Benefits of Recycling Waste Tires in Rubber Asphalt Paving

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More than 2 billion waste tires are stockpiled across the country. In addition, the United States disposes of 279 million waste tires, representing over 4 million tons of scrap waste. Although a limited number of waste tires are used for resource and energy recovery, the majority go to landfills or are disposed of in an environmentally unacceptable manner. In an effort to clean up old stockpiles of used tires and to promote the recycling of today's used tires, many road agencies are evaluating the use of discarded tires to modify asphalt cement mixtures. Ground tire rubber from waste tires has been used as an additive in various types of asphalt pavements in recent years. The use of rubber is of interest to the paving industry because of the additional elasticity imparted to the binder and enhanced safety related to improved roadway skid resistance. However, it is the additional benefit of resource recovery, recycling used tires into rubber granulate for use in rubber-modified asphalt concrete, that has prompted a growing interest in its use. There are two primary reasons why rubber-modified asphalt mixes have not achieved widespread use. First, the capital costs for these surfacing alternatives is higher than conventional asphalt mixtures by 40 to 80 percent. Second, there is a lack of dissemination of information regarding properties and performance of these surfacing alternatives. Three different asphalt paving systems are described and the economics of each system is compared to conventional asphalt concrete. Also, a potential solution to the mentioned obstacles is described.

The use of ground tire rubber as an additive in various types of asphalt pavement construction has been demonstrated in recent years and is of interest to the paving industry because of the additional elasticity imparted to the binder. However, additional environmental benefits, such as resource recovery, have also been observed by creating a use for recycled waste tires. Approximately 480 million tons of asphalt are laid each year in the United States (*1*). If only 10 percent of this total was laid in rubber-modified asphalt concrete using 3 percent granulated rubber, all of the tires that need disposal each year would be consumed. Also, at a rate of only 10 percent of total paving, rubber-modified asphalt concrete could be laid in specific locations to fully realize the advantages of rubber-modified asphalt concrete: increased durability, reduced reflective cracking, thinner lift, and increased skid resistance.

With the increased burden placed on our national roadway system by higher tire pressures and increased traffic volumes, there is a need to improve conventional asphalt concrete mixes. Rubber-modified asphalt concrete has been shown to increase the fatigue resistance and durability. Its widespread use would also have the ecological benefit of recycling some of the 279 million tires needing disposal each year (*2*).

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Tires stockpiled in above-ground locations offer an ideal habitat for vermin and a breeding ground for mosquitos. If these stockpiles catch on fire, not only do they contaminate the soil, but efforts to extinguish the fire can also cause surface and ground water contamination. Recognizing these problems, legislatures across the country are enacting laws to regulate used tires (*3*). However, until a market develops for the economical and beneficial use of recycled tire products, the problem of tire disposal will remain.

In recent years, the most overlooked aspect of rubber-modified asphalt has been the attention it has received by Congress. Congress, in order to stimulate the use of recycled materials, requested that the Environmental Protection Agency (EPA) and FHWA issue guidelines for the procurement of paving materials containing ground tire rubber. In response to the request, the February 20, 1986, issue of the *Federal Register* describes a proposed rule by the EPA for Federal Procurement of Asphalt Materials Containing Ground Tire Rubber for Construction and Rehabilitation of Paved Surfaces (*3*). To date, the guideline has not been implemented.

The paving processes that use crumb rubber or granulated used-tire rubber to modify asphalt concrete are defined, identified, compared, and evaluated. The effect of each process as a method of whole-tire recycling is evaluated. An economic analysis of the rubber-modified asphalt concrete processes is presented and, based on this analysis, the most technologically feasible and economically viable process is recommended.

CRUMB RUBBER ASPHALT PROCESSES

The term "crumb rubber," when used to describe modified asphalt concrete, encompasses two types of rubber. These types include

1. Crumb rubber from tire buffings or tire peelings. Tire buffings and tire peelings are the waste product of the tire encapping industry. A used tire, suitable for recapping, is buffed of remaining tread, or the tread is peeled from the tire, to leave a smooth, uniform surface for the installation of the new tread. The material removed from the old tire was once disposed of with other solid waste. Now, however, this waste material is sold to rubber processors. The processors grind the rubber to various mesh sizes. Because this material is from the tread portion of the used tire, it is free of steel and fabric and is a more uniform product than rubber processed from the whole used tire.
2. Crumb rubber from whole-tire processing. This rubber is produced by recycling the whole used tire with mechanical

granulation equipment at ambient temperature. The used tire is granulated into rubber particles to various gradations passing sieve sizes from ¼ in. to Number 40 mesh. The steel is removed by magnetic separation and the free fabric removed by an air vacuum system.

Both types of rubber can be used as additives in asphalt pavement construction.

Two main processes incorporate the use of crumb rubber to modify asphalt concrete mixes. The method of addition of the crumb rubber to the asphalt mixture distinguishes the processes between "wet" and "dry". In the dry process, crumb rubber is added to the asphalt cement mixture to replace some of the aggregate in the mixture. The wet process adds the crumb rubber to the asphalt cement to modify the physical and chemical properties of the asphalt cement. The following sections describe the different processes.

Rubber-Modified Asphalt Concrete (Dry Process)

Two main systems currently use the dry process to incorporate used-tire rubber into paving mixes: the PlusRide system and the generic system.

PlusRide System

A paving mixture of rubber-modified asphalt concrete is prepared by the PlusRide process, which typically uses 3 percent, by weight of total mix, granulated coarse and fine rubber particles to replace some of the aggregate in the mixture (Figure 1). This concept was originated by the Swedish companies Skega AB and AB Vaegfoerbaettringar (ABV); it was patented in the United States under the trade name PlusRide and is marketed by PaveTech Corporation of Seattle, Washington (*4*).

This concept, developed in the late 1960s after the introduction of studded tires, improved the pavement's durability and resisted excessive wear. Today this mixture is used to increase flexibility and durability to overcome the problem of the early reflection of fatigue cracking in resurfaced asphalt pavements. Laboratory and field testing show that this mixture provides extended durability at thinner lifts (*5,6*). Testing of rubber-modified asphalt pavements in the laboratory also indicated a potential for greatly increased pavement fatigue life as a result of the elasticity of this material (*7*).

The surface texture and protruding rubber granulate is reported to give the pavement improved skid resistance during icy conditions. Measurements by the Alaska Department of Transportation and Public Facilities on roads overlaid with this material have shown a reduction in stopping distance averaging 25 percent under icy road conditions (*8,9*). The ice-control mechanism apparently results from the flexing of the protruding rubber particles and the greater flexibility of the mix under traffic action; lack of adhesion between the surface of the rubber-modified asphalt concrete pavement and the ice layer causes a breakdown of surface ice deposits. Roadway surface ice deposits become a major problem in urban areas with high traffic volumes and stop-and-go traffic movements. Costs of maintaining ice-free pavements with chemicals or improving traction through sand applications are very high. Considerably increased expenditures on pavement construction would be justified if ice-free pavements could be obtained. Accordingly, in June 1989, the Alaska Department of Transportation requested from the Federal Highway Administration a statewide finding of public interest for use of rubber-modified asphalt concrete. The request was denied.

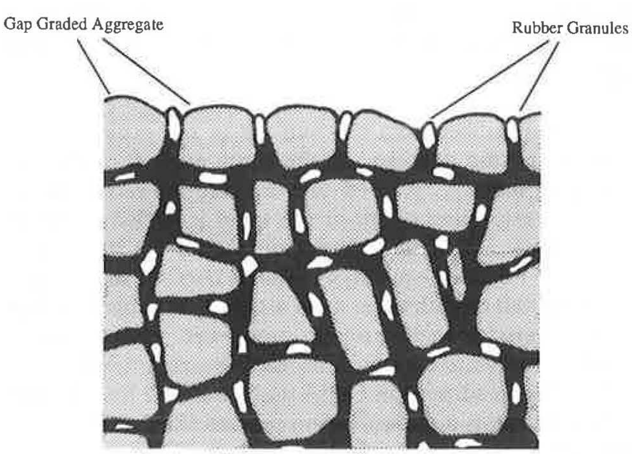

FIGURE 1 Illustration of rubber granules in rubber-modified asphalt.

Generic System

The generic system was developed by H. B. Takallou in 1989. The system attains the advantages of rubber-modified asphalt concrete, but uses mix designs and standards very similar to conventional asphalt concrete. Another objective of using this mix was to evaluate the whole-tire, rubber-modified pavement as a recycler of used tires. In this process the rubber gradation is designed to be compatible with a specific dense-graded aggregate gradations at the rate of 1, 2, and 3 percent rubber, or 20, 40, and 60 lb per ton of mixture (*10*).

Projects using the generic system were constructed in summer 1989 for the state of New York and in Canada without any significant problems and are performing as well as the control sections of conventional asphalt. This new mix has outperformed conventional asphalt in the laboratory.

This system is a public domain process, therefore, no license fees are required to use the system. This system uses a dense-graded aggregate gradation so no unique or gap-graded gradation requirement is necessary. Also, roadway agencies can use their own requirements to tailor a mixture to obtain optimum performance for different traffic levels, traffic types, and environments.

Rubber-modified asphalt concrete is a whole-tire recycler. This process utilizes all of the used tire, including the sidewall, interliner, and tread, recycling all but the steel and fabric. Three percent or 60 lb of rubber granules are used in the mix, requiring the recycling of five used tires per ton of mixture.

The average net yield of rubber from a used passenger tire, after steel and fabric removal, is about 12 lb; hence, five tires must be recycled to acquire the 60 lb of granulated tire rubber necessary for production of 1 ton of rubber-modified asphalt concrete mix. Therefore, 16,000 tires can be recycled per mile in a two-lane highway overlaid with 3 in. of rubber-modified asphalt concrete pavement.

Construction

Mix Ingredients Rubber-modified asphalt paving mixes are prepared by a process that typically uses up to 3 percent by weight of coarse and fine granulated rubber particles to replace some of the aggregate in the mixture. The granulated rubber is from ambient ground passenger or light truck tires.

The ground rubber is angular in shape; individual particles are not to be longer than 5/16 in. The ground rubber should be free of wire and fabric, with a maximum allowable moisture content of 2 percent. The rubber is delivered in 60-lb plastic sacks for direct addition into the pugmill in whole sacks. The sacks are packaged in low-density polyethylene, having a melting point of less than 250°F (*11*). In the most recent projects, the rubber was added via a belt conveyor system without problem. The contractor estimated that the additional conveyor belt and laborer equipment added about 53 cents per ton to the cost of the mix (G. Miller, unpublished).

In the PlusRide process, the aggregate gradation must provide space for the rubber granules so it is necessary to create a gap in the aggregate to provide space for the rubber to be uniformly dispersed throughout the paving mixture (Figure 2). The asphalt cement used in a rubber-modified asphalt mix is the same as that used in a conventional mix. The mix typically requires 1.5 to 2 percent more asphalt than a conventional mix (*11*).

The generic process is prepared by adding up to 3 percent by weight (60 lb/ton) of fine and coarse rubber particles to a dense-graded aggregate mixture. In this process the rubber gradation is designed to be compatible with a specific dense-graded aggregate gradation. The rubber granulate is produced from whole-tire recycling. Passenger and light truck tires are recycled to the gradations necessary to fit into the dense-graded aggregate mixture.

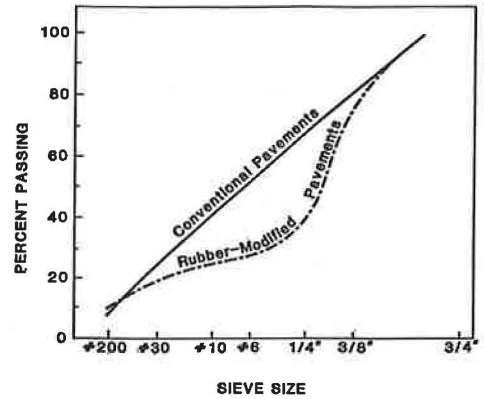

FIGURE 2 Comparative aggregate gradation curves for conventional and rubber-modified asphalt pavements.

Mix Production Batch, continuous, and drum-dryer plants have been used for mix production. A batch mixing plant is preferred because the required quantities of rubber, asphalt, and aggregates can be measured exactly and added separately to the pugmill mixing chamber. In this type of plant, pre-weighted and sacked rubber can be used to advantage, with quantity control by bag count. However, both continuous mix and drum-dryer mix plants have been used. In these plants, the mixing operation goes on continuously rather than in batches, and the rubber is added from a separate bin with a belt feed to the midentry (recycle fit opening). No modification or additional equipment is needed to produce rubber-modified asphalt concrete at any type of asphalt production plant (*11*).

Laydown The laydown of rubber-modified asphalt concrete mixture is performed by conventional paving machines equipped with full-width vibratory screens to aid in compaction. The laydown machinery used includes both the hopper and pickup types. Handwork (such as raking longitudinal joints or placing radii) for the rubber-modified asphalt mixes is affected by the mix gradation and temperatures. According to contractors, the best results were observed while the mix was at normal laydown temperatures (280°F to 300°F) (*12,13*).

Compaction Conventional compaction equipment has been used to roll the rubber-modified asphalt concrete mixes. The breakdown rollers are typically 10- to 12-ton vibratory steel drum units. The intermediate and finish rollers are also steel drum units. To prevent pickup of material by the roller drum, a fully operational water spray system, with some liquid soap in the water reservoir, is recommended. Tire rollers can be used with the generic mix rubber but not with the PlusRide mix because the PlusRide process uses high percentages of asphalt content and coarse aggregate.

Asphalt-Rubber Binder (Wet Process)

The asphalt-rubber binder process (Arizona Refinery system) was developed in the early 1970s primarily to overcome the early reflection of fatigue cracking in resurfaced asphalt pavements (*14*). The concept is based on the use of a composite material of hot asphalt cement mixed with 18 to 22 percent ground crumb rubber by weight of binder to establish a reaction and diluted with an oil extender for ease of application. In addition to its initial use as a reflection crack control membrane and waterproofing for pavements, it has also been used for crack and joint sealing and for control of swelling in expansive clays (*15*).

Considerable experimental work and field trials have been performed with this system in the United States, particularly in Arizona, California, and Colorado. These installations have used finely ground crumb rubber (Number 16 to 25 sieve size) reacted with various grades of asphalt. At elevated temperatures (300°F to 400°F) for periods of 30 minutes to 1 hour, this reaction forms a thick elastic-type material which is then diluted with 5 percent kerosene to aid in application. The net result of the reaction is a marked thickening of the mixture to a consistency similar to that of a very thick slurry with discernible rubber particles throughout the mass. At room temperature, the asphalt-rubber composition is a tough, rubbery and elastic binder material. The elastic quality of this mixture is caused by the mechanical action of the undissolved rubber particles performing as a completely elastic aggregate within the asphalt, which is modified by the dissolved rubber (*16*).

Using asphalt-rubber binder for seal coat construction of fatigue-cracked bituminous concrete pavements helps prevent reflection cracking from the substrate pavement because of the propagation of cracks. The undissolved rubber particles serve as units of elastic interference to the propagation of cracking. Should a crack begin to propagate through the membane, it encounters an elastic rubber particle and is stopped or redirected, whereupon it will encounter another elastic rubber particle, and so on (*16*).

Ambient ground rubber from used tires is blended into the asphalt binder. Only the fine reclaimed rubber or tire buffings from the tread portion of the tire are used, to ensure uniformity of the rubber to be reacted with the binder. Seven percent of the rubberized mix is binder containing 20 lb of tire buffings. A 1-mile section of a two-lane highway overlaid with 3 in. of rubberized asphalt would recycle the equivalent of 5,274 tires.

Construction

Mix Ingredients A blend of crumb rubber and asphalt cement has been used as a binder in various types of bituminous construction, rehabilitation, and maintenance. This blend is called asphalt rubber and consists of 18 to 22 percent crumb rubber by total weight of the blend. It is formulated at elevated temperatures to promote chemical and physical bonding of the two constituents as described (*16*).

Mix Production The major difference between production of an asphalt-rubber binder and a conventional hot mix asphalt is the preblending of the rubber with the asphalt. The preblending has taken place in insulated trucks and tanks. Also, the production temperatures required are higher than those used for typical asphalt mixes.

The temperature of the asphalt cement must be between 350°F and 400°F at the addition of the crumb rubber. The asphalt and crumb rubber are combined and mixed in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the crumb rubber is added to the asphalt cement. The temperature of the asphalt-rubber mixture is maintained between 325°F and 375°F during the reaction period.

After the material has reacted for at least 45 minutes, the asphalt-rubber binder is metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the job-mix formula. The rubber-asphalt mix is produced in either batch or continuous mix plants.

The specialized equipment used in production and proportioning of the asphalt-rubber binder includes (*16*)

1. An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the granulated rubber. This unit normally is capable of heating a minimum of 3,000 gallons of asphalt cement.
2. An asphalt-rubber mechanical blender with a two-stage continuous mixing process capable of producing a homogenous mixture of asphalt cement and crumb rubber at the mix design specified ratios. This unit must be equipped with a crumb rubber feed system capable of supplying the asphalt cement feed system so the continuity of the blending process is not interrupted. A separate asphalt cement feed pump and finished product pump are required. These units have an asphalt cement totalizing meter, in gallons, and a flow rate meter, in gallons per minute.
3. An asphalt-rubber storage tank. This tank is equipped with a heating system to maintain the proper temperature for pumping and adding the binder to the aggregate and an internal mixing unit within the storage vessel capable of maintaining a proper mixture of asphalt cement and crumb rubber.
4. An asphalt-rubber supply system equipped with a pump and metering device capable of adding the binder by volume to the aggregate at the percentage required by the job-mix formula.

Laydown and Compaction The laydown and compaction equipment and procedures used in the asphalt-rubber binder process are the same as those used with the rubber-modified asphalt concrete systems (*16*).

ECONOMIC ANALYSIS OF RUBBER-MODIFIED ASPHALT CONCRETE

The economics of using any of the rubber-modified asphalt concrete processes is based largely on the cost differential between each of the processes and paving with a conventional asphalt concrete mix.

The increases in cost for the PlusRide process are bid as a price per ton. The increases in the cost per ton should reflect the additional costs for an additional 2 to 2.5 percent asphalt binder, a change from a conventional aggregate gradation, the 60 lb of granulated rubber per ton of mixture, and the royalty fee (Table 1).

The increase in cost for using the generic process is limited to the cost for up to 1 to 1.5 percent more asphalt binder and the cost of the granulated rubber (Table 1).

With the Arizona Refinery process, the cost increases beyond a conventional asphalt concrete is packaged in the supply of the rubber-asphalt binder. The additional costs for mixing, reacting, blending, on-site support, and a special mix design using the rubberized binder are all packaged into a quote for rubberized binder (Table 1).

One factor offsets some of the additional costs when using rubber-modified asphalt concrete. There is an increase in the yield per ton based. With the addition of the rubber to the mix or replacement of aggregate, as with PlusRide and generic processes, the maximum specific gravity decreases (Table 2).

This analysis does not put a cost savings on either the societal benefit of finding a practical use for used tires or the savings derived in diverting waste tires from the already overcrowded landfills.

TABLE 1 COMPARATIVE SCHEDULE OF INCREASES IN COST OF ASPHALT MIXES USING USED-TIRE RUBBER TO CONVENTIONAL ASPHALT MIX

	Conventional Asphalt (Control)	INCREASES In Cost Beyond Conventional Asphalt - Standard (Control): Asphalt/Rubber Binder Arizona Process	RUMAC PlusRide Process	RUMAC Generic Process
Asphalt Binder			2.40	1.80
Asphalt/Rubber Binder		23.10		
Aggregate			3.00	
Contractor Overhead		3.00	3.00	3.00
Royalty			4.50	
Rubber (60 lbs. dry) @ .12/#			7.20	7.20
TOTAL INCREASE PER TON		26.10	20.10	12.00

<u>Table Based on Following Assumptions:</u>

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

MARKET BARRIERS FOR USED-TIRE UTILIZATION IN ASPHALT PAVING

Rubber-modified asphalt concrete mixes have been used in the United States since the 1970s. They have won grudging support on a local basis where demonstration projects have been laid and have performed to expectations. Questions on performance of the rubberized mixes are being answered with the long-term performance now proven by some of the earlier projects.

Each of the rubberized asphalt paving systems faces one or more of the following barriers to widespread use:

1. High initial costs (Table 2),
2. High capital costs for equipment modification,
3. Lack of information transfer between states,
4. Lack of used-tire processing technology, and
5. Use of a proprietary product.

High initial costs are a problem for all three systems because initial projects are usually demonstration projects of limited production. A contractor not only faces an unknown material but also must charge all changes in production to the limited tonnage of rubberized asphalt laid. Spreading those costs to the limited tonnage production dramatically increases the apparent cost per ton.

The Arizona Refinery process uses capital-intensive specialized equipment for the blending unit and an agitated storage tank for the reacting and mixing of the rubberized binder (*15*).

TABLE 2 COMPARATIVE PROJECT COST OF ASPHALT MIXES USING USED-TIRE RUBBER TO CONVENTIONAL ASPHALT MIX

	Conventional Asphalt (Standard)	Asphalt/Rubber Binder Arizona Process	RUMAC PlusRide Process	RUMAC Generic Process
COST/TON ($)	$28.00	$54.10	$48.10	$40.00
TONNAGE REQUIRED PER MILE, 36 FEET WIDE, 3" THICK, (TONS)	3,564	3,516	3,326	3,374
COST/MILE ($)	$ 99,792	$190,216	$159,981	$134,960
NUMBER OF TIRES RECYCLED/MILE	--	5,274	16,630	16,630
DIFFERENCE IN PAVING COSTS/RECYCLED TIRE	--	$17.14	$ 3.62	$ 2.11

Lack of information transfer between states on the demonstration projects using rubberized asphalt is a result of not having a common nationwide clearing house for these projects (*17*).

Lack of used tire processing technology will remain until the demand increases for used-tire rubber granulated to the specifications for the rubberized processes. Sustained increases in market demand will persuade manufacturers to modify or develop the technology and equipment necessary to produce the equipment for efficient and economical used-tire recycling (*10*).

Both the Arizona Refinery process and the PlusRide process are protected by patents. Production of the PlusRide mix also requires a license fee be paid to the license holder. Agencies are reluctant to specify products requiring license fees.

CONCLUSIONS

Ground tire rubber has been used as an additive in various types of asphalt pavement construction in recent years. The use of rubber is of interest to the paving industry because of the additional elasticity imparted to the asphalt cement mixture. In field trials, rubber-modified asphalt paving mixtures have proven to be superior to conventional asphalt paving. The three main rubber asphalt systems are rubber-modified asphalt concrete (PlusRide), conventional rubber asphalt (generic process), and asphalt-rubber binder (Arizona Refinery system). The increase in the cost of the rubber-modified asphalt products, when related to the cost of recycling the used tires necessary to produce the products, is presented. The increase in cost per ton to a conventional mix on a per recycled tire basis ranges from a high of $17.14 per tire to a low of $2.11. Therefore, a subsidy of as little as $2.11 per recycled tire would put a ton of the rubber-modified asphalt mix on an equal cost basis with a ton of conventional asphalt mixes, regardless of potential benefits from reduced layer thickness or improvement in durability of the rubber-modified asphalt mixes.

Of the three rubberized asphalt processes presented, the use of rubber-modified asphalt concrete (generic process) appears to have the best outlook for widespread use on a national basis because it requires the least amount of change from a conventional asphalt project. In the generic process, the material is mixed and laid with the same equipment and in the same manner as conventional asphalt. Also, there is no need for a specialized mix design or a license fee as with the PlusRide process.

The adoption of a national standard for a generic rubber-modified asphalt concrete is needed before widespread use of the material is seen. A national generic specification would encourage competitive bidding through the use of public domain specifications. Adoption of a standard would help minimize the impact on contractors' operations and promote the use of rubber in asphalt mixes. A standard specification would, through a combination of advantages, increase the cost-effectiveness of using rubber in asphalt mixes.

Perhaps the most important reason that generic rubber-modified asphalt has the best outlook for widespread use is that it is the process with the lowest cost differential when compared to conventional asphalt and shares the highest utilization rate of recycled rubber, 60 lb of rubber per ton of asphalt. The combination of lowest cost and highest use of tire rubber makes generic rubber-modified asphalt concrete the least costly used-tire recycling method of the three rubberized systems presented.

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Publication of this paper sponsored by Committee on Soil and Rock Properties.