Asphalt-Rubber Pavement Construction and Performance: The Sudan Experience

Mona Nourelhuda[1], PhD, P.E., and Galal Ali[2], PhD, Prof & ConsultEng

1MAJIG International Consulting Group, P.O. Box 2643, Khartoum, Sudan

2 Sudan University of Science & Technology (SUST), P O Box 12281, Khartoum, Sudan – Corresponding Author

Cell Tel.: +249 912345507 Fax: +249 183 463614

E-mail: ga03ali@yahoo.com galalabdalla@sustech.edu

ABSTRACT: *Recent years have witnessed several advances in pavement industry and technology, such as the super-pave mix design, mechanistic-empirical guide to structural design, and recycling asphalt pavements. However, of more notable development in the past twenty-two years were the extensive research and application of asphalt rubber (AR) in hot mix asphalt and flexible pavement construction. The primary purposes were to reduce various crack types and pavement thickness, tire noise and cost while increasing its service life. Additionally, its high elasticity would also facilitate provision of a waterproof layer over new constructions of cement-stabilized base with shrinkage cracking. The successful long-term performance over the past two decades largely contributed to the good standing of AR binder. This paper presents the state-of-the-art review of AR research and applications as background prior to addressing the Sudan experience with AR pavement construction and performance. Included also in the literature survey is a recent study at Sudan University of Science and Technology to evaluate the effect of crumb rubber content on bitumen and hot mix asphalt. While Arizona State in the United States has used this distinct paving material as early as since 1988, the experience of Khartoum State, the Capital of North Sudan, with Asphalt Rubber (AR) is rather recent since 2006. Nevertheless, this was the first ever introduction to pavement construction of asphalt-rubber (AR) binder in hot mix asphalt in Sudan. The AR was considered the preferred modified binder and used in double surface chip seal, gap graded hot mixture, and stress absorbing membrane interlayer (SAMI). The AR binder used was a mixture containing 80 to 83% hot asphalt and 17 to 20% crumb rubber imported from ground waste tires. These hot mixes were used in double surface chip seals, a gap-graded mix containing 7 to 8% AR binder with thickness varying from 45 mm to 50 mm and a 19-mm SAMI layer. After 5 years in service, to date the field performance is excellent with phenomenal savings in pavement construction cost. This paper addresses and reports with discussion the construction and performance of Asphalt Rubber wearing course regarding reduction in the required pavement thickness, providing smooth surface ride quality of very good skid resistance, with essentially no maintenance cost. The study of pavement performance during the five-year period showed that Asphalt Rubber is a robust surface course material, with a noteworthy saving in construction cost. Conclusively, a 5-year of an outstanding AR performance has been observed, documented and experienced compared to the conventional ones. Furthermore, there were no indications that significant changes in these performance trends would be expected.*

KEYWORDS: Asphalt-Rubber, Laboratory tests; Construction; SAMI; Performance; Ride quality; Construction Cost

1. Introduction

Recent advances in pavement industry and technology included mechanistic-empirical guide to structural design (Hanna, 2003), in conjunction with the associated super-pave mix design (Ramzi, Ali and Delwar, 1998), and recycling asphalt pavements (Ramzi, Ali and Al-Turk, 1999). However, more notable pioneer development in the past twenty-five years was the extensive research and application of asphalt-rubber (AR) in hot mix asphalt and flexible pavement construction. As early as quarter of a century ago, Lansdom (1976) addressed construction technology requirements for placement of asphalt-rubber membranes. Nourelhuda evaluated performance of asphalt-rubber pavement (1997) in addition to its rutting prediction.

The main characteristics of the newly introduced technology by Arizona State in pavement design and construction were the reduction of various crack types and pavement thickness (Way et al., 2006) and tire noise and cost while increasing its service life (Sousa et al., 2006). Additionally, its high elasticity would also facilitate provision of a waterproof layer over new constructions of cement-stabilized base with shrinkage cracking. The successful long-term performance over the past two decades largely contributed to superior performance of flexible pavements with AR binder. Extensive novel work was undertaken by Arizona State research team and at the Council for Scientific and Industrial Research (CSIR) in South Africa. The investigations of these two groups covered a wide range of issues in AR studies and applications. They included future of AR (Sousa, 2011a) and crumb rubber (CR) specifications and recycling (Sousa, 2011b); AR design, specifications and reduction of pavement life-cycle costs (Way, 2011a; 2011b); pavement design guide with AR (Kaloush et al., 2011). Other areas of AR research in the United States and Portugal dealt with the California experience with AR (Shatnawi, 2011) and AR overlays (Shatnawi and Minhoto, 2011). Rheological aspects of AR, pavement design-based mix testing, and chip-seal design were the main concerns of CSIR of South Africa (Mturi and O'Connell, 2011; Anochie-Boateng et al., 2011; Milne, 2011).

The above brief state-of-the-art review of AR research and applications were intended as background prior to addressing the Sudan experience with AR pavement construction and performance. Included also as part of Sudan experience in laboratory testing are the findings of a recent study at Sudan University of Science and Technology (SUST) to evaluate the effect of crumb rubber content on bitumen and hot mix asphalt (Adam and Osman, 2010).

While this distinct paving material has been used in Arizona State since 1988, the first application of asphalt rubber (AR) in Sudan was on Khartoum State road network in 2006. A double-surface AR treatment was placed in a new 9-km road construction of low-medium traffic. It was an earth road in poor condition, especially during the rainy season. The road crosses an urban area where traditional paving construction was considered very expensive. Instead, the use of a double-surface chip seal of AR binder would allow for the reduction in the pavement total thickness, as compared to 5-cm conventional hot mix asphalt (HMA) concrete. The intension was to benefit from the established characteristics of AR which included improved resistance to reflection and fatigue cracking. Since then, AR has been used in a number of new projects.

With the first use of AR in Sudan as adopted for Khartoum State roads gaining interest and popularity, the Building and Road Research Institute (BRRI) of University of Khartoum started cooperating in experimental testing of AR within their well-established and equipped laboratory. Main tasks were to follow up the AR verification work, the job mix formula, and to study the behavior of rubber modified binder and the AR mixture. Additional objectives were to monitor the performance behavior and gather as much information as possible from laboratory testing in order to develop recommendations for use of this unique binder in Sudan.
Besides supporting the State of Khartoum Infrastructure Ministry as well as the private sector in the know-how and quality control, the work performed at the BRRI laboratory included, but not limited to, the following:

- AR-modified binder characterization using conventional binder consistency tests (penetration, softening point, and viscosity);
- Aggregate characterization tests (Los Angeles abrasion, crushing value, adhesion, etc.)
- Determination of bitumen and rubber contents as well as Marshall properties;
- Checking that gap-graded mix design specifications were satisfied regarding voids filled with bitumen.

The scope of the present study was concerned with the use of the AR double-surface treatment, AR gap-graded mixture as a binder course as well as a wearing course in pavement construction for new roads.

2. Asphalt Rubber Pavement Design and Construction Projects

The first Asphalt Rubber mix used on the 9-km road in Khartoum State was during November 2006. The second project for a private company was constructed in June 2007. The first project consisted of constructing a double-surface chip seal applied in a new road with low-medium traffic volume. The specification limits and selected gradation are shown in Figure 1.

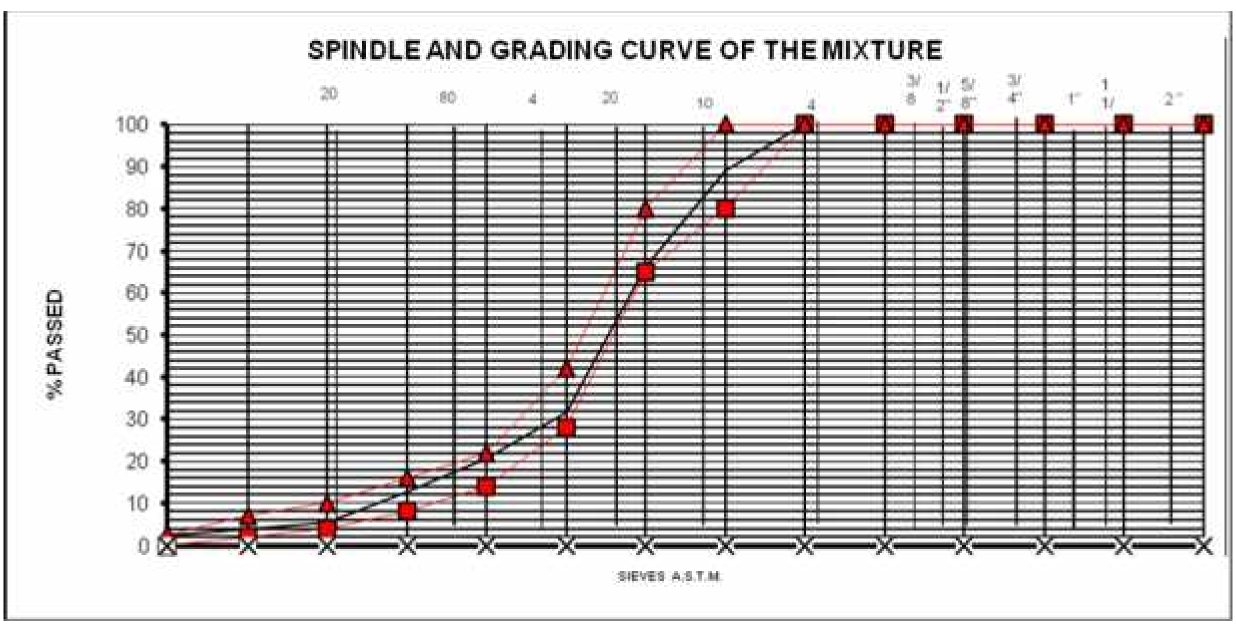

Figure 1. *Gap-graded aggregate gradation curve*

The AR chip seal containing 17-20 % rubber by weight of the virgin asphalt binder was placed on top of a well-compacted base having minimum California Bearing Ratio (CBR) of 80. Continuous observations revealed no cracks on the surface. However, some of the sections showed minor rutting. As an indication of promising success of this technique, a larger AR project with double-surface chip seal was constructed. The AR contained 17-20 % ground tire crumb rubber by weight of 60-70 penetration grade asphalt. Further extension of the AR work included of construction of a trial pavement structure for a private company. The structural design consisted of 5-cm gap-graded AR placed over 5-cm HMA concrete with a thin stress absorbing membrane interlayer (SAMI) in-between. The layers were constructed on a 20-cm base course of minimum 80 CBR compacted to a density of 98-100 %. The 20-cm sub-base of minimum 30 CBR was compacted to 95 % density on a heavy loading and unloading parking lot. Figure 2 illustrates construction details of the structural layers. The purpose of the parking lot project was to investigate the structural layer system different from the conventional 10-cm HMA concrete which lasted only for three years and resulting in high maintenance cost. Another 45-mm gap-graded AR mix was used on internal and external roads in a residential compound. The latest monitoring of the constructed sections in January 2012 indicated no performance problems.

4.5 Gap-Graded AR **Tack Coat**

5 cm AC **SAMI**

20-cm 80 CBR Base Compacted to 98-100 %

20-cm 30 CBR Sub-base Compacted to 95 %

///////////////////Sub-grade///////////////////

Figure 2. ***Parking lot pavement structure***

3. Asphalt Rubber Pavement Constructions

3.1 *Asphalt Rubber Chip-Seal Construction*

The construction of AR double-surface chip-seal pavement project involved first adding the ground rubber to 60-70 penetration-grade asphalt-cement heated to a temperature of about 190^{o}C. The mix components were accurately proportioned in accordance with the design requirements, typically between 17-20 % ground tire rubber that satisfied the gradation specifications shown in Table 1. The process was followed by thorough mixing by the approved AR blending device prior to the beginning of the one-hour reaction period. The AR was kept at a temperature of 175^{o} C until it was introduced into the calibrated AR-distributor truck to perform the application at a temperature of 195^{o} C. Upon completion of the asphalt-rubber mixing process in the blending device, it was kept thoroughly agitated while the AR mix was in use in order to prevent settling of the rubber particles. During production of asphalt-rubber concrete, the temperature of the mix was maintained between 163 and 191°C. For each load or batch of asphalt-rubber, the following was documented:

- The source, grade, amount and temperature of the asphalt cement before adding rubber.
- The source and amount of rubber and the rubber content expressed as percent by the weight of the asphalt cement.
- Times and dates of the rubber additions and resultant viscosity test.
- Record of temperature, with time and date reference for each load or batch. The record began at the time of addition of rubber and continued until the load or batch is completely used. Readings and recordings made at every temperature change in excess of 11°C, and as needed to document other events which are significant to batch use and quality.

Table 1. ***Specifications limits for ground tire rubber gradation***

Sieve size	% Passing
2mm, #10	100
1.18 mm, #16	65-100
600 um, #30	20-100
300 um, #50	0-45
75 um, #200	0-5

The spray pattern was made in such a way to cover the road evenly. The road base of 100 % compaction density and 80 CBR was cleaned with a broom and an air compressor making the primed base ready for the spray of the first layer of AR mix. The AR was applied at the rate of 2 to 2.5 kg/m^2, which was based on experience. However, the Engineer was permitted to make adjustment by taking the field conditions into consideration. Immediately ¾-inch aggregate having the Specifications given in Table 2 was uniformly distributed by a self-propelled aggregate distributor at a rate of 14-16 kg/m^2, also based on experience. Spreading was then completed within 2-3 minutes of the application of the binder, followed by 10-Ton pneumatic roller compaction within 2 minutes of the application of the chips. This included complete coverage for the initial rolling and three additional coverages for completion.

Table 2. ***Chip-seal cover ¾-inch and 3/8 inch aggregate specifications***

Aggregate Property	¾-inch Aggregate	3/8-inch Aggregate
Flakiness, % max	25.0	20.0
Dust, % max	0.5	0.5
Aggregate Crushing Value(ACV), % max	30.0	30.0
Average Least Dimension (ALD), mm	10.5	5.0

Sweeping was carried out initially using manual brooms. Extra sweeping took place for any loose aggregate missed by the manual brooms. A second layer of AR binder was uniformly distributed by the AR distributor at a rate of 1.5 to 2.0 kg/m^2, with the Engineer, again, allowed to adjustment based on field conditions. The process was followed by 3/8-inch aggregate (Tables 2 and 3) uniformly distributed by the self-propelled aggregate distributor at a rate of 16-18 kg/m^2. Spreading was completed within 2-3 minutes of the application of the binder as well. Immediately rolling was performed again using a 10-ton pneumatic roller within 2 minutes of the chips application. This included complete coverage for initial rolling and three additional coverages for completion to achieve the required density. Sweeping was carried out initially using manual brooms. Extra sweeping took place for any loose aggregate missed by the manual brooms. This was done before opening the road to traffic. A fog seal was applied as a final layer. The application rate was based on undiluted asphalt at a rate of 0.45 liter/m^2 after the final sweeping. The bulk specific gravity of the cover materials was within 2.30 to 2.85 as specified by AASHTO T 85. The road was not opened to traffic during fog sealing. Samples were obtained from the rubber, asphalt, aggregates and AR binder and tested according to the standard Specifications.

Table ***3. 3/8-inch Aggregate gradation specification limits for chip-seal mix***

Sieve Size, mm	% Passing
9.5	100
6.3	0-15
2.36	1-5
0.075	0-2.0

3.2 *Asphalt Rubber Gap-Graded Mix Construction*

Similar to AR chip-seal project, the construction of AR gap-graded pavement involved initially adding 17-20 % ground rubber of Table 1 to 60-70 asphalt cement heated to 190^o C, and thoroughly mixing by the AR blender until brought into the calibrated hot mix asphalt plant at a temperature of 195^o C. During the production of asphaltic concrete the temperature of the AR was maintained at 163 - 191°C. For each batch of AR the following information:

- The source, grade, amount and temperature of the asphalt cement prior to rubber addition.
- The source and the rubber content as percent by the weight of the asphalt cement.
- Dates and times of rubber additions and results viscosity tests.
- A record of the temperature with time and date reference for each load or batch. Recording began at the time of rubber addition and continued until the batch was fully utilized. Readings and recordings were made at every temperature change in excess of 11° C and any other relevant information significant to batch use and quality.

The gap-graded aggregate gradation is shown in Table 4. Samples of the rubber, asphalt, aggregates and AR mixture were tested accordingly. The AR gap-graded mix which had one percent cement added as mineral filler (Table 5) to the mix, was placed with the conventional
The mix was then immediately compacted with a 10-ton steel roller (on the breakdown close to the paver). Additional compaction was achieved by an 8-ton steel roller. Lime water was used to reduce the pickups by the tires. Cores were taken as well and tested for density, gradation, binder content and layer thickness.

Table 4. ***Aggregate gradation specification for the gap-graded mix***

Sieve Size	% Passing
19 mm, 3/4”	100
12.5 mm, 1/2”	80-100
9.5 mm, 3/8”	65-80
4.7 mm, #4	28-42
2.36 mm, #8	2-14
75 um, #200	0-2.5

Table 5. ***Percent aggregate and binder composition for AR gap-graded mix***

Mix Component	% Composition
12/19 mm size	15
5/12 mm size	54
0/5 mm size	30
Filler	1
Asphalt Rubber %	7.6

The results of Marshall mix design for the AR gap-graded mix are summarized in Table 6. The results indicate that the AR gap-graded mix satisfies the requirements of Arizona (AZ), USA shown in Table 7. Similar results were obtained by Adam and Osman (2010) from laboratory investigation of hot mix asphalt–rubber using 15-25 % rubber by weight of 60-70 asphalt cement (2010). Their findings Indicated that crumb rubber modifier results in better engineering properties.

Table 6. Asphalt-*Rubber gap-graded mix design*

Marshall Property	Test Design Value
Density, g/cm^3	2.38
Breaking Strength, kgf	1500
Deformation, mm	4.1
VMA, %	19.2
Porosity, %	4.1
Optimum AR, %	7.6

Table 7: ***Asphalt rubber gap-graded mix requirements for Arizona (AZ), USA***

Property / Criterion	AZ, USA Specs
Voids content, %	5.5 +/- 1.0
Binder Content, %	5.5 - 9.5
VMA, %	19 min.
Asphalt Absorption, %	0 - 1.0

4. Performance of AR Constructions

AR projects had been monitored since construction. In general, no cracking or rutting was detected. Ride quality and skid resistance were observed to be satisfactory. Additionally, AR reduced the amount of reflection cracking, with 15 % fatigue cracking. The average rut depth was not as low as anticipated in the double surface project (Fig.3). This might be due to poor compaction of the base, while the case was different for the gap-graded project.

Figure 3. ***The chip seal project*** (Photo taken June10, 2012)

Figure 4. ***The gap-graded construction project***

(Photo taken June10, 2012)

The average smoothness over the 5-year period for all the projects was very satisfactory (Fig. 4). In addition, major distresses such as potholes and spreading of cracks were practically absent.

5. Cost Considerations

Cost comparative analysis after incorporating AR into the double-surface chip-seal was found to be 20 % less expensive than the conventional construction. On the other hand, the 50-mm conventional dense-graded AC mix was 30 % over priced compared to the gap-graded AR mix. In addition, AR was even less expensive to construct. About 50 % reduction in thickness was achieved in these studies as called for the 1992 Asphalt-Rubber Guide (Shatnawi and Long, 2000). The double- surface AR chip-seal provided 50-mm thick conventional pavement, where the 45-mm thick AR gap-graded was equivalent to 90-mm thick conventional pavement. Thus, the comparison should be between the 50-mm conventional pavement with the performance of the AR chip-seal.

The double-surface AR chip-seal was constructed at the cost of 10 Sudanese Pound* (SDG) per m^2 in 2006, while the corresponding value for the 45-nm gap-graded AR mix was 13.73 SDG per m^2. Table 5 details the cost comparison between 50-mm thick AR gap-graded mix and the 50-mm thick conventional dense mix. AR proved to be cost-effective solution, particularly for the gap-graded since, it provides twice as much in the pavement thickness thereby resulting rn long-term better performance and savings on maintenance cost.

Table 8. ***Total cost of gap-graded AR mix (SDG*/m^2/50-mm thickness)***

Material/ton	Costs in SDG* /ton	Road Department			
		Conventional		**AR**	
Bitumen	1350	5%	67.50	6.4%	86.40
Rubber	1250			1.6%	20.00
Cement	650			1.84%	11.96
Aggregates	44	95%	41.80	90.16	39.67
Total		**100%**	**109.30**	**100%**	**158.03**
Transformation cost, conventional/mix ton			43.66		43.66
Transformation cost, AR / mix ton					4.31
Selling price Conventional / mix ton			**152.96**		**226.00**
Applied Tons (1000 m x7,5 x 0,05 conventional)		8.78		4.56	
Price per km			**13, 422, 350**		**10,297,125**
Price per sq m			**17.90**		**13.73**
Over-price			**30 %**		

***** 1 US $ 3.00 SDG

6. Summary and Conclusions

In this paper the cost effective use of AR as binder in chip-seal and gap-graded HMA concrete mix in Khartoum State, Sudan was experimentally investigated. The objective was to find if such constructions would increase pavement life and reduce maintenance costs. The grade of Asphalt grade AC 20 (penetration grade 60-70), commonly used for conventional HMA in Sudan, was blended with tire rubber crumb to produce the more viscous AR. For the AR chip double surface 3/8” and ¾” aggregates were used topped with a fog seal. The gap-graded mix was 4.5-cm thick. AR binder application in the chip seal was determined based on the average least dimension (ALD) of the aggregate, as well as other aggregate properties, such as shape, density, absorption and gradation.

Minor rutting developed through densification of the poorly-compacted base material, in addition to shoving and lateral displacement due to traffic. Laboratory testing of AR showed slightly larger tensile strength. The significant parameters in the performance of AR binder included mixing time, mixing temperature, and rubber gradation. Although Khartoum State in Sudan has built few km of well performing AR pavements, up to date, the field performance showed that AR chip-seal and gap-graded are capable of reducing reflection and fatigue cracking. For Sudan, conditions, materials, and workmanship, AR mixes present excellent alternative for the paving industry. The Sudan experience might allow for an evolution of the knowledge about the use of the tire rubber modified asphalt mixes. The performance offered after 5 years performance revealed that no significant defects or distresses were detected.

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