Asphalt Rubber

What is Asphalt Rubber?

Asphalt rubber is a mixture of hot asphalt and crumb rubber derived from waste or scrap tires. It is used extensively in the highway paving industry, particularly in the states of Arizona, California and Texas. It is a material that can be used to seal cracks and joints, be applied as a chip seal coat and added to hot mineral aggregate to make a unique asphalt paving material. The American Society of Testing and Materials (ASTM D8) defines asphalt-rubber as “a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles,” [AST05] This definition was developed in the late 1990’s, however the story of how asphalt rubber was originally invented, patented, how it has been and how it is presently used, how it is made, and its benefits which have increased with time, that story begins in the 1960’s. The initial development of asphalt-rubber started in the mid 1960’s when Charles McDonald, then City of Phoenix Materials Engineer, began searching for a method of maintaining pavements that were in a failed pavement condition as a result of primarily cracking [MOR93]. McDonald’s early efforts resulted in the development of small, prefabricated asphalt rubber patches that he called “Band-Aids”, Figure 1. These patches were generally 24” x 24” (0.61m x 0.61m) and consisted of asphalt-rubber placed on paraffin coated paper with 3/8” (9.5mm) chips embedded.

Asphalt Rubber as a Slurry Material

Recognizing that fatigue cracking generally occurred in larger areas rather that small patches couldn’t handle, the concept was extended to full pavement sections by spreading the asphalt-rubber with slurry seal equipment, Figure 2, followed by aggregate application with standard chip spreaders [MCD81]. This process had two distinct construction problems. First, in order to achieve the desired reaction of the asphalt and crumb rubber in the limited time available in the slurry equipment, it was necessary to employ asphalt temperatures of 450°F (232°C) and higher. Second, the thickness of the membrane varied directly with the irregularity of the pavement surface. This resulted in excessive materials in areas such as wheel ruts and insufficient membrane thickness in between.
Asphalt Rubber as a Chip Seal Application

In 1971, technology had developed to the point that standard asphalt distributor trucks were employed to apply a uniform thickness of binder to the pavement Figure 3. Although problems with distribution and segregation of materials were encountered on the early projects, these were recognized as primarily equipment limitations. Within the next few years equipment was developed with pumping, metering and agitation capabilities needed to handle the highly viscous asphalt-rubber materials.
1975. This patented process is described as the MacDonald Process or Wet Process for making Asphalt Rubber (AR). It should be noted that AR patents ended in 1992. As noted earlier the Arizona Department of Transportation (ADOT) monitored the development of AR and placed a band aid type maintenance application of AR in 1964. In 1968, experience from trial and error and the burning of a couple of distributor boot trucks lead to improvements in mixing to a satisfactory degree that AR could be safely and consistently placed with a distributor truck by using a diluent (kerosene). From 1968 - 1972, ADOT placed AR on six projects that were slated for reconstruction. The cracking on these projects was generally typical of a failed pavement needing at least a six inch overlay or complete reconstruction, Figure 4.

For these seal coat type application projects a boot truck distributor was used to apply the AR. In these early applications the ground tire rubber was introduced into the top of the boot.
truck and mixed by rocking the truck forward and backward. Even with this rather primitive early technology it was possible to construct the first full scale ADOT field experiment in 1972 using AR as a seal coat or Stress Absorbing Membrane (SAM), as well as an interlayer under a hot mix asphalt (HMA) surfacing. The interlayer application is typically referred to as a Stress Absorbing Membrane Interlayer (SAMI), Figure 5 and 6. Both the SAM and SAMI applications showed great promise in reducing reflective cracking [WAY79].

![Figure 5- Asphalt Rubber Stress Absorbing Membrane (SAM)](image)

![Figure 6- Asphalt rubber Stress Absorbing Membrane Interlayer (SAMI)](image)

From 1974 until 1989, approximately 1100km (660 miles) of state highways were built using a SAM or SAMI application of AR. In addition to this, ADOT and the Federal Highway Administration (FHWA) sponsored numerous research studies, thus greatly increasing the state-of-the-knowledge concerning AR. In addition to reducing reflective cracking, it was noted early on that AR is a waterproofing membrane. Several projects were built to control subgrade moisture in order to control expansive (swelling) clays or to reduce structural pavement sections. This application proved to be very successful [FOR79]. In 1989 ADOT documented in a research report the history, development, and performance of asphalt rubber at ADOT [SCO99]. In that report the following conclusion is stated, "asphalt rubber has successfully been used as an encapsulating membrane to control pavement distortion due to expansive soils and to reduce reflection cracking in overlays on both rigid and flexible pavements. During the twenty years of asphalt rubber use, ADOT has evolved from using slurry applied asphalt rubber chip seals to utilizing reacted asphalt rubber as a binder in open and gap graded asphalt concrete." He noted that AR could be used as a binder for HMA. Concurrent with this conclusion, it became evident that AR as a binder could provide a HMA mix suitable for addressing cracked pavements.
Asphalt Rubber in Hot Mix Applications

In 1985 ADOT began experimenting with two asphalt rubber mixes an open graded (ARFC) and a gap graded (ARAC). ADOT had experienced cracking problems with its dense graded mixes and raveling of its open graded mixes, Figure 7 and 8.

Figure 7- Cracked highway

Figure 8- Raveled pavement

Given the good results with AR as a chip seal coat material ADOT thought that a hot mix asphalt with AR binder might reduce the cracking and resist raveling. To fully utilize AR properties two aggregate gradations that would provide a high voids in the mineral aggregate (VMA). Both gradations are shown in Figure 9. The ADOT began to use Open Graded Friction Courses (OGFC) with conventional asphalt as early as 1954 [MOR73]. The primary reason for using this material was to provide a surface with good skid resistance, good ride and appearance. Over the years the gradation has changed slightly but has remained virtually the same since 1973. In 1985 ADOT began experimenting with two asphalt rubber mixes an open graded (ARFC) and a gap graded (ARFC). The Gap Graded mix (ARAC) was
Current Asphalt Rubber Composition and Mix Design

After some early and small experiments with asphalt rubber mixes starting in 1985 ADOT built its first real AR mix project in 1988. This first project consisted of a 25 mm (one inch) layer of an open-graded asphalt rubber asphalt concrete friction course commonly referred to as ARFC placed on several miles of Interstate 19, south of Tucson, Figure 10. This ARFC mix, contained 10.0 percent asphalt rubber by weight of the mix as the binder, was placed on top of a plain jointed concrete pavement. Since 1988, no cracks reflected through until 1996, when only a few transverse cracks appeared over the concrete joints. In 2004 District Maintenance reviewed this project and concluded that as before no maintenance was needed and amazingly to date sixteen years later no maintenance has been performed on this section, Figure 11.
From this first project, dozens of projects have been successfully built with asphalt rubber as the binder. The AR contains approximately 20 percent ground tire crumb rubber by weight of the asphalt content and is commonly referred to as the Arizona asphalt rubber binder. These projects were built with the expressed purpose of controlling reflective cracks with a very thin layer of very elastic material.

**Asphalt Rubber Mix Construction**

Construction of an AR pavement involves first mixing and fully reacting the crumb rubber with the hot asphalt as required by specification. Typically 20 percent ground tire rubber that meets the gradation shown in Table 1 and Figure 12 is added to the hot base asphalt heated to a temperature of about 190°C (375°F) and mixed for at least one hour Figure 13 and 14. After reaction the AR mixture is kept at a temperature of about 175°C (350°F) until it is introduced into the mixing plant, Figure 13 and 14. Samples of the rubber, base asphalt, and AR mixture are taken and tested accordingly. The ARFC which typically has one percent lime added to the mix is placed with a conventional laydown machine and immediately rolled with a steel wheel roller, Figure 15 and 16. In the past on rare occasions a small amount of sand, 1 kg/mm (two pounds per square yard) was specified in case it was needed as a release agent. Presently
lime water is used on rare occasions (high temperatures) in place of sand to reduce pickup from tires. Generally one bag of lime is added to a water truck and sprayed on the pavement.

Table 1 Ground Tire Rubber Gradation

<table>
<thead>
<tr>
<th>Percent Passing</th>
<th>Sieve</th>
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<tbody>
<tr>
<td>100</td>
<td>2 mm, #10</td>
</tr>
<tr>
<td>65-100</td>
<td>1.18 mm, #16</td>
</tr>
<tr>
<td>20-100</td>
<td>600 um, #30</td>
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<tr>
<td>0-45</td>
<td>300 um, #50</td>
</tr>
<tr>
<td>0-5</td>
<td>75 um, #200</td>
</tr>
</tbody>
</table>

Figure 12- Crumb rubber

Crumb rubber

Minus No. 10 mesh is used; free of wire and other contaminants; up to 0.5% fiber.
Figure 13- Asphalt rubber blender reaction process

Figure 14- Self contained mobile small asphalt rubber blender
ARFC is generally used as the final wearing surface for both concrete and HMA pavements. For concrete pavements the joints are cleaned and resealed with AR. Spalled areas are cleaned and filled with HMA to level the surface. A 25 mm (one inch) ARFC is placed to improve the smoothness, reduce reflective cracking, improve skid resistance, and reduce noise, Figure 17.
If the concrete is in poor condition and the roadway geometrics allow a leveling and strengthening course of ARAC is placed 50 mm (two inches) thick before the ARFC is placed. For HMA pavements a standard deflection based design is conducted to correct structural deficiencies. The ARFC is used as the final wearing surface. It is placed 12.5 mm (one half inch) thick and is used to improve smoothness, reduce cracking, provide adequate skid resistance, and reduce noise. On some badly cracked pavements a gap-graded ARAC, generally 37.5 mm (1.5 inches) to 50 mm (2 inches) thick, is placed to address cracking. An ARFC may be placed depending upon the traffic volume and type of highway. In reviewing numerous pavement designs over the last 15 years asphalt rubber pavement sections are typically thinner than those constructed with HMA. The average HMA pavement section is typically 100 to 125 mm (4 to 5 inches) in thickness, whereas the asphalt rubber pavement sections are generally 37-62 mm in thickness (1.5 to 2.5 inches). Thus the asphalt rubber pavement will be on the order of half or less than half the thickness of the HMA pavements without asphalt rubber, Figure 18.
Cost and Benefits

Cost comparisons would indicate that the AR binder alone is as much as twice as expensive as asphalt binder. However, after incorporation into the HMA, the finished AR product is generally from 25 to 75 percent more expensive for the gap-graded AR mix than the typical dense-graded HMA and 80 to 160 percent more expensive than the typical open-graded friction course. These higher costs need to be examined in light of actual usage.

On the I-19 project, only a 25 mm (one inch) ARFC was placed at a cost of about $2.45 per square meter. The comparable repair strategy is to grind the concrete, which costs about $5.00 dollars per square meter, thus the AR mix was actually less expensive to construct. The ARFC continues to provide a smooth riding, virtually crack free, good skid resistant, quiet and virtually maintenance free surface for a period as long as seventeen years. One of the best examples of the beneficial cost effectiveness of asphalt rubber is a major national concrete pavement rehabilitation project conducted as part of the Strategic Highway Research Program, in Flagstaff, Arizona on Interstate 40, Figure 19, 20 and 21.

Figure 19- Concrete pavement in 1989 before asphalt rubber overlay
The price of AR binder reduced significantly after 1992. In 1992 the patents on AR binder ended and the price of the material dropped from about $450 dollars per ton to about $250 per ton [WAY00M]. At present, seven companies supply AR in Arizona. ADOT monitors the price of all the products it buys and has used asphalt rubber only when its usage appeared to be well suited to the problem and cost effective. In 1992 the patents on AR ended. Since then, the AR price has dropped significantly with increased competition. Table 2 shows the cost of AR HMA mixes compared to dense-graded HMA made with neat asphalt binders. Asphalt rubber is more expensive and that has often been sighted as a major disadvantage. However, AR does compete with other dense mixes and has proven to be cost effective to such a degree that ADOT has constructed over 33 333 lane-km (20 000 lane-miles) of AR mixes since 1988.
Table 2 Total Cost (Dollars Per Sq Meter Per 25 mm thickness)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>AC</th>
<th>ARAC</th>
<th>ACFC</th>
<th>AR-ACFC</th>
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<tbody>
<tr>
<td>1992</td>
<td>1.89</td>
<td>3.71</td>
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<td>1996</td>
<td>1.60</td>
<td>2.93</td>
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<td>1997</td>
<td>1.59</td>
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</tr>
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<td>1.61</td>
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<tr>
<td>2004</td>
<td>1.68</td>
<td>3.03</td>
<td>1.94</td>
<td>2.53</td>
</tr>
</tbody>
</table>

Statewide Performance

Pavement performance has been routinely monitored by ADOT’s pavement management system since 1972. Over that time a general trend of cracking, rutting, ride, maintenance cost, and skid resistance have been observed. Figure 22 shows a comparison of the average percent cracking for conventional overlay/inlay projects and those projects built with an ARFC.

Figure 22- Statewide cracking performance with and without asphalt rubber

AR has reduced the amount of reflective cracking as expected and designed for. A value of ten percent cracking is considered as fatigue cracking, therefore virtually no fatigue cracking has been seen in the AR rubber projects. The average rut depth over the seventeen year period has been surprisingly better than expected. This could be due to less cracking as well as the use of a very stable stone structure in the ARFC. Rut depths over the seventeen year period have generally stayed below 6 mm (0.25 inches) which is considered low and not of any major concern. The average smoothness for AR projects over the seventeen year period has been very good with smoothness values below 1415 mm/km (93 inches per mile)
which is considered very satisfactory and not in need of any correction. ARFC is typically used as the final pavement surface and has produced some of the smoothness riding surfaces as measured as part of ADOT’s smoothness specification. Figure 23 shows the average maintenance cost versus time; again, AR has performed better as expected due to less cracking and less rutting. A value of $400 per lane kilometer ($666 dollars of maintenance cost per lane mile) per year is considered high and worthy of attention. Projects with AR typically need much less maintenance and rarely exceed the $400 threshold even after fifteen years of service.

![Figure 23- Statewide Maintenance cost with and without asphalt rubber](image)

The average skid resistance over time has been good and there is good splash and spray characteristics, Figure 24.

![Figure 24- Reduced splash and spray with open graded asphalt rubber](image)
With regard to traffic noise, a 1996 Arizona Transportation Research Center study [ATR96], indicated that an AR-ACFC can lower the noise by as much as 5.7 decibels. The report went on to say, “Human hearing can distinguish noise level differences of 3.0 decibels or more. Therefore, the ARFC overlay appears to be capable of noticeably reducing roadside noise levels in certain situations.” In 2002 noise became a very big issue in the Phoenix metropolitan area. It became evident from a recently completed freeway concrete widening and overlay with an ARFC that the pavement had become much quieter. The highway became so much quieter that it was decided to overlay all 150 miles of the Phoenix concrete freeway system with the ARFC, Figure 25. Noise studies in Arizona and California found similar results, Figure 26.

![ADOT US 60 LOWEST NOISE ROAD](image)

<table>
<thead>
<tr>
<th>Location</th>
<th>Before Dba</th>
<th>After Dba</th>
<th>Difference Dba</th>
</tr>
</thead>
<tbody>
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<td>Shoulder (15m)</td>
<td>79.8</td>
<td>72.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Soundwall (30m)</td>
<td>76.6</td>
<td>67.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Residential (120m)</td>
<td>51.7</td>
<td>45.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Figure 25- Noise reduced after asphalt rubber placed
Figure 26- Noise measurements for many surfaces asphalt rubber the lowest

Arizona State University (ASU) has also been looking at the Heat Island effect of higher night time temperatures. This effect has been noted in Phoenix, Arizona where the summer time night temperature has increased from 1950 to 2005 by 10°F (6°C), Figure 27. The cause of this increase in night time temperatures is attributed to the absorption of heat during the day time by concrete and asphalt pavements, roofs, buildings and other manmade structures. ASU is conducting research to determine whether an open graded asphalt rubber surface placed on top of a concrete surface can help to release the day time accumulation of heat during the day and thus help to reduce the degree of heat island effect, Figure 28.
Figure 27- Phoenix, Arizona

Figure 28- Night time temperatures appear less for open graded asphalt Rubber surfaces

**Benefits**

In general, objective pavement performance measurements taken over time all indicate that AR is a very good durable surface wearing course material. AR mixes can generally be placed much thinner than conventional dense mixes and thus can be cost effective. Seventeen years of excellent service and cost effectiveness has been documented to date with little sign of change in the near future, Figure 29 is a summary of benefits derived from using asphalt rubber. In general, ADOT is using AR as a binder in HMA mixes in a cost effective manner to reduce reflection cracking, improve durability of surface courses, reduce maintenance
costs and in urban areas to reduce noise and over 20 million tires have been beneficially recycled into pavement hot mix, Figure 30.

![Asphalt Rubber Benefits](image)

* Less Reflective Cracking
* Less Maintenance/More Durable
* Resist Truck Tire Damage
* Good in hot & cold climates
* Less Splash & Spray Better
* Drainage
* Less Noise
* Engineering Use for Old Tires

Figure 29- Asphalt rubber benefits

![Tires Put to Good Use](image)

Over 20 million tires
Put to Good
Engineering Use
By Arizona DOT

Figure 30- 20 million tires beneficially recycled into pavement hot mix

**Disadvantages**

Disadvantages as previously stated generally focus on additional cost. Other disadvantages that have been mentioned include lack of availability of suitable crumb rubber processing facilities in the vicinity and cost of such facilities, need for suitable blending and mixing equipment and the cost of such equipment, degree of difficulty in preparing mix design, lack of asphalt rubber binder and mix standards, lack of trained personnel, and uncertainty and doubt about how long AR will last. Although, all of these disadvantages have been addressed by the AR industry doubts and concerns still persist and typically only trial test sections can be built and observed to satisfy many of these doubts.
Closure

The story of asphalt rubber began on or about the year 1965 with the simple goal of developing a maintenance patching material to hold old crack pavements long enough to allow for the future overlaying or reconstruction of the pavement. In the intervening 40 years its use has grown an expanded into a myriad of areas and now is a routine paving material in Arizona, California and Texas. Additional useful asphalt rubber reference material can be found at the Rubber Pavements website [RPA06] as well as in the proceedings of two International Asphalt Rubber Conferences [SOU00, SOU03]. Useful products from adding crumb rubber to pavements will continue to be developed because pavements that last longer and need less maintenance will always be in demand.

References

[RPA06] Rubber Pavements Association, Website xxxxx, Tempe, Arizona.