Rubberised Bitumen in Road Construction

Project code: TYR0009-07

Date of commencement of research: 28 December 2005
Finish date: 24 February 2006

Written by: George Way, PE
Recycled Tire Engineering & Research Foundation

Edited & Supplemented by: Russ Evans
EER Limited

Published by:
The Waste & Resources Action Programme
The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH
Tel: 01295 819900 Fax: 01295 819911 www.wrap.org.uk
WRAP Business Helpline: Freephone: 0808 100 2040

May 2006
Rubberised Bitumen

1. Summary

This section deals with rubberised bitumen, a binder in hot mix asphalt and chip seal applications that results from the proper addition of crumb rubber to hot bitumen and then left in a heated state to react.

Rubberised bitumen is used extensively in California, Arizona and Texas in the USA, in several countries of Western Europe, and in South Africa. It is also used to a lesser extent in parts of Canada and in a dozen more states in the USA.

The benefits are many, including reduced long-term road maintenance and expense, significant noise reductions, improved traction and reduced accident rates in wet road conditions.

This is the story of rubberised bitumen, as told by one of its greatest practitioners.

2. What is Rubberised Bitumen?

Rubberised bitumen is a mixture of hot bitumen and crumb rubber derived from post-consumer waste or scrap tyres. It is used extensively in the highway paving industry in the USA, 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 rubberised bitumen as “a blend of asphalt cement [bitumen], reclaimed tyre 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 [bitumen] sufficiently to cause swelling of the rubber particles,” [AST05] This definition was developed in the late 1990’s.

However the story of how rubberised bitumen was originally invented, patented, how it has been and how it is presently used, how it is made, and its benefits that have increased with time, that story begins in the 1960’s. The initial development of rubberised bitumen 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 rubberised bitumen patches that he called “Band-Aids”, Figure 1. These patches were generally 24” x 24” (0.61m x 0.61m) and consisted of rubberised bitumen placed on paraffin coated paper with 3/8” (9.5mm) chips embedded.
3. Rubberised Bitumen as a Slurry Material

Recognizing that fatigue cracking generally occurred in larger areas that small patches couldn’t handle, the concept was extended to full pavement sections by spreading the rubberised bitumen 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 bitumen and crumb rubber in the limited time available in the slurry equipment, it was necessary to employ bitumen 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.

Figure 2- Rubberised bitumen applied as a slurry seal
4. **Rubberised Bitumen as a Chip Seal Application**

In 1971, technology had developed to the point that standard bitumen distributor lorries 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 rubberised bitumen materials.

Following the development of suitable equipment to spray apply rubberised bitumen Charles MacDonald and his colleagues were granted a patent in 1975 in the development of this material. This patented process is described as the “MacDonald Process or Wet Process for making Asphalt Rubber (AR)” [note: “rubberised bitumen” and “AR” are used interchangeably]. It should be noted that AR patents ended in 1992. In the chip seal or slurry applications, rubberised bitumen needs to be maintained at between 191°C and 218°C (375°F and 425°F) to ensure a viscosity thin enough for spraying. An ambient and surface temperature of at least 18°C (65°F) is recommended so the applied material does not set too quickly.

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 lorries led to improvements in mixing to a satisfactory degree that AR could be safely and consistently placed with a distributor lorry 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 tyre rubber was introduced into the top of the boot lorry and mixed by rocking the lorry 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), Figures 5 & 6. Both the SAM and SAMI applications showed great promise in reducing reflective cracking [WAY79].
From 1974 until 1989, approximately 660 miles (1,100 km) of state highways were built using a SAM or SAMI application of AR. In addition to this, ADOT and the US 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 rubberised bitumen at ADOT [SCO99]. In that report the following conclusion is stated, “asphalt rubber [rubberised bitumen] 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 [rubberised asphalt] use, ADOT has evolved from using slurry applied rubberised bitumen chip seals to utilizing reacted asphalt rubber [rubberised bitumen] as a binder in open and gap graded bitumen 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.

5. Rubberised Bitumen in Hot Mix Applications

In 1985 ADOT began experimenting with two rubberised bitumen mixes, an open graded mix (ARFC) and a gap graded mix (ARAC). ADOT had experienced cracking problems with its dense graded mixes and raveling of its open graded mixes, Figures 7 & 8.
Given the good results with AR as a chip seal coat material ADOT thought that a hot mix asphalt with rubberised bitumen 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 bitumen 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 rubberised bitumen mixes, an open graded mix (ARFC) and a gap graded mix (ARFC). The Gap Graded mix (ARAC) was developed by the City of Phoenix in Arizona for use as a thin overlay (25 mm) on city streets. Both gradations are shown in Figure 9.
After some early and small experiments with rubberised bitumen 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 using rubberised bitumen 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 rubberised bitumen, by weight, of the mix as the binder. It 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 the District Maintenance department reviewed this project and concluded that as before no maintenance was needed and amazingly to date, eighteen years later, no maintenance has been performed on this section, Figure 11.
From this first project, dozens of projects have been successfully built with rubberised bitumen as the binder. The AR contains approximately 20 percent ground tyre crumb rubber by weight of the bitumen 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.
6. Rubberised Bitumen Mix Construction

Construction of an AR pavement involves first mixing and fully reacting the crumb rubber with the hot bitumen as required by specification. Typically 20 percent ground tyre rubber that meets the gradation shown in Table 1 and Figure 12 is added to the hot base bitumen. The bitumen needs to have a temperature of about 177°C (about 350°F) before being put into the blending unit, that heats the bitumen to 191°C to 218°C (375°F to 425°F) just prior to adding the rubber particles. The rubber and bitumen are mixed for at least one hour, Figure 13 & 14.

After reaction, the rubberised bitumen mixture is kept at a temperature of between 163°C and 191°C (325°F and 375°F) until it is introduced into the mixing plant, Figures 13 & 14. Samples of the rubber, base bitumen, 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/m² (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 tyres. Generally, one bag of lime is added to a water truck and sprayed on the pavement.

<table>
<thead>
<tr>
<th>Table 1 Ground Tyre Rubber Gradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>2 mm, #10</td>
</tr>
<tr>
<td>1.18 mm, #16</td>
</tr>
<tr>
<td>600 µm, #30</td>
</tr>
<tr>
<td>300 µm, #50</td>
</tr>
<tr>
<td>75 µm, #200</td>
</tr>
</tbody>
</table>

Figure 12- Crumb rubber

Minus No. 10 mesh is used; free of wire and other contaminants; up to 0.5% fiber.
Once blended, the Asphalt-Rubber binder is reacted in agitated tanks for 60 minutes.

Figure 13- Rubberised blender reaction process

Figure 14- Self contained mobile small rubberised bitumen blender
Figure 15- Rubberised bitumen construction

Figure 16- Rubberised bitumen construction

Paving can be done when ambient temperatures are at or above 13°C (55°F) and the road is dry. At this ambient temperature, the hot mix should be near the upper temperature in the range above. When the ambient temperature is at or above 18°C (65°F) there is more discretion with the hot mix temperature. In either case, however, it is essential that good paving practices and techniques be used, and that the hot bitumen with rubberized bitumen binder be rolled immediately upon its laying and not allowed to cool off before being worked.

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, rubberised bitumen 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 rubberised bitumen pavement sections are generally 37-62mm in thickness (1.5 to 2.5 inches). Thus the rubberised bitumen pavement will be on the order of half or less than half the thickness of the HMA pavements without rubberised bitumen, Figure 18.
7. Cost and Benefits

Cost comparisons would indicate that the AR binder alone is as much as twice as expensive as bitumen 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 Interstate 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, that costs about $5.00 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 eighteen years. One of the best examples of the beneficial cost effectiveness of rubberised bitumen is a major national concrete pavement rehabilitation project conducted as part of the Strategic Highway Research Program, in Flagstaff, Arizona on Interstate 40, Figures 19, 20 & 21.

Figure 18- Cross section of a pavement core with all three layers of mix

Figure 19- Concrete pavement in 1989 before rubberised bitumen 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 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 rubberised bitumen only when its usage appeared to be well suited to the problem and cost effective. Table 2 shows the cost of AR HMA mixes compared to dense-graded HMA made with neat bitumen binders. Rubberised bitumen 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 Metre Per 25 mm thickness)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>AC</th>
<th>ARAC</th>
<th>ACFC</th>
<th>AR-ACFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>1.89</td>
<td>3.71</td>
<td>2.09</td>
<td>3.18</td>
</tr>
<tr>
<td>1996</td>
<td>1.60</td>
<td>2.93</td>
<td>1.85</td>
<td>2.72</td>
</tr>
<tr>
<td>1997</td>
<td>1.59</td>
<td>2.99</td>
<td>1.84</td>
<td>2.56</td>
</tr>
<tr>
<td>1998</td>
<td>1.61</td>
<td>2.38</td>
<td>1.86</td>
<td>2.02</td>
</tr>
<tr>
<td>1999</td>
<td>1.64</td>
<td>2.77</td>
<td>1.84</td>
<td>2.10</td>
</tr>
<tr>
<td>2000</td>
<td>1.65</td>
<td>2.76</td>
<td>1.86</td>
<td>2.30</td>
</tr>
<tr>
<td>2001</td>
<td>1.66</td>
<td>2.99</td>
<td>1.90</td>
<td>2.49</td>
</tr>
<tr>
<td>2002</td>
<td>1.67</td>
<td>3.00</td>
<td>1.92</td>
<td>2.50</td>
</tr>
<tr>
<td>2003</td>
<td>1.68</td>
<td>3.02</td>
<td>1.93</td>
<td>2.52</td>
</tr>
<tr>
<td>2004</td>
<td>1.68</td>
<td>3.03</td>
<td>1.94</td>
<td>2.53</td>
</tr>
</tbody>
</table>

8. 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 rubberised bitumen

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) that is considered low and not of any major concern.
The average smoothness for AR projects over the eighteen year period has been very good with smoothness values below 1415 mm/km (93 inches per mile) that 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 rubberised bitumen](image)

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

![Figure 24- Reduced splash and spray with open graded rubberised bitumen](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>
<tr>
<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 rubberised bitumen placed*
Arizona State University (ASU) has also been looking at the Heat Island effect of higher night time temperatures [ASU06]. 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 bitumen pavements, roofs, buildings and other manmade structures. ASU is conducting research to determine whether an open graded rubberised bitumen 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 bitumen Rubber surfaces
9. European Use of Crumb Rubber in Pavements

Since about 2003 Portugal and Spain both have acquired modern AR blending equipment and are placing AR mixes very similar to those used in the United States. These mixes are performing in a manner consistent with the experience in the United States. Germany has also experimented with this same blending equipment with their own brand of AR mixes, however performance information about them is not presently available.

In addition Germany has also been placing dry process crumb rubber mixes. These dense graded dry process hot mixes typically use larger size crumb rubber as an aggregate. The dry process mixes can be mixed with hot bitumen with or without special modifiers that aid in binding the rubber to the bitumen. In France, proprietary crumb rubber mixes have been developed to reduce noise. Varying amounts of crumb rubber are used in preparing these mixes and in some cases the rubber content is less than 15 percent and/or the blending reaction process may not be utilized. These mixes all contribute to some degree to recycling waste tires, however performance of all these various crumb rubber mixes that are not rubberised bitumen is not as well documented and thus at this time cannot be fully evaluated.

The UK Highways Agency does not permit the use of the Dry Process in the United Kingdom.

10. The Terminal Blend Process

The Terminal Blend Process digests the crumb rubber into the bitumen cement at the refinery. The process has been used in Texas (USA) since 1995. It uses about half the amount of crumb rubber that is used by either the Wet Process or the Dry Process (10% of the bitumen binder versus 20% of the bitumen binder). In the Terminal Blend Process, the rubber melts into the bitumen and none of it remains rubber, per se. The total binder content is also lower (5.5% versus 8.5%).

11. Benefits of Rubberised Bitumen

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 rubberised bitumen. 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 tyres have been beneficially recycled into pavement hot mix, Figure 30.
Asphalt Rubber Benefits

* 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- Rubberised bitumen benefits

Tires Put to Good Use

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

Figure 30- 20 million tyres beneficially recycled into pavement hot mix
12. Why is Rubberised Bitumen a Best Practice?

1. It is a less expensive application when used as a thin top course over failed pavement that would otherwise need replacement (California & Arizona studies);

2. It is less expensive to maintain per lane-kilometre (lane-mile) in years 6 through 15 of pavement life over conventional pavements, and the same in years 1 through 5 (Arizona & California studies);

3. It significantly reduces noise as opposed to concrete pavements, and also is quieter than bituminous pavements; rubber bitumen makes urban environments more habitable (Arizona DOT studies);

4. It significantly improves wet surface traffic safety (Texas DOT studies);

5. It creates less of a “heat island” effect than with concrete pavement at surface (Arizona State University studies);

6. It provides better surface road drainage when used in an Open Grade Friction Course (Texas & Arizona studies); and

7. It is a hugely beneficial use for post-consumer waste tyre materials, using about 1,000 waste passenger tyres per lane-mile (about 621 waste passenger tyres per lane-kilometre).

Each of these, on its own, is a significant benefit and reason enough for the use of rubberised bitumen to be a Best Practice. In total, the seven benefits together are huge.

13. Challenges

The challenges of using rubberised bitumen, as previously stated, generally focus on additional cost if highway designers will not allow a reduced pavement layer thickness due to the proven properties of rubberised bitumen. Other challenges that have been mentioned include lack of availability of suitable crumb rubber processing facilities in the vicinity and the cost of such facilities, the need for suitable blending and mixing equipment and the cost of such equipment, the degree of difficulty in preparing mix design, the lack of rubberised bitumen binder and mix standards, the lack of trained personnel, and uncertainty and doubt about how long AR will last. Although all of these challenges 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.
14. Conclusion

The story of rubberised bitumen 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 rubberised bitumen reference material can be found at the Rubber Pavements website [RPA06] as well as in the proceedings of two International Rubberised bitumen 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.

15. Acknowledgements

This Chapter on Rubberised Bitumen was prepared by George B. Way, P.E., a registered consulting professional civil engineer. Mr Way recently retired from the Arizona Department of Transportation (ADOT) as the Chief Pavement Design Engineer after 35 years of service. Mr Way served in various capacities with the ADOT from 1969 to 2004. His work with ADOT included research, pavement management and pavement design. In the course of his long tenure with the ADOT he was involved in the earliest experiments with rubberised bitumen and was a contemporary colleague of Mr Charles McDonald and all the other early pioneers of rubberised bitumen. He continued his close contact with the research and development of rubberised bitumen and has authored numerous research and technical design papers about rubberised bitumen over the last 30 years. As the ADOT Chief Pavement Design Engineer he oversaw the development of hundreds of rubberised bitumen pavement designs since 1988. Presently he is a private civil engineering consultant and also serves as the Chairman of the Technical Advisory Board of the Rubber Pavements Association (RPA) and Chairman of the Board of Directors of the Recycled Tire Engineering & Research Foundation (RTERF).

The RPA and RTERF are both excellent sources of additional information on rubberised bitumen use in the United States and most of its use worldwide. The RPA has a very complete library of rubberised bitumen papers and their website is linked to many other sources of information about the use of crumb rubber. RPA's website is www.rubberpavements.org. The RTERF is a very newly formed non-profit charitable foundation that promotes the engineering use of recycle tyre rubber primarily in pavements by means of research and training. The RTERF can be contacted at the email address of gway517855@aol.com.
16. References


---

**Important Warning**

The information set out in the above is of a general nature only and not intended to be relied upon in specific cases. The information does not take account of environmental issues which should be discussed as a matter of routine with the regulatory authorities (the Environment Agency in England and Wales, the Scottish Environment Protection Agency in Scotland and the Department of the Environment in Northern Ireland). Consequently, the information contained in this website is provided only on the condition that WRAP and their sub-contractors will not be liable for any loss, expense or damage arising from the use or application of such information. Individuals and organisations proposing to utilise any of the practices and methodologies within these publications are advised to seek appropriate expert professional advice in respect to their specific situation and requirements. Any errors or omissions contained within the reports are the responsibility of the respective authors.