OGFC Meets CRM
Where the Rubber meets the Rubber
12 Years of Durable Success

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ABSTRACT: The Arizona Department of Transportation (ADOT) has used crumb rubber from ground tires since the late 1960’s to primarily reduce reflective cracking. In 1988, ADOT started to use crumb rubber mixed with hot asphalt, commonly referred to as asphalt rubber (AR) as a binder in hot mix asphalt (HMA). Typically, these mixes are either open-graded or gap-graded and from 12.5 mm (half inch) to 25 mm (one inch) or 25 mm (one inch) to 50 mm (two inches) in thickness, respectively. Open-graded mixes generally contain 9 to 10 percent AR binder, whereas the gap-graded contains generally 7.5 to 8.5 percent AR binder. To date, field performance has been very good. As an extra benefit, the ground tire rubber from over eight and one half million tires in Arizona has been recycled since 1988, in the making of HMA with AR.
1. OGFC Meets CRM. History of OGFC in Arizona

The Arizona Department of Transportation (ADOT) began to use Open Graded Friction Courses (OGFC) as early as 1954(1). The primary reason for using this material was to provide a surface with good skid resistance, good rideability and appearance. Over the years the gradation has changed slightly (Illustration 1). In particular, more emphasis has been placed on the use of a single size aggregate. Also, the passing 2.36 mm (#8) sieve material has been consistently reduced to a value of about 15%. OGFC’s typically have been placed 12.5 mm (one half inch) in thickness with 5.5% to 6.5% asphalt (AC-20/PG 64-16) binder.

2. CRM/Asphalt Rubber Background of use in Arizona

Charles MacDonald, as the City of Phoenix Materials Engineer, began to experiment with mixing crumb rubber from ground tires with asphalt in the early 1960's. He, along with other associates, patented what is currently described as the MacDonald Process or Wet Process for making Asphalt Rubber (AR). It should be noted that AR patents ended in 1992.

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 six projects with AR in a seal coat type application using a boot truck distributor. 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 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). Both the SAM and SAMI applications showed great promise in reducing reflective cracking (2). From 1974 until 1989, approximately 660 miles of state highways were built using a SAM or SAMI application of AR. In addition to this, ADOT and the FHWA sponsored numerous research studies which resulted in 42 research reports being published, 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 (3).
**Past Practice**

In 1989, Larry Scofield documented in a research report the history, development, and performance of asphalt rubber at ADOT (4). 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.

**3. Current OGFC/CRM Composition and Mix Design**

In 1988, a 25 mm (one inch) layer of an open-graded asphalt rubber asphalt concrete friction course commonly referred to as AR-ACFC was placed on several miles of Interstate 19, south of Tucson. The gradation of this mix is shown on Figure 1. This AR-ACFC mix, containing 10.0 percent asphalt rubber by weight of the mix as the binder (note: diluent is no longer used), was placed on top of a plain jointed concrete pavement. Table 1 shows the mix design equation used to determine the AR-ACFC binder content. All AR mixes for ADOT projects are designed in the Materials Central Laboratory. Since 1988, no cracks reflected through until 1996, when only a few transverse cracks appeared over the concrete joints. In 1999 District Maintenance reviewed this project and concluded that as before no maintenance was needed and amazingly to date twelve years later no maintenance has been performed on this section. From this first project, dozens of projects have been successfully built with asphalt rubber as the binder.

The AR contains 20 percent ground tire crumb rubber by weight of the asphalt content. These projects were built with the expressed purpose of controlling reflective cracks with a very thin layer of very elastic material. To date, all projects have performed as expected. As a further extension of this work, a structural overlay called a gap graded AR-AC (Figure 1) was designed and built in 1990 on Interstate 40 near Flagstaff, using AR as the asphaltic concrete binder (5 & 7). This project also contained numerous Strategic Highway Research Program (SHRP) test sections as well as ADOT test sections. The purpose of the project was to overlay a severely cracked and failed concrete pavement. As of the most recent objective crack mapping review in May 1999, the asphalt rubber sections built as the top portion (overlay top 50 mm (two inches) AR-AC, 12.5 mm (half inch) AR-ACFC) have the least percentage of reflective cracks. Indeed the percent cracking of the AR section is less than one third of the 100 mm (four inch) conventional overlay and less than one half the 200 mm (eight inch) overlay.
4. **OGFC/CRM Construction**

Construction of an AR pavement involves first mixing and fully reacting the crumb rubber as required by specification. Typically 20 percent ground tire rubber that meets the gradation shown in Table 2 is added to a hot base asphalt heated to a temperature of about 190°C (375°F) and mixed for at least one hour. After reaction the AR mixture is kept at a temperature of about 175°C (350°F) until it is introduced into the mixing plant. Samples of the rubber, base asphalt, and AR mixture are taken and tested accordingly. The AR-ACFC 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. 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.

4.1. **General Usage**

AR-ACFC 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. Spall areas are cleaned and filled with HMA to level the surface. A 25 mm (one inch) AR-ACFC is placed to improve the smoothness, reduce reflective cracking, improve skid resistance, and reduce noise. If the concrete is in poor condition and the roadway geometrics allow a leveling and strengthening course of AR-AC is placed 50 mm (two inches) thick before the AR-ACFC is placed. For HMA pavements a standard deflection based design is conducted to correct structural deficiencies. The AR-ACFC 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 AR-AC, generally 37.5 mm (1.5 inches) to 50 mm (2 inches) thick, is placed to address cracking. An AR-ACFC may be placed depending upon the traffic volume and type of highway.

4.2 **Cost**

Cost comparisons would indicate that AR binder can be up to twice as expensive as asphalt binder. 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) AR-ACFC 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 AR-ACFC continues to provide a smooth riding, virtually crack free, good skid resistant, quiet and virtually maintenance free surface for twelve years.

Similarly, the AR-AC, AR-ACFC project on the I-40 Flagstaff cost about ten dollars per square meter including the cost of the cracking and seating. The adjacent reconstruction project was built at a cost of about $25 per square meter for the paving alone. When all other costs including detours are included the cost for reconstruction is about $45 per square meter. In addition, the 16 km (ten mile) AR overlay project was built in four months, whereas the adjacent 8 km (five mile) reconstruction project took two years to build. Also, the reconstruction project was overlaid with AR after ten years of service due to excessive cracking and rough ride. The AR overlay project built in 1990 as of today, ten years after construction, still has no cracking. It should be noted that the Flagstaff projects are located at about 2134 m (7,000) feet elevation. Typical rainfall is about 625 mm (25 inches) per year with an average annual snowfall of about 2250 mm (90 inches) per year. The coldest temperature recorded since construction on this project has been – 32 C (-25°F). The use of AR on this I-40 project alone conservatively saved at least $18 million dollars and about four years of construction traffic disruption. Attached pictures of I-40 before overlay (Illustration #2) and pictures taken in November 1997 (Illustration #3), clearly show the long term benefit of the use of AR on this project. In 1998 additional comparative photos were taken from a higher vantage point and also clearly show the reduction in reflective cracking due to AR (Illustration #4).

With regard to the price of AR, Table 3 shows usage and bid prices since 1985. In 1985, one Arizona company became the owner of all asphalt rubber patent rights which had previously been owned by two Arizona companies (8). As can be seen, since 1985, asphalt rubber prices have been going down. 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 4 shows the cost of AR HMA mixes compared to dense-graded HMA made with neat asphalt binders. Asphalt rubber has proven to be so cost effective that over 2500 miles of AR mixes have been placed since 1988 (Illustration #5).

4.3 Performance

Pavement performance has been routinely monitored by ADOT’s pavement management system since 1972. Over that time a general trend of cracking, rutting, rideability, maintenance cost, and skid resistance have been observed. Figure 2 shows a comparison of the average percent cracking for conventional overlay/inlay projects and those projects built with an AR-ACFC.
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.

Figure 3 shows the average rutting performance which 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 AR-ACFC. Rut depths below 6 mm (0.25 inches) are considered low and not of any major concern. Even projects placed on very heavy truck traffic interstate highways have shown very little rutting.

Figure 4 shows the average smoothness over time. AR has performed a little better than expected, again perhaps due to less cracking and attendant maintenance. Smoothness values below 1415 mm/km (93 inches per mile) are considered satisfactory and not in need of any correction. AR-ACFC 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 5 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 ten years of service.

Figure 6 shows the Mu Meter skid resistance versus time; it shows that the AR-ACFC has a slightly higher skid resistance over time than the conventional ACFC. This could be due to less maintenance activities and therefore, less asphalt on the surface. A Mu Meter number of skid resistance above 43 is considered high and of good quality and not in need of attention.

With regard to traffic noise, an Arizona Transportation Research Center study (6) printed in 1996, 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 AR-ACFC overlay appears to be capable of noticeably reducing roadside noise levels in certain situations.”

In general, objective pavement performance measurements taken over time all indicate that AR is a very good durable surface wearing course material. Twelve years of excellent service and cost effectiveness has been documented to date with little sign of change in the near future.

5. Summary and Conclusion

In general, ADOT is using AR as a binder in HMA mixes to reduce reflection cracking, improve durability of surface courses, and in urban areas to reduce noise.
By using asphalt rubber as a binder the film thickness is increased to a value of 19 - 36 micrometer compared to the typical dense-graded HMA film thickness of about 9 micrometer.

The grade of asphalt binder used as a base to make AR is an PG58-22 (AC-10), in contrast to typically stiffer grade of PG 64-16 (AC-20) used in the mountains. In the desert the AR base asphalt grade is PG 64-16 (AC-20) compared to PG 70-10 (AC-40) typically used for dense grade mixes. The 20 percent ground tire crumb rubber particles change the AR temperature susceptibility such, that at high temperatures, the AR is much more viscous than the neat asphalt. However, at cold temperatures, the AR acts like an AC-10 asphalt. SHRP asphalt binder tests indicate that AR can be graded from a PG 70-22 to a PG 82-28, which is indicative of a low temperature susceptible asphalt binder.

Typically, the asphalt rubber mixes are 12.5 mm (one half inch) to 25 mm (one inch thick) when open-graded and 25 mm (one inch) to 50 mm (two inches) thick when gap-graded. For Arizona's climate and materials, AR provides an excellent durable wearing course. The attached map shows the more than 2500 miles of very good performing AR pavement built since 1988 (Illustration #5). As an extra benefit, the ground tire crumb rubber from over eight and one half million tires has been recycled into these in service HMA projects.

6. References

8. Annexes

**Table 1. AR-ACFC binder content**

\[
\text{binder content} \% = (0.38 \times \text{W} + 8.6) \times \frac{2.620}{C}
\]

W = % WATER ABSORPTION of Aggregate (Note value cannot be greater than 2.5%)
C = COMBINED Oven Dry SPECIFIC GRAVITY of Aggregate (Note value must be between 2.35 and 2.85)

Example

\[
(0.38(1.10) + 8.6) \times \frac{2.620}{2.65} = 8.92
\]

**Table 2. Ground Tire Rubber Gradation**

<table>
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<tr>
<th>Sieve</th>
<th>Percent Passing</th>
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<tbody>
<tr>
<td>2 mm, #10</td>
<td>100</td>
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<tr>
<td>1.18 mm, #16</td>
<td>65-100</td>
</tr>
<tr>
<td>600 um, #30</td>
<td>20-100</td>
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<tr>
<td>300 um, #50</td>
<td>0-45</td>
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<tr>
<td>75 um, #200</td>
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**Table 3. Asphalt Rubber Bid (Prices And Usage)**

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<tr>
<th>YEAR</th>
<th>NUMBER OF PROJECT</th>
<th>TOTAL TONS OF AR</th>
<th>AVERAGE LOW BID/$TON</th>
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<td>3</td>
<td>900</td>
<td>506</td>
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<tr>
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<td>3</td>
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<td>1999</td>
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### Table 4. Total Cost (Dollars Per Sq Meter Per 25 mm)

<table>
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<tr>
<th>YEAR</th>
<th>AC</th>
<th>ARAC</th>
<th>ACFC</th>
<th>AR-ACFC</th>
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<tbody>
<tr>
<td>1990</td>
<td>1.75</td>
<td>3.39</td>
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<td>1.76</td>
<td>3.49</td>
<td>1.87</td>
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<td>2.72</td>
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<tr>
<td>1994</td>
<td>1.70</td>
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<td>1.89</td>
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<tr>
<td>1995</td>
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<td>3.09</td>
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<tr>
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<td>1.64</td>
<td>2.77</td>
<td>1.84</td>
<td>2.10</td>
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**Figure 1**  
Arizona D.O.T., Materials Group  
AR-AC & AR-ACFC Gradation Chart  
Sieve Sizes to 0.45 Power
Figure 2
Arizona D.O.T., Materials Group
Percent Cracking

Figures 2 and 3 show the performance of overlays and inlays compared to AR-ACFC for cracking and rut depth, respectively. Overlays and inlays generally perform better than AR-ACFC in terms of both cracking and rut depth.
**Figure 4**
Arizona D.O.T, Materials Group
Smoothness mm / Km

**Figure 5**
Arizona D.O.T, Materials Group
Maintenance Cost $/lane-Kilometer
Fig. 6  Skid Resistance Vs. Time
Arizona D.O.T, Materials Group

![Graph showing skid resistance vs. time over years.](image)

ILLUSTRATION # 1

![Graph showing percent passing vs. screen size.](image)

.1954

ILLUSTRATION # 1


Graphs showing the percent passing of Screen Size for 1965 and 1973.
INTERSTATE 40 PRIOR TO CONCRETE PAVEMENT REHABILITATION