APPLICATION OF SCRAP TIRE RUBBER IN ASPHALTIC MATERIALS: STATE OF THE ART ASSESSMENT

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ABSTRACT

Currently, due to insufficient utilization of scrap tires, large volumes of these tires are either landfilled, stockpiled, or destroyed (i.e. burned) in an environmentally unfriendly fashion. Stockpiling not only occupies valuable space, causes loss in resources, and waste of energy, but also results in health hazards and creates ideal conditions for breeding mosquitoes and rodents. Based on analysis of potential applications of scrap tires, it was concluded that the best use for scrap tires is in application as an ingredient of asphaltic paving materials and other construction materials. This report primarily presents information on uses of discarded tires in construction of asphaltic concrete pavements.

In general, two processes, wet and dry, are used in manufacture of asphaltic paving materials incorporating scrap tires. Prior to their use, scrap tire rubber is ground to a particulate form which is known as Crumb Rubber Modifier (CRM). In the wet process, CRM is blended with asphalt-cement to produce a modified asphalt-rubber (AR) binder. The resulting binder is used in the same manner as the conventional asphalt. Two technologies that use wet processes are the McDonald (batch) technology and the continuous technology. In the case of dry processes, CRM is mixed with the aggregate prior to inclusion of asphalt-cement to the resultant mixture. The two most common technologies that involve the use of dry processes are the PlusRide technology and the generic technology (TAK System).
In general, rubberized pavements are expected to outperform conventional asphaltic pavements. However, available field performance data are limited to substantiate this trend. More research is needed to compare the performance of rubberized systems with conventional materials and to establish design specifications for rubberized materials for paving and other applications.

Installation cost of CRM rubberized pavements are 50-100% higher than that for unmodified asphaltic materials. In order to recover this increased initial cost, service life of rubberized systems has to increase by 50-100% over conventional asphaltic mixtures. This is yet to be established for many of the CRM containing paving materials. Economic analyses has revealed that the dry processes are more economical than the wet processes. At the present time, the cost of the rubberized material produced by the generic ("dry") system is minimum among all the technologies available. Additionally, this involves asphalt mixing process very much similar to that used for conventional materials. Therefore, this system appears to have the best outlook for its widespread commercial applications. However, limited published data are available on this system. Thus, more research data must be developed and published for widespread use in order to derive both economical and technical advantages. The data obtained from such investigations can be utilized in establishing optimum mixture proportions for such generic systems.
ACKNOWLEDGEMENTS

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acknowledged.
CHAPTER 1
INTRODUCTION

Wisconsin produces approximately 5 million used tires per year. In the U.S.A., nearly 285 million used tires are generated each year (1). Of these, nearly 33 million tires are retreaded, 22 million are reused, and 42 million tires are consumed in various other alternative uses. Due to low reuse of tires, significant numbers of discarded tires are either stockpiled, landfilled, or destroyed in an environmentally unacceptable manner. EPA has reported that nearly 2 to 3 billion discarded tires are stockpiled in the USA (2).

Stockpiled tires create an ideal atmosphere for breeding mosquitoes and a habitat for rodents. Currently landfills in many states, including Wisconsin, restrict the burial of whole tires in municipal landfills due to several factors including: (1) tires are not biodegradable and cannot be easily compacted, resulting in more space requirements; and, (2) tires "float up" to the surface due to settlement of other materials surrounding it and buoyancy effects of gases trapped by the tires. This, in turn, exposes landfill to insects, rodents, and birds. It also permits landfill gases to escape resulting in loss of income.

Many uses for discarded tires have been reported. They include: (1) use of tires in tire retreading; (2) use of tires in the manufacture of gaskets, seals, automotive tailpipe insulators, mats, etc.; (3) use of tires as reclaimed rubber; (4) use of tires as a
fuel by burning; (5) use of tires in the production of chemicals and raw materials such as gas, oil, char, carbon blacks, etc. by the use of destructive distillation technique; (6) miscellaneous use of tires in manufacture of erosion control structures and artificial reefs; (7) use of crumb rubber tires in pavements; and, (8) use of tires in low-cost construction materials and sound absorbing products, etc.

The largest potential market for discarded tires is in rubberized roads and construction materials. A federal law, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), mandates the use of scrap tire material in federally funded state roads [3,4]. This law requires that beginning 1994, 5% of all the federally funded state roads must contain a minimum of 20 lbs of ground rubber per ton of paving material applied. This percentage will be increased to 10% for 1995, 15% for 1996, and 20% for 1997. The bill also requires that the FHWA and the EPA, in cooperation with the states, carry out investigations to evaluate economic and environmental benefits of using rubberized material containing scrap tires. However, the implementation of ISTEA has been delayed to further study the performance, and economic and environmental impacts associated with hot mix asphalt pavements containing rubber. Based upon the study conducted as a part of this project, it appears highly essential to establish technology for manufacture of materials using discarded tire rubber. The results of such investigations would help enhance the utilization of discarded tire rubber in construction materials, including paving materials.

This report primarily presents the state-of-the-art information on the use of scrap
tire rubber in construction materials.
CHAPTER 2
PRODUCING CRUMB RUBBER MODIFIER (CRM) FROM USED TIRES

Prior to use, tire rubber is ground to a particulate form. This form of tire rubber is called crumb rubber modifier (CRM) because its introduction modifies properties of asphaltic material. Used tires are reduced to crumb rubber by basically using ambient grinding (¼" to 40 Mesh), ambient granulating (¼" to 40 Mesh), cryogenic grinding (¼" to 100 Mesh) and wet grinding (40 Mesh to 100 Mesh) techniques.

2.1 PRODUCTION OF CRM

Either whole tires, buffings, tread rubber pieces, or a combination of these materials, can form the basic raw materials for production of CRM. These materials are generally run through a shredder producing chips from ½" to 2". These chips are then further processed into pieces of uniform size from ¼" to 100 Mesh or finer. During the processing, the fabric and metal particles from tires are separated and removed.

A brief description of the techniques used for processing scrap tire rubber into CRM are presented below:

2.1.1 Ambient Grinding

The ambient grinding is performed by using crackermill process at room
For this process, scrap tires are preprocessed by shredding. Then, further size reduction is accomplished by tearing action by passing the material between rotating corrugated steel drums.

### 2.1.2 Ambient Granulating

This process involves shearing action in which scrap rubber is cut by revolving steel plates that pass at a close tolerance. The raw material for this process could be in any form of scrap tire rubber, including whole tire.

### 2.1.3 Gryogenic Grinding

This process involves cooling of scrap tire rubber by submerging it in a bath of liquid nitrogen. As a result, the rubber becomes very brittle and can be easily crushed to the desired particle size in a hammer mill.

### 2.1.4 Wet Grinding

The wet grinding process mixes coarse CRM with water to produce a rubber slurry. The resulting slurry is ground between rotating abrasive discs to a finer size. Then the ground slurry is extruded and dried to produce fine particles of CRM.

In all the above grinding process, except wet process, fiber and steel separators are used. These separators remove fibers and metal from the ground rubber during the processing. Thus, CRM is free from fiber and metals. Talc or other inert materials are added to CRM to avoid sticking of rubber particles together. This also helps
improve its handling and flow characteristics from shipping containers. Dosages of talc should not exceed 4% by weight of CRM (1). Physical properties of particles present in CRM depend upon processing technique used. The rubber particles produced by crackermill are irregular in shape with large surface area. These particles are generally called ground CRM. A granulator produces cubical particles with a low surface area. These particles are termed as a granulated CRM. A tire weighing 20 lbs can yield 10-12 lbs of CRM (1).

2.2 COMPOSITION OF CRM

Tire rubber is primarily a composite of a number of blends of natural rubber, synthetic rubber, carbon black, and other additives. Tire rubber with fiber and steel belting comprise the key elements of today's tires. The composition of CRM depends not only upon the original chemistry of the tire rubber, but also on the source of the discarded tires. Recycled tires are also contaminated by foreign objects, such as stone, sand, clay, fiber, and even metals. These foreign objects may affect the composition and quality of CRM. Chemical analysis of tire rubber has been used as an effective means of quality control. The following tables list chemical compositions for passenger tires, heavy duty truck tread rubber, whole tire rubber, and a comparison of these.

CRM is generally shipped in 50-60 lbs. paper or plastic bags. Other methods of shipment, such as bulk shipment, can also be used. However, bulk shipment may
pose segregation problems as finer particles have a tendency to settle down to the
bottom of a container.
TABLE 2-1: Chemical Compositions for Passenger/Light Truck Tread Rubber (5)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Mean (%)</th>
<th>Standard Deviation (%)</th>
<th>Min. (%)</th>
<th>Max. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone Extract</td>
<td>17.2</td>
<td>1.12</td>
<td>15.5</td>
<td>19.1</td>
</tr>
<tr>
<td>Ash</td>
<td>4.8</td>
<td>0.5</td>
<td>3.9</td>
<td>5.4</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>32.7</td>
<td>1.7</td>
<td>30.4</td>
<td>35.5</td>
</tr>
<tr>
<td>Rubber Hydrocarbon</td>
<td>42.9</td>
<td>1.5</td>
<td>41.5</td>
<td>44.4</td>
</tr>
</tbody>
</table>

TABLE 2-2: Chemical Compositions for Heavy Duty Truck Tread Rubber (5)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Mean (%)</th>
<th>Standard Deviation (%)</th>
<th>Min. (%)</th>
<th>Max. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone Extract</td>
<td>11.4</td>
<td>1.1</td>
<td>10.0</td>
<td>16.1</td>
</tr>
<tr>
<td>Ash</td>
<td>5.1</td>
<td>0.5</td>
<td>3.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>33.2</td>
<td>1.5</td>
<td>30.0</td>
<td>36.9</td>
</tr>
<tr>
<td>Rubber Hydrocarbon</td>
<td>50.2</td>
<td>2.0</td>
<td>45.0</td>
<td>54.9</td>
</tr>
</tbody>
</table>

TABLE 2-3: Chemical Compositions for Whole Tire Rubber (5)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Mean (%)</th>
<th>Standard Deviation (%)</th>
<th>Min. (%)</th>
<th>Max. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone Extract</td>
<td>15.1</td>
<td>1.3</td>
<td>13.1</td>
<td>17.5</td>
</tr>
<tr>
<td>Ash</td>
<td>5.0</td>
<td>0.6</td>
<td>4.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>32.0</td>
<td>1.0</td>
<td>30.5</td>
<td>33.2</td>
</tr>
<tr>
<td>Rubber Hydrocarbon</td>
<td>47.9</td>
<td>1.3</td>
<td>44.9</td>
<td>49.7</td>
</tr>
<tr>
<td>Composition</td>
<td>Mean (%)</td>
<td>Standard Deviation (%)</td>
<td>Min. (%)</td>
<td>Max. (%)</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------</td>
<td>------------------------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>Acetone Extract</td>
<td>17.2</td>
<td>5.8</td>
<td>11.4</td>
<td>15.1</td>
</tr>
<tr>
<td>Ash</td>
<td>4.8</td>
<td>0.3</td>
<td>5.0</td>
<td>5.1</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>32.7</td>
<td>1.2</td>
<td>32.0</td>
<td>33.2</td>
</tr>
<tr>
<td>Rubber Hydrocarbon</td>
<td>42.9</td>
<td>7.3</td>
<td>47.9</td>
<td>50.2</td>
</tr>
</tbody>
</table>
This chapter deals with the processes used in manufacture of paving materials incorporating scrap tire rubber. Scrap tire rubber is called crumb rubber modifier (CRM) because its introduction modifies properties of asphaltic materials. Two processes, namely, wet and dry processes, are used to include CRM in hot mix asphalt (HMA). In the wet process, the CRM is premixed with the asphalt-cement binder in order to produce a modified binder. The resulting binder is then used in a fashion similar to that of conventional asphalt-cement. The dry process involves blending of the CRM with the HMA aggregate prior to adding asphalt-cement to the blended mixture. The wet and dry process technologies are briefly described in the following sections.

3.1 WET PROCESS

In all wet processes, a modified binder is manufactured by blending CRM with asphalt-cement. The modified binder, asphalt-rubber binder (AR binder) is expected to have improved properties relative to conventional asphalt-cement without CRM. The technologies that use wet processes are: (1) the McDonald or batch technology; and, (2) the continuous blending technologies.

3.1.1 McDonald or Batch Technology
In the batch technology, 15-22% CRM is blended with asphalt-cement in a blending tank, and then transferred to a reaction tank where the materials are allowed to react for 45 minutes to 1 hour. The reaction tank has provisions to maintain a uniform blend as well as a constant temperature for obtaining consistent, predictable results. The reaction temperature ranges from 350° to 450°F to avoid hot spot which can burn or "cake" the modified binder (1). This technology produces a thick elastic binder with improved properties compared to conventional asphalt-cement. The asphalt-rubber binder finds applications in several materials including crack and joint sealant, chip or seal coats, stress absorbing membrane (SAM), hot mix asphalt (HMA), subgrade seal, etc.

When the binder is sprayed onto the road surface, followed by distribution and rolling of a cover aggregate, the resulting material is called a seal coat, chip seal, or surface treatment. This treatment acts as a stress absorbing membrane (SAM). The binder is applied at the rate of 0.5 gallon per square yard with approximately 35 pounds per square yard of chips (6). When the above treatment is placed between the layers of pavements, the resulting treatment is termed as stress absorbing membrane interlayer (SAMI). This type of treatment is used to retard reflective cracking, and to restrict water penetration into the underlying layers.

In the asphaltic concrete, the asphalt-rubber binder is used in place of conventional asphalt cement binder for either dense graded, open graded, or gap-graded systems. When the concrete is used in the road surface to enhance
friction, it is called a friction course.

The batch technology requires that 15% of CRM should meet the gradation reported in Table 3-1. In order to accommodate the AR binder, the aggregate gradation for dense-graded HMA concretes should be maintained on the coarse side of the gradation band.

**TABLE 3-1: Suggested Gradations for Dense-Graded (DG) and Open-Graded (OG) Systems (6,7)**

<table>
<thead>
<tr>
<th>Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dense-Graded</td>
</tr>
<tr>
<td>No. 10</td>
<td>100</td>
</tr>
<tr>
<td>No. 16</td>
<td>96-100</td>
</tr>
<tr>
<td>No. 30</td>
<td>20-70</td>
</tr>
<tr>
<td>No. 50</td>
<td>10-40</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-5</td>
</tr>
</tbody>
</table>

For the dense-graded rubberized systems, both Marshall and Hveem mixture design techniques available for HMA can be adopted. However, some modification are needed to take into account the properties of the new binder. To avoid compaction problems, the gradation of aggregate should be on the coarse side of the gradation band. The binder content requirement for asphalt rubber is higher compared to conventional asphalt. For both Marshall and Hveem procedures, the design level of the VTM (void in total mixture) should be maintained at 3 to 4% instead of 3 to 5
percent used in HMA. The Marshall flow requirements are also increased. The Hveem stability should be 20 to 30% instead of 35 to 40% as used with conventional asphalt binder. The procedures given in the FHWA-RD 74-2 "Design of Open Graded Asphalt Friction Courses" should be taken as a general guideline for design of open-graded friction courses containing asphalt-rubber cement. However, the binder content is substantially higher in the rubberized system compared to those used in the standard open-graded mixtures.

The major difference between production of the asphalt-rubber systems and a convention hot mix asphalt is the preblending of the rubber with asphalt. The preblending operation is performed in insulated trucks and tanks. In order to produce asphalt-rubber binder, asphalt and CRM are mixed together in a blending unit. The temperature of asphalt is kept at between 350° and 400°F at the time of inclusion of CRM. The blended mixture is then pumped into an agitated storage tank for reaction. During the reaction, temperature is maintained between 325° and 375°F for at least 45 minutes. Then the required amount of the asphalt rubber is metered into the mixing chamber of the HMA manufacturing plant.

Construction technology for the asphalt-rubber system is similar to that of conventional HMA but the asphaltic material placement, i.e. laydown, temperature is higher, and compaction should be performed while the material is hot due to the faster increase in viscosity of the AR binder.

3.1.2 Continuous Blending Technology
The continuous technology is very similar to that of the McDonald technology but it differs in the process of mixing CRM with asphalt concrete. This technology produces an asphalt-rubber binder by using a continuous mixing unit and a finer CRM. The finer CRM is used to shorten reaction time between the CRM and asphalt-cement. The continuous mixing unit can be installed at the HMA plant and then it can be interlocked into the conventional asphalt binder system. The CRM contents vary between 5 and 20%. A typical gradation for the continuous technology is shown in Table 3-2.

**TABLE 3-2:** CRM Gradation for Continuous Blending Technology (6,9)

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 60</td>
<td>98 to 100</td>
</tr>
<tr>
<td>No. 80</td>
<td>88 to 100</td>
</tr>
<tr>
<td>No. 100</td>
<td>75 to 100</td>
</tr>
</tbody>
</table>

3.2 DRY PROCESS

The dry process involve adding of CRM directly into asphaltic concrete mixtures. Typically, the CRM is preblended with the heated aggregate and then hot asphalt is added to the mix for manufacture of the asphaltic concrete. The paving concrete made with this process is generally referred to as rubber-filled concrete.
Some of the CRM particles will react with the asphalt during the process of mixture preparation. However, the reaction of the particles will greatly depend upon their size. An increase in fineness increases reactivity of the particles. Therefore, the amount of fine CRM present in the mixture will determine the degree of modification of the asphalt binder. The two technologies that use the dry process include: (1) the PlusRide system; and, (2) the generic (TAK) system. These systems are described in the following sections.

Addition of CRM causes increase in resiliency/elasticity of the PlusRide mixtures. As a result, the conventional properties of stability and flow do not apply for the rubberized systems. The primary parameter for design is the percentage of air voids. Batch, continuous, and drum-dryer have been used in manufacture of asphaltic concrete mixture incorporating CRM. At batch plants, aggregates are added in the mixing plant, and then CRM bags are added to the aggregate. The aggregates and CRM are mixed dry for about 15 minutes prior to addition of the asphalt. Each batch is mixed to obtain a uniformly coated asphaltic concrete mixture. The process and equipment that are used for introducing reclaimed asphalt pavement (RAP) are also appropriate for introducing CRM into the drum mixer. EnvirOtire, Inc. developed a CRM proportioning and feeding system. This system can be used to introduce CRM into both the batch and drum facilities. Other equipment for hauling, placing, and compaction are essentially the same as used for conventional asphaltic concrete systems.
3.2.1 PlusRide System

This system employs CRM as a partial replacement of aggregate in asphaltic concrete mixtures. The PlusRide process was developed in the 1960’s by the Swedish Companies Skega AB and AB Vaegfoerbaettringar (ABC). The system was marketed by Paveteck Corp. of Seattle, Washington. The mixture design was further refined in the mid 1980’s (6). Currently, EnvirOtire, Inc. sells this technology as PlusRide II. The CRM in the PlusRide mixture can vary between 1 and 4%. Typically, this system uses 3% granulated coarse and fine rubber particles. Asphalt content requirements are increased from 4 to 6% for conventional mixture to 7.5 to 9% for the PlusRide systems. As a rule of thumb, the PlusRide mixtures require nearly 2% more asphalt than a comparable conventional asphaltic mixture (6). This system uses gap-graded coarse aggregates to provide space for the rubber particles. Also, a predetermined, specific gradation of CRM is used. Mixture design details for the PlusRide systems are given elsewhere (8).

3.2.2 Generic Technology

This system was developed by Takallou in 1986. For this system, CRM gradation is designed to suit individual aggregate gradations for dense-graded asphaltic concrete mixtures. Since this system employs the available "generic" aggregate gradation for individual localities, it was named as "generic system". This system is also referred to as the TAK system. The size of CRM should be smaller (by one sieve size) relative to the gap that will be created in the mineral aggregate. The CRM used in the generic system are finer than that for the PlusRide system. The finer rubber particles present in the generic mixture modify the asphalt-cement considerably due to their high
reactivity, whereas the coarser rubber particles act primarily as elastic aggregate in the HMA mixture.

For this system, crumb rubber can be derived from ambient granulated or ground from whole passenger and/or light truck tires. The CRM having size greater than 10 Mesh is generally manufactured by ambient granulation technique. Whereas, the CRM passing through the 10 Mesh sieve is manufactured by using either ambient granulation or ambient grinding techniques.

The maximum amount of CRM for the generic system is determined based on the specified minimum stability requirement. Optimum asphalt content is established on the basis of air voids. However, selected mixture should confirm to the minimum stability requirement for control mixture containing no CRM. Hauling, placing, and compaction equipment are practically the same as that used for conventional HMA system.

A modified generic system was used in Florida where an experimental pavement was constructed with 80 mesh CRM in an open-graded friction course (6). The maximum size of aggregate was 9.5 mm. The CRM was used at a rate of 10% by weight of the binder.
CHAPTER 4
PREVIOUS INVESTIGATIONS

4.1 INTRODUCTION

Rubber has been used in butimen for approximately 150 years. The earliest use of natural rubber in butimen began in 1840's (10). Initial work was primarily directed toward blending natural rubber and synthetic rubber in asphalt-cement. In general, elastic properties of asphalt cement was found to increase due to addition of rubber. However, the concept of inclusion of tire rubber in asphaltic concrete developed in 1950's. In the early 1960's Flinsteal Corporation and U.S. Rubber Reclaiming studied reaction between crumb rubber and asphalt-cement under laboratory condition. Practical use of CRM in asphaltic mixture began in 1964.

4.2 REACTION MECHANISM IN ASPHALT - RUBBER SYSTEMS

Addition of CRM results in its interaction with asphalt cement. This interaction is termed as asphalt-rubber reaction (1). Several variables including physical and composition properties of asphalt and CRM, temperature, time, and mixing conditions can influence this reaction (1, 11). The reaction between asphalt and CRM is not a chemical reaction. It is primarily due to polymer swell. This reaction involves absorption of aromatic oils from asphalt cement into the polymer chains of the rubber particles (1). The rate of reaction of natural rubber with asphalt is higher than that for
synthetic rubber. The reaction causes swelling of CRM, leading to about 3 to 5 times the original volume. The reacted particles of CRM become sticky and develop adhesive property (1). In accordance with the Federal Highway Administration (FWHA) asphalt Rubber (AR) is defined as asphalt cement modified with CRM (1). Whereas ASTM (12) requires at least 15% rubber in order to produce a rubberized binder.

4.3 RUBBERIZED PAVING AND OTHER MATERIALS

McDonald developed a method to add small ground scrap rubber to asphalt cement. A test patch of asphalt-rubber pavement system was placed in 1964 at Sky Harbor Airport in Phoenix and on U.S. Route 666. Extensive field testing of the pavement at Sky Harbor Airport was carried out in 1965. The test results exhibited adequate performance of the material. The successful application of this material at the airport led to its routine use on city streets in Phoenix, Arizona.

Numerous investigators (1, 11, 13-24) have reported properties of asphalt-rubber (AR) binder. The various applications of asphalt rubber systems include stress absorbing membranes and interlayers (25-36), binder for asphaltic concrete (36-49), and pavement cracks and joint sealants (36, 45, 46).

In general, addition of CRM in asphalt-cement improves its properties to a great extent. These include decreased temperature susceptibility, increased viscosity, and increased softening point by 20° to 50°F, reduced aging, and increased elasticity (6, 7,
In the mid 1960's, the City of Phoenix pioneered the use of asphalt-rubber binder in chip seal treatments (36). This binder is composed of 70 to 80 percent hot asphalt-cement and 20 to 25 percent ground recycled rubber (29, 47). Applications of Asphalt-rubber in Arizona were primarily in two different types of surface treatments. These included: (1) stress absorbing membrane (SAM), a hot-asphalt-rubber chip seal was applied to a distressed crack surface; and, (2) stress absorbing membrane interlayer (SAMI), this system involved the use of a hot-asphalt-rubber chip seal to the surface, followed by a 1-1/2 to 2-in. asphaltic concrete overlay. Pavements treated with asphalt-rubber binder were found to last about 2 to 5 times longer than with conventional asphalt sealer (29). A pavement made with SAMI of 0.11-in plus 2-in of asphalt concrete showed durability equivalent to a 7-in asphalt concrete overlay (47).

Charania et al.(36) summarized studies related to rubberized chip seal coats (SAM's and SAMI's) used in Arizona. They reported the following major benefits of rubberized seal coats.

(1) The asphalt-rubber seal coats retard reflective cracking in the pavement with less than 0.25 in. cracks for 8 to 12 years. They tend to stop secondary cracks up to 15 years.

(2) The rubberized seal coat also waterproofed the structures which result in improved stability.

(3) They seal and preserve the in-situ original quality of asphaltic material.

(4) They act as excellent crack filling materials and joint sealer.
(5) The maintenance cost is reduced due to the use of rubberized materials.

(6) Their service life is approximately 2 to 5 times greater than for most standard seals.

Although the rubberized (seals) showed several favorable properties, they posed some problems to motorists. The rubberized systems often exposed loose chips which were scattered by moving cars. This resulted in damage to windshields and made motorists unhappy. As a result, another rubberized material as an alternative to chip seals was developed. The developed material was a gap-graded asphalt-rubber hot mix concrete incorporating large amount of asphalt binder (8 to 10% asphalt-rubber). The results showed that 1-in. asphalt-rubber concrete overlay to be adequate to resist reflective cracks (36). This treatment have shown improved riding surface and decreased in traffic noise. The asphalt-rubber systems have been used in experimental as well as in field trials in several states, including Arizona, California, and Colorado, and several other countries (7).

Inclusion of rubber particles in pavements using dry process was developed in 1960's in Sweden. This mixture in Sweden was reported to have improved durability and skid resistance relative to comparable conventional asphaltic concrete mixtures. The use of such mixtures, a.k.a. PlusRide mixtures, began in the US in the late 1970's. Addition of this material in pavements improves their performance in regards to fatigue properties, skid resistance, noise reduction, reduction in reflective shrinkage and thermal of cracking in resurfaced asphalt pavements, etc. (48-56). The rubber-filled mixtures showed extended durability with relatively thinner sections compared to that
used for conventional asphaltics materials (54,55). Also, these mixtures are expected to have increased fatigue life due to elastic nature of the materials (48).

Tests conducted by the Alaska Department of Transportation exhibited a reduction of about 25% in stopping distance under icy road conditions compared to conventional asphaltic pavements (50). Additionally, the rubber-filled system also provided a mechanism to restrict formation of ice layers on the road surface. The mechanism primarily stems from increased flexibility of the rubberized materials and poor bond between the road surface and ice, causing disintegration of the ice deposited on the road surface during vehicle movements.

Lundy et al. (54) evaluated performance of rubber-filled pavement as well as conventional asphaltic concrete pavement under both laboratory and field conditions. The rubber-filled system was proportioned using the PlusRide mixture design technology. The results exhibited: (1) increase in modulus of elasticity of both the rubber-modified and control mixtures with time; (2) decreasing fatigue life of both the materials with time; (3) higher expected fatigue life of the rubberized mixture compared to the control for a given strain level; (4) lower tensile strength for rubberized mixtures compared to the control mixtures; (5) roughness of the rubberized systems was slightly higher; and, (6), approximately 25 to 75% higher fatigue strength in the case of the rubberized materials. On the basis of fatigue tests under laboratory conditions, layer equivalency values for rubber modified materials were of the order of 1.2 to 1.8 times that for control mixtures without CRM.
Doty (55) evaluated performance of a number of rubber-modified paving materials in California and compared their performance with conventional asphaltic materials. These were rubberized dense-graded asphalt concrete overlays with or without a SAMI, PlusRide dense-graded AC overlays, and four thicknesses of conventional dense-graded AC overlays. Single and double stress absorbing membrane interlayers (Fig. 4-1) of the mixture were tested. The properties of various materials considered are given in Table 4-1. The lowest permeability was observed for the PlusRide DGAC. The permeability of the asphalt-rubber system (ARS
<table>
<thead>
<tr>
<th>Materials</th>
<th>Segment Number</th>
<th>Overlay Thickness (ft)</th>
<th>As-Built Design</th>
<th>% Comp.</th>
<th>Permeability (ml/min)</th>
<th>Surface Abrasion (grams loss)</th>
<th>Skid No. (SN40)</th>
<th>Deflection (0.001&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARS</td>
<td>1</td>
<td>0.27</td>
<td>0.28</td>
<td>93.3</td>
<td>36.3</td>
<td>17.1</td>
<td>55</td>
<td>54 26</td>
</tr>
<tr>
<td>DGAC</td>
<td>2</td>
<td>0.17</td>
<td>0.18</td>
<td>91.7</td>
<td>22.3</td>
<td>17.6</td>
<td>57</td>
<td>43 25</td>
</tr>
<tr>
<td>DGAC</td>
<td>3</td>
<td>0.12</td>
<td>0.15</td>
<td>92.8</td>
<td>--</td>
<td>18.7</td>
<td>54</td>
<td>25 16</td>
</tr>
<tr>
<td>PlusRide</td>
<td>4</td>
<td>0.19</td>
<td>0.15</td>
<td>97.1</td>
<td>--</td>
<td>9.7</td>
<td>39</td>
<td>55 27</td>
</tr>
<tr>
<td>DGAC</td>
<td>5</td>
<td>0.21</td>
<td>0.18</td>
<td>98.4</td>
<td>11.0</td>
<td>14.8</td>
<td>39</td>
<td>30 26</td>
</tr>
<tr>
<td>DGAC</td>
<td>6</td>
<td>0.28</td>
<td>0.28</td>
<td>96.1</td>
<td>6.8</td>
<td>11.4</td>
<td>44</td>
<td>27 16</td>
</tr>
<tr>
<td>Conv.</td>
<td>7</td>
<td>0.20</td>
<td>0.15</td>
<td>91.7</td>
<td>177.0</td>
<td>47.8</td>
<td>66</td>
<td>23 18</td>
</tr>
<tr>
<td>Conv.</td>
<td>8</td>
<td>0.18</td>
<td>0.20</td>
<td>91.2</td>
<td>--</td>
<td>48.2</td>
<td>68</td>
<td>60 44</td>
</tr>
<tr>
<td>DGAC</td>
<td>9</td>
<td>0.32</td>
<td>0.30</td>
<td>91.4</td>
<td>--</td>
<td>32.5</td>
<td>65</td>
<td>63 28</td>
</tr>
<tr>
<td>DGAC</td>
<td>10</td>
<td>0.52</td>
<td>0.50</td>
<td>92.1</td>
<td>--</td>
<td>35.1</td>
<td>67</td>
<td>46 13</td>
</tr>
<tr>
<td>Double</td>
<td>11</td>
<td>0.10</td>
<td>0.04</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>62</td>
<td>44 42</td>
</tr>
<tr>
<td>SAM</td>
<td>12</td>
<td>0.13</td>
<td>0.04</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>59</td>
<td>51 35</td>
</tr>
<tr>
<td>SAM</td>
<td>13</td>
<td>0.14</td>
<td>0.03</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>57</td>
<td>54 54</td>
</tr>
</tbody>
</table>

**Notes:**
1. Includes SAMI, segments 1, 2, 5, and 6, as shown in Figure 4-1
2. Per Calif. Test 341
3. Per Calif. Test 360, Method B
4. Per ASTM E274, Meas 10/83
5. 80th percentile deflections per Calif. Test 356 (Dynaflect Method)
DAGAC) was lower compared to the conventional DGAC. As a result, the rubberized pavements are expected to have higher resistance to surface water intrusion. Abrasion resistance of the materials followed the same general characteristics as observed for the permeability (Table 4-1). Test data showed adequate skid resistance for the PlusRide pavement, but very good results were obtained for the other surfaces. Analysis of the results further revealed that the initial stiffening effect to the asphalt-rubber overlays is equal to or greater than that for the equivalent thickness of conventional DGAC. The results also indicated that the tolerable deflection of the rubberized asphalt overlays is greater compared to equivalent thickness of conventional DGAC. The amount of cracking in the various paving materials is shown in Table 4-2. This should provide a measure of remaining life of the pavements. In general, the rubberized paving materials exhibited either equal to or better than conventional dense-graded concrete with respect to resistance to cracking.

Chamberlin and Gupta (56) presented the performance results of the rubberized pavements constructed in U.S.A. during the period 1977 through 1984. The results are shown in Fig. 4-2. They summarized findings of the past studies as follows:

Out of 50 projects studied about one-half of the projects showed no appreciable differences between the performance of asphalt-rubber seal coats and conventional asphalt materials. Less than 20% of experimental asphalt-rubber pavements exhibited better results than that of conventional asphalt pavements. In the remaining 30% projects, the worst performance was observed for the
rubberized systems.
Performance of asphalt-rubber interlayers (SAMI) were compared with conventional asphalt material in 90 different projects. No significant difference was observed between the rubberized and non-rubberized materials for nearly 50% of the projects completed. Approximately twenty percent of the projects
exhibited better results in the case of asphalt-rubber systems.
Out of total 54 projects studied, about 30% of the projects with rubber-filled asphalt concrete outperformed the conventional asphalt concrete pavements.

Because of limited number of projects completed during the period of 1977 to 1984 concerning performance of asphalt-rubber friction courses, asphalt-rubber concrete, and rubber-filled friction course treatments, no definite conclusions could be drawn for these systems. The authors further reported that the poor performance of the rubberized pavements compared to conventional asphalt pavement was primarily attributed to deficient construction practices and insufficient quality controls for materials mixed rather than to fundamental deficiencies of the rubber-modified materials.

In the past rubber has been used in asphalt for manufacturing of asphalitic materials for tennis courts, basements, floors, tiles, roofs, adhesives, waterproofing, expansion joints, etc. (48). It is well known that rubber has high capacity to absorb shock and vibrations. In general, addition of tire rubber should help increase vibration and shock absorbing capacity of materials (48). Due to this reason, in general, rubberized materials are expected to have increased service life compared to nonrubberized materials. Naik and Singh [48, 49] based on past data and potential for various applications, described various uses of scrap tire rubber in construction materials and products. Those include: (1) application of tire rubber in manufacture of protective barrier for highway bridges; (2) manufacture of asphalritic blocks for construction of slope pavements under highway bridges and other similar uses; (3)
manufacture of crash barriers on highways; (4) manufacture of railroad crossing ties; (5) construction of elastic foundations for railroads, highways, airport structures, and other foundations where vibrational damping is required; (6) embankments; (7) artificial reefs; (8) manufacture of low-strength concretes for construction of parking lots and other cementitious materials requiring low-strength; etc.

Scrap tires are also used in construction of subgrades and embankments. Shredded tires can be used as a lightweight fill material, and whole tire or side walls can be used as soil reinforcement in construction of embankment (57). The use of tires in subgrades and embankments improves stability of steep slopes along the highway, and protection of coastal roads from erosion (57). Discarded tires can be used as lightweight aggregates, especially construction of roads across soft soil that can present stability problems. Application of waste tire as lightweight fill is economically attractive and can consume large volumes of discarded tires.

In France, a weather-resistance base for gravel covered mountain roads was made using discarded tires (58). The rolling surfaces were removed from sides of tires and clamped together in a subsurface layer over fill and the surface was finally covered with gravel. This type of base consumed nearly 10,000 tires per kilometer of road. Such roads did not require frequent resurfacing.
CHAPTER 5
ECONOMIC EVALUATION OF CRM IN PAVING MATERIALS

Cost of introducing CRM in asphaltic materials depends greatly upon type of materials and manufacturing processes (wet or dry process) used. In general, material produced by dry processes are more economical than those produced by wet processes. However, the economics of using CRM in asphaltic materials is governed by the cost differential between rubberized and non-rubberized (conventional) materials.

The cost of manufacturing asphalt-rubber binder includes cost of manufacturing and packaging CRM, mixing, reacting, and blending the CRM in asphaltic materials, etc. The binder can be purchased from a supplier such as International Surfacing Inc., Rouse Rubber Industries, Inc., or others (59). It can also be manufactured by retrofitting existing plant for the blending and reaction of the asphalt and a CRM. The price quoted by the rubberized binder supplier may also include services such as mixture design, delivery of materials to the plant, quality control support, etc. The cost of manufactured asphalt binder can range from $200 to $500 per ton versus $80 to $150 per ton for conventional asphalt (59).

The two most commonly used dry processes of manufacturing paving materials are the PlusRide and generic systems. As compared with conventional asphaltic concrete systems, increased cost of the PlusRide system is associated with the revised
aggregate gradation requirements, increase in the amount of asphalt binder (2 to 2.5%), cost of CRM, increase in operational costs, royalty fee, etc. Whereas for the generic system, major cost increase is primarily due to increase in asphalt requirement (1 to 1.5%), and cost of CRM. In the case of the wet process, especially the Arizona refinery process, additional cost is basically related to the cost of manufacturing the asphalt-rubber (AR) binder.

Chamberlin and Gupta (56), based on pooled data in the US, reported that service life of rubberized materials must be significantly higher than conventional materials in order to recover the first cost. To accomplish this, they concluded, the increase in life of rubberized systems relative to conventional materials should be 100 to 200% for asphalt-rubber seal coat, 50 to 100 percent for asphalt-rubber interlayer, and 100 to 150 percent for asphalt-rubber concrete (56). However, it is expected that this cost is expected to decrease with increased uses of rubberized materials, improvement in tire processing technology, and experience gained in the use of CRM in pavements and other construction materials.

Recently, Takallou and Takallou (52) made an economic analysis of use of CRM in asphaltic concrete systems. The results of their investigation are presented in Table 5-1 and 5-2. As expected, the generic technology was the least cost system of all the three systems analyzed. Total per ton cost increase was $26.10 for the asphalt-rubber binder system, $20.10 for the rubber modified hot mix asphalt concrete (RUMAC) system manufactured by using PlusRide process, and $12.00 for RUMAC
manufactured by using the generic process.

Stroup-Gardiner (59) described the costs associated with various asphalt cement products incorporating CRM. The results showed approximately 10% increase in cost of asphalt-rubber crack and joint sealant over sealant made with conventional material. Application of the asphalt-
TABLE 5-1: Comparative Schedule of Increases in Cost of Asphalt Mixes Using Used-Tire Rubber to Conventional Asphalt Mix (52)*

<table>
<thead>
<tr>
<th>Conventional Asphalt (Control)</th>
<th>Increases in Cost Beyond Conventional Asphalt (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asphalt/Rubber Binder</td>
</tr>
<tr>
<td></td>
<td>Arizona Process (dollars)</td>
</tr>
<tr>
<td></td>
<td>RUMAC PlusRide Process (dollars)</td>
</tr>
<tr>
<td></td>
<td>RUMAC Generic Process (dollars)</td>
</tr>
<tr>
<td>Asphalt Binder</td>
<td>-</td>
</tr>
<tr>
<td>Asphalt/Rubber Binder</td>
<td>23.10</td>
</tr>
<tr>
<td>Aggregate</td>
<td>-</td>
</tr>
<tr>
<td>Contractor Overhead</td>
<td>3.00</td>
</tr>
<tr>
<td>Royalty</td>
<td>-</td>
</tr>
<tr>
<td>Rubber (60 lbs. dry) @ $0.12/lb.</td>
<td>-</td>
</tr>
<tr>
<td>Total Increase Per Ton</td>
<td>$26.10</td>
</tr>
</tbody>
</table>

* Assumptions:

Percentage of Asphalt Binder:
- Conventional A/C: 5.5%
- Asphalt/Rubber Binder: 7.0%
- RUMAC - PlusRide: 7.5%
- RUMAC - Generic: 7.0%

- Binder Cost: $120.00 per ton
- Asphalt/Rubber Binder Cost: $450.00 per ton

Maximum Specific Gravity of Mix:
- Conventional A/C: 150 pounds per cubic foot
- Asphalt/Rubber Binder: 148 pounds per cubic foot
- RUMAC - PlusRide: 140 pounds per cubic foot
- RUMAC - Generic: 142 pounds per cubic foot
rubber binder in construction of chip seals and interlayers can increase the cost by about 30% over unmodified asphalt binder systems. The estimated cost of HMA mixtures using conventional and asphalt rubber binders is presented in Table 5-3. This analysis does not include any increased costs associated with increased mixing and storage temperature. The use of the AR binder can increase the cost up to 60%(59). A cost comparison between RUMAC and modified HMA is presented in Table 5-4. Application of the RUMAC (generic process) can result in 15 to 55% increase in the cost over conventional HMA mixture depending upon amount of CRM included.

**TABLE 5-2: Comparative Project Cost of Asphalt Mixes Using Used-Tire Rubber to Conventional Asphalt Mix (52)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/ton</td>
<td>$28.00</td>
<td>$54.10</td>
<td>$48.10</td>
<td>$40.00</td>
</tr>
<tr>
<td>Tonnage required per mile, 36 feet wide, 3&quot; thick</td>
<td>3,564</td>
<td>3,516</td>
<td>3,326</td>
<td>3,374</td>
</tr>
<tr>
<td>Cost/mile</td>
<td>$99,792</td>
<td>$190,216</td>
<td>$159,981</td>
<td>$134,960</td>
</tr>
<tr>
<td>Number of tires used/mile</td>
<td>--</td>
<td>5,274</td>
<td>16,630</td>
<td>16,630</td>
</tr>
<tr>
<td>Difference in paving Costs/recycled tire</td>
<td>--</td>
<td>$17.14</td>
<td>$3.62</td>
<td>$2.11</td>
</tr>
</tbody>
</table>
TABLE 5-3: Examples of Estimated Costs of HMA, Conventional Binder, and Asphalt Rubber Binder (59)*

<table>
<thead>
<tr>
<th>Mixture type</th>
<th>$/Ton Unmodified Mixture (Cost_{HMA})</th>
<th>$/Ton Unmodified Mixture (Cost_{AC})</th>
<th>%AC Unmodified Mixture (P_B)</th>
<th>$/Ton Modified Binder (Cost_{AR})</th>
<th>%AC, Modified Mixture (P_{AR})</th>
<th>Total Est. Cost of Asphalt Rubber Hot Mix, dollar (Cost_{HMAR})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense-grade</td>
<td>35</td>
<td>100</td>
<td>5.5</td>
<td>400</td>
<td>6.5</td>
<td>55.50</td>
</tr>
<tr>
<td>Gap-graded</td>
<td>45</td>
<td>100</td>
<td>6.5</td>
<td>400</td>
<td>8.0</td>
<td>70.50</td>
</tr>
<tr>
<td>Open-graded</td>
<td>50</td>
<td>100</td>
<td>7.5</td>
<td>400</td>
<td>9.0</td>
<td>78.50</td>
</tr>
</tbody>
</table>

* Supplier-produced asphalt rubber binder. A general formula for computing the cost of HMA mixture with asphalt-rubber binder used was as follow.

\[
\text{Cost}_{HMAR} = \text{Cost}_{HMA} - (\text{Cost}_{AC} \times P_B) + (\text{Cost}_{AR} \times P_{AR})
\]

where:
- \(\text{Cost}_{HMAR}\) = Cost per ton of hot mix with asphalt-rubber binder
- \(\text{Cost}_{HMA}\) = Cost per ton of conventional hot mix
- \(\text{Cost}_{AC}\) = Cost per ton of unmodified asphalt cement
- \(P_B\) = Percent of asphalt cement binder by total weight of mix (decimal form)
- \(\text{Cost}_{AR}\) = Cost per ton for asphalt rubber binder
- \(P_{AR}\) = Percent of asphalt rubber binder by total weight of mix (decimal form)
### TABLE 5-4: Examples of Estimated Costs of RUMAC Compared to Unmodified HMA

<table>
<thead>
<tr>
<th>Mixture type</th>
<th>$/Ton Unmodified</th>
<th>$/Ton Asphalt %AC, Unmodified</th>
<th>%AC, Modified</th>
<th>$Rubber/Ton HMA* (Cost_{Rubber})</th>
<th>$/Ton RUMAC (Cost_{RUMAC})**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense-graded</td>
<td>35</td>
<td>100</td>
<td>5.5</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Gap-graded</td>
<td>45</td>
<td>100</td>
<td>6.5</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Open-graded</td>
<td>50</td>
<td>100</td>
<td>7.5</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

* Percentages of rubber based on total weight of mixture. Cost assumed $0.15/pound for the crumb rubber and $0.15/pound for labor/handling at plant.

** The general formula used for computing the cost of RUMAC was as follows:

\[
\text{Cost}_{\text{RUMAC}} = \text{Cost}_{\text{HMA}} + \text{Cost}_{\text{AC}} (P_{\text{RUMAC}} - P_{\text{HMA}}) + \text{Cost}_{\text{Rubber}}
\]

where:
- \(\text{Cost}_{\text{RUMAC}}\) = Cost per ton of RUMAC
- \(\text{Cost}_{\text{HMA}}\) = Cost per ton of conventional hot mix asphalt
- \(\text{Cost}_{\text{AC}}\) = Cost per ton of unmodified asphalt cement
- \(P_{\text{HMA}}\) = Percent of asphalt cement binder by total weight of mix (decimal form) for unmodified binder
- \(P_{\text{RUMAC}}\) = Percent of asphalt cement binder by total weight of mix (decimal form) for RUMAC
- \(\text{Cost}_{\text{Rubber}}\) = Raw material costs plus the labor costs involved in adding rubber
CHAPTER 6
SUMMARY AND CONCLUSION

Several potential applications exist for utilization of discarded tires. However, due to lack of acceptable markets, majority of discarded tires find their way to landfilled and/or stockpiled, or destroyed (burned) in environmentally unacceptable manner. Therefore, in order to have increased utilization of scrap tires, it is necessary to establish economically and environmentally feasible technologies to solve this challenging problem. Recently, an increased emphasis has been placed on the use of scrap tire in manufacture of paving materials. This report present the state-of-the-art knowledge on use of scrap in asphaltic pavements and other highway construction work. Use of scrap tire in portland cement-based products should also be explored.

Discarded tires have been utilized as an ingredient in asphaltic materials for over four decades. Prior to its use, it is ground to particulate form designated as crumb rubber modifier (CRM). When CRM is added to asphalt, it swells due to interactions that occur between rubber particles and asphalt.

CRM is introduced in hot mix asphalt (HMA) by using wet as well as dry processes. In the case of wet process, CRM is blended with asphalt to manufacture a new binder called asphalt-rubber (AR) binder. The new binder works in a similar way as that of conventional asphalt cement. The wet process employs two technologies: the McDonald (batch) and continuous technologies to manufacture the AR binder. The
former acts in a batch mode and uses 15 to 22% of CRM (10-30 Mesh) by weight of the total binder. Whereas the later works in continuous mode and uses a finer CRM in amounts varying from 5 to 20% of the total binder.

The dry process involves blending of CRM with aggregate before mixing with asphalt cement. Two technologies, namely, the PlusRide and generic technologies are most commonly used. The amount of CRM typically used is 3% for the PlusRide and ranges between 1 and 3% by weight of total mixture for the generic system.

The PlusRide mix is patented by the Swedish AB and VA Vaegfoerbaettrinar (ABV). This system uses a gap-graded aggregate. Introduction of CRM in this system produces a rubber modified hot mix concrete (RUMAC). The rubber particles behave like elastic aggregates. For the generic system, greater amounts of finer CRM are used compared to the PlusRide mixture. The coarser particles, similar to that used in the PlusRide system, behave like elastic aggregates, and finer rubber particles modify the binder to some extent. The generic system, also known as the TAK system, uses mixture design and test standards similar to that of conventional asphaltic concrete. This system uses a dense graded aggregate gradation, and therefore it does not require any special aggregate requirement similar to the PlusRide system.

It is claimed that rubberized asphaltic binder experiences reduced aging, and exhibits increased softening point and decreased temperature susceptibility, compared to unmodified asphalt binder. This binder has been used in crack and joint sealants,
Stress Absorbing Membranes (SAM), or seal coats, Stress Absorbing Membrane Interlayers (SAMI), hot mix asphalt (HMA) which can include dense-graded, open-graded, and gap-graded HMA systems.

Use of asphalt-rubber in SAM and SAMI is well documented in the USA as well as other countries. However, in the US a limited number of projects have involved the use of asphalt-rubber in manufacture of HMA concrete pavements. The use of asphalt-rubber binder in SAM and SAMI has shown increased service life, about 2 to 5 times that obtained for conventional system. Additionally, the mixtures containing AR binder are less sensitive to temperature variations and show improved sound attenuation, increased fracture toughness, etc.

The PlusRide system has been successfully used in construction of RUMAC. This system was introduced in the USA in the late 1970s in order to improve properties of asphaltic materials. These properties include sound attenuation, improved fatigue strength, better skid resistance, and deicing ability. Very limited amount of work has been reported concerning the use of generic systems. Because of its simplicity in application and low-cost, evaluation of performance of rubberized pavements utilizing generic technology has become a subject of many current investigations, including one at the University of Wisconsin-Milwaukee for the last two years.

The use of rubberized pavements in the USA is limited. This stems from the fact that the installation cost of rubberized roads is 50 to 100% higher compared to that for conventional pavements. Additionally a number of experimental investigations
showed poorer performance for rubberized pavements than for conventional pavements. However, the poor performance in the case of rubberized systems was generally attributed to deficient mixing, batching, testing and construction practices, and due to limited experience with the use of such materials. The performance of pavements containing CRM would significantly improve with further understanding through research and testing in laboratory and field conditions. Hence, more development efforts are needed to improve mixtures containing CRM which are economically and technically attractive for pavement and other applications.

There is a very high potential for the uses of scrap tires in other rubberized constructional materials including Portland cement-based materials of construction, vibration absorbing medium, subgrade and embankments, etc. Scrap tires are appropriate for applications as a lightweight fill materials for construction of roads across soft soils to avoid stability problems. Scrap tires may also be used as a reinforcement of soil in construction of embankments.
CHAPTER 7

REFERENCES


