregate has a small nominal size (9.5-millimeter (3/8-inch) sieve or smaller), the specified CRM gradation may also need to be smaller than usual (all passing 425-micron (No.40) sieve versus all passing 2.00-millimeter (No. 10) sieve). Although the CRM is fully reacted, each spongy swollen rubber crumb occupies volume. This volume should fit into available VMA and minimize the potential to interfere with aggregate to aggregate contact. Aggregate gradations which closely follow the maximum density line (0.45 power line) will need to be adjusted below the line to improve VMA.

The binder reaction time should take into consideration the entire paving operation, not just the blending and reaction period. After the formal reaction phase, the binder remains at elevated temperatures until it is placed. This period of time includes binder transport and holding, mixing, mixture surge bin retention, hauling and placement. The viscosity/time curve for the proposed asphalt rubber binder can be compared to the projected total reaction time to ensure that the properties of the binder are not adversely affected. Normally, this will not be a problem unless there are delays in the HMA operation.

During the mix design procedure, compacted specimens should be allowed to cool in their mold. This reduces the problem of specimen swell related to the reaction which continues while the specimen remains at an elevated temperature. Some studies also recommend placing a confining pressure on the ends of the specimen. The effect on the properties of the specimen from this additional confining effort have been inconclusive.

The construction of HMA with asphalt rubber binder is very similar to constructing conventional mixes. There are only five significant changes in the construction process. First, blending of the modified binder is a separate operation which can be accomplished at the HMA facility or off site. Second, the target temperatures for mixing, laydown, and compaction are typically higher. The mix design and temperature viscosity curve will provide information on the required temperatures. The mixing temperature is generally 150 to 165 °C (300 to 325 °F), except for OGFC where mixing temperature is determined as a part of design. The laydown temperature should be higher than 120 °C (250 °F) and the mat compacted as soon as possible. Compacting the material "hot" is essential since the viscosity of the binder increases rapidly as the mix cools. Third, release agents for the equipment, particularly the truck beds and steel wheel roller drums, must never be a petroleum-based product. Detergent-based solutions are recommended. Asphalt rubber binder becomes tacky when mixed with petroleum products and would build up on the equipment surfaces. Fourth, pneumatic tire rollers are generally not permitted because the asphalt rubber binder tends to build up on rubber materials. The fifth change is similar to the fourth. When traffic is permitted on a new HMA surface with asphalt rubber binder, the tacky binder may pick-up on vehicle tires. To reduce the amount of pick-up, blotter sand can be spread at a rate of 1 to 1.5 kilograms per square meter (2 to 3 pounds per square yard) after the roller compaction is completed. Blotter sand should not be applied to OGFC.

The field inspection of HMA with asphalt rubber is similar to conventional mixes. A guide specification can be found in Appendix E. Revisions to the mix design should be reviewed by the inspectors. Particular attention should be given to the revisions in mixing, placement, and compaction temperatures. The high viscosity asphalt rubber binder produces thicker binder film on the aggregate and may have the appearance of excess asphalt. Adjustment to the binder content should not be based on visual observation. The use of standard extraction test procedures is not practical with these modified mixes. The reacted (and unreacted) CRM is not completely soluble in the extraction solvents. The extraction procedure must be modified and additional steps taken to separate the CRM from the aggregate.[25] As an alternative, nuclear asphalt content gauges can be used to measure the modified binder content of a mix applying normal calibration procedures for each mixture.

There is no test procedure to determine the ratio of asphalt cement to CRM once the asphalt cement and CRM are blended and reacted. The only means of monitoring the modified binder is through the field measurement of its viscosity using a rotational shear viscometer. The viscosity/time curve established in the laboratory can be used to verify that the production blended binder is comparable to the known laboratory binder. Any significant deviation from the laboratory curve should be considered suspect and investigated further.

There are potential benefits to using an asphalt rubber binder in HMA applications. The blending and reaction of asphalt cement and CRM enhances the engineering characteristics of the binder. The temperature susceptibility of the binder is reduced; therefore, the fatigue characteristics of the HMA can be more uniform over the pavement's operating temperatures. This reduced temperature susceptibility may increase the rutting resistance in the higher temperature range and resist thermal cracking in the lower temperature range. Oxidation and aging of the binder may be reduced by the thicker film on the aggregate and carbon black in the CRM. The thicker binder film may also reduce the potential for stripping. The enhanced elasticity can increase the resistance to reflective cracking, however, as with a SAM, any cracks which induce significant strain into the HMA will not benefit from asphalt rubber as a crack inhibitor.

The degree of improvement depends on many factors. For example, if rutting is a problem, the stability of the HMA through aggregate contact is the principal factor. Any enhancement of the binder will not correct the situation unless the optimum aggregate gradation is selected. The degree of improvement is also reflected in the importance of the binder for a given mix. The properties of the binder in an OGFC are more critical than in a dense graded HMA. The anticipated operating temperatures for the pavement are also a key factor. Moderate climates will not benefit as much as severe climates.

The design and construction of HMA mixtures is a conventional paving procedure, but the use of an asphalt rubber (McDonald) binder is proprietary.[7] Like SAM's, there are a number of companies licensed to manufacture and sell asphalt rubber binder.

There are no State highway agencies which routinely use HMA with asphalt rubber binder for any particular application. The majority of documented field test sections with appropriate evaluation programs were placed during and after the mid 1980's. California's Department of Transportation has performed the most extensive amount of field performance research and has not yet resolved all the issues. Their work has shown that these modified mixes can perform better than conventional mixes in certain situations, but has not resolved structural thickness/performance correlations which are key to establishing the mix cost-effectiveness.[23] The cost of asphalt rubber HMA mixtures (in-place) has ranged from 50 to 100 percent higher than the conventional mix. All of these projects have been relatively small experimental applications. The increase in cost is associated with the cost of the asphalt rubber binder (which includes a royalty fee) and increased binder content. The projected future cost of HMA's with asphalt rubber could reduce to between 20 and 30 percent above conventional HMA if the mix is routinely applied.

2) HMA - PlusRide technology

PlusRide is a **modified gap-graded mix** and the mix design does not follow normal Marshall or Hveem procedures. Conventional specimen preparation equipment and procedures are performed with some modifications, but the specimens are not tested for stability. The only measured specimen property used to establish the mix design asphalt content is percent air voids. The aggregate gradation and CRM content and gradation are specified by the patent description.

The target air void content is 2 to 4 percent. The aggregate gradation follows a narrow, gap graded band with a relatively high content of material passing the 75-micron (No. 200) sieve. Three aggregate gradings are available which reflect different maximum aggregate sizes. The CRM is predominantly a granulated crumb passing the 6.3-millimeter (1/4-inch) sieve with the fraction passing the 2.00-millimeter (No. 10) sieve supplemented with buffings or ground CRM. Like the aggregate, the gradation of the CRM follows a specific band. As specified in the design, the CRM content is 3 percent by weight of the total mix. Some earlier projects, however, have successfully used CRM contents from 2.5 percent to 4.0 percent. The asphalt cement chosen for the mix should be the same grade chosen for conventional HMA in the project area. The asphalt binder content will generally range from 7.5 to 9 percent.

After the materials are selected and proportioned, the CRM is dry mixed with the heated aggregate. Then the asphalt cement is added and mixed. The combined sample is then "cured" in a 160 °C (320 °F) oven for one hour before compaction. After compaction, the sample is allowed to cool in the specimen mold ring with confining pressure on the ends of the specimen. Once extruded, the specimens are measured for air voids and the appropriate asphalt content selected.

The PlusRide HMA is designed to modify the stability of a gap graded aggregate matrix with the elastic properties of CRM and a certain amount of binder modification (reaction). The coarse granulated CRM acts as rubber aggregate while the fine CRM (passing 2.00-millimeter (No. 10) sieve) partially reacts with the asphalt cement to modify the binder properties. The high asphalt content improves the workability of the mix and, as a modified binder, improves the resilience of the mix. Although a certain amount of binder modification is desired, compatibility between the asphalt cement and CRM is not usually a major consideration.

There are only a few modifications to the construction practices for PlusRide HMA. The CRM is added directly to the HMA facility. This will require a separate CRM feed system tied into the aggregate feed system. On a batch plant, this is presently accomplished by manually feeding the pug mill with a predetermined number of CRM sacks. The batch weight should correspond to the addition of whole sacks of CRM. On drum plants, the CRM feed system introduces the CRM at the RAP hopper and must be tied to the cold-feed aggregate weigh system. A sensitive weigh system is necessary to monitor the small amount (3 percent by weight of mix) of CRM being introduced into the drum. Except for an extended dry mix cycle during batch plant production, the only other modification to mix production is mix temperature. The temperature of PlusRide HMA mixture should be at 150 to 175 °C (300 to 350 °F) after mixing.

Compaction concerns are similar to asphalt rubber HMA. The material should be compacted hot to achieve density before the binder stiffens as the mat cools. The use of rubber surfaced equipment, particularly pneumatic rollers, should be avoided. Only detergent based release agents should be used on the haul trucks and rollers. In addition to these modifications, the finish roller must continue to compact the PlusRide mat until it cools below 60 °C (140 °F). Because the CRM is only partially "reacted," the material in the compacted lift continues to react at elevated temperatures. The reaction causes the rubber crumb to swell and expand the mixture. The additional rolling retains the mat density until the increasing binder viscosity can counteract the reaction's decreasing potential to expand.

Attention to detail is very important for PlusRide HMA. The mix is sensitive to variations in the material quality (gradation) and content. Poor production, placement, or compaction control will lead to premature failure of the pavement. Inspectors should be knowledgeable of the required construction practices. A guide specification can be found in Appendix E. Extraction methods will not provide accurate means of monitoring CRM content nor binder content. Similarly, asphalt content gauges will measure all the CRM in the sample as a part of the binder content. Therefore, proper calibration of the equipment which measures the materials fed into the HMA facility is critical.

There are potential benefits associated with the use of PlusRide HMA. The gap grading of the aggregate produces a relatively coarse textured mix with the potential for less rutting and improved skid resistance. As a surface mix, the gap grading provides an aggregate matrix with high stability to resist rutting and a macro-texture to improve tire/pavement contact. During the production and laydown of this HMA, the smaller particles of CRM and the asphalt cement will react, resulting in some modification of the binder. With properties similar to asphalt rubber, the enhanced binder provides elastic and adhesive characteristics to the HMA. This may increase the mix's ability to resist reflective cracking if the amount of strain is not too large.

The larger particles of crumb rubber in the mix which act as an rubber aggregate may also modify the mix's performance. The exposed rubber crumb on the surface may play a secondary role to improve skid resistance. Under certain climate conditions, the larger crumb exposed on the surface of the pavement may deflect under tire loading sufficiently to inhibit the formation of ice on the pavement. This has been observed in a few projects, but must be kept in perspective. The de-icing characteristic of PlusRide is not expected to perform for all types of winter conditions, such as heavy snowfall or ice storms. Within the body of the HMA, the rubber aggregate may delay reflective cracking by acting as a stress absorbing particle which intercepts the propagating crack.

The design and construction of gap-graded HMA mixtures is a conventional paving procedure, but the specific use of the PlusRide HMA design and construction process is proprietary.[9] Similar to the McDonald asphalt rubber patents, the PlusRide patents holder, EnvirOtire Inc., has standing license agreements with other engineering companies to design and sell PlusRide. Each project that incorporates this proprietary rubber modified HMA must arrange a licensing agreement with EnvirOtire Inc.

Experimental applications of PlusRide began in 1979. Since then, a number of States have evaluated this material, but have not expanded their experimental program. Alaska has the only State highway agency with a substantial background in developing PlusRide in the United States. The cost of PlusRide HMA (in-place) has ranged from 50 to 100 percent higher than conventional HMA.

There are a number of factors which enter into this additional cost. The special gap-graded aggregate normally requires the contractor to develop new aggregate blends. The granulated, blended CRM is generally 10 to 20 percent higher in cost than ground CRM with broader gradation requirements. The asphalt binder content is higher and, as a proprietary material, there is a royalty fee. The higher construction cost also reflects the fact that most projects are relatively small and experimental. The projected future cost of this rubber modified hot mix asphalt could reduce to between 20 and 40 percent above conventional HMA if these mixes are routinely applied.

D. Composite Designs (SAMI)

Composite designs with CRM paving materials offer similar theoretical benefits as the use of paving fabrics. The principal theory of the design is to place a membrane beneath the overlay which can resist the stress/strain of reflective cracks and delay the propagation of the crack through the new overlay. The membrane applied with CRM is asphalt rubber binder. Similar to a SAM, the asphalt rubber membrane is called a SAMI, Stress Absorbing Membrane Interlayer. The application of a SAMI is dependent on the underlying existing pavement. For the SAMI to be effective the amount of strain in the existing joints and cracks must be small. Jointed PCC pavements and thermal cracked AC pavements with crack spacings greater than 4.5 meter (15 feet) are not expected to be appropriate candidates for composite designs in most cases. Moisture related pavement distress (particularly stripping) in the underlying pavement should be repaired and prevented before applying a composite design, or the SAMI may accelerate the moisture damage.

There are two composite design systems: a two-layer SAMI and a three-layer SAMI. A two-layer SAMI places the SAMI directly on the existing pavement and overlays the SAMI with 25 to 75 millimeters (1 to 3 inches) of HMA. This system is applicable when the existing pavement surface is relatively uniform and smooth. The existing cracks and joints should not be deteriorated so the SAMI forms an uniform continuous membrane.

A three-layer SAMI begins with the placement of a leveling course of HMA. This initial overlay provides an acceptable uniform surface for placing the SAMI. The SAMI is followed by an additional 25 to 75 millimeters (1 to 3 inches) of HMA overlay. This system applies when there is deterioration of the existing pavement cracks and joints. If a two-layer SAMI were used, the deteriorated cracks would create a discontinuity in the membrane at the location where the membrane will be subjected to the highest levels of stress. Consequently, the performance of the SAMI would be diminished. By placing the initial overlay, the SAMI will be applied across the crack as a uniform membrane and optimize its effectiveness to resist (delay) the propagation of the reflective crack. The leveling course should be kept to a minimum allowable thickness. It is believed that the SAMI performs best when it is kept close to the existing pavement. An additional advantage to placing the SAMI as deep as possible is the ability to rehabilitate the surface of the pavement while maintaining the integrity of the SAMI.

The design of the SAMI may be slightly different from a SAM depending on the construction phasing. In many cases, the construction phasing will require the SAMI to perform as a temporary driving surface until the surface paving operation begins. In this case, the SAMI should be designed as a SAM. When the construction phasing permits the SAMI to be overlaid prior to opening the section to traffic, the design of the SAMI may be altered to further enhance the stress-absorbing characteristic of the membrane. This is accomplished by a slight increase in the spray application and decrease in the aggregate spread rate. The higher binder to aggregate ratio allows for a thicker asphalt rubber membrane with more resilience to absorb the reflective crack stress. Applying the asphalt rubber binder at spray rates above the design may cause flushing and should be avoided.

Construction and inspection of a SAMI is the same as a SAM. The only additional consideration is to assure that any diluent added to the asphalt rubber binder prior to the spray application has adequately evaporated from the membrane before the HMA overlay is placed. It is critical that these petroleum volatiles are dissipated. If the HMA overlay is placed too soon, the diluent will migrate upward through the overlay and cause flushing and/or raveling. The amount of time required to cure the SAMI is dependent on the type of diluent used and the climate.

The delay of reflective cracking is the principal benefit of a composite design. This potential performance benefit is similar to the benefit of paving fabrics. The cost of a SAMI has been generally found to be slightly higher than the cost of a paving fabric.

VI. NEW CONCEPTS

Throughout the 1960's and 1970's, crumb rubber modifier (CRM) technology focused solely on the development of the McDonald wet process. In the late 1970's, the dry process was introduced when PlusRide became available in the United States. Most of the 1980's has concentrated on the development of HMA applications for McDonald's asphalt rubber and PlusRide's rubber modified mixes. The primary effort in HMA's has been the development of acceptable engineering applications, but the high cost of these patented materials limited the research effort by most State highway agencies.

The 1980's also witnessed an increase in environmental concern for the effects from the growing scrap tire stockpiles across the country. A number of major scrap tire stockpile fires brought this concern to the attention of the public and legislators. Beyond the need to regulate the growing scrap tire volume, there is also the desire to find alternative uses for this material. An examination of known available alternative use markets identified CRM as having the potential to absorb a significant number of scrap tires.

The combination of an existing exclusive, proprietary CRM paving market and growing nationwide interest in alternative uses for scrap tires provided CRM technologists the catalyst to develop new concepts for applying CRM. Initial laboratory work in this area did not begin until the mid to late 1980's. The first experimental field applications were placed in 1989.

Two conditions should be noted regarding these new concepts. First, the design and construction practices are still being developed, and there is no field performance record to demonstrate that they can provide an acceptable level of service over a normal performance period. The second condition is that McDonald's asphalt rubber and PlusRide are patented products.[7,9] The FHWA has not reviewed the extent of the patents nor examined the association of the new concepts to the patented products. State and local highway agencies should be aware of the known patented products and make their own determination of any conflict between a proposed new concept and its comparable patented product.

A. Generic Dry Technology (Takallou)

A major interest has been to develop generic dry process mixes. The concept was originated by Dr. Barry Takallou as a result of his research and practical experience with PlusRide.[26] The principal focus of this concept in CRM technology is to incorporate CRM into conventional dense and gap graded HMA mixes using the dry process. Unlike PlusRide, which specifies a particular gap gradation for the aggregate, the proposed technology considers the available "generic" aggreagate gradations for the locality; hence the name, generic dry technology.

Much of the theory and understanding needed to design and construct PlusRide mixes also applies to generic dry mixes. Although the theory is similar, the variability of application is much greater. There are a number of factors which must be considered in the design, particularly how the CRM is to modify the mix. The PlusRide concept modified the HMA primarily through aggregate substitution. It is possible with generic dry process mixes to achieve a greater degree of binder modification. By specifying a smaller particle-size ground crumb rubber, the dry process combined with the HMA production sequence may be sufficient to permit the CRM and asphalt binder to achieve a substantial degree of reaction prior to placement and compaction of the mix.

Since the intent of generic dry process technology is to use conventional aggregate gradations, the design process must determine the appropriate CRM gradation for the proposed mix properties. The designer must take into consideration the capabilities of the CRM manufacturer. Present grading flexibility in most CRM plants is very limited. If unusual CRM grading requirements are specified, the cost of the CRM will increase or the gradation may not be attainable.

The generic concept has been successfully constructed in experimental field applications in New York and Florida.[27,28] The New York projects included three generic dry process designs. The designs varied the amount of CRM added to the mix from 1 to 3 percent by weight of total mix. The aggregate gradation was a standard 12.5-millimeter (1/2-inch) nominal maximum (25-millimeter, 1-inch) maximum) dense graded surface mix. The CRM gradation had a 2.00-millimeter (No. 10) sieve nominal maximum size. The asphalt cement content increased to 7.2 percent for the 3 percent CRM mix compared to the 6.0 percent for the conventional design. All the mixes used the same grade of asphalt cement. In Florida, a June 1989 experimental project using CRM included one section of generic dry process. The aggregate was a standard 9.5-millimeter (3/8-inch) nominal maximum open graded friction course. Along with four sections of asphalt-rubber, the section of generic dry process contained 180-micron (No. 80) sieve CRM at 10 percent by weight of binder. The binder content of the control mix was 6.3 percent compared to the design binder content of the generic CRM mix at 7.0 percent, both using the same grade of asphalt cement.

Additional experimental sections were constructed in a number of States in 1991. Iowa, Kansas, Oregon, and Illinois have constructed projects to evaluate the generic dry technology.

B. Chunk Rubber Asphalt Concrete (CRREL)

As a part of the Stategic Highway Research Program, the Cold Regions Research and Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers was contracted to evaluate the ice-disbonding characteristics of several asphalt paving materials. One of those materials was PlusRide. In addition to this research effort, the CRREL began modifying the design to determine if the use of CRM could further modify the properties of the paving material. Their work focused on increasing both the maximum size of the crumb and the percent of CRM in the HMA.[29]

The CRREL concept revised the aggregate gradation from the gap graded PlusRide design to a dense graded aggregate, while maintaining the same nominal maximum aggregate size. The CRM gradation was revised to a narrow grading band (12.5-millimeter to 4.75-millimeter sieve, 1/2-inch to No. 4 sieve) with a larger maximum crumb size. This revision of the gradations applies to mixes with CRM contents similar to PlusRide, namely 3 percent CRM by weight of mix. As the CRREL research increased the percent of CRM, adjustments were made in the aggregate gradation to provide space in the aggregate matrix for the substitute "rubber aggregate." This research examined chunk rubber asphalt concrete mixes with 3, 6, 12, 25, 57 and 100 percent crumb rubber by weight of aggregate. As expected, the optimum asphalt cement content (based primarily on air voids) increased as the percent CRM increased. Actual Marshall mix designs produced asphalt cement contents ranging from 6.5 percent for 3 percent CRM to 9.5 percent for 12 percent CRM.

This research initiative has been confined to laboratory testing. There are no scheduled experimental field applications established for this concept. The CRREL is presently seeking sources of research funding to continue the development of these unique mixes. Until the material is subjected to actual field conditions, it is impossible to estimate its performance or practical application.

C. Continuous Blending Asphalt Rubber (Rouse)

One concern regarding the McDonald wet process is the required batching and reaction time associated with blending CRM and asphalt cement to produce asphalt rubber. As previously discussed, the time required to "react" these materials is dependent on a number of factors, including the size of the CRM. Rouse Rubber Industries applied the wet process technology, blended their 180-micron (No. 80) sieve CRM with an asphalt cement and developed a continuous blending procedure. The prototype blending equipment is still being evaluated.

The first experimental field application of the concept was achieved with the cooperation of the Florida DOT in 1990. Results on the performance of this continuous blended asphalt rubber will not be known for several years. Particular attention will be given to the uniformity of the binder properties as they relate to the uniformity of the blending operation.

In addition to the uniformity of the binder, the actual engineering characteristics of the binder may behave different from the commonly known McDonald asphalt rubber. The very fine gradation of 180-micron (No. 80) sieve CRM substantially increases the dispersion of the CRM throughout the asphalt cement. It has not been determined if this additional dispersion will improve or reduce the performance of the modified binder. It is possible that the optimum CRM content will not be the same as for other asphalt rubber binders with coarser CRM.

VII. FURTHER RESEARCH

There are two principal issues related to the use of crumb rubber modifier (CRM) in asphalt paving materials which need to be evaluated. On the national level, the ability to recycle asphalt paving mixes containing CRM has not been demonstrated. At the State and local level, these modified HMA mixtures must be field evaluated to establish expected levels of performance. There are other areas, as well, which are unclear or need further development, but are not as critical for acceptance of this technology by the highway community. The remainder of this section divides the further research areas into three categories: national, State and industry issues.

National Issues

National issues are areas of concern which can be resolved and/or addressed on a national basis and can be applied on a national basis. As noted, the ***ability to recycle*** asphalt pavements containing CRM is a principal research issue. This aspect of the technology is critical to its long-term application. If we are unable to recycle these modified paving materials, their benefit is substantially reduced and a new waste problem is created.

Two questions need to be addressed in the recycling area. First, can materials containing CRM be successfully processed as recycled asphalt pavement (RAP); and second, how does the recycled paving material containing CRM perform? The first question addresses the physical operations involved with recycling. This question could be further broken into several parts based on the general variations in present recycling methods. For simplicity, there are three general methods which should be examined, hot recycling with mechanical blending (pugmill operation), hot recycling with internal blending (drum plant operation), and surface recycling. Each of these operations have unique features which may affect the ability to process RAP containing CRM.

The second question, the performance of recycled CRM mixes, is more difficult to define. The number of variables involved in the performance of RAP mixes is greater than conventional mixes. Above this complexity, however, the critical factor is the initial performance period. The first 2 to 4 years of the pavement's performance can determine if the recycled material's design procedure and construction practices are acceptable.

Recycling asphalt pavements containing CRM is a national issue because it has not been performed or documented in this country. The reason for this lack of data has been the lack of recycling projects that have been identified as containing CRM modified asphalt paving material. The initiative to identify these projects has improved since 1990 and resolution of this area of research could be accomplished within 3 to 5 years. Once the national emphasis in this question is satisfied, the issue can be addressed at the State and local levels to be refined for the specific conditions encountered.

Another area of national concern is the ***development of standards***, particularly for material testing and the environment. It is important for the highway community to develop and adopt standard material testing methods so that data collected from various sources across the country can be shared on a relatively equal basis. The introduction of CRM into the asphalt paving material presents numerous questions. Do we have a standard for measuring the viscosity of binders modified with CRM? How does CRM affect the present binder and mixture tests? When necessary, can we measure the CRM content of the binder or mix? Some of these questions have been discussed in this document and recommendations made, but final resolution will require additional analysis and concurrence of the material testing community. As the Strategic Highway Research Program products are implemented, CRM technology will have to evolve as well.

The area of establishing environmental standards for emissions and fumes is not the responsibility of the highway agencies. Our role is secondary. As highway agencies we are responsible for enforcing those standards developed by the environmental agencies, who coordinate with the industry as the standards are developed. The concern over the types and quantities of emissions and fumes related to incorporating CRM into asphalt paving has been raised. These same concerns are still unresolved for the use of conventional asphalt cement. Until standards are developed for production with conventional asphalt cement, the research effort for CRM should focus on developing a data base of emissions and fumes tests with direct correlation to identical production with conventional asphalt cement. An emissions testing program developed by the National Asphalt Paving Association in consultation with EPA is being used to collect data on production of paving mixtures with conventional asphalt cement. This program, found in Appendix F, should be used when projects using CRM are monitored for production emissions. The testing program for measuring worker exposure to asphalt fumes is still being developed. The Asphalt Rubber Producers Group has conducted one study on worker exposure to paving fumes which concluded that there were no significant differences between asphalt rubber and conventional asphalt exposure.[30]

State Issues

State issues are areas of CRM technology which can only be resolved through proper evaluation at the State and local levels. The principal research issue at this level is the field evaluation of these CRM modified materials to establish their ***expected performance***. Before a State or local highway agency uses any paving application of CRM as a routine construction product, it should be able to determine the expected performance.

The performance of CRM has been documented in some applications. In other applications, particularly as a HMA mixture, the use of CRM is still being evaluated. As applications vary, so do the performance criteria and the cost-effectiveness. Therefore, the performance data must be application-specific. Actual field performance data on HMA applications of CRM is needed to establish the cost-effectiveness of the material for those applications.

While the experience of other highway agencies and laboratory data are excellent sources of supplemental performance related data, they are not an acceptable alternative to local field performance. Studies have concluded that laboratory tests using CRM modified mixes do not correlate with measured field performance.[25,31] Therefore, laboratory results used to predict field performance may not be accurate and may not accurately reflect the cost-effectiveness of the material.

Although the production of modified asphalt paving material using the wet process and the dry process has been successfully demonstrated, the details of material compatibility, mix design and construction are State and local variables which affect the performance. Existing experimental projects, still being evaluated, indicate that HMA applications which contain CRM are performing equal to, or better than, the conventional asphalt control sections when the experimental CRM sections are properly designed and constructed.

Each State highway agency interested in using CRM should develop an experimental work plan to determine which applications of CRM technology are appropriate for the variables encountered in that State. As the State highway agency develops the work plan for a given application, the work plan should define what criteria will be examined to measure the performance of the pavement section. The criteria should focus on the key characteristics of the specific application, while ensuring that the overall pavement performance is not diminished. The work plan must require sufficient documentation of the entire project development to record the adequacy of the design procedures and construction practices. The ultimate goal of the experimental work plan is to establish the expected performance of a properly designed and constructed paving application. A guide workplan is provided in Appendix G.

The results of each highway agency's experience with CRM should be documented and shared with the highway community. Numerous approaches can be used to ensure that there is an appropriate distribution of the data measuring performance. Individual project reports [6,8,14,20,21,27,28], pooled-fund studies [19], and symposia [10,12,16] are several examples.

Industry Issues

Industry issues are areas of CRM technology which can be addressed to improve the material, process, and technology. The material, process, and technology are continually evolving. An improvement in one area becomes a catalyst for improvements in other areas.

Developments in CRM technology continue to refine the variables which define the material called crumb rubber. The process used to produce the crumb, the gradation of the crumb, and the composition of the crumb are all specifying parameters. As the technology expands, these specifying parameters will require the crumb rubber producers to add ***flexibility and quality control*** to their production. This may be particularly true for the gradation control. As an asphalt paving material, the gradation of the material may be critical to the performance of the pavement. Special gradations of the crumb may be specified and could require blending of various crumb sizes by the producer.

To date, the wet and dry processes have required significant amounts of manual labor to feed the CRM into the system. Typically, 22- to 27-kilogram (50- to 60-pound) sacks of CRM are delivered to the project sites and then manually emptied into the feed hopper. Larger production rates will require larger ***material handling systems*** equipped with mechanical feed systems. Methods and equipment to handle larger containers of crumb rubber could improve the overall efficiency of the wet and dry processes.

In addition to the crumb rubber handling system, the ***blending and metering systems*** for adding CRM (dry process) and asphalt rubber (wet process) into a HMA facility will need to be interlocked with the other material feed systems to eliminate manual adjustment of feed rates during HMA production.

Finally, the technology should continue to develop. Efforts like those of CRM and paving technologists developing the generic dry process and continuous blending asphalt rubber should continue. The production of CRM modified binder should examine methods to decrease the time and energy required to "react" the asphalt cement and CRM as well as quantify storage time (shelf life). Compatibility and optimum CRM content are also areas of additional research. The dry process, particularly the role of CRM in the aggregate matrix, is just beginning to emerge. Laboratory testing is an important beginning to these areas of research, but ultimate development of CRM technology will require field performance evaluation.

TABLE 1 -- List of crumb rubber modifier producers

Company	Plant Location
Midwest Elastomers, Inc.	Wapakoneta, Ohio
Atlos Rubber Inc.	Los Angeles, California
Tire Eliminators, Inc.	Fort Lauderdale, Florida
Centrex Corp	Findlay, Ohio
WRC, Inc.	Castle Rock, Colorado
Rubber Granulators, Inc.	Fort Lauderdale, Florida
Osage Tire Recycling, Inc.	Kansas City, Kansas
Diversified Waste Mgmt.	
B A S	Irvine, California
Baker Rubber, Inc.	South Bend, Indiana
Granular Products & Services	Fort Worth, Texas
Rouse Rubber Industries	Vicksburg, Mississippi
ReDeMan, Inc.	Neosho, Missouri
Resource South Corp	New Bern, North Carolina
A.I.M. International, Inc.	Macon, Georgia
Envirotire, Inc.	Seattle, Washington
Gibson Recycling	Atlanta, Texas
Rubber Recycling Reclamation Corp.	Bay City, Michigan
Spartan Enterprises	Baberton, Ohio
Rubber Granulators, Inc.	Snohomish, Washington
ReGenesis, Inc.	Brownsburg, Indiana
F & B Enterprises, Inc.	New Bedford, Massachusetts
Community Recycling Co.	West Bloomfield, Michigan
Tire Shredders, Inc.	Port Huron, Michigan
Trash Depot, Inc.	Moorhead, Minnesota
Tirec Systems, Inc.	Bridgewater, New Jersey
Jack Coletta, Inc.	Far Rockaway, New York
Safe Tire Disposal	Choctaw, Oklahoma
Tiregator, Inc.	Fort Worth, Texas
Western Tire & Rubber	Salt Lake City, Utah
Winnebago Tire Co.	Kewaskum, Wisconsin

NOTE: This list of CRM suppliers only contains those companies presently known to FHWA. Other companies, not listed here, may also be capable of supplying CRM to the highway industry.

Sources: Asphalt Rubber Producers Group (communication) and Tire Business, November 19, 1990, pages 51-53

TABLE 2 -- The effect of crumb rubber modifier on binder properties

Binder Property	Percent Rubber (by wieght of binder)						
	0	6	9	12	15	18	21
Viscosity at 176 °C (cp) (350 °F)	60	550	800	900	1500	2500	6000
Cone Penetration at 25 °C (77 °F)	48	40	43	44	40	30	27
Resilience at 25 °C (77 °F)	-1	-1	12	19	23	40	47
Softening Point °C (°F)	50 122	52 126	58 136	60 140	61 142	63 146	72 162

NOTES: Asphalt is AC-20, rubber is a 1.18-millimeter (No. 16) sieve nominal maximum size.

Interaction (reaction) period is 90 minutes at 175 °C (350 °F).

SOURCE: "Design Methods for Hot-Mixed Asphalt Rubber Concrete Paving Materials," James G. Chehovits, Proceedings of the National Seminar on Aspahlt Rubber, October 1989.

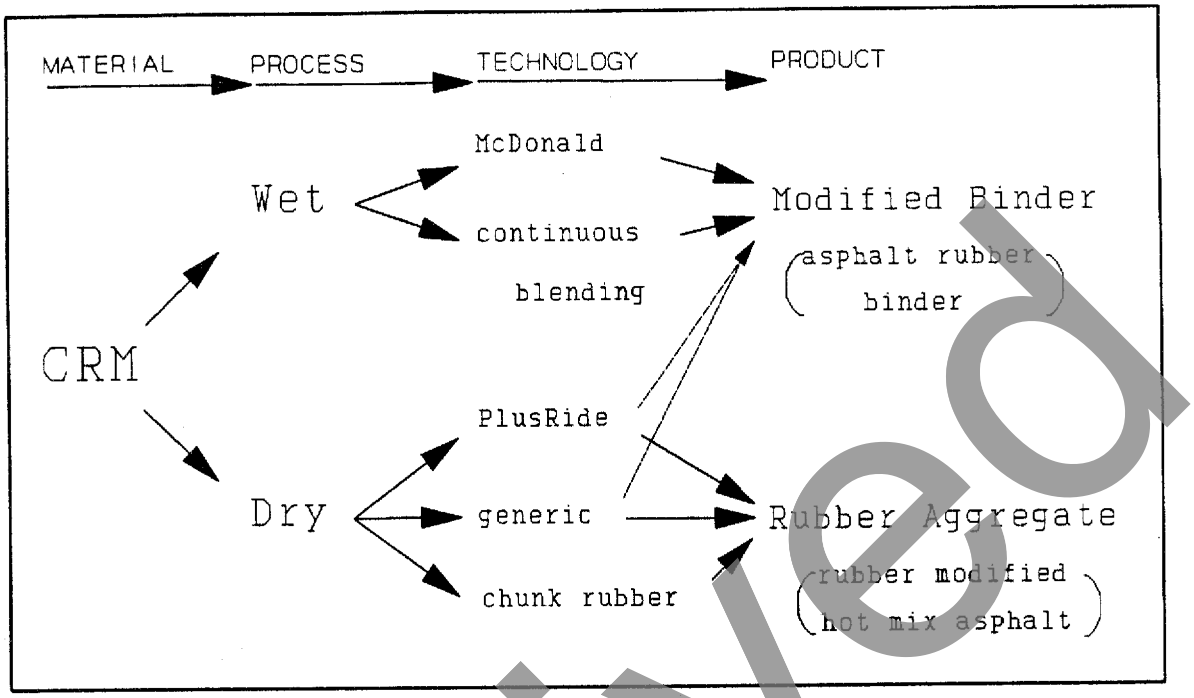

Figure 1 The relationship of crumb rubber modifier (CRM) terminology and technology

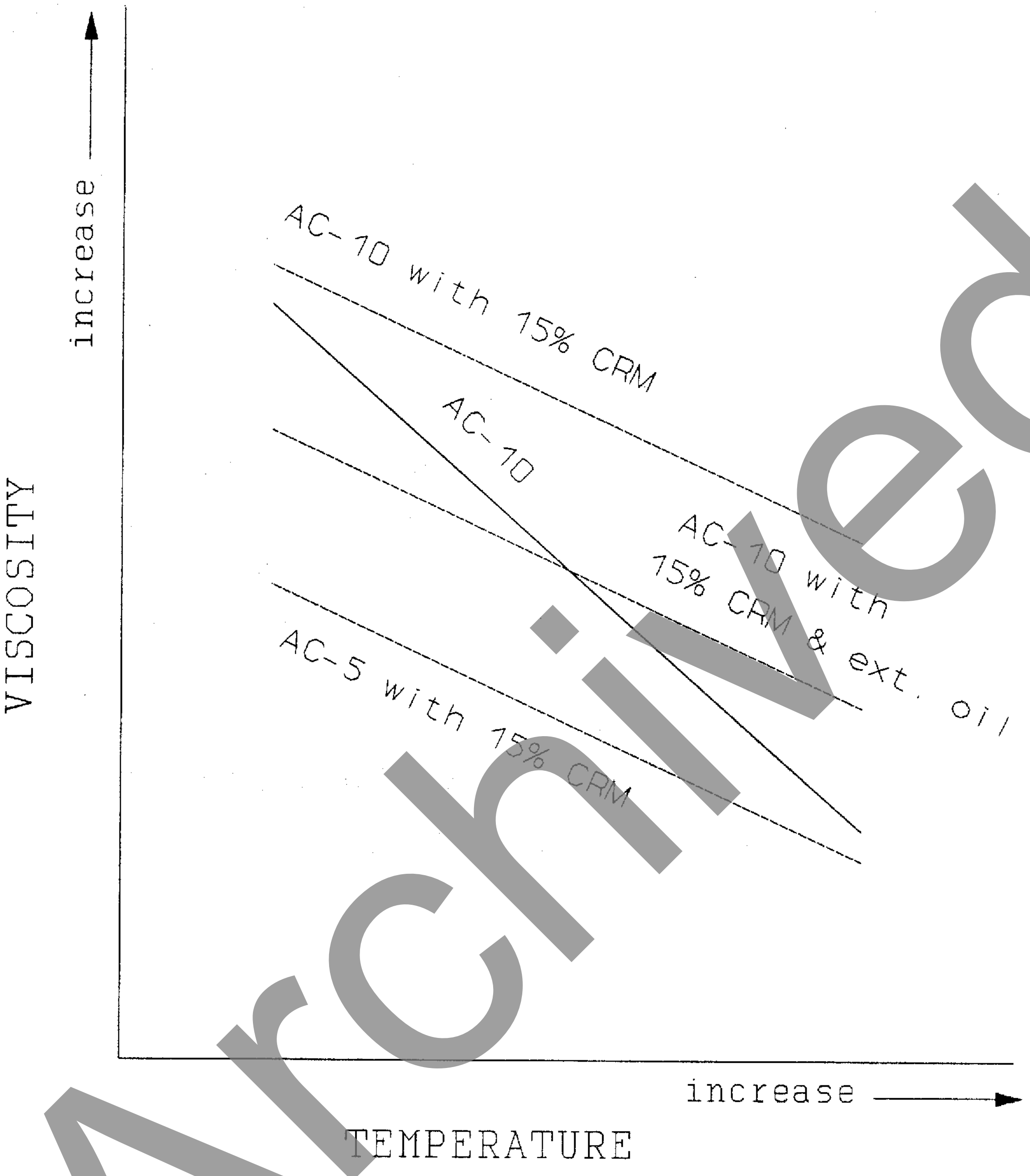

Figure 2 The effect of crumb rubber modifier (CRM) on the binder temperature/viscosity curve

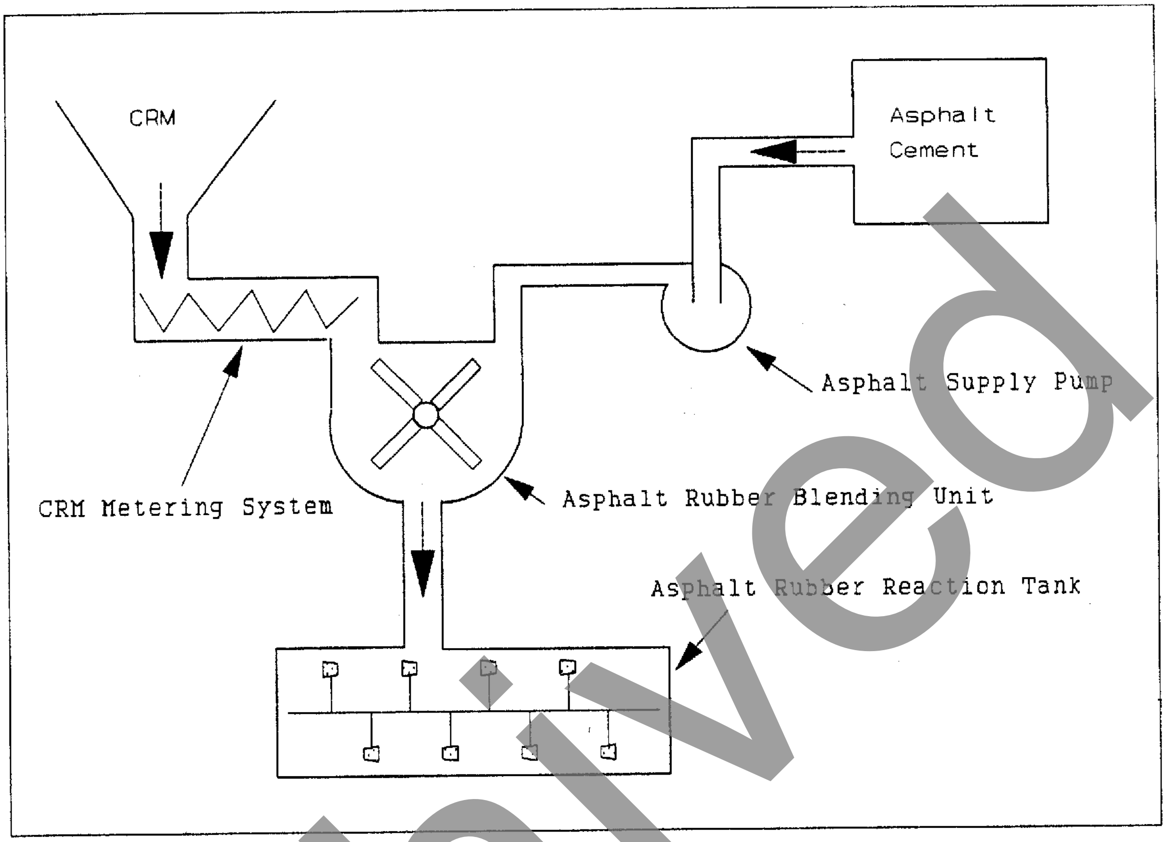

Figure 3 Schematic of the wet process

APPENDIX A - Summary of Terminology and Abbreviations

Summary of Terminology and Abbreviations

Asphalt Rubber (AR) -- asphalt cement modified with crumb rubber modifier.

Buffing Waste -- high quality scrap tire rubber which is a by-product from the conditioning of tire carcasses in preparation for retreading.

Crackermill -- process 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-millimeter to 425-micron (No.4 to No.40) sieve).

Crumb Rubber Modifier (CRM) -- a general term for scrap tire rubber that is reduced in size and is used as a modifier in asphalt paving materials.

Cryogenic -- process that freezes the scrap tire rubber and crushes the rubber to the desired particle size.

Diluent -- a lighter petroleum product (typically kerosene) added to asphalt rubber binder just before the binder is spray applied to the pavement surface.

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

Extender oil -- an aromatic oil used to supplement the asphalt/crumb rubber modifier reaction.

Granulated CRM -- cubical, uniformly shaped, cut crumb rubber particle with a low surface area which are generally produced by a granulator.

Granulator -- process that shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance, reducing the size of the rubber to a crumb particle (generally 9.5-millimeter to 2.00-millimeter (3/8-inch to No.10) sieve).

Ground CRM -- irregularly shaped torn crumb rubber particles with a large surface area which are generally produced by a crackermill.

Micro-mill -- process that further reduces a crumb rubber to a very fine ground particle, reducing the size of the crumb rubber below a 425-micron (No. 40) sieve.

Reaction -- The interaction between asphalt cement and crumb rubber modifier when blended together. The reaction, more appropriately defined as polymer swell, is not a "chemical reaction." It is the absorption of aromatic oils from the asphalt cement into the polymer chains of the crumb rubber.

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

Rubber Modified Hot Mix Asphalt (RUMAC) -- hot mix asphalt mixtures which incorporate crumb rubber modifier primarily as rubber aggregate.

Shredding -- process that reduces scrap tires to pieces 0.15 meter (6 inches) square and smaller.

Stress Absorbing Membrane (SAM) -- A surface treatment using an asphalt rubber spray application and cover aggregate.

Stress Absorbing Membrane Interlayer (SAMI) -- a membrane beneath an overlay designed to resist the stress/strain of reflective cracks and delay the propagation of the crack through the new overlay. The membrane is often a spray application of asphalt rubber binder and cover aggregate.

Wet Process -- any method that blends crumb rubber modifier with the asphalt cement prior to incorporating the binder in the asphalt paving project.

APPENDIX B - Experimental Projects with CRM in FHWA Test & Evaluation Project No.3

Experimental Projects with CRM in FHWA Test & Evaluation Project No.3

TE-3 PROJECT NO.	STATE	CRM TYPE	PAVEMENT SECTION	CONSTRUCTION DATE
84-4503-MN-08	Minnesota	PlusRide	bit. overlay	1984
84-4503-OR-84	Oregon	PlusRide, McDonald	bit. overlay	1985
84-4503-WA-09	Washington	PlusRide	bit. overlay	1985
88-503-IN-04	Indiana	McDonald	HMA base & surf	1990
90-503-AK-03	Alaska	PlusRide, McDonald	HMA surf & SAMI	1988
90-503-AR-27	Arkansas	McDonald	pccp ovly & SAMI	1990
90-503-KS-14	Kansas	McDonald	pccp overlay	1990
91-TE03-IA-30	Iowa	generic, cont. blend	pccp overlay	1991
91-TE03-OR-15	Oregon	generic	bit. overlay	1991

APPENDIX C - Guide Material Specifications

- crumb rubber modifier
- asphalt rubber binder

SUGGESTED GUIDE MATERIAL SPECIFICATION FOR CRUMB RUBBER MODIFIER

This specification is intended to be a guide for highway agencies. Appropriate modifications should be made to reflect local conditions and contracting requirements.

1.0 SCOPE

This specification covers scrap tire crumb rubber for use as a modifier in asphalt paving applications.

2.0 APPLICABLE DOCUMENTS

AASHTO Standards
- M 17 Mineral Filler for Bituminous Paving Mixtures
- T 2 Sampling Aggregates
- T 27 Sieve Analysis of Fine and Coarse Aggregate
- T 255 Total Moisture Content of Aggregate by Drying

ASTM Standards
- D 242 Mineral Filler for Bituminous Paving Mixtures
- C 136 Sieve Analysis
- D 297 Methods for Rubber Products - Chemical Analysis (natural rubber content)

3.0 GENERAL CHARACTERISTICS

Crumb rubber modifier (CRM) is scrap tire rubber which has been processed by ambient grinding or granulating methods, reducing the rubber to particles which generally pass the 4.75-millimeter (No. 4) sieve. The CRM may be obtained from any combination of passenger and truck tires which meet this specification. It shall be free of injurious amounts of steel, fabric or other deleterious substances as specified in Section 4.2.

4.0 PHYSICAL REQUIREMENTS

4.1 *Grading* -- The gradation of the CRM shall conform to one of the following gradations.

Sieve Size	CRM-I	CRM-II	CRM-III	CRM-IV	CRM-V	CRM-VI
	percent of weight passing					
6.3 mm (1/4")	100					
4.75 mm (No. 4)	75-100	100				
2.36 mm (No. 8)	35-50	80-100	100			
1.18 mm(No. 16)	20-30	40-70	80-100	100		
600 μm (No. 30)		0-20	40-60	70-100	100	
300 μm (No. 50)			0-20	20-40	40-60	100
150 μm (No. 100)						50-80

A mineral powder (such as calcium carbonate) meeting AASHTO M 17 may be added, up to a maximum of 4% by weight, to reduce sticking and caking of the crumb rubber particles.

4.2 *Deleterious Substances* -- The fiber content shall be less than 0.1% by weight for spray applications and less than 0.5% by weight for all other applications. The CRM shall contain no metal particles. The moisture content shall be less than 0.75% by weight. Mineral contaminants (prior to the addition of mineral powder) shall not be greater than 0.25% by weight.

5.0 SUPPLEMENTARY REQUIREMENTS

5.1 *Specific Gravity* -- The specific gravity of the CRM shall be 1.15 ± 0.05.

5.2 *Chemical Analysis* -- The CRM shall meet the following limits:

natural rubber	15% - 30%
carbon black	25% - 38%
ash	8% maximum
acetone extract	10% - 18%
rubber hydrocarbon	40% - 50%

5.3 *Packaging* -- The method of packaging shall take into consideration the proposed CRM production method and the degree to which the gradation of the CRM affects the final paving product. Segregation may occur during shipment, therefore the size of the packaging unit (bag or bulk) shall be approved by the Engineer.

When the proposed production method specifies adding whole units of CRM into a batch facility mixing chamber (pug mill), the containers shall be a low density polyethylene material having a melting point of less than 115 °C (240 °F).

6.0 METHODS OF SAMPLING AND TESTING

The gradation shall be tested in accordance with ASTM C-136 using a 50 gram sample.

Fiber content shall be determined by weighing fiber balls which are formed during the gradation test procedure. Rubber particles shall be removed from the fiber balls before weighing.

The metal content shall be determined by thoroughly passing a magnet through a 50 gram sample.

The moisture content shall be determined in accordance with AASHTO T-255, using a controlled temperature oven at 60 °C (140 °F) and 50 gram sample.

The mineral contaminant content shall be determined by saline float separation. Stir a 50 gram sample into a 1 liter glass beaker filled with saline solution (1 part table salt into 3 parts distilled water) and allow the sample to stand for 30 minutes. The mineral contaminant is that material which does not float to the top of the beaker.

SUGGESTED GUIDE MATERIAL SPECIFICATION FOR ASPHALT RUBBER BINDER

This specification is intended to be a guide for highway agencies. Appropriate modifications should be made to reflect local conditions and contracting requirements.

Asphalt rubber may be covered by patents 4,609,182; 4,085,078; 4,068,023; 3,891,585; 4,166,049. Any use of this technology should include a determination of the validity of the patent rights and risk of infringement.

1.0 SCOPE

This specification covers asphalt rubber binder graded by climate zones for use in asphalt paving construction.

2.0 APPLICABLE DOCUMENTS

Crumb Rubber Modifier Material Specification

AASHTO Standards	
M 226	Viscosity Graded Asphalt Cement
M 20	Penetration Graded Asphalt Cement
T 49	Penetration of Bituminous Materials
T 51	Ductility of Bituminous Materials
T 179	Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
ASTM Standards	
D 2994	Standard Test Methods for Rubberized Tar
D 36	Standard Test Methods for Softening Point of Bitumen (Ring and Ball)
D 3407	Standard Test Methods for Joint Sealants, Hot-Poured, for Concrete and Asphalt Pavements
D 88	Standard Test Method for Saybolt Viscosity
D 92	Standard Test Method for Flash and Fire Points by Cleveland Open Cup
D 2007	Test Method for Characteristic Groups in Rubber Extender and Processing Oils by the Clay-Gel Absorption Chromatographic Method

3.0 GENERAL CHARACTERISTICS

Asphalt rubber binder is an asphalt cement binder modified with crumb rubber modifier (CRM). An extender oil may be added to supplement the composition of the binder. The blend of asphalt and CRM is allowed to interact prior to incorporation into the construction.

4.0 BINDER REQUIREMENTS

4.1 *Asphalt Cement.* The asphalt cement shall meet the requirements of AASHTO M 226 or M 20. The selected source and grade shall be compatible with the CRM to provide a uniform blend meeting the specified asphalt rubber binder properties.

4.2 *Crumb Rubber Modifier.* The CRM shall meet the requirements of the CRM Material Specification. The selection of the CRM properties, particularly the gradation, shall be established in the job mix formula (JMF) design.

4.3 *Asphalt Extender Oil.* The extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements:

viscosity, SSU, 38°C (100°F) ASTM D 88	2500 min.
flash point, COC, ASTM D 92	199°C (390°F) min.
asphaltenes, % by weight, ASTM D 2007	0.1 max.
aromatics, % by weight, ASTM D 2007	55.0 min.

4.4 *Asphalt Rubber Binder.* The asphalt rubber binder shall conform to the requirements given in Table 1.

5.0 MANUFACTURING REQUIREMENTS

Asphalt rubber binder shall be prepared by blending and reacting the materials in accordance with the conditions and the proportions established by the designed JMF. The equipment shall be capable of preheating the asphalt cement to the reaction temperature, accurately proportioning the materials, blending the materials into a uniform mixture and maintaining circulation and even heat distribution at the reaction temperature during the reaction phase.

6.0 METHODS OF SAMPLING AND TESTING

Measuring the apparent viscosity of the asphalt rubber binder may be determined using a portable rotational shear viscometer in lieu of a Brookfield (ASTM 2994). The portable viscometer shall be correlated against the Brookfield for each modified binder developed. A standard test procedure shall be established for the particular portable viscometer.

TABLE 1 - REQUIREMENTS FOR ASPHALT RUBBER BINDER GRADES

GRADE	ARB-1	ARB-2	ARB-3
	CLIMATE ZONE		
TEST METHOD	HOT	MODERATE	COLD
Highest Mean Weekly Temp. °C (°F)	>38 (>100)	26 to 38 (80 to 100)	<26 (<80)
Lowest Mean Monthly Temp. °C (°F)	>0 (>30)	-12 to 0 (10 to 30)	<-12 (<10)
Apparent Viscosity (P) 175°C (347°F) ASTM D 2994 spindle 3, 12 rpm	1000 min 4000 max	1000 min 4000 max	1000 min 4000 max
Penetration (1/10 mm) 25°C (77°F) AASHTO T 49 100 gram, 5 sec	25 min 75 max	50 min 100 max	75 min 150 max
Penetration (1/10 mm) 4°C (39.2°F) AASHTO T 49 200 gram, 60 sec	15 min	25 min	40 min
Softening Point °C ASTM D 36 (°F)	54 min (130 min)	49 min (120 min)	43 min (110 min)
Resilience (percent) 25°C (77°F) ASTM D 3407	20 min	10 min	0 min
Ductility (cm) 4°C (39.2°F) AASHTO T 51 1 cm/min	5 min	10 min	20 min
Tests on Thin Film Oven Residue, AASHTO T 179			
Penetration (percent of original retained) 4°C (39.2°F) AASHTO T 49 200 gram, 60 sec	75 min	75 min	75 min
Ductility (percent of original retained) 4° (39.2°F) AASHTO T 51 1 cm/min	50 min	50 min	50 min

NOTE: The binder measured for compliance shall include the extender oil and any other additive proposed in the job mix formula.

APPENDIX D - Mix Design Guidelines

- surface treatments and interlayers

SUGGESTED GUIDE SPECIFICATION FOR THE DESIGN OF SURFACE TREATMENTS USING ASPHALT RUBBER BINDER

1.0 DESCRIPTION

This design guide evaluates the compatibility of the materials and determines the application rate for asphalt rubber binder and cover aggregate for surface treatments.

2.0 TESTING STANDARDS

AASHTO T 182 Coating and Stripping of Bitumen-Aggregate Mixtures
ASTM C 29 Unit Weight and Voids in Aggregate
ASTM C 127 Specific Gravity and Absorption of Coarse Aggregate
ASTM C 128 Specific Gravity and Absorption of Fine Aggregate

3.0 MATERIALS SELECTION

3.1 Aggregate Typically, a 9.5-millimeter (3/8-inch) nominal maximum aggregate gradation is specified. Aggregate sizes from 12.5 to 6.3 millimeter (1/2 to 1/4 inch) can be considered. Suggested gradations are as follows:

SIEVE	PERCENT PASSING		
16mm (5/8")	100		
12.5 mm (1/2")	90-100	100	
9.5 mm (3/8")	0-20	70-100	100
6.3 mm (1/4")	0-5	0-10	70-100
2.36 mm (No. 8)	0-2	0-5	0-5
75 μm (No. 200)	0-1	0-1	0-1

3.2 Asphalt Cement The grade of asphalt selected will be based on the desired asphalt rubber binder properties and the amount of extender oil added to the binder. In general, a softer asphalt cement is required if no extender oil is used. The use of a binder diluent (kerosene) is not a consideration when determining the grade of asphalt cement. When no extender oil is used, the suggested grades of asphalt cement are as follows:

CLIMATE	ASPHALT CEMENT GRADE
Cold	AC-2.5 or AC-5
Moderate	AC-5 or AC-10
Hot	AC-10 or AC-20

3.3 Crumb Rubber Modifier (CRM) The nominal maximum size of CRM is directly related to the size of aggregate selected. The nominal maximum size of CRM may be equal to or less than the following:

Nominal maximum particle size	
Aggregate	CRM
12.5 mm (1/2")	2.36 mm (No. 8)
9.5 mm (3/8")	1.18 mm (No. 16)
6.3 mm (1/4")	600 μm (No. 30)

4.0 AGGREGATE DESIGN

The quantity of aggregate required to cover the road surface can be determined using the following equation:

$$S = \frac{27 \times W}{Q}$$

where S = Quantity of aggregate (sq.yd./cu.yd.)
W = Dry loose unit weight (lbs./cu. ft.)
Q = Spread rate of aggregate (lbs./sq.yd.)

The aggregate spread rate is determined from the Board Test.

Board Test. Place a sufficient quantity of aggregate on a board with an area of 1/2 sq.yd. so that full coverage one stone in depth is obtained. Convert that quantity of aggragate to units of lbs./sq.yd.

5.0 BINDER DESIGN

Determining the proportions of asphalt cement, crumb rubber and extender oil (if needed) is trial and error. Over time, the design engineer will develop an understanding of the proportions which satisfy the binder criteria, knowing the common sources of materials available to the area. Some general rules of thumb include:

(1) to meet the asphalt rubber binder material specifications will normally require at least 15 percent CRM;
(2) the typical CRM content will range from 15 to 25 percent;
(3) a standard blending / reaction temperature is 175°C (350°F);
(4) the time to achieve complete interaction (full reaction) is approximately one hour.

The Brookfield Viscometer, ASTM D 2669, is used to monitor the reaction and establish the limits of the CRM content. Once the limits are determined, the other binder tests can be measured for the chosen CRM content and any necessary adjustments in the CRM content made accordingly.

The quantity of asphalt rubber required for the surface treatment can be determined using the following equation:

$$A = 5.61ET\left(1 - \frac{W}{62.4G}\right) + V$$

where A = Quantity of asphalt rubber (gal./sy.yd. at 60°F)
E = Embedment depth from Figure 1 (inches)
T = Traffic correction factor from Table 1
G = Dry bulk specific gravity of aggregate
V = Surface condition correction from Table 2 (gal./sq.yd.)

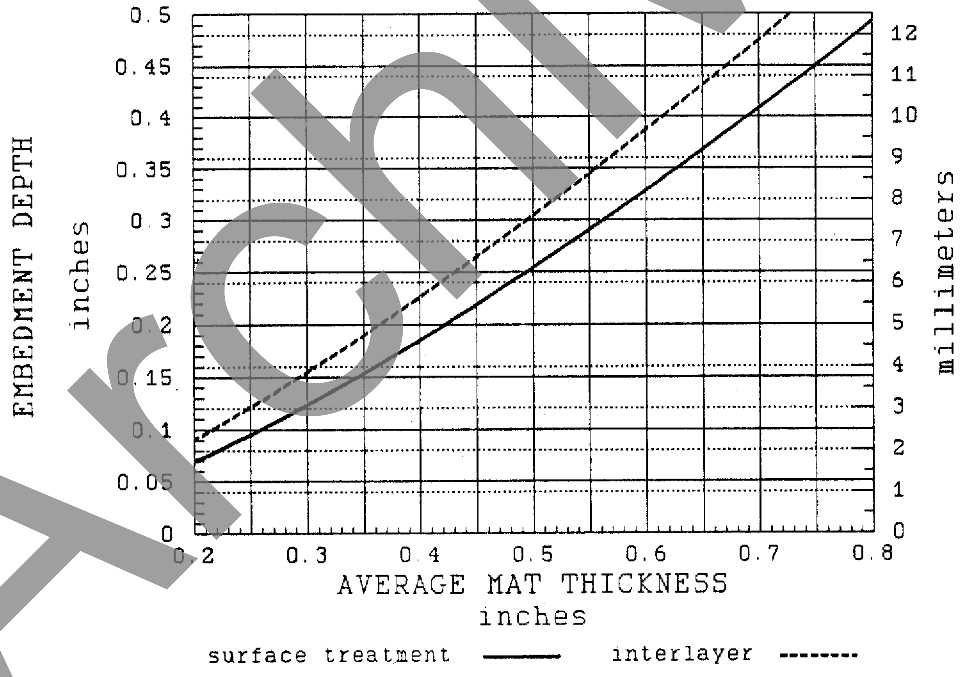

FIGURE 1 EMBEDMENT DEPTH FACTOR

TABLE 1
TRAFFIC CORRECTION FACTOR

Vehicles per day per lane	Traffic Factor (T)
over 1000	1.00
500 - 1000	1.05
250 - 500	1.10
100 - 250	1.15
under 100	1.20

TABLE 2
PAVEMENT CONDITION CORRECTION

Pavement Surface Condition	Asphalt Quantity Correction (V)
flush asphalt surface	-0.06 gal./sq.yd.
smooth, nonporous surface	-0.03 gal./sq.yd.
slightly porous, oxidized	0.00
porous, oxidized, slightly pocked	+0.03 gal./sq.yd.
porous, oxidized, badly pocked	+0.06 gal./sq.yd.

6.0 MIXTURE DESIGN

The viscosity of the binder may be adjusted for spraying and/or "wetting" of the cover aggregate by the addition of a diluent. The viscosity of the binder for spraying should be approximately 1000 poises and may be adjusted relative to the distributor equipment. The amount of diluent shall not exceed 7.5 percent by volume of the binder. When a diluent is used, the temperature of the binder shall not exceed 150°C (300°F).

The selected aggregate and binder shall be tested for stripping potential in accordance with AASHTO T 182. The binder should include any additives, particularly extender oil, diluent, and antistrip agent. The procedure for cutback asphalts should be used, modifying the preheat temperature of the binder to 150°C (300°F). Combinations that do not pass this test may be re-examined if a satisfactory antistripping additive is used.

At the option of the design engineer, the cover aggregate may be preheated and coated to improve chip retention on the pavement surface. The aggregate should be heated to 150°C (300°F) and may be coated with the asphalt rubber binder or conventional asphalt cement. The asphalt cement should be the same source and grade used to produce the asphalt rubber binder. The amount of precoating shall produce a uniform, dust free material and should be between 0.30 - 0.50 percent by total weight of precoated aggregate.

7.0 JOB MIX FORMULA Table 3 summarizes the JMF parameters.

TABLE 3 Surface Treatment / Interlayer Job Mix Formula Summary

MATERIAL	PARAMETER	CONSTRUCTION TOLERANCE
Aggregate	source	
	gradation	mat'l spec
Asphalt Cement	source	
	grade	
Extender oil	source	
	type	
Diluent	source	
	type	
Crumb Rubber	source	
	gradation	mat'l spec
Additive	source	
	type	
Asphalt Rubber	amount of CRM (lbs./ton AC)	±0.5
	amount of extender oil	±
	amount of additive	±
	mix/reaction temperature (°F)	±25
	reaction time (minutes)	±10
Aggregate Precoating	type of binder	
	amount of binder (percent)	±0.1
	preheat temperature (°F)	±25
Surface Treatment	spray application rate (gal./sq.yd.)	±0.03
	spray temperature (°F)	±25
	amount of diluent (percent)	±0.5
	aggregate spread rate (lbs./sq.yd.)	±2.0

APPENDIX E - Guide Construction Specifications

- surface treatments and interlayers
- hot mix asphalt (aspahlt rubber)
- hot mix asphalt (rubber modified HMA)

SUGGESTED GUIDE SPECIFICATION FOR THE CONSTRUCTION OF SURFACE TREATMENTS USING ASPHALT RUBBER BINDER

This specification is intended to be a guide for highway agencies. Appropriate modifications should be made to reflect local conditions and contracting requirements.

1.0 DESCRIPTION

This work shall consist of the application of asphalt rubber binder followed by an application of cover aggregate.

2.0 MATERIALS

The materials for this work shall meet the following requirements:

2.1 *Asphalt Rubber Binder* -- The asphalt rubber binder shall meet the requirements of the Asphalt Rubber Binder Material Specification. The selection of the grade of asphalt rubber binder shall be determined as a part of the job mix formula (JMF) design.

2.2 *Cover Aggregate* -- Aggregates shall be crushed stone, crushed slag, crushed gravel or natural gravel. Only one type of aggregate shall be used. Aggregates shall meet the requirements of AASHTO M 283. If specified in the JMF, the aggregate shall be precoated with asphalt.

The aggregate shall have a retained asphalt film above 95 percent when tested in accordance with AASHTO T 182. Aggregates that do not meet this requirement may be considered if a satisfactory antistripping additive is used.

2.3 *Binder Diluent* -- The binder diluent shall be a kerosene-type diluent compatible with all other materials as determined in the JMF design. The kerosene shall meet the following additional requirements:

Flash Point (ASTM D 92)	27°C (80°F) minimum
Initial Boiling Point (ASTM D 850)	177°C (350°F) minimum
Dry Point (ASTM D 850)	232°C (450°F) maximum

NOTE: All kerosene may not meet these requirements.

2.4 *Job Mix Formula* -- The job mix formula (JMF) shall specify the source, composition and proportion of the aggregate, asphalt rubber binder and additives for each surface treatment to be supplied for the contract. Only the materials approved in the JMF may be used. All surface treatment materials incorporated into the project shall conform to the individual tests' tolerance ranges established in the JMF.

The JMF shall be established by the Contractor and approved by the Engineer in accordance with the mix design specifications. At least 30 days prior to production, the Contractor shall submit to the Engineer a JMF for each mixture, the supporting test data, and samples of materials from each source. The JMF for each surface treatment shall be in effect until a modification is approved by the Engineer.

3.0 CONSTRUCTION REQUIREMENTS

3.1 *Weather Limitations* -- The application of an asphalt rubber surface treatment shall only be permitted under the following minimum conditions and when weather conditions will permit proper construction.

ambient air temperature	15°C (60°F) and rising
surface temperature	15°C (60°F) minimum
surface condition	dry

3.2 *Delays* -- When a delay in surface treatment application occurs, the asphalt rubber binder shall be allowed to cool. Just prior to use, the asphalt rubber shall be slowly reheated to the specified JMF mixing temperature, thoroughly mixed and the viscosity checked. If the viscosity is outside the JMF specification, the asphalt rubber binder in question shall not be accepted for further use.

3.3 *Equipment* -- DISTRIBUTOR: The distributor shall be capable of uniformly applying the asphalt rubber binder at the temperature and application rate specified in the JMF. The distributor shall be equipped to maintain the specified temperature and provide continuous circulation of the binder in the tank and distributor bar to maintain binder homogeneity. The distributor shall be equipped with appropriate gauges and meters for monitoring the operation.

AGGREGATE SPREADER: The aggregate spreader shall be self-propelled and of sufficient capacity to apply the aggregate within the specified time. The spreader shall have positive controls to deposit the quantity of material required in the JMF uniformly over the full width of the binder application.

ROLLERS: The rollers shall be self-propelled, pneumatic tire and capable of reversing without backlash. Each tire shall be inflated to a minimum of 700 kPa (100 psi) and carry a minimum 1,360 kg (3000 lb). The number of rollers and speed of operation shall be approved by the Engineer.

3.4 *Surface Preparation* -- The entire surface shall be cleaned using approved methods until the surface is acceptable to the Engineer. After cleaning, the surface shall receive a tack coat as directed in the JMF.

3.5 *Preparation of Asphalt Rubber Binder* -- Production of the binder shall conform to the Asphalt Rubber Binder Material Specification. The binder shall be maintained at the specified mixing temperature without local overheating and shall be circulated to maintain uniformity until it is applied to the pavement surface.

3.6 *Application of the Binder* -- The rate of application shall be specified in the JMF. The amount of binder applied shall not exceed the capability of the aggregate spreader and rollers to immediately cover the application and properly embed the aggregate.

The binder viscosity may be adjusted to improve the spray application by adding a kerosene diluent. The type and amount of diluent shall be established in the JMF. The addition of the diluent should occur in the distributor immediately prior to the spray application. The blending process should achieve a uniform viscosity in the minimum possible time. When a diluent is used, the binder temperature for spraying shall not exceed 150°C (300°F).

Building paper shall be used at the beginning and end of each application of the binder. Proper construction techniques shall be used for longitudinal and construction joints.

3.7 *Application of the Cover Aggregate* -- The application of the cover aggregate shall immediately follow the application of the binder. Spreading shall be accomplished so the tires of the trucks and aggregate spreader do not contact the uncovered binder. The rate of aggregate spread shall comply with the JMF.

The entire application of cover aggregate shall be rolled immediately after the aggregate is placed. The rolling pattern shall properly embed the cover aggregate into the binder. A minimum of three passes of the pneumatic roller shall be obtained.

After the rolling is completed, the entire surface shall be lightly swept to remove any loose cover aggregate. Traffic will not be permitted on the surface until the asphalt rubber binder has cured sufficiently to minimize any dislodging of cover aggregate.

4.0 METHOD OF MEASUREMENT

5.0 BASIS OF PAYMENT

SUGGESTED GUIDE SPECIFICATION FOR THE CONSTRUCTION OF HOT MIX ASPHALT CONCRETE USING ASPHALT RUBBER BINDER

This specification is intended to be a guide for highway agencies. Appropriate modifications should be made to reflect local conditions and contracting requirements.

1.0 DESCRIPTION

This specification provides general requirements that are applicable to all types of hot mix asphalt concrete using asphalt rubber binder (HMAR) irrespective of aggregate type and gradation, type and amount of binder, or pavement use.

This work shall consist of one or more courses of HMAR constructed on a prepared foundation.

2.0 MATERIALS

The materials for this work shall meet the following requirements:

2.1 *Asphalt Rubber Binder* -- The asphalt rubber binder shall meet the requirements of the Asphalt Rubber Binder Material Specification. The selection of the grade of asphalt rubber binder shall be determined as a part of the job mix formula (JMF) design.

2.2 *Coarse Aggregate* -- Coarse aggregate (retained on the 2.36 mm (No. 8) sieve) shall be crushed stone, crushed slag, or crushed gravel meeting the requirements of AASHTO M 283.

2.3 *Fine Aggregate* -- Fine aggregate (passing the 2.36 mm (No. 8) sieve) shall consist of stone screenings, slag screenings, manufactured sand, natural sand, or a combination thereof, meeting the requirements of AASHTO M 29.

2.4 *Mineral Filler* -- Mineral filler shall meet the requirements of AASHTO M 17.

2.5 *Additives* -- Anti-stripping and/or other additives (in addition to crumb rubber) shall be approved in the JMF. Additives shall be added at the specified rate using appropriate in-line blending or other approved method.

2.6 *Job Mix Formula* -- The job mix formula (JMF) shall specify the source, composition and proportion of the aggregates, mineral filler, asphalt rubber binder and additives for each mixture to be supplied for the contract. Only the materials approved in the JMF may be used. All mixtures incorporated into the project shall conform to the individual tests' tolerance ranges established in the JMF.

The JMF shall be established by the Contractor and approved by the Engineer in accordance with the mix design specifications. At least 30 days prior to production, the Contractor shall submit to the Engineer a JMF for each mixture, the supporting test data, and samples of materials from each source. The JMF for each mixture shall be in effect until a modification is approved by the Engineer.

3.0 CONSTRUCTION REQUIREMENTS

3.1 *Weather Limitations* -- The HMAR shall only be placed under the following minimum conditions and when weather conditions will permit proper construction.

For compacted thickness less than 1½ inches	
ambient air temperature	15°C (60°F) and rising
surface temperature	15°C (60°F) minimum
surface condition	dry

For compacted thickness 1½ inches and greater	
ambient air temperature	10°C (50 °F) and rising
surface temperature	10°C (50°F) minimum
surface condition	dry

3.2 *Delays* -- When a delay in HMAR production occurs, the asphalt rubber binder shall be allowed to cool. Just prior to use, the asphalt rubber shall be slowly reheated to the specified JMF mixing temperature, thoroughly mixed and the viscosity checked. If the viscosity is outside the JMF specification, the asphalt rubber binder in question shall not be accepted for further use.

3.3 *Equipment* -- Equipment used for the production, placement and compaction of HMAR shall conform to the AASHTO Guide Specifications for Highway Construction with the following modifications:

> The hot mix asphalt mixing facility shall have automatic controls that coordinate the proportioning, timing and discharge of the mixture.
>
> The hauling equipment and compaction rollers may be thinly coated with a light application of a non-petroleum based wetting agent to reduce sticking of the mixture to the equipment. Oiling the surfaces with kerosene or diesel fuel will not be permitted.
>
> Pneumatic-tired rollers will not be used.

3.4 *Surface Preparation* -- Surface preparation shall conform to the AASHTO Guide Specifications for Highway Construction.

3.5 *Preparation of Asphalt Rubber Binder* -- Production of the binder shall conform to the Asphalt Rubber Binder Material Specification. The binder shall be maintained at the specified mixing temperature without local overheating and shall be circulated to maintain uniformity until it is metered into the hot mix facility mixing chamber.

3.6 *Mixing, Placing and Compacting* -- Mixing, placing and compaction shall conform to the JMF and the AASHTO Guide Specifications for Highway Construction.

4.0 METHOD OF MEASUREMENT

5.0 BASIS OF PAYMENT

SUGGESTED GUIDE SPECIFICATION
FOR THE CONSTRUCTION OF
RUBBER MODIFIED HOT MIX ASPHALT CONCRETE

This specification is intended to be a guide for highway agencies. Appropriate modifications should be made to reflect local conditions and contracting requirements.

Rubber modified hot mix asphalt concrete may be covered by patents 4,086,291 and 4,548,962. Any use of this technology should include a determination of the validity of the patent rights and risk of infringement.

1.0 DESCRIPTION

This specification provides general requirements that are applicable to all types of rubber modified hot mix asphalt concrete (RUMAC) irrespective of aggregate type and gradation, crumb rubber type and gradation, type and amount of asphalt binder, or pavement use.

This work shall consist of one or more courses of RUMAC constructed on a prepared foundation.

2.0 MATERIALS

The materials for this work shall meet the following requirements:

2.1 *Asphalt Binder* -- The asphalt binder shall meet the requirements of the AASHTO M 266 or M 20. The selection of the grade of asphalt binder shall be determined as a part of the job mix formula (JMF) design.

2.2 *Coarse Aggregate* -- Coarse aggregate (retained on the 2.36 mm (No. 8) sieve) shall be crushed stone, crushed slag, or crushed gravel meeting the requirements of AASHTO M 283.

2.3 *Fine Aggregate* -- Fine aggregate (passing the 2.36 mm (No. 8) sieve) shall consist of stone screenings, slag screenings, manufactured sand, natural sand, or a combination thereof, meeting the requirements of AASHTO M 29.

2.4 *Mineral Filler* -- Mineral filler shall meet the requirements of AASHTO M 17.

2.5 *Crumb Rubber* -- Crumb rubber shall meet the requirements of the Crumb Rubber Modifier Material Specification. The selection of the CRM properties, particularly process method and gradation, shall be determined as a part of the JMF design.

All crumb rubber retained on the 2.36 mm (No.8) sieve shall be cubical in shape and individual particles shall have a flat or elongation ratio no greater than 2:1.

2.6 *Additives* -- Anti-stripping and/or other additives shall be approved in the JMF. Additives shall be added at the specified rate using appropriate in-line blending or other approved method.

2.7 *Job Mix Formula* -- The job mix formula (JMF) shall specify the source, composition and proportion of the aggregates, mineral filler, crumb rubber, asphalt binder and additives for each mixture to be supplied for the contract. Only the materials approved in the JMF may be used. All mixtures incorporated into the project shall conform to the individual tests' tolerance ranges established in the JMF.

The JMF shall be established by the Contractor and approved by the Engineer in accordance with the mix design specifications. At least 30 days prior to production, the Contractor shall submit to the Engineer a JMF for each mixture, the supporting test data, samples of materials from each source, and a production work plan. The work plan shall detail the equipment and sequence for adding the crumb rubber into the mixing process. The JMF for each mixture shall be in effect until a modification is approved by the Engineer.

3.0 CONSTRUCTION REQUIREMENTS

3.1 *Weather Limitations* -- The RUMAC shall only be placed under the following minimum conditions and when weather conditions will permit proper construction.

For compacted thickness less than 1½ inches	
ambient air temperature	15°C (60°F) and rising
surface temperature	15°C (60°F) minimum
surface condition	dry

For compacted thickness 1½ inches and greater	
ambient air temperature	10°C (50°F) and rising
surface temperature	10°C (50°F) minimum
surface condition	dry

3.2 *Equipment* -- Equipment used for the production, placement and compaction of RUMAC shall conform to the AASHTO Guide Specifications for Highway Construction with the following modifications:

The hot mix asphalt mixing facility shall have automatic controls that coordinate the proportioning, timing and discharge of the mixture. The facility shall be capable of uniformly feeding and measuring the amount of crumb rubber placed into the mixing chamber.

Transporting RUMAC on rubber belts is prohibited.

Drum mixing facilities shall not add the crumb rubber to the aggregate cold feed system. The crumb rubber must be added beyond the aggregate drying and heating section of the mixing chamber.

The hauling equipment and compaction rollers may be thinly coated with a light application of a non-petroleum based wetting agent to reduce sticking of the mixture to the equipment. Oiling the surfaces with kerosene or diesel fuel will not be permitted.

Pneumatic-tired rollers will not be used.

3.3 *Surface Preparation* -- Surface preparation shall conform to the AASHTO Guide Specifications for Highway Construction.

3.4 *Mixing, Placing and Compacting* -- Mixing, placing and compaction shall conform to the JMF and AASHTO Guide Specifications for Highway Construction with the following modifications:

When the production method uses units of CRM for proportion at a batch facility, the batch size and CRM unit size shall be adjusted to use whole units of CRM. Adding partial units of CRM into the mixing chamber will not be permitted.

Finish rolling shall continue until the temperature of the mat drops below 60°C (140 °F).

4.0 METHOD OF MEASUREMENT

5.0 BASIS OF PAYMENT

APPENDIX F - EPA/NAPA Stack Emission Testing Program

SAMPLE OF PREFERRED TITLE PAGE:

Draft date: Wednesday, February 6, 1991, 12:19 pm

PROTOCOL FOR AIR POLLUTION SOURCE TESTING AT

Company Name
City in which Company is located

Submitted to:

Company Name
Company Street Address
City in which Company is located

and

NATIONAL ASPHALT PAVEMENT ASSOCIATION
5100 Forbes Boulevard
NAPA Building
Lanham, Maryland 20706-4413

Submitted on:

Date on which report is submitted

Submitted by:

Testing Firm Name
Company Street Address
City in which Company is located

telephone number of Company

NAPA

NATIONAL ASPHALT PAVEMENT ASSOCIATION
NAPA Building ▪ 5100 Forbes Boulevard ▪ Lanham, Maryland 20706-4413 ▪ Tel: (301) 731-4748 ▪ Fax: (301) 731-4621

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GENERAL INFORMATION

Source Owner: ____________________
Address: ____________________
____

Contact: ____________________
Telephone: ____________________
Fax: ____________________

Association: National Asphalt Pavement Association
5100 Forbes Boulevard
NAPA Building
Lanham, Maryland 20706-4413

Contact: Thomas E. Brumagin or John Rugg
Telephone: 301-731-4748
Fax: 301-731-4621

Source Location: ____________________
____

Source Description: ____________________
Control Equip.: ____________________

Cognizant Agency: USEPA
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

Contact: Michael Hamlin MD-14
Telephone: 919-541-5232
Fax: 919-541-5663

Testing Firm: ____________________
____
____

Contact: ____________________
Telephone: ____________________
Fax: ____________________

Scheduled Test Date: ____________________

FORM FOR FILLING IN GENERAL INFORMATION ON PREVIOUS SHEET

Source Owner: *Name of Source Owner*
Address: *Street Address of Source Owner*
City, State, Zip

Contact: *Name of person to contact*
Telephone: *Phone number of contact*
Fax: *Fax number of contact*

Association: National Asphalt Pavement Association
5100 Forbes Boulevard
NAPA Building
Lanham, Maryland 20706-4413

Contact: Thomas E. Brumagin or John Rugg
Telephone: 301-731-4748
Fax: 301-731-4621

Source Location: *Street address of source location*
City, State, Zip

Source Description: *Type of HMA facility to be tested*
Type of Control Equip.: *Air Poll'n Control Equip.*

Cognizant Agency: USEPA
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

Contact: Michael Hamlin MD-14
Telephone: 919-541-5232
Fax: 919-541-5663

Testing Firm: *Name of Testing Firm*
Company Address
City, State, Zip

Contact: *Name of Contact*
Telephone: *contact phone no.*
Fax: *contact fax no.*

Scheduled Test Date: *date of test*

PLEASE NOTE THE FOLLOWING:

The results of the Stack Sampling are to be submitted in report form (as described at the end of this document) within six (6) to eight (8) weeks from the day the sampling is completed.

Copies of the report are to be submitted according to the box(es) checked below:

☐ Submit _____ copy(s) to the Source Owner in care of the Contact Person listed in the General Information section, and _____ copy(s) to the NAPA office in care of the Contact Person listed for NAPA in the General Information Section. NO COPIES are to be sent to the EPA office by the Testing firm, to be handled by the NAPA staff.

☐ Submit _____ copy(s) to the Source Owner in care of the Contact Person listed in the General Information section. NO COPIES are to be sent to the NAPA or EPA offices by the Testing firm, to be handled by the Source Owner's Contact person. HOWEVER, Testing firm should send letter to NAPA Contact Person advising that the report has been submitted to the Source Owner.

☐ Submit _____ copy(s) to the Source Owner in care of the Contact Person listed in the General Information section. NO COPIES are to be sent to the NAPA or EPA offices by the Testing firm, to be handled by the Source Owner's Contact person.

☐ USEPA is funding stack sampling for Formaldehyde collection and analysis, therefore, a separate report for the Formaldehyde results should be sent to the USEPA Contact Person, along with the data collected by Methods 1 through 4 that would normally be included with Formaldehyde "ONLY" sampling.

FOLLOWING ARE SECTIONS OF TEXT THAT SHOULD BE INCLUDED IN THE PROPOSAL AND PROTOCOL AS THEY APPEAR:

Air pollution source testing will be conducted to determine the emission concentration and rates of nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), total hydrocarbons--which will be referred to as 'volatile organic compounds' throughout this protocol--(VOC), condensible particulate matter, lead (Pb), polynuclear-aromatic hydrocarbons (PAHs), benzene, toluene, xylenes (BTX), and methane. Additionally, the stack gas volumetric flow and stack gas temperature, and the concentrations of moisture (H_2O), oxygen (O_2), and carbon dioxide (CO_2) in the stack gas will also be determined.

PROCESS DESCRIPTION:

Choose one of the following paragraphs or follow the appropriate instructions:

BATCH HMA FACILITY DESCRIPTION:

The air pollution source is what is commonly called a Batch Mix Facility by the Hot Mix Asphalt Industry. The aggregate is dried continuously in a direct-fired, rotary drum, with counter-flow heat exchange being employed. The aggregate is transferred to a piece of equipment called a mixing tower. In the mixing tower, the hot aggregate is separated according to diameter and stored in bins. It is metered out according to specifications and mixed with asphalt cement in batches.

DRUM MIX HMA FACILITY DESCRIPTION:

The air pollution source being tested is commonly called a Drum Mixer by the Hot Mix Asphalt Industry. The aggregate is dried continuously in a direct-fired, rotary dryer with parallel-flow heat exchange being employed. The asphalt cement is injected into the drum, about one third of the drum length from the aggregate discharge point.

OTHER TYPE OF HMA FACILITY CONFIGURATION:

The air pollution source being tested is commonly called a Drum Mixer by the Hot Mix Asphalt Industry. However, it is a modification of the original drum mixer equipment as the mixing of the aggregate with the asphalt cement is performed outside of the exhaust gases. The ***Enter whether heat exchange is parallel or counter -flow***-flow heat exchange process is used in this equipment. The aggregate and asphalt cement are mixed together in another section of the drum. ***Describe this mixing section here***

ADDITIONAL FOR SOURCE DESCRIPTION:

The HMA facility being tested was originally manufactured by ***Enter manufacturer's name***, and installed ***Enter year (as "in 19XX") of installation or number of years ago (as "XX years ago)***. Modifications have ***if no modifications have been made to equipment enter "not", otherwise leave blank*** been made to the equipment since it was installed. Its maximum rated capacity is ***Enter production capacity as tons per hour"** TPH at ***Enter aggregate moisture % for rating***% moisture removal.

This HMA facility is equipped with a ***Enter type of particulate control equip., include primary collector description, if it exists*** for particulate emissions control. Emissions controls for other pollutants does ***Enter "not" if there are no other controls*** exist at this HMA facility.

Describe this additional control equipment here

This HMA facility has *Enter "not" if it has never been stack tested* been previously stack tested for *Enter the pollutants for which it has been tested, if no testing has been done enter "any pollutant emissions"*. These tests were conducted in *Enter month and year of previous tests*.

INCLUDE THIS TEXT WITH THE APPROPRIATE INFORMATION REQUESTED BETWEEN THE ASTERISKS IN YOUR DESCRIPTION OF THE SOURCE TESTING:

Three test runs per pollutant will be performed while the HMA facility is operating at its maximum capacity of *Enter Production Rating (TPH) of facility* TPH, or no lower than *percentage amount*% of its maximum capacity, as determined by customer demand. Each day's run will be at least *Enter minimum no. of hours* hours, up to *Enter maximum no. of hours* hours.

The relative humidity will be determined with a wet bulb thermometer and recorded with the ambient temperature every two hours while the testing is in progress.

Responsibilities of NAPA Representative, or other designated individual:

One sample of aggregate will be collected during the middle of each test run of the testing program and will be analyzed for moisture content.[1] If only continuous sampling is being conducted on any particular day of the testing program, then a sample of aggregate is to be collected three times during the sampling, at the beginnning, at the estimated halfway-point, and just before sampling is going to be terminated. There should be three aggregate samples for each day of stack stampling. If the moisture content is determined by the Quality Control laboratory at the HMA facility, the remaining sample should saved and sent to the NAPA office with the other samples collected. The aggregate sample will be collected on the conveyor belt between the scalper screen and the drum.

One *Enter fuel type* fuel sample will be collected by *Testing Firm name* and will be analyzed for carbon, hydrogen, oxygen, nitrogen, sulfur (C, H, O, N, S) and heating value (in BTUs/unit of fuel). If fuel is a reclaimed oil, it will be analyzed to determine the concentrations of contaminants specified by USEPA's Used Oil rules.

One gallon samples of asphalt cement will be collected at the beginning of the first day and with each new delivery during testing.

One sample of baghouse fines will be collected during the testing program, when the opportunity arises (not to be collect before commencing operations for the testing program), e.g., before production is started on the second or third day, approximately one quart in size. This sample will be analyzed by USEPA's TCLP requirements to determine if it is a hazardous waste.

If Reclaimed Asphalt Pavement (RAP) is part of the mix being produced during the stack testing, collect a one gallon sample of the RAP from the pile being used for the mix, material should be crushed or milled (no large chunks).

Provide the superintendent and/or operator several copies of the Facility Operations form for

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[1] If the HMA facility has a Quality Control laboratory on the premises they will be asked to perform the moisture checks.

recording the requested operating parameters, and review the form with them. Request HMA facility superintendent or operator, if available, to run a print-out of operational data after each entry to the HMA Facility Operating Data form. If the print-out machine is programmable through the equipment computer system, ask the superintendent or operator to program the print-out machine to print operating information every 15 minutes. (Please note, this should take the place of recording on the Operating Data form.)

Request the HMA facility superintendent or operator to insert an unused temperature chart, corresponding to the correct time of day, at the beginning of each operating day when stack sampling is conducted. Collect the temperature chart at the end of each day. If the company keeps this chart for its records, ask for five (5) copies (sometimes a copy of a copy loses clarity with these types of charts).

(end of NAPA rep. or designated ind'l. responsibilities)

The testing procedures proposed herein are based on USEPA's and ______________________[2] published methods and are listed immediately below. Following this is a brief overview of each of the test methods (including sample collection and analytical procedures) to be used.

SAMPLE TO BE COLLECTED	*EPA REF. NO.*	*STATE REF. NO.*	*OTHER*
Gas Velocity/Volume/Stack Gas Moisture	Methods 1-4		
Carbon Dioxide and Oxygen (continuous)	Method 3A		
Particulate Matter	Method 5		
Oxides of Nitrogen (continuous)	Method 7E		
Sulfur Dioxide (continuous)	Method 6C		
Carbon Monoxide (continuous)	Method 10		
Volatile Organic Hydrocarbons (continuous)	Method 25A		
Toxic Compounds (PAHs)	Modified Meth. 5/SW-846 Method 8270: with Hi-resolution GC/MS analysis, DMSO extraction and 3-7 ring PAH wt. concentration determination (% wt. of total sample)		
Benzene & Ethyl- Toluene Xylene Methane	Method 18 (semi-continuous)		
Lead and other Heavy Metals (when used oil or RAP are used, ONLY, using RM5 filter, after particulate weight determination)	Method 12		
Condensible Particulate	Proposed Method 202		
Burner Fuel analyzed for:			
Higher Heating Value: ______________[3]			ASTM _________
Specific Gravity			ASTM D 1298
SSU Number			_____________
Carbon			_____________
Hydrogen			_____________
Oxygen			_____________
Nitrogen			_____________
Sulfur			ASTM D 1552
Waste Fuel analyzed for:			
Lead			ASTM D 2788
PCBs			
Total halides	EPA 600/4-81-045		ASTM D 1317
Chloride			
pH			ASTM D 1093
Flash point			ASTM D 93
Process Materials Moisture Determination			ASTM C 566
Ambient Humidity			ASTM D 4230 or ASTM E 337
Toxicity Characteristic Leaching Procedure (TCLP) on Baghouse fines, Used Oil, RAP	EPA ______________, FR, Vol. 51, No. 216, Appendix I to Part 268		
Formaldehyde (optional)	DRAFT EPA _________		

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[2] Enter name of the state for which compliance sampling is being performed.

[3] Enter type of burner fuel being used, the ASTM method for HHV for oil is ASTM D 240.

SUBSTANCE	*DETECTION LEVEL (include units)*	*SUBSTANCE*	*DETECTION LEVEL* (include units)
Continuous, Semi-Continuous, and PM/Condensibles Results			
NO_x		BENZENE	
SO_2		TOLUENE	
CO		XYLENE	
O_2		METHANE	
CO_2		THC	
Particulate matter		Condensible matter	
Polynuclear Aromatics (PAHs):			
Acenaphthene		Chrysene	
Acenaphthylene		Dibenzo(a,b)anthracene	
Anthracene		Fluoranthane	
Benz(a)anthracene		Fluorene	
Benzo(a)pyrene		Indeno(1,2,3-cd)pyrene	
Benzo(b)fluoranthene		Naphthlalene	
Benzo(e)pyrene		Phenanthrene	
Bezno(g,h,i)perylene		Pyrene	
Benzo(k)fluoranthene		Cumene	
o-Cresol		p-Cresol	
m-Cresol			
Heavy Metals (required only with used oil or RAP in process)			
Arsenic		Lead	
Barium		Mercury	
Cadmium		Selenium	
Chromium		Silver	
Waste Fuel and/or RAP Analysis (when used)			
Lead		pH	
PCBs		Flash point	
Total Halides		Chloride	

SUBSTANCE	***DETECTION LEVEL*** *(include units)*	***SUBSTANCE***	***DETECTION LEVEL*** (include units)
Burner Fuel Analysis			
Higher Heating Value		Oxygen	
Specific Gravity		Nitrogen	
Carbon		Sulfur	
Hydrogen		SSU no.	
TCLP—Substances for Analysis			
Benzene		Tetrachloroethylene	
Carbon tetrachloride		Trichloroethylene	
Chlordane		2,4,5-trichlorophenol	
Chlorobenzene		2,4,6-trichlorophenol	
Chloroform		Vinyl chloride	
o-Cresol		Arsenic	
m-Cresol		Barium	
p-Cresol		Cadmium	
1,4-Dichlorobenzene		Chromium	
1,2-Dichloroethylene		Lead	
1,1-Dichloroethylene		Mercury	
2,4-Dinitrotoluene		Selenium	
Heptachlor		Silver	
Hexachlorobenzene		Endrin	
Hexachloro-1,3-butadiene		Lindane	
Hexachloroethane		Methoxychlor	
Methyl ethyl ketone		Toxaphene	
Nitrobenzene		2,4-D	
Pentachlorophenol		2,4,5-TP (silvex)	
Pyridine			

SUBSTANCE	*DETECTION LEVEL (include units)*	*SUBSTANCE*	*DETECTION LEVEL* (include units)
Formaldehyde Collection and Sampling **(optional)**			
Formaldehyde			
Process Materials Moisture Determination			
Aggregate		Reclaimed Asphalt Pavement	

PROJECT DESCRIPTION AND SCOPE OF WORK

METHOD NUMBER	METHOD NAME	COMMENTS	COST	C	N
EPA METHOD 1	SAMPLING POINT DETERMINATION	The number and locations of the sampling or traverse points will be determined according to the procedures outlined in EPA Method 1. Yaw Angle Check: The yaw angle of the flow direction at each traverse point defined in EPA Method 1 is to be measured. The measured angles are to be averaged. If this reveals that the average of the measured yaw angles does not exceed 20°, then proceed with the testing program.			
EPA METHOD 2	FLUE GAS VELOCITY AND VOLUMETRIC FLOW RATE	The flue gas velocity and volumetric flow rate will be determined according to the procedures outlined in EPA Method 2. Velocity measurements will be made using Type S pitot tubes conforming to the geometric specifications outlined in EPA Method 2. Assign a coefficient of 0.84. Differential pressures will be measured with Magnehelic gauges of appropriate range or with fluid manometers. Effluent gas temperatures will be measured with chromel-alumel thermocouples equipped with hand-held digital readouts.			
EPA METHOD 3A	FLUE GAS COMPOSITION AND MOLECULAR WEIGHT	EPA Method 3A will be used to determine the oxygen (O2) and carbon dioxide (CO2) concentrations in the flue gas stream. Concentration measurements will be made using instrumentation and test procedures that conform with the requirements of EPA Method 3A. An extractive sampling system is to be used to provide a continuous, conditioned sample (i.e., free of water vapor and particulate matter) to the analyzers.			
EPA METHOD 4	FLUE GAS MOISTURE CONTENT	The flue gas moisture content is to be determined in conjunction with each EPA Method 5 type train and according to the sampling and analytical procedures outlined in EPA Method 4.			
EPA METHOD 5	PARTICULATE MATTER	If probe lengths are less than 10 feet, liners of borosilicate glass are to be used. For lengths over 10 feet, the probes should be clean, rust-free stainless steel. All nozzles, probe liners, and filter holders are to be rinsed thoroughly prior testing.			
EPA METHOD 6C	SULFUR DIOXIDE	SETUP COSTS FOR SO_2 COSTS AS ADDITIONAL POLLUTANT			
EPA METHOD 7E	NITROGEN OXIDES	SETUP COSTS FOR NO_x COSTS AS ADDITIONAL POLLUTANT			

METHOD NUMBER	*METHOD NAME*	*COMMENTS*	*COST*	*C*	*N*
EPA METHOD 10	CARBON MONOXIDE	To ensure data accuracy of the analyzer, a set of four calibration gases is to be injected through the reference Method 10 sampling system before the compliance testing to demonstrate the linearity of the analyzer. All gases will be documented traceable to National Bureau of Standards Reference Materials. The reported ppm CO measurements are to be corrected for the volume of CO_2 removed from the sample gas by the ascarite as determined by the Method 3A analysis results. SETUP COSTS FOR CO COSTS AS ADDITIONAL POLLUTANT			
EPA METHOD 12	INORGANIC LEAD	In all cases, the test runs will be performed within ± 10% of 100% isokinetic conditions. Pretest preparations, preliminary determinations, and leak check procedures are identical to those outlined in EPA Method 5. Each test run is to be a minimum of one (1) hour in duration with a 30 DSCF minimum sample volume. After filter and impinger adsorbing solution recovery, all sample exposed components of the sampling train are to be rinsed into appropriate containers with 0.1 N nitric acid. To avoid possible contamination, borosilicate glass probe liners are to be used. A reagent and filter blank are to be analyzed.			
EPA METHOD 18	GASEOUS ORGANIC COMPOUNDS - Benzene - Toluene - Ethyl-Benzene - Xylene - Methane	All transfer lines, connections, and pumps are to be heated to 220°F (104.4°C) to prevent condensation of the volatile organics or water in the line. A schematic of a typical Method 18 sampling train is to be provided. The gas chromatograph is to be calibrated before testing with three (3) concentrations of prepared standards or an external standard gas. If external standard gas is used, a response factor relating the response of the gas(es) being analyzed to the standard gas is to be determined. The calibration gas is to be introduced to the GC by the same heated gas injection port at the same conditions used for the sample. A gas of known concentration is to be introduced at the sampling probe and analyzed to ensure the integrity of the sampling system. This procedure is to be performed before and after each run. If the analysis does not agree with the known concentration, the cause of the discrepancy will be located and rectified. Upon request, an audit cylinder in the appropriate concentration range is to be analyzed and the results reported. A post test calibration is to be performed to assure that instrument drift does not vary greater than 5% from the mean of the pretest and post test calibrations.			

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METHOD NUMBER	***METHOD NAME***	***COMMENTS***	***COST***	***C***	***N***
EPA METHOD 18 (continued)		**Since this sampling procedure is a semi-continuous method, a minimum of one sample approximately two (2) times per hour, but as many samples should be taken as is possible, from the beginning of the first run through the end of the last run. The sampling time for this procedure will be a minimum of six (6) hours up to eight (8) hours.**			
EPA METHOD 25A	**NON-METHANE HYDROCARBONS**	**The instrument is to be calibrated using NIST Traceable concentrations of propane in nitrogen (N_2), EPA Protocol 1 propane. The wet-basis concentration of the total hydrocarbons is to be reported in p 20pmv as methane.** **Calibration and linearity checks are to be performed through the entire sampling system before and after each test period. "Zero drift" checks are to be made after each run to adjust the concentration bias due to drift. All parts of the sampling train are to be heated to a temperature of at least 250°F (121.1°C).** **The non-methane fraction of the gas sample is to be determined by analyzing for the methane concentration and subtracting it from the total hydrocarbon concentration. The results for methane of EPA Method 18 can be used for this determination and subtracted from the average total hydrocarbon concentration.** **SETUP COSTS FOR THC** **COSTS AS ADDITIONAL POLLUTANT**			
MODIFIED EPA METHOD 5 (MM5) and EPA SW-846 METHOD 8270	***SAMPLE AND COLLECTION FOR SEMIVOLATILE ORGANIC COMPOUNDS***	**This method will be used to collect semivolatile organic compounds for analysis for the following seventeen (17) polynuclear aromatic hydrocarbons (PAHs):** **Acenaphthene** **Acenaphthylene** **Anthracene** **Benzo(a)anthracene** **Benzo(a)pyrene** **Benzo(b)fluoranthene** **Benzo(e)pyrene** **Benzo(g,h,i)perylene** **Benzo(k)fluoranthene** **Chrysene** **Dibenzo(a,h)anthracene** **Fluoranthene** **Fluorene** **Indeno(1,2,3-cd)pyrene** **Naphthalene** **Phenanthrene** **Pyrene** **Cumene** **o-Cresol** **m-Cresol** **p-Cresol** **The MM5 sampling train will include a cartridge of precleaned XAD-2 resin to capture hydrocarbons that pass through the particulate filter. The sample gas will be cooled by a water-cooled condenser prior to entering the XAD-2 cartridge. Following are specific requirements for each component of the MM5 sampling train.**			

METHOD NUMBER	*METHOD NAME*	*COMMENTS*	*COST*	*C*	*N*
MODIFIED METHOD 5 (continued)		Sampling Train Description. A schematic of the MM5 sampling train is to be provided. The flue gas will be pulled from the stack through a stainless steel nozzle and a borosilicate glass probe. Particulate matter will be removed from the gas stream by means of a glass fiber filter housed in a glass filter holder, supported by a Teflon frit, maintained at 248 ± 25°F (120 ± 14°C). The sample gas will pass through a water-cooled condenser and into the XAD-2 sorbent trap for removal of the organic constituents. The condenser and XAD-2 trap are arranged in a manner that allows the condensate to drain vertically through the XAD-2 trap. A chilled impinger train will be used to remove water from the flue gas and a dry gas meter will be used to measure the sample gas flow. Sealing greases are not be used on the sample train. XAD-2 Preparation. The XAD-2 resin will be purchased precleaned. Care is to be taken to ensure that the resin is kept at temperatures below 120°F (48.9°C) before and after sample collection to prevent decomposition of the resin. The sorbent trap will contain 20 to 30 grams of the precleaned resin. The period of time between when the cartridge is filled with the resin and when it is used in the field is to be kept to a minimum and is not to exceed 14 days. Glassware Preparation. All glass parts of the MM5 sampling train, including the sorbent trap glassware, will be precleaned prior to sampling according to the procedures listed: 1. Soak all glassware in hot soapy water (Alconox) at 122°F (50°C) or higher 2. H_2O rinse, three (3) times 3. Distilled/deionized H_2O 4. Pesticide grade methylene chloride rinse, three (3)times 5. Pesticide grade methanol/methylene chloride rinse, three (3) times 6. Bake at 450°F (232.2°C) for 2 hours 7. Cap glassware with clean glass plugs or methylene chloride rinsed aluminum foil. Clean glassware will be capped with precleaned foil or glass plugs until assembly of the sampling train. Following sample recovery, the glassware will be reused at the same sampling location. Operation of Sampling Train. The sample train will be operated according to SW-846 Method 0010. Special attention should be given to the following Quality Control checks: The entire sample train should be leak tested to ensure that leakage does not exceed the lesser of a) 4% of the average sampling rate, or b) 0.02 CFM. The probe exit temperature should be maintained above 248°F (120°C), and the filter compartment should be maintained at 248°F (120°C) ± 25°F (14°C) during sampling. Gas entering the sorbent module should be maintained at or below 68°F (20°C). Isokinetic sampling should be maintained within ± 10% of 100. Stored resin should be kept below 120°F (49°C) at all times.			

METHOD NUMBER	METHOD NAME	COMMENTS	COST	C	N
MODIFIED METHOD 5 (continued)		Recovery of the Sample. The environment in which the MM5 samples are recovered and the sampling trains reassembled shall be free from uncontrolled dust, such as a lab or vehicle if a lab is not available. The sampling train components will be washed twice, once with acetone followed with an methylene chloride wash. The washes are to be sent to the analytical laboratory in separate containers. The sample containers from a typical MM5 test run should include: Container # 1: Filter(s) Container # 2: Acetone rinses of the nozzle, probe, and front half of the filter holder Container # 3: Methylene chloride rinses of the nozzle, probe, and front half filter holder Container # 4: XAD-2 cartridge and resin Container # 5: Knockout impinger contents (if one is used) Container # 6: Acetone rinses of the back-half of the filter holder, transfer line, condenser, knockout impinger, and connecting glassware Container # 7: Methylene chloride rinses of the back-half of the filter holder, transfer line, condenser, knockout impinger and connecting glassware Container # 8: First, second, and third impinger contents Container # 9: Acetone rinses of the first, second, and third impingers Container #10: Methylene chloride rinses of the first, second, and third impingers Container #11: Silica gel Blanks of each solvent lot used at the test site are to be saved in the event it is necessary to analyze them for potential contamination. All of the sample containers containing water will be extracted for analysis by the designated laboratory within 14 days after the sample has been collected. Depending on the particulate loading and/or the flue gas moisture, the actual number of containers for each sample collected may vary. Sampling Train Blanks. A field blank is to be recovered during each operating condition of the testing program. A field blank will consist of a complete MM5 sampling train (probe, filter, transfer line, condenser, XAD-2 trap, and impinger set) which is to be assembled as though a sample will be collected with it, but the flue gas is not to be pulled through it. The field blank train is to be leak checked the same number of times as a sampling train used during a test run. The field blank train is to be placed at the sampling location for the duration of one test run. This train is then to be returned to the laboratory and disassembled for recovery using the same procedure used to recover actual samples. The field blank is to be obtained using sampling train equipment that has previously been used to collect at least one actual sample from the test site.			

METHOD NUMBER	*METHOD NAME*	*COMMENTS*	*COST*	*C*	*N*
MODIFIED METHOD 5 (continued)		A proof blank is to be obtained by rinsing a complete set of MM5 sampling train glassware that has been cleaned according to the procedures presented previously with acetone and then with methylene chloride, keeping the washes separate until analysis by the laboratory. The pre-cleaned glassware is to consist of the probe liner, condenser coil, and the impinger set. These rinses are to be used to check the effectiveness of the glassware pre-cleaning procedure, if necessary.			
EPA SW-846 METHOD 8270	ANALYSIS FOR SEMI-VOLATILE ORGANIC COMPOUNDS COLLECTED WITH MODIFIED EPA METHOD 5	The XAD-2 traps, filters, washes, and impinger solutions are to be analyzed for Polynuclear Aromatic Hydrocarbons (PAHs). The PAHs for which specific identification is required have previously been listed. In addition, one of the samples from each site tested will include identification of PAHs from a semi-volatile GC/MS scan according to SW-846 Method 8270, except that high resolution mass spectrometry, gas chromatography analysis will be used. The analysis is to be performed on a high resolution gas chromatograph, mass spectrometer. All of the extracts and washes for each test run are to be combined and the volume reduced to 1 milliliter, resulting in one (1) extract per test run from which an aliquot is to be taken for analysis. DMSO (dimethylsulfoxide) extraction of an aliquot of the final extract obtained from MM5 and SW-846, and quantification of the weight percent in the extract of the PAHs made up of 3 to 7 benzene rings (for further details, please call the NAPA office).			
EPA DRAFT METHOD 202	FILTERABLE AND CONDENSIBLE PARTICULATE	The concentration and emission rate of condensible particulate is to be determined by using the procedures and equipment described in EPA Method 5 and EPA Draft Method 202, in conjunction with EPA Methods 1 through 4, which have previously been described. Each test run is to be followed by a gaseous nitrogen purge of the impinger contents. The post-test nitrogen purge is to be at a rate of 20 L/minute for a duration of one (1) hour. Analysis of the organic and inorganic fractions of the impinger contents will allow determination of emissions which condense at temperatures below the filter temperature. The filter particulate matter catch (front-half) is to be determined according to Method 5, 40 CFR Part 60, Appendix A. The particulate matter in the impinger catch (back-half) is to be analyzed and this back-half catch shall be included as particulate matter. The back-half weight will be the sum of the weight of the impinger catch (organic and inorganic) and the weight of the back-half acetone rinse. The impinger liquid is to be extracted and a back-half acetone rinse is to be performed for analysis of the back-half. The extraction of the impinger liquid will be completed as follows:			

METHOD NUMBER	*METHOD NAME*	*COMMENTS*	*COST*	*C*	*N*
EPA DRAFT METHOD 202 (continued)		1. Separate the organic fraction from the sample by adding 75 mL of methylene chloride to the impinger contents in a 1,000 mL separatory funnel, and mix. 2. Allow the aqueous and organic phases to fully separate 3. Drain each phase into separate tared beakers, leaving a small amount of the organic/methylene chloride phase in the funnel to ensure that no water is collected in the organic phase 4. Repeat steps 1, 2, and 3 with the aqueous phases This extraction should yield about 250 mL of organic extract. Determine the weight of the organic fraction as follows: 1. Evaporate the organic extract at room temperature and pressure in a laboratory hood 2. Desiccate the evaporated organic fraction for 24 hours, weighing to a constant weight, reporting the results to the nearest 0.1 mg Determine the weight of the <u>inorganic</u> fraction as follows: 1. Evaporate the inorganic fraction to approximately 50 mL on a hot plate, then evaporate to dryness in an oven at 221°F (105°C). 2. Desiccate the evaporated inorganic fraction for 24 hours, weighing to a constant weight, reporting the results to the nearest 0.1 mg NOTE: Check the pH of the sample in the impinger contents. If it is less than 4.5, the inorganic residue must be redissolved in 100 mL of water. Add five (5) drops of phenolphthalein, then add concentrated NH_4OH (14.8 M) until the solution turns pink. Evaporate the sample again, desiccate, weigh to constant weight, report results to nearest 0.1 mg. If it is necessary to perform the steps outlined in the NOTE above, determine the amount of sulfate in the impinger contents using the aliquot taken before proceeding with the extraction using the procedures described in EPA Method 5A (Appendix A, 40 CFR Part 60). Blanks of water and methylene chloride are to be analyzed as described above. The sum of the values of the water blank and the methylene chloride blank must be less than 2 mg or 5% of the mass of the condensible particulate matter, whichever is greater. If the sum of the actual blank values is greater, then 2 mg or 5% of the mass of the condensible particulate matter, whichever is greater, is to be subtracted from the total sample value.			
EPA DRAFT METHOD 0011	FORMALDEHYDE, FOR THE COLLECTION AND ANALYSIS OF				
ANALYSIS OF BURNER FUEL		Basically, this analysis would include both a Proximate Analysis and an Ultimate Analysis.			

METHOD NUMBER	METHOD NAME	COMMENTS	COST	C	N
ANALYSIS OF WASTE FUEL (if used for burner fuel) OR RAP (if used in the process)		Lead, PCBs, Total halides, Chloride, pH, Flash point			
MOISTURE DETERMINATION OF PROCESS MATERIALS					
DATA REDUCTION		Include no. of hours estimated and cost per hour.			
REPORT PREPARATION		Include no. of hours estimated and cost per hour.			
MANHOURS		Include no. of manhours estimated and cost per hour, overtime rate, at what point overtime pay commences, no. of persons expected to be in the field.			
TRAVEL: PER DIEM PER MILE AIRFARE LODGING & FOOD OTHER		Include per diem rate and no. of days for per diem calc'n, estimated travel time to from testing site and hourly rate per person; "Other" might include rental car, etc.			
PROTOCOL PREPARATION		For the entire stack testing program for this HMA facility.			
STATE PROTOCOL PREPARATION		For just methods that are required by the State for compliance purposes.			
GRAND TOTAL					

QUALITY ASSURANCE PROGRAM

Provide a description and brief detail about the organization of your firm's quality assurance program and how responsibilities are handled. Include the names, resumes, and responsibilities of the Project Manager(s), Quality Assurance Manager(s), Field Operations Manager(s) and other technical people that will be involved in the testing program for this particular HMA facility.

For any work that is to be performed with a contract firm, provide a description and brief detail about how your firm will interface with the contract firm with respect to the samples collected. Include information about what the contract firm will be doing on the project, along with the names, resumes, and responsibilities of the individuals at the contract firm who will be handling samples collected for this project. Also, please provide information regarding the equipment that will be used to analyze these samples. List the name of the individuals from your firm that will be the key contact with the contract firms.

SAMPLE CUSTODY PROCEDURES

The sample custody procedures used for this program should be based on EPA's recommended procedures as found in their publication "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume 3, Stationary Source-Specific Methods (1977)." Since it is likely that the samples will be analyzed by one or more laboratories as well as in the field, there should be an emphasis on documenting the samples collected and the field analytical data, as well as on the chain of custody records for the samples that are transported. Please provide a description and brief detail on the Sample Custody Procedures that your firm will utilize. If samples of the forms that will be used are available, please include them with the protocol.

INTERNAL QUALITY CONTROL

Describe the following:

Equipment inspection and maintenance
Equipment calibration and list of equipment requiring calibration with brief detail about the calibration procedure for each, including:
    Pitot Tubes
    Differential Pressure Gauges
    Impinger Thermometer
    Dry Gas Meter Thermometer
    Flue Gas Temperature Sensor
    Dry Gas Meter and Orifice
    Dry Gas Meter
    Orifice
    Barometer

Quality Control Procedures for SAMPLING, including descriptions:

Pretest QC checks
QC checks made <u>prior to start of tests</u>
QC checks made <u>prior to testing EACH day</u>
QC checks made <u>DURING testing on each day of testing</u>
QC checks made <u>AFTER testing each day</u>

Quality Control Procedures for Determination of the Volumetric air flow rate, including:

Flue Gas Velocity
Flue Gas Molecular Weight
Moisture Content

Quality Control Procedures for ANALYTICAL work, including:

Procedures for the Orsat analyzer
Procedures for the GC analysis used in Method 18
Procedures for the GC/MS analysis used in SW-846

REQUIREMENTS FOR THE REPORT

1. At a minimum, three copies of the final report will be made. One copy is to go to the HMA company whose facility was stack tested, and two copies will be sent to the NAPA office.

2. The individual in your firm who is responsible for putting the report together will also have the responsibility of coordinating with NAPA to obtain copies of operational data and equipment information that was collected by other individuals other than your firm's employees. These copies are to be included as an appendix in the report.

3. Following is a basic outline of what is expected in the final report:

   Title Page: which should include the name of the company where the testing was performed, the company's location and location of the equipment tested, additional parties for whom the testing was performed, and the date(s) on which the testing was conducted.

   Report Certification: This should serve as verification that the report was reviewed and certified by the firm's individual who was present during the testing and a Professional Engineer.

   Table of Contents: The TOC should be an outline of the test report sections, including appendices, with the starting page number for each section.

   Introduction: The introduction should include a background statement that addresses the purpose of the sampling (which should be coordinated with NAPA), the location, and the dates of the testing. It should also include a table that outlines the program and indicates the dates of testing for each test method, the appropriate run numbers for each test, etc. It should also include a list of the participants that were present during the testing--from your firm, contract firm (if any), the host company, state agency, NAPA, etc.

   Summary of Results: This summary should present a summary of the emission rates and concentrations of the pollutants for which analysis was performed and of the constituents of the flue gas. Please provide concentrations as parts per million or percent by volume on a dry basis (ppmdv) for gaseous substances. Report concentrations for particulate substances in both "English" units (grains per dry standard cubic foot) and in metric units (grams per dry standard cubic meter)[1]. Also, please report the emission rates of both gaseous and particulate substances in both "English" units (lbs per hour) and metric units (grams per hour). The summary should list what values were used for Standard Temperature and Pressure. Additionally, it should contain a discussion of any sampling or analytical problems that were encountered during the test program.

Process Description and Operation: This section should be coordinated with NAPA. A final version should be signed off by NAPA before inclusion in the final report. It should include a description of the process that was tested and a summary of its operation during the testing. If necessary, use a table format for quick and easy reference. Also to be included is a schematic drawing of the process and the stack. Include the sampling locations on this drawing.

Sampling and Analytical Procedures: The sampling and analytical procedures for each method conducted should be discussed in separate sections wherever possible. The results for each run and the average of the runs should be placed at the beginning of each section discussion for quick reference.

Quality Assurance: Discuss the parameters that were established for quality assurance and show those parameters were met during the course of the sample collection and analyses.

Appendices: The appendices should include, but not be limited to, the following:

- test results and example calculations--test and analytical results & sample calcs
- field and analytical data--raw field and analytical data
- process data--burner and production process data
- sampling and analytical procedures copied from the regulations, primarily 40 CFR 60
- calibration data--including on-site calibrations of equipment
- temperature charts obtained from the HMA facility control room or copies

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[1] Metric units should follow English units and be enclosed in parentheses.

- Upon submitting your cost proposal to the HMA company, please include three references for each method you propose to perform. By references, we are referring to the names of companies who have hired you to perform a specific test method and the individual contact with whom you worked. Please use the following form. On the following page is another form that can be copied for additional lists. PLEASE NOTE: If you are using any contract firms also submit a list of References for them.

REFERENCES

REFERENCES FOR TEST METHOD ______________________________

DATES	*COMPANY NAME, CONTACT PERSON, ADDRESS & PHONE*
	1.
	2.

REFERENCES FOR TEST METHOD ______________________________

DATES	COMPANY NAME, CONTACT PERSON, ADDRESS & PHONE
	1.
	2.

REFERENCES FOR TEST METHOD ______________________________

DATES	COMPANY NAME, CONTACT PERSON, ADDRESS & PHONE
	1.
	2.

APPENDIX G - Guide Experimental Workplan

Guide Work Plan
For the Evaluation of
Crumb Rubber Modifier (CRM)

<u>Objective of Project</u>:

This work plan will provide guidelines to highway agencies interested in evaluating CRM. These guidelines will allow for the systematic gathering of information on the design, construction, cost and performance of CRM. Information should be gathered and reported in the following areas:

1. Experimental Features

Two essential elements required for a performance evaluation are:

a. Comparative experimental and control sections as nearly identical as possible, and
b. Detailed information on the design, construction, and performance of those sections.

2. Design and Preconstruction Testing Details

The following information should be documented for both the test section(s) and the control section.

a. Structural design date and assumptions (ADT, percentage of trucks, etc.),
b. Cross section of the test section(s) and the control section, their location, length, and condition, including a crack survey,
c. Subgrade, subbase, and base data,
d. Materials data (asphalt grade, asphalt source, CRM type, aggregate types and gradation, etc.,
e. Mix design,
f. Results of materials and design testing, and
g. Special design of materials, concerns, or features.

3. Construction Procedures

- a. Plant Operations
  - (1) Plant type and needed modifications
  - (2) Mix temperatures
- b. Mix Control Testing Results (Gradations, Extractions, Stabilities, VMA, VTM, etc.)
- c. Laydown Temperature and Densities
- d. Weather Conditions
- e. Laydown and Compaction Equipment Used
- f. Worker Fumes and Stack Emissions During Construction
- g. Special Construction Concerns or Features

4. Performance Measurements

- a. Rutting
- b. Raveling
- c. Cracking
- d. Stripping
- e. Deflections
- f. Roughness
- g. Skid resistance
- h. Densities, void contents

5. Cost

The analysis should include a comparison of the costs (dollars per ton) of the material with the CRM verses the material without the asphalt modifier.

6. Environmental Considerations

A documented evaluation of fumes and emission testing results, if appropriate, should be include in this report.

7. Performance Reporting

There is a need to perform a two-phase evaluation. The first phase would be a detailed and frequent investigation that lasts a suggested minimum 3 years. The second phase would be a long-term evaluation that would involve selective investigations at periodic intervals throughout the life of the project.

a. Phase I Reporting:
   (1) Initial Report: This report should be prepared within 90 days of completion of an agreement to perform this evaluation or within 90 days of completion of construction of the project, as appropriate. It should contain all information as required under Items 1 through 6.
   (2) Interim Reports: Information obtained from Item 4, should be reported annually, presented in a form easily understood, and summarized. If appropriate, it should include any discussions useful in assessment of the CRM.
   (3) Final Report: This should include a comprehensive summary of all data collected, an overall evaluation of the cost-effectiveness of the CRM and recommendation based on the information collected.

b. Phase II Reporting:
   (1) Periodic Progress Reports: After completing Phase I of the evaluation, highway agencies are encouraged to continue to monitor the project until pavement failure. Date on information included under Item 4 should be reported every 2 1/2-years or as appropriate.
   (2) These periodic progress reports can be similar to the interim reports described above.

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3. National Cooperative Highway Research Program, Project 20-5, Topic 22-02, *Uses of Recycled Rubber Tires in Highways*

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6. Arizona Department of Transportation, *The History, Development, and Performance of Asphalt Rubber at ADOT*, AZ-SP-8902, December 1989

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21. Texas Transportation Institute, *Use, Availability and Cost-Effectiveness of Asphalt Rubber in Texas*, TTI: 2-8-90-1902-1F, September 1990

22. California Department of Transportation, *Performance of Asphalt-Rubber Stress Membranes (SAM) and Stress Absorbing Membrane Interlayers (SAMI) in California*, undated (1990)

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Recycled
Recyclable

HTA-21/5-92(1M)E
HTA-21/R8-92(1M)EW
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