Rehabilitation of Portland Cement Concrete Pavements With Thin Asphalt-Rubber Open Graded Friction Course Overlays In Arizona

Douglas D. Carlson
Rubber Pavements Association 1801 South Jentilly Lane Suite A-2 Tempe, Arizona 85281-5738

ABSTRACT

The Arizona Department of Transportation (ADOT) has designed and constructed many large-scale Asphalt-Rubber (A-R) overlay projects on heavily used highways and Interstates in climatically diverse regions within the state to rehabilitate the aging highway system. One overlay design used by ADOT is called an asphalt-rubber asphalt concrete friction course (AR-ACFC). This overlay is also known as an open graded friction course. Open graded friction courses are also commonly known as plant mix seals or popcorn mixes.

Three overlays using this design are examined as rehabilitation strategies for aged portland cement concrete pavement (PCCP) in climates ranging from –30 to122 degrees Fahrenheit, 6 to 30 inches of annual rainfall, 0 to 100 inches of annual snowfall and with traffic from 400,000 to 1,200,000 Equivalent Single Axel Loads (EASLS). The overlays were constructed between 1988 and 1995.

The A-R binder commonly used by ADOT is 80% hot paving grade asphalt and 20% ground tire rubber. The aggregate gradations commonly used with A-R binder in Arizona hot mixes are called open grade and gap grade. The open grade mix is typically placed in thicknesses of a half inch to one inch. When overlaid on PCCP the thickness is typically one inch. One thousand tires can be used on each lane mile in an economic and environmentally beneficial fashion in addition to enhancing the engineering properties of the OGFC.

The A-R OGFC mixtures have performed remarkably well. Long-term crack resistance and corresponding low maintenance costs appear to be unique in A-R pavements. The expected design life of the one inch thin overlays is between seven to ten years.

Project data is presented in tabular format using percent cracking, rutting, skid resistance, ride and maintenance costs as performance indicators. Mix design information and recent photographs of the projects are included.

INTRODUCTION

Since 1988, the Arizona Department of Transportation (ADOT) has constructed approximately 3000 miles of pavement overlays using asphalt-rubber hot mixes.[1] In the span of fourteen years ADOT has constructed over 384 asphalt-rubber projects and a majority of them (270) have used the thin AR-OGFC overlays. This is a remarkable feat considering that most states have not had favorable experiences with open graded mixtures[2] or with crumb rubber modified binders[3]. A summary table of ADOT A-R projects is provided in Appendix 1. The first experimentation of OGFC with asphalt-rubber in Arizona occurred as early as 1973 and the first project was placed in 1975[4]. Approximately 8 AR-ACFC projects have been placed over PCCP since 1988[5].

Typical current costs are near $2.15 per square yard per inch thickness[6] for the material and the spread rate is about 59 pounds of mix per square yard and about 89 tons of mix per lane mile per inch of overlay thickness[7]. The costs for the early projects were near $3.70 per square yard per inch. The price reduction is primarily due to the expiration of the patents in 1992 and increased competition among the suppliers of the binder material. Arizona can be considered a mature market for asphalt-rubber materials. Six to eight binder suppliers will frequently bid on over 40 projects each year let by the DOT, Counties and Cities.

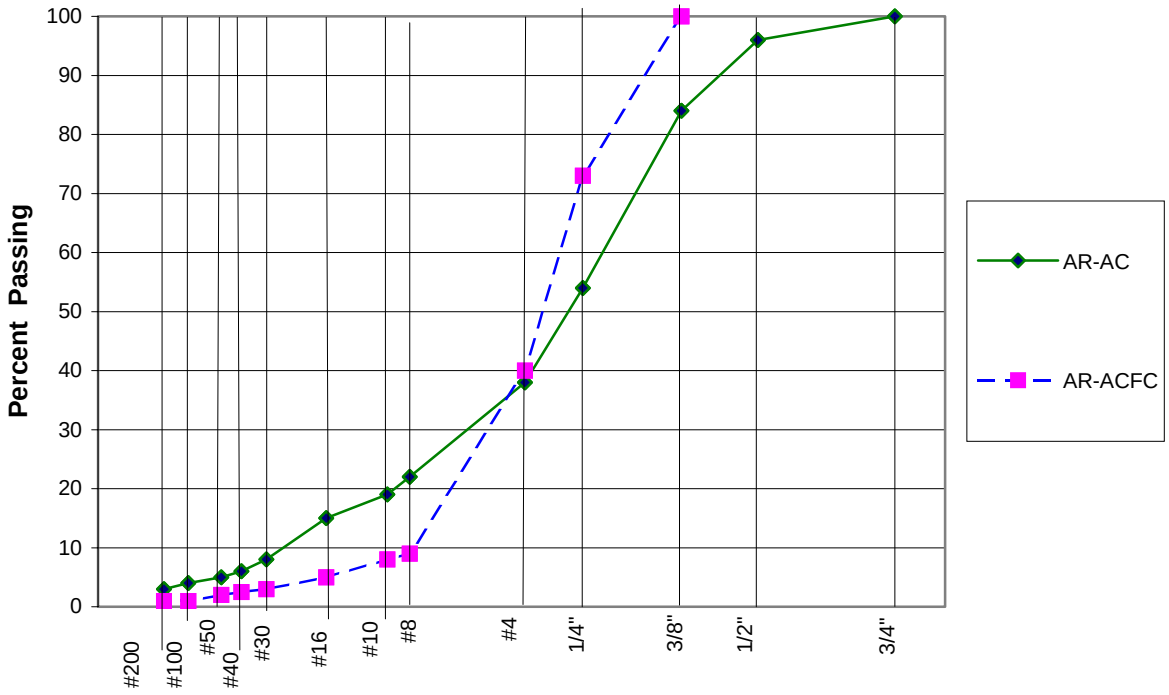
Asphalt-Rubber binder is defined by the American Society for Testing and Materials standard specifications (ASTM D 6114-97) as a mixture of 85% hot paving grade asphalt and a minimum of 15% ground tire rubber. However, the A-R binder commonly used by ADOT is 80% hot paving grade asphalt and 20% ground tire rubber. One ton of mix will contain about 36 pounds of granulated tire rubber, which is known as crumb rubber in the tire processing industry. Tire processors capture about ten pounds of rubber for every passenger tire. Tires are discarded at a rate approximately equal to a given population each year[8]. About 5 million tires are discarded in Arizona each year and ADOT uses about 15 million pounds or tire rubber in paving applications.

Two different hot mix designs are used, dependent on pavement type, field conditions, and climate. One mix, used solely as a surface course, is an open-graded mixture with design voids of a minimum of 15%. This mix generally has 9% binder and has high friction characteristics. The second mix is essentially a dense graded mixture designed to have approximately 3% voids. However, portions of the smaller aggregate and fines in this mixture are significantly reduced to give a gap grade. The product is very similar to what is known as a stone-mastic (SMA) mixture with the oil saturated rubber particles used in place of inert fillers[9]. The binder content in this mix will generally fall between 7.5 and 8.5%. Aggregate gradations for gap graded (ARAC) and open graded (AR-ACFC) mixtures are exhibited in Figure 1. ADOT uses a smaller nominal aggregate [100% passing the 9.5mm (3/8”) sieve] than what is typical for an OGFC in other states. A comparison of various OGFC gradations can be seen in Appendix 2. ADOT nomenclature for the open graded mix is Asphalt-Rubber, Asphalt Concrete Friction Course (AR-ACFC). The Gap-graded mix is Asphalt-Rubber, Asphalt Concrete (AR-AC).

The AR-ACFC has had extensive use over both Portland Cement Concrete Pavements (PCCP), and asphalt concrete (AC) Pavements. Where used directly on the existing, structurally sound pavement, the design thickness is one inch. In some cases the overlay may be as thin as ¾ of an inch. Where used in connection with another overlay, recycle, or new pavement layer the

thickness of the AR-ACFC placed is typically a half inch. When additional structural improvements are necessary an AR-AC mixture will be placed prior to the AR-ACFC. The AR-AC mixture is generally less than two (2) inches in thickness and in most cases is one to one and one half inches (1-1.5) thick.

Figure 1. Aggregate gradations for Gap and Open mixtures



Three of the 76 projects that have met or exceeded the seven to ten year design life are reviewed. These three were selected based on the their age, traffic loadings and locations, but specifically for the unique placement of the thin overlays directly on aged, structurally sound PCC Pavements that were in need of a surface treatment to improve the ride and friction characteristics. An example of this type of overlay can be seen in a photograph supplied by ADOT in Figure 2.

Figure 2. A core specimen of a thin AR-ACFC on PCCP.

The original PCC pavements were constructed in the 1960s and 1970s and served very well, but time, traffic and weather conditions had caused them to exhibit very rough ride and poor friction characteristics. The three overlays in this report are in diverse climatic zones, ranging from very hot desert conditions (Maximum air temperature = 124 ^{o}F, rainfall 4 inches per year) to severe cold (Minimum temperature –31^{o}F, 100+ inch snow, and 20 inches rain.)

In addition to the field reviews, the data in ADOT pavement management system was also reviewed and is presented where applicable. The projects in the reviewed are:

Interstate 19, Tucson South MP 58-60 constructed 1988
Interstate 17, Buckeye Rd. – Van Buren MP 198.2-199.8 constructed 1990
Interstate 17, County Line – Flagstaff (SB) MP 311.0 – 337.0 constructed 1994

Interstate 19, Tucson South MP 58-60 Constructed 1988

This project is a four lane, divided highway located on the edge of urban Tucson at an elevation of 2584 feet. The climate is moderate desert with maximum air temperature of 111 ^{o}F and a minimum of 16 ^{o}F. The typical annual traffic is 400,000 Equivalent Single Axle Loads (ESAL), with a total of 5,600,00 ESALS on the overlay since construction. This was the first full-scale non-experimental project constructed with a thin asphalt-rubber hot mix overlay. It consisted of a one inch thick AR-ACFC placed over a jointed, non-doweled 9 inch PCCP. The PCCP is 24 feet wide and is reinforced at the centerline with tie bars. The PCCP was built in 1965, the overlay was designed to improve the rough ride and poor skid resistance that had developed over 23 years of service. The length of the project is 2 miles. The approximate price for the overlay was near $3.65 per square yard. The ADOT pavement management system (PMS) contains the following data:

Table 1. Interstate 19, Tucson South Performance Data

Performance Indicators	Values Before Overlay	Values 14 Yrs After Overlay
Ride inches/mile	172	70
Skid (Mu Meter)	38	64
Rutting	N/A	0.11
% Cracking	N/A (Transverse Joint)	1%
Maintenance Costs/lane mile/year	$857	$59

Maintenance values for the overlays are averages taken over the life of the project.

At the time of placement the design binder content was 10%. With this open-graded mix this correlates with an aggregate volume of 55%, binder volume of 25%, and air voids of 20%. In the 14 years of service the air voids have decreased to 15%. The original binder at time of placement had a penetration of 48 mm and a softening point of 140^{o} F. Measurements conducted in 2000, after 12 years of service, the penetration had decreased to 22 mm and the softening point increased to 160^{o} F. This indicated an excellent resistance to aging as would be expected with the higher binder content.

A visual inspection of the project revealed that the overlay was still in excellent condition. There was no discernable rutting nor was there any evidence of maintenance repairs. There were a very limited number of reflective cracks above the underlying joints and these

cracks are all hairline in width or they are “ghost” cracks and are completely closed in the wheel paths. Noise measurements were not made but there is a very discernable difference in noise level between this pavement and the adjacent pavements. A noise study conducted by ADOT in 1989 indicated a 6.7 dB reduction when comparing the AR-OGFC overlay to an adjacent PCCP.[10] Before and after photographs are presented as Figure 3. As of this writing, the overlay has been milled and replaced as part of another project. The project had doubled the expected seven year design life.

Figure 3. Before (left) and after photographs of I-19

Interstate 17, Buckeye Rd. – Van Buren MP 198.2-199.8 Constructed 1990

The next project discussed is located on Interstate 17 between Buckeye Road & Van Buren in urban Phoenix that was constructed in 1990. This project is located on the northbound freeway in urban Phoenix and the one inch thick AR-ARFC was placed over three lanes plus a distress lane of a PCCP originally constructed in 1960 with a thickness of nine inches. After thirty years of good performance the PCCP had met the end of its design life. The ride was very rough, producing a rhythmic bouncing motion in vehicles that traveled upon it. Joints were severely spalled in some areas with very noticeable sounds produced as vehicle tires passed over them. Approximately forty full slabs were replaced prior to overlay.

The Phoenix climate is somewhat hotter than Tucson with a maximum air temperature of 122^{o}F. A typical “summer” will produce one hundred days with temperatures over one hundred degrees.

The elevation is 1117 feet. Perhaps more importantly, the traffic level has averaged 2,100,000 ESALS over the last ten years. The Arizona PMS statistics for this project are listed in Table 2.

Table 2. Interstate 17, Buckeye Rd –Van Buren Performance Data

Performance Measures	Before Overlay	12 Years After Overlay
Ride (IRI) inches/mile	179	65
Skid (Mu Meter)	28	57
Rutting	N/A	0.11
% Cracking	N/A	0%
Maintanance Costs $/lane mi/year	$1,200	$256

Photographs from the recent inspection are displayed in Figure 4. The pavement is in good condition and the overlay has provided excellent service over it's twelve year life.

Figure 4. Before (upper left) and after photographs of I-17 in Phoenix

A visual inspection in 2000 revealed the following conditions:

1) All joints had reflected through in the distress lanes and the shoulder but the cracks were either closed or hairline in the travel lanes.
2) Some structural failure had occurred with three potholes developing. The holes were relatively equidistant and inline with each other. The pattern suggests underlying repair work to the longitudinal joints prior to the overlay, which can be seen in the top right of Figure 4. These holes have been recently been patched with a quick setting concrete.
3) Noise reduction is good.
4) Ride is smooth.
5) Overlay color is still a very dark black which provides good contrast to pavement markings, striping, and reflectors.

Interstate 17, Flagstaff –County Line (SB), MP 311-337 1995

In contrast to the Phoenix and Tucson projects, this pavement is subject to severe cold weather and is in a moist environment. Flagstaff has an elevation of 7000 feet and the climate is alpine in nature. Minimum temperature may be as low as -30°F and the average annual snowfall is 100 inches. High temperatures seldom are above 90°F with the highest reading of 94°F since construction of this project. In addition, the area experiences an average of 28 inches of rain annually. The area is classified by the Long-Term Pavement Performance (LTPP) program as a "wet freeze" climatic region similar to the northeastern section of the United States.

The original PCCP was built in 1974. After twenty years of service in this harsh environment the pavement was still structurally sound but had developed a significant "step-off" between slabs which severely affected the ride. Some slabs were replaced and the raised areas along the joints were smoothened and leveled by grinding. The AR-ACFC was placed in 1995 and has served well for the last seven years. The annual traffic on the project is near 650,000 ESAL and 25,000 vehicles per day.

Some areas along the project have been repaired due to continued deterioration of the underlying concrete and sub-grade materials. Although the reflective cracking above the joints are more pronounced on the project, they are not spalling. The lower portion of the project near mile post 335 indicates that a rejuvenator has been applied. This project is near the end of its design life may be scheduled for a mill and replace activity in the next few years. Performance data is listed in Table 3 and before and after photographs are displayed in Figure 5.

Table 3. Interstate 17, Flagstaff –County Line Performance Data

Performance Measures	Before Overlay	7 Years After Overlay
Ride (IRI) inches/mile	198	64
Skid (Mu Meter)	52	56
Rutting	N/A	0.05
% Cracking	N/A	4%
Maintanance Costs $/lane mi/year	$445	$214

Figure 5. Before photos on top, after photos below

CONCLUSION

Asphalt-rubber open graded friction courses can be used effectively to rehabilitate aged Portland Cement Concrete Pavements. The projects reviewed in this report demonstrate AR-OGFCs performing beyond the expected design life in very hot/dry and cold/wet climates and under heavy traffic conditions. The AR-OGFC surfaces provide a smooth ride and can significantly reduce noise compared to aged PCCP. With costs of $2.50 a square yard and very low maintenance costs, AR-ACFC provide an economical rehabilitation treatment to our nation's aging interstate system and help reduce the amount of scrap tires that are discarded in landfills.

APPENDIX 1 — SUMMARY TABLE OF ADOT AR-ACFC AND ARAC PROJECTS

Source – A Report on Arizona Asphalt Rubber Projects, 1988-2001, Ali Zareh, P.E. ADOT Materials Group, Pavement Design Section

ARACFC Projects ADOT

Year	# Projects	Tons Mix	Tons Binder	Ton Aggregate	% Binder	Tons Rubber	Pounds Rubber	Tires (10 lbs)
2001	33	181,434	16,234	165,200	8.9%	3,247	6,493,600	649,360
2000	38	206,578	18,654	187,924	9.0%	3,731	7,461,600	746,160
1999	48	266,133	24,197	241,936	9.1%	4,839	9,678,800	967,880
1998	39	376,814	33,621	343,193	8.9%	6,724	13,448,400	1,344,840
1997	22	115,696	10,424	105,272	9.0%	2,085	4,169,600	416,960
1996	21	122,947	11,004	111,943	9.0%	2,201	4,401,600	440,160
1995	30	196,826	18,380	178,446	9.3%	3,676	7,352,000	735,200
1994	14	136,703	12,611	124,092	9.2%	2,522	5,044,400	504,440
1993	12	116,486	10,866	105,620	9.3%	2,173	4,346,400	434,640
1992	10	106,970	9,954	97,016	9.3%	1,991	3,981,600	398,160
1991	3	18,650	1,742	16,908	9.3%	348	696,800	69,680
1990	5	78,529	5,353	73,176	6.8%	1,071	2,141,200	214,120
1989	1	6,830	649	6,181	9.5%	130	259,600	25,960
1988	1	4,080	390	3,690	9.6%	78	156,000	15,600
14	**277**	**1,934,676**	**174,079**	**1,760,597**	**9.0%**	**34,816**	**69,631,600**	**6,963,160**

ARAC Projects ADOT

Year	# Projects	Tons Mix	Tons Binder	Ton Aggregate	% Binder	Tons Rubber	Pounds Rubber	Tires (10 lbs)
2001	14	269,356	21,061	248,295	7.8%	4,212	8,424,400	842,440
2000	16	271,863	17,936	253,927	6.6%	3,587	7,174,400	717,440
1999	15	421,781	33,811	387,970	8.0%	6,762	13,524,400	1,352,440
1998	13	396,601	32,902	363,699	8.3%	6,580	13,160,800	1,316,080
1997	9	219,492	18,286	201,206	8.3%	3,657	7,314,400	731,440
1996	7	124,290	9,327	114,963	7.5%	1,865	3,730,800	373,080
1995	11	144,359	10,447	133,912	7.2%	2,089	4,178,800	417,880
1994	5	51,545	4,055	47,490	7.9%	811	1,622,000	162,200
1993	4	57,117	4,219	52,898	7.4%	844	1,687,600	168,760
1992	3	23,530	1,774	21,756	7.5%	355	709,600	70,960
1991	4	14,997	1,061	13,936	7.1%	212	424,400	42,440
1990	3	22,178	1,650	20,528	7.4%	330	660,000	66,000
1989	3	45,334	2,892	42,442	6.4%	578	1,156,800	115,680
13	**107**	**2,062,443**	**159,421**	**1,903,022**	**7.7%**	**31,884**	**63,768,400**	**6,376,840**

APPENDIX 2 — SUMMARY TABLE OF OGFC MIX DESIGNS

Table 1. Summary of 9.5 mm Open-Graded Friction Course Mixture Designs

	Arizona Unmodified AC		Arizona Asphalt Rubber		California		Florida		Nevada		Wyoming		Georgia	
Grading	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
12.5 mm	100		100		100		100		100		100		100	
9.5 mm	100		100		90	100	85	100	95	100	97	100	85	100
4.75 mm	35	55	30	45	29	36	10	40	40	65	25	45	20	40
2.36 mm	9	14	4	8	7	18	-	-	-	-	10	25	5	10
2.00 mm	-	-	-	-	-	-	4	12	-	-	-	-	-	-
1.18 mm	-	-	-	-	-	-	-	-	12	22	-	-	-	-
0.075 mm	0	2.5	0	2.5	0	0	2	5	0	4	2	7	2	4

Asphalt	PG 64-16	PG 64-16 Plus 20% Rubber	AR 4000 AR 8000 Or PBA-6	AC 30 plus 12% rubber	AC 20 P or AC 30	PG 64-22 or PG 70-28	PG 67-22
Content	6.0%	7.5-8.5%	-	5.5-7.0%	6.5% typical	6.3-6.8%	6.0-7.3%

Source – Draft ASTM Standard Guide for Materials and Construction of Open-Graded Friction Course

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