

POTENTIAL FOR USE OF DISCARDED TIRES IN
HIGHWAY CONSTRUCTION AND MAINTENANCE

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INTRODUCTION

A document prepared by W. C. Robinson of the Department of Waste Management provides a broad view of the problems and considers some of the options available for establishing a Virginia strategy for disposing of or utilizing used tires discarded in the Commonwealth (1). One such option is the use of the tires in applications relating to highway construction and maintenance. This paper reviews the potential use of crumb or granulated rubber in transportation in greater detail and makes an initial evaluation of both potential advantages and problems in this area.

BACKGROUND

Efforts to utilize rubber in asphalt pavements date back to the 1920s (2), and significant studies were conducted in the United States during the 1950s. At that time, there was an interest in using relatively small amounts (3 to 5 percent) of natural or synthetic rubber latex or crumb rubber as a means of modifying the properties of the asphalt binder to increase its resilience and toughness and thereby reduce the tendency of asphalt concretes to crack in cold weather and to shove or rut in hot weather. These efforts were marginally successful but not cost effective because of the high cost of the rubber.

During the 1960s, Charles McDonald, Materials Engineer for the City of Phoenix, developed a method of combining ground vulcanized rubber from discarded tires with asphalt (2). McDonald's process involved heating 15 to 33 percent of ground vulcanized rubber with asphalt cement under controlled conditions to form a significantly modified binder, which is now referred to as asphalt-rubber.

McDonald's first concept, which he patented, was to use the asphalt-rubber binder as a small prefabricated patch to control reflective cracking. However, its usefulness as a membrane layer over the full roadway to prevent reflective fatigue cracking in new overlays was recognized early. In effect, McDonald's process involves the creation of a new binder for the aggregate.

A second process, patented as "Plus Ride" is based on a different principle. In this case, granulated rubber is added as a part of the aggregate system with modification of the grading to make room for the rubber. Such products are referred to as rubber-filled systems. The chief advantage claimed for this system is its flexibility and the consequent rebound properties of the surface. Thus, cracking is reduced. Another benefit claimed is that the flexibility under loading prevents ice from sticking to the pavement, thereby providing the pavement with "self-cleaning" properties.

These technologies have been applied to pavement construction and maintenance in several different ways--usually on a trial-and-error basis. All such uses of recycled rubber cost more than conventional applications utilizing usual aggregate and asphalt products. Thus, strictly from the viewpoint of highway construction and maintenance, longer life or safer conditions must be attained by the products containing the rubber to justify the additional costs. Such longer life is claimed by present producers of the material, especially asphalt-rubber, but unfortunately this claim has not been fully substantiated on a nationwide basis.

A study to evaluate the performance of asphalt-rubber and rubber-filled systems was conducted by the Texas Transportation Institute. This was a pooled-fund study involving 16 state highway agencies and the Federal Highway Administration (3). The report, which was published in 1986, included 219 test sections constructed between 1977 and 1982. The study showed that many of the sections did not perform as well as sections using conventional procedures with normal asphalt materials and that only marginal benefits were attained in other cases. However, it was pointed out that poor performance in many cases was related to inexperience with the materials and improper construction procedures. Since these earlier tests sections were placed, the efforts of the Asphalt Rubber Producers Group (ARPG) and various state highway agencies have provided better knowledge of what is required, and new specialized equipment and procedures have been developed. Interest remains high in utilizing asphalt-rubber and asphalt rubber-filled systems both as a means for prolonging the life of old pavements and as a way of utilizing discarded tires to avoid the increasing problem of finding safe and healthful disposition of such tires. Increases in knowledge and environmental concerns warrant a continuing evaluation of these systems.

PREPARATION OF ASPHALT-RUBBER BINDER

The term asphalt-rubber has recently been defined by the American Society for Testing and Materials (ASTM) and is included in ASTM D8-88 Standard Definitions of Terms Relating to Materials for Roads and Pavements. The definition reads as follows: "A blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles."

The key to better performance of the asphalt-rubber systems lies in the proper preparation of the asphalt-rubber binder. Experience has demonstrated that the best asphalt grade to use varies with the climate at the location where it is to be used. According to Chehovits (4), AC-20 or AC-10 is used in hot climates, AC-5 or AC-2.5 in moderate climates, and AC-2.5 with up to 3 percent extender oil in cold climates. The rubber should be free from contaminants, including mineral matter, fiber, and metal. The rubber hydrocarbon content should be between 40 and 50 percent and should be uniform throughout the rubber shipment. The rubber gradation is very important. If the rubber particles are too large for the voids within the aggregate, compaction of the rubber-asphalt concrete will be difficult and mixtures will be "spongy" after compaction. The optimum size of the rubber will vary according to the aggregate gradation depending on whether dense graded or open graded mixtures are being used. Although the minimum rubber content is established by definition at 15 percent, the usual rubber percentage will vary from 16 to 25 percent depending on the specific application. The temperature of the asphalt must be between 325° and 375° F. In this temperature range, the interaction proceeds quickly to reach the desired properties within 30 minutes to 1 hour after adding the rubber. At lower temperatures, the reaction period becomes too long for adequate production rates, and at higher temperatures, the proper properties of the blend are not retained for a sufficiently long period. The consistency (viscosity) of the asphalt-rubber blend, which is determined by a rotating type viscometer, is usually used as the primary indication that the proper reaction has occurred. For some applications, extender oils or kerosene may be used to soften the blend for proper consistency at the application or mixing (with aggregate) temperatures. In addition to the physical attributes, the chemical characteristics of the rubber and the asphalt also influence the speed and efficiency of the reactions. Asphalt-rubber is produced at the asphalt plant and is generally used simultaneously with its production. However, it can be reheated and the properties adjusted when necessary. The final product is not a homogenous liquid; it still retains partly reacted rubber particles and carbon black dispersed throughout its mass. Constant stirring or agitation is required and special pumps are needed to add the binder to the pugmill or drum mixer. Asphalt-rubber producers have developed special equipment for these purposes.

Number of Tires Utilized

Based on the assumptions given in the Appendix, about 210 reclaimed tires are required to prepare 1,000 gallons of asphalt-rubber. However, only approximately 10 to 12 pounds of rubber (40 percent) from the tire is useful for this purpose. This leaves from 14 to 16 pounds of the tire in the form of casing, sidewalls, etc. that is not used in this process that must be discarded or used for other applications.

ASPHALT-RUBBER APPLICATIONS

Surface Treatments

Surface treatments, or seal coats, involve the application of a sprayed coating of the asphalt-rubber binder over the surface, which is immediately covered with aggregate chips that are then rolled into the binder layer. It is postulated that the flexibility of the asphalt-rubber membrane will absorb stresses created by traffic and thus retard cracking and deterioration. The term stress-absorbing membrane (SAM) is often applied to this type of construction, and the acronym SAM is frequently used.

The asphalt-rubber for this application contains 16 to 25 percent rubber. Kerosene or other diluents may be used to lower the viscosity to the proper range for application. The grade of asphalt selected is dependent on the ambient temperature in the area in which it is used. The application rate of the asphalt-rubber is usually about 0.6 gal/yd², but it may vary from 0.4 to 0.7 gal/yd², depending somewhat on the size of the stone chips. Usually 1/4- to 1/2-in chips are used for single applications, and for double applications 1/2- to 3/4-in chips are used for the first layer and 3/8-in chips for the second.

Number of Tires Utilized

About 4,200 gal of asphalt-rubber are used as the binder for 1 lane-mile (12-ft lane) of this surface (based on the assumptions detailed in the Appendix). Preparation of this amount of binder utilizes the tread rubber from about 900 tires.

Cost-Effectiveness

General estimates in the literature are that surface treatment applications of this type will cost about 1.5 to 2.0 times the cost of surface treatments using asphalt cements as the binder. Asphalt-rubber producers claim that using present day techniques, the life of such treatments will be 2 1/2 to 3 times the life of normal surfaces. On this basis, use of this material would be cost-effective.

Potential for Use in Virginia

An experimental surface treatment using this material was placed in Virginia in 1989. No serious difficulties were encountered in the installation, but the cost was \$3.00 per yd² which is about 6 times the cost of surface treatments usually applied in Virginia. However, this type of application has generally been found to be most useful for extending the

life of badly deteriorated roads carrying low volumes of traffic. Modifications of the quantities of materials used could substantially reduce the cost. Thus, further experiments under Virginia conditions appear justified and are now being considered.

Stress-Absorbing Interlayers

Interlayers, similar to the seal coats or SAM, are often referred to as SAMI (stress-absorbing membrane interlayer). They are used over either old asphalt pavements or portland cement concrete pavements that are to be overlaid with asphalt concrete. Their main purpose is to prevent or delay reflection cracking by absorbing stresses as a result of their flexibility. It is claimed that the use of such a layer reduces the thickness of the overlay needed for performance equal to that attained by the usual asphalt concrete overlays. In some cases, a SAMI is part of a three-layer system consisting of an asphalt concrete leveling course, covered by an asphalt-rubber seal coat (SAM), and followed by an open-graded friction course 1/2 in to 3/4 in thick. This method is claimed to be effective for use in rehabilitating portland cement concrete pavements.

Number of Tires Utilized

The amount of rubber per lane-mile used in this application is essentially the same as that used for surface treatments (900 tires per lane-mile).

Cost-Effectiveness

Overlays constructed to include a SAMI cost substantially more to build than overlays of asphalt concrete only. Accordingly, to be cost-effective, the lifetime of the overlays including SAMIs must be substantially longer than similar overlays of equal thickness, or else equal performance must be attained for substantially reduced thickness.

Although California (5) has conducted some studies indicating improved service life and lower life cycle costs for overlays with SAMIs, other states have not shown clear-cut advantages for this type of construction.

Potential for Use in Virginia

The general conditions prevailing in Virginia tend to make this type of application unattractive for experimental installation at the present time.

Asphalt-Rubber Concrete

Asphalt-rubber concrete (ARC) is a hot mixture utilizing asphalt-rubber binder with aggregate in much the same manner as asphalt cement is used in normal asphalt concrete. The job mix formula must be determined as is done for asphalt concrete. Generally, mixtures will contain greater amounts of asphalt-rubber than the amount of asphalt cement normally used for similar aggregate gradations because of the higher viscosity of asphalt-rubber, which results in thicker films of binder. Higher mixing and placement temperatures may also be needed depending on the quantity of extender oils used for a given mixture design.

Rubber particles used in preparing the binder may be one of two grades. The finer grade, used in dense graded mixtures, requires 100 percent passing the No. 16 sieve and 70 to 100 percent passing the No. 30 with a maximum of 5 percent passing the No. 200. The coarser grade, used in open-graded mixtures, requires 100 percent passing the No. 10 sieve and 5 to 100 percent passing the No. 16 with a maximum of 5 percent passing the No. 200.

Number of Tires Utilized

ARC utilizes the rubber from about 1,900 tires per lane-mile based on the assumptions given in the Appendix.

Cost Effectiveness

Costs for a ton of asphalt-rubber mixture have been reported to be from about 1 3/4 to 2 times the cost of similar asphalt mixtures in the same locality. However, ARC producers claim that cost-effectiveness is attained by reducing the thickness of the pavement layer, which still allows equal or better performance. It is also claimed that dense graded overlays of ARC provide better resistance to cracking at low temperatures and better resistance to rutting at higher temperatures than do asphalt concrete overlays. Better durability because of thicker films of asphalt is also expected.

To date, there appears to be relatively little performance data available to assess the overall cost effectiveness of this type of construction. However, asphalt-rubber binders are reported to provide significant improvement in performance when used with aggregates known to be of marginal quality with conventional binders (7). Recent overlays of airport runways with ARC are also reported to provide superior performance, but long-term records are not yet available.

Potential for Use in Virginia

Because of the high potential for rubber utilization and benefits in improved performance if these systems perform as claimed, experimental construction of ARC in Virginia is warranted and should be constructed in the near future. Such construction should be on roads carrying large numbers of heavily loaded trucks. A section of Rte. 1 in Fairfax County scheduled to be overlaid this summer will include a test section utilizing an asphalt-rubber binder.

RUBBER-FILLED SYSTEMS

One rubber-filled system developed in Sweden and patented in the United States as "PLUS RIDE" makes use of substantially larger rubber particles (1/16 in to 1/4 in cubical shapes) than does the asphalt-rubber system.

The rubber is considered to be primarily a part of the aggregate, and the mineral aggregate grading is adjusted to accommodate the rubber particles. One of the major claims for this type application is that the characteristics of the roadway surface is such that it facilitates ice removal (7). It is reported that the ice control mechanism apparently results from the flexing of the protruding rubber particles and greater flexibility of the surface under the action of traffic.

Installations of asphalt-filled systems have generally been difficult to compact because of excess stickiness of the mixture and its flexibility and rebound under the roller. Asphalt contents 1 to 2 percent higher than are required by comparison with similar dense-graded mixtures without rubber, and beneficial results are obtained by mixing temperatures as high as 350° F.

Under Alaskan conditions of icy nonsalted roadways, stopping distances on the installations were consistently reduced by the use of rubber-filled asphalt. Stopping distances averaged 25 percent less than on normal pavements.

Studies have shown that the usual Marshall design criteria for this type of mixture does not indicate optimum characteristics (7,8). It has been shown that the asphalt content needed to reach a certain minimum voids level depends on the rubber and aggregate gradations and rubber contents (8). Proper compaction is also needed to obtain good results. Void contents should be in the 3 to 5 percent range. Higher voids can lead to very poor durability and early failure of these surfaces. Those findings are generally confirmed by experimental installations in Minnesota (6), California (5), Washington (9), and in Virginia.

Fine ground rubber in asphalt concrete has very recently been installed in a New York state project. This process is not proprietary, and a report on the installation has been requested. The potential advantage of this

use, in addition to not having to deal with patents, is that the rubber will not be in conflict with the aggregate size as is the case in "Plus Ride."

Mr. G. W. Maupin, Jr. of the Research Council plans to conduct a preliminary laboratory study in FY 1991 based on the recent work in New York.

Number of Tires Utilized

From the standpoint of potential use of used tires, the rubber-filled system is attractive because about 3 percent of the total pavement mixture is rubber. On this basis, the rubber from about 3,500 tires would be utilized per lane mile of pavement.

Cost-Effectiveness

The cost per cubic yard of this system is generally reported at 2 to 2 1/2 times that of conventional asphalt concrete. Thus, substantially added durability is required to justify its use on this basis. However, under long time icy conditions such as those in Alaska and possibly other areas in the northern part of the United States, better safety might outweigh added cost. Another plus factor is the larger amount of waste rubber utilized.

Potential for Use in Virginia

Under intermittent icing conditions in Virginia and the general policy of using de-icing salts, the ice removal characteristics of the rubber-filled system are likely to be of minimal benefit. The reported extreme difficulties in obtaining proper compaction is a deterrent to further experimental installations until optimum construction procedures can be identified. However, the potential for use of large amounts of relatively large particles of rubber may warrant further study. Such study should be of a lower priority than that involving the asphalt-rubber system.

OUTLOOK AND RECOMMENDATIONS

As a result of this literature survey and conferences with asphalt-rubber producers, the following assessment of the potential involvement of the Virginia Department of Transportation (VDOT) with respect to used tire management appears warranted.

1. ARC applications cost substantially (1 1/2 to 2 times) more than similar applications using conventional materials. This price differential is likely to continue into the foreseeable future.

However, paying the tire reclaimers for collecting the discarded tires might reduce the cost of the prepared ground rubber to the asphalt-rubber manufacturer. Also, as competition increases in the tire-rubber reclaiming business and as the volume used increases, rubber prices should stabilize or decrease. If petroleum prices increase substantially, asphalt prices will also increase, thereby decreasing the price differential between asphalt-rubber binder and asphalt cement.

Also, if there is a shortage of asphalt, the addition of 20 to 25 percent rubber would extend the supply of available binder. However, the need to use more asphalt-rubber in a mixture would counteract this to some extent.

2. The fact that both asphalt-rubber and the rubber-filled asphalt concretes are patented processes is likely to have a negative effect on the number of firms qualified to use the systems. Also the cost of the equipment needed to properly produce ARC requires a capital expenditure of \$700,000 to \$1,000,000. Thus, asphalt hot mix producers cannot easily add this process to their production.
3. The advantage of SAMs (stress absorbing membranes) for extending the life of badly deteriorated pavements appears to be well established, but there may not be a great need for this by VDOT. (Small cities and towns might benefit more.) There is a need to evaluate the potential number of such applications in Virginia. Additional experimental installations in several areas of the state appear warranted.
4. SAMIs (stress absorbing membrane interlayers) used to retard reflective cracking are of questionable value. They generally retard the time it takes the crack to form, and the resulting cracks are generally smaller. Attempts to show sufficient superior durability to justify extra cost usually have not been successful. Studies of this application are not recommended at the present time.
5. Dense graded ARC has not been used as extensively as other applications to date. However, there is a new emphasis on this type of construction based partly on the development of better equipment for making such mixtures and better knowledge about what mixture design modifications are necessary to get good lay down and compaction. Also, some basic research indicates greatly increased fatigue life and better rheological properties for asphalt-rubber, so longer life should result from ARC. Such installations have not been in service sufficiently long to calculate life-cycle costs for comparison with conventional asphalt concrete.

It thus appears that early experimental construction of dense graded ARC by VDOT is warranted. Consideration might be given to different thicknesses of ARC compared to standard AC. Roadways carrying large numbers of heavily loaded trucks should be used for this application.

6. The use of whole or split tires in embankments for slope stability, etc. would be a useful application, but the total impact of such use is not likely to be significant in Virginia.
7. Overall, it appears that a large near-term increase in the use of reclaimed rubber for highway construction cannot be expected unless there is a legislative mandate (which is not desirable) or price incentives. From the standpoint of the highway industry, such incentives or subsidies would be most effective by reducing the cost of reclaimed rubber by providing assistance to the reclaimed rubber industry. In this manner, the discarded tires would be used in a number of different ways, and the residual would be minimized.

In the long-term, with removal of patent restrictions and better basic information, substantial use of ARC might be developed for conditions for which it is most cost-effective.

8. A FHWA demonstration project on the use of reclaimed rubber in highways is not now active. A conference held in 1981 in San Antonio and a pooled fund study reported in 1986 ended active FHWA promotion of this concept. The Federal Highway Administration registered strong opposition to an EPA proposal (now withdrawn) to issue a mandate that rubber be used in federal highway construction. The asphalt-rubber industry also opposed such a mandate. Its representatives would rather sell their product on its merits. However, they believe that the value of eliminating the rubber as an environmental hazard should be credited as a cost reduction factor for ARC. The industry also very strongly objects to the requirement that the rubber used for asphalt-rubber in a particular state come from tires discarded in that state. This concept is not considered workable by the industry. Colorado, Oregon, and Arizona are shifting to the exclusive use of asphalt-rubber as the binder for open-graded friction courses, and others will possibly follow.

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APPENDIX

Estimates of Tires Utilized

Assumptions

12-ft lane width = 7,040 sq yds/mile

Surface Treatments

Application rate = 0.6 gal/yd²
= 4,224 gal/lane mile

Sp. Gr. of Rubber-asphalt = 1.11

Percentage rubber (by weight) = 25%

1 gal asphalt-rubber = 3.785 liters at 1.110 gms/l
= 4,163 gm
= 9.17 lb/gal of asphalt-rubber

at 25 percent rubber = 2.29 lb rubber per gallon of asphalt rubber
2,290 lb per 1,000 gal
210 tires per 1,000 gal

at 10 lb of rubber per tire = 968 tires per lane mile

at 12 lb of rubber per tire = 802 tires per lane mile

use 900 as estimate

Asphalt-Rubber Concrete

Application rate = 165 lb/yd²
= 580 tons/mile

Percentage rubber (by weight) = 20%

Percent asphalt-rubber in mixture = 8%

Therefore, 1 ton asphalt-rubber concrete contains .20 x .08 =
.016 tons rubber = 32 lb rubber.

32 x 580 = 18,560 lb rubber/mile

At 10 lb of rubber per tire = 1,856 tires/mile (use 1,900)

Asphalt-Filled Dense Graded Asphalt

Application rate = 165 lb/yd²
= 580 tons/mile

Percentage of Rubber in total mixture = 3%
= 17.4 tons rubber per mile
= 34,800 lb rubber
= 3,480 (use 3,500 tires per mile)