Asphalt-Rubber 45 Years of Progress

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ABSTRACT. *Since the mid 1960's the state of Arizona in the United States has used a unique asphalt binder called asphalt-rubber (AR) which contains a large percentage of crumb rubber from ground scrap tires as an asphalt binder. This unique paving asphalt material consisting of approximately 20 percent ground scrap tires and 80 percent paving grade asphalt is used to primarily reduce all types of cracking, including reflective cracking, thermal cracking, fatigue cracking and it is used as a crack and joint sealant. This paper describes and summarizes the 45 years of progress in the development of AR from both a technical and non-technical perspective. AR's progressive development has been helped along by early inventors and later by the Asphalt Rubber Producers Group (ARPG) and presently by the Rubber Pavements Association (RPA). In addition, soon after the formation of the RPA it was decided that a Technical Advisory Board (TAB) composed of members from industry, academia and government agencies was needed to develop and shape a long term technical vision of future asphalt rubber research. The TAB was formed in 1997 and began to lay plans for future research. Recommendations were made to compile a good literature review and library of the present state of the art and practice of asphalt rubber. Since 1997 the TAB has made recommendations to further advance the state-of–knowledge about Asphalt Rubber. The TAB along with RPA members have influenced and supported technical advances of AR as documented in previous AR International Conferences and ASTM standard specifications. They have helped to document AR's numerous benefits both mechanical (cracking and rutting) and environmental (noise, energy and CO_2). This report reviews the technically progressive development and use of AR and of the people and organizations that have been responsible for supporting and sponsoring technical research and development of AR over a 45 year period in US and in countries across the world.*

KEYWORDS: *asphalt-rubber, history, rpa, tab, keyword*

1. Asphalt-rubber Development

Asphalt-rubber (AR) is a mixture of hot asphalt and crumb rubber derived from waste or scrap tires. It is used extensively in the highway paving industry, particularly in the states of Arizona, California, Texas and Florida. 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) defines AR as “a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles,” [1] This definition was developed in the late 1990’s, however the story of how AR was originally invented, patented, how it has been and how it is presently used, how it is made, and its benefits which have increased with time, that story begins in the 1950’s.

The initial development of AR 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 [2]. McDonald’s early efforts resulted in the development of small, prefabricated AR patches that he called “Band-Aids”, Figure 1. Others had investigated the use of rubber in various forms in asphalt as noted in a Federal Highway Administration (FHWA) report in 1971, [3]. As noted in this report most of the reviewed studies involved the incorporation of unvulcanized natural rubber or latex rubber in asphalt. Some research did involve the testing of vulcanized rubber in asphalt but results were somewhat inconclusive.

2. Asphalt-rubber Inventor Charles McDonald

Charles McDonald is considered the modern day developer of the wet process AR, Figure 1. He had been a long time employee of the federal agency responsible for the highway programs, the Bureau of Public Roads, later the Federal Highway Administration (FHWA). In the early 1960's McDonald had retired from the FHWA and accepted a position as Chief Engineer of the materials division for the City of Phoenix, Arizona. Because of his long experience with pavements, McDonald knew that flexibility at ambient temperatures was needed in the pavement systems. A previous part of McDonald's life also came into play. In the 1930's McDonald had worked on a survey crew locating highway routes at remote locations. To overcome the housing situation, usually at best a tent camp, McDonald had constructed a small building on a trailer. Unfortunately every time he moved this building the roofing material cracked. In about 1959 McDonald found an elastomeric material and coated the entire roof with it and this solved his problem. In considering the need for a thin flexible coating for pavements he remembered this experience. McDonald reasoned that a similar type of material, an elastomeric material, might solve the problem for the roadways. This led to numerous, probably

hundreds, of simple experiments in the early 1960's wherein he tried combining many other materials with asphalts. McDonald did not have a sophisticated laboratory to conduct these experiments, and in fact the laboratory equipment and procedures to evaluate such materials had not been developed in the 1960's.

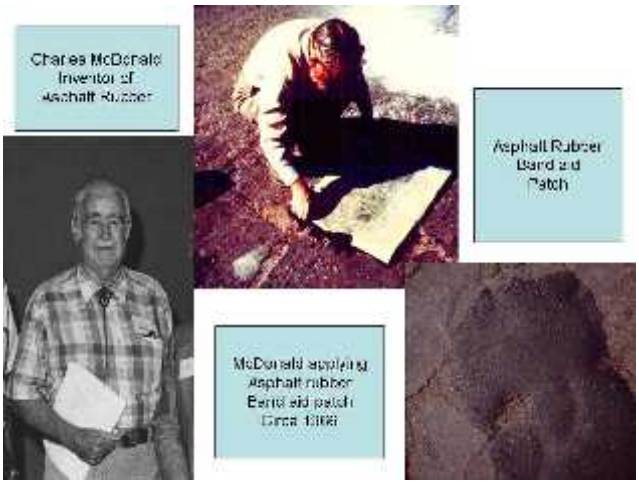

Figure 1. *Charles McDonald Asphalt-rubber Band-aid*

During this process McDonald found that low cost elastic material was available in the form of crumb rubber ground from old tires. One source of this was the grindings from shops where tires were retreaded for renewed use. To combine a liquid rubber to asphalt was relatively easy but the cost was too great. To combine ground solid vulcanized rubber to asphalt, one would assume that you had to provide sufficient temperature to melt the rubber. This required temperatures in excess of 260°C (500°F). This was very costly and was also impractical for field application. Others had tried this approach with unsatisfactory results since the elastic properties of the combination were not sufficiently improved. During his experiments McDonald discovered that if he cooked the rubber and asphalt together at a lower temperature, a reaction of some type occurred. The viscosity of the mixture increased in time and after a period of time reached a plateau level. Later research revealed that with this reaction the rubber particles expanded to about twice their original size and became soft and sticky. At this level the material also exhibited excellent viscous characteristics at high temperatures and developed an elastic phase. With hundreds and perhaps thousands of simple experiments McDonald evaluated how the percentage of rubber, time and temperature of cooking, and various types of rubber affected the final products properties.

By today's standards McDonald's procedures were crude. However they were practical and effective for evaluating pavement materials. He studied high temperature behavior by placing samples on the roof of his Phoenix laboratory and

also on the city streets. He studied the low temperature behavior in his refrigerator and freezer. He also placed small test sections in cold climate areas in northern Arizona. He evaluated elasticity by simple and effective rebound tests. He developed procedures to evaluate viscosity. The results of the tests indicated that a threshold of a minimum rubber content of approximately 15% depending on rubber type and asphalt source was necessary to achieve a desirable viscosity and elasticity. It has since been postulated that at or near this threshold value, the reacted rubber particles form a continuous phase or matrix throughout the mixture. An optimal percentage of rubber was probably between 20 and 25%. McDonald also settled on a reaction temperature of 177°C (350°F) and a reaction time of 45 minutes minimum for an optimal and potential production procedure. This wet process was patented by McDonald in 1978 [4]. Other patents associated with the McDonald patent were also issued at about this same time. The most notable of these patents was another wet patent issued to Arizona Refining Company [5]. The patents for both products expired in 1995, yet they both remain the two most popular AR binders.

3. Patented Asphalt-rubber Products

McDonald's asphalt rubber (AR) was patented in 1970' and at about this same time Arizona Refining Company (ARCO) patented another AR material. Thus, there were two competing materials that had been patented separately in the 1970's. Both products had been used in Arizona with a good deal of success. The McDonald material was composed of 75% asphalt binder and 25% vulcanized crumb rubber from scrap tires. These ingredients were mixed together for about 45 minutes to one hour at about 177°C (350°F). After the heating and mixing were complete about 7.5% kerosene (diluent) was added to thin the material enough to be spray applied. Sahuaro Asphalt and Petroleum of Arizona marketed the McDonald AR product as Overflex. Later after spray applied equipment improvements were made the need for kerosene was eliminated. The competing ARCO product consisted of four ingredients; asphalt binder, extender oil, unvulcanized rubber from primarily tennis balls and vulcanized rubber from scrape tires. ARCO of Arizona marketed their product under the name Arm-R-Shield.

Sahuaro marketed their product primarily in the United States. ARCO marketed not only in the United States and primarily California, but also in several foreign countries including Canada, Belgium and South Africa.

From 1969 until 1978 there was considerable research and development and then in 1978 both AR products were patented. In particular a means was needed to spray apply the very hot and viscous material as a chip seal. Within these formative years Bearcat Manufacturing of Arizona [6] developed equipment with pumping, metering and agitation capabilities needed to handle the highly viscous AR materials. Bearcat company of Arizona invented a special distributor truck to spray apply the AR binder as part of a chip sealing operation. Both the Sahuaro and

ARCO companies bought and used the Bearcat distributor truck to spray apply their products, Figure 2.

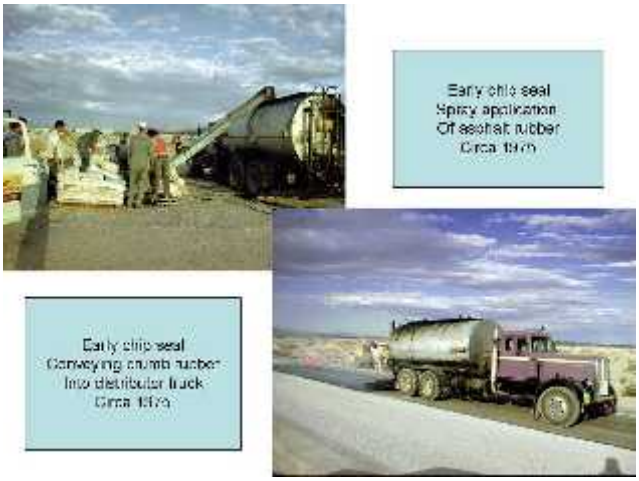

Figure 2. *AR chip seal*

With this 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 hot mix asphalt (HMA) surfacing. The interlayer application is typically referred to as a Stress Absorbing Membrane Interlayer (SAMI), Figure 3 and 4. Both the SAM and SAMI applications showed great promise in reducing reflective cracking [7]. Starting in about 1985 AR binder usage was expanded by adding AR to hot mixes including gap graded and open graded mixes, Figure 5, [8].

Figure 3. *Asphalt-rubber Stress Absorbing Membrane (SAM)*

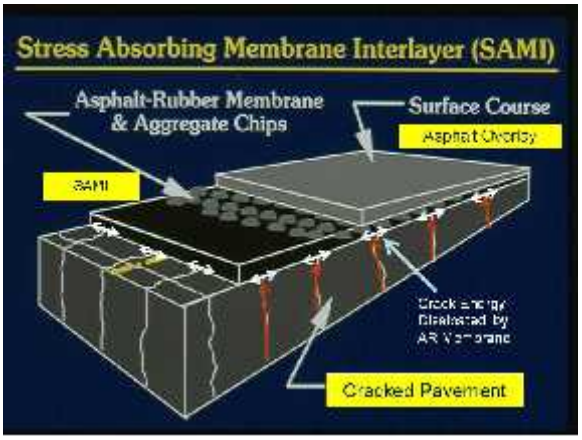

Figure 4. *Asphalt-rubber Stress Absorbing Membrane Interlayer (SAMI)*

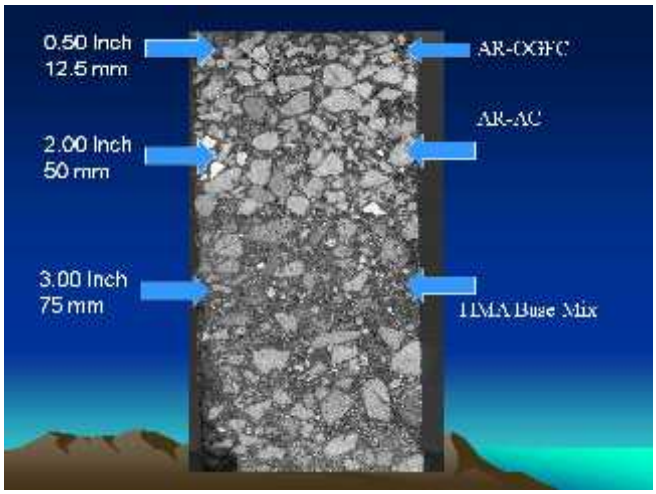

Figure 5. *AR Open Graded and Gap Graded Mixes*

4. AR and the Economy

By 1978 the future looked bright for AR. The inventors had obtained industry support from Sahuaro Petroleum and ARCO for the product and Bearcat Manufacturing had developed a means to spray apply AR. Charles McDonald enlisted the help of Gene Morris the Research Engineer of the Arizona Department of Transportation (ADOT) to cooperate on supporting further research and development. Both Charles McDonald and Gene Morris convinced their bosses, Fred Glendenning, Director of Public Works for the City of Phoenix and William N.

Price who was the state engineer of the Arizona Highway Department, later the Arizona Department of Transportation. Both Charles McDonald and Gene Morris agreed that without Mr. Glendening and Price's strong and continuing support throughout the 1970's it would not have been able to develop or implement the use of AR in Arizona or later in the United States or worldwide.

One other ingredient was needed to further inspire the use of AR was a local source of crumb rubber from scrap tires. During the latter half of the 1970's a major Canadian corporation explored the potential future for AR and decided to establish itself strongly in crumb rubber supply from scrap tires. Genstar, a group with strong interests in the financial world, owned some nineteen cement mills, ready mix concrete producers, and concrete block manufacturing facilities. They developed a plan to become a major supplier of crumb rubber from scrap tires. This plan included purchasing of U.S. Rubber Reclaiming, obtaining a facility in Chicago, and building ten additional plants strategically located throughout the United States. The first of the plants was built in Chandler, Arizona in 1978. There plan indicated that this plant was to provide a needed research facility for the industry. Fernly Smith, who had previously operated a rubber reclaiming facility in Ohio, was named to direct this effort. Smith in turn employed Ken Wardlaw, a civil engineer and former field engineer for the Asphalt Institute, to assist with the marketing promotion for the industry. Wardlaw's experience with the Asphalt Institute had provided him with a solid knowledge of the state highway departments and how to market products to them. Smith and Wardlaw organized the first industry sponsored national conference on AR and it was held in Scottsdale, Arizona in 1980 [9].

Although the 1980 national conference on AR was successful there was an economic cloud hovering over the fledgling AR industry. In 1979 the world and the United States in particular was rocked by the second Middle East oil crisis in the wake of the Iranian revolution. This was followed by the Iraq and Iran war that began in 1980, which did not end until 1988. In 1979 the barrel of oil price went from roughly $35 to $75. All oil related products like AR saw the cost of their products skyrocket while revenues for highway construction declined due to less driving. The net result to the AR industry was to see a shrinking amount of activity and revenue. This changed the market place and in 1983, the controlling management of Genstar changed and the decision was made to divest the company of all interests except those directly connected to the financial world. To this end all of the facilities associated with reclaiming rubber were sold and the plant in Arizona dismantled. This action severely crippled the AR industry which lost a strong force for the marketing of their products.

During these lean years several other significant changes occurred in the industry. The Edgington Refinery had previously been sold to the Penn Companies because of the health of the owner, Ralph Edgington. In a few short years the Penn Companies found that the rehabilitation of their aging refinery was too costly and in 1983 declared bankruptcy. Their subsidiary, Sahuaro Petroleum, was a profitable enterprise but they were also forced to close their doors. ARCO

was a wholly owned subsidiary of Unocal, and was the only portion of the corporation that dealt with asphalt supply. Donald Nielsen had served as President of ARCO for many years but decided to retire in 1982. Within a short time Unocal decided to divest itself of ARCO. Jacobson and Johnson owners of a local Arizona construction company JWJ purchased all of the AR equipment from these two companies and in May, 1983 established International Surfacing, Inc. The use of the patents outstanding on AR was also acquired by JWJ at this time and many of the experienced employees were hired by I.S.I.

5. Asphalt Rubber Producers Group

It became clear to by 1985 it was recognized that a need existed for an organization to represent the AR producers. The Asphalt Rubber Producers Group (ARPG) was formed in 1985 to advance the use of AR. The group represented several companies that either used the McDonald or ARCO wet process patents. ARPG was in existence when the United States congress passed the INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT OF 1991, which contained **SEC. 1038. USE OF RECYCLED PAVING MATERIAL,** which mandated the use of AR binder throughout the United States, [10]. There are varying interpretations as to what part ARPG played in developing or supporting Section 1038. There is no doubt that the individual states blamed ARPG for this very unwise piece of legislation which was repelled in 1995.

Ultimately as the patents ended I.S.I. faced competition from other contractors and I.S.I sold out to International Surfacing Systems a California based company. In the crumb rubber area Baker Rubber built a new and updated rubber grinding facility in the east of metropolitan area east of Phoenix. Tim Baker took up where Fernly Smith left off, revitalizing the AR industry in Arizona. Subsequently, Baker Rubber had to sell out. Various companies came and went at the scrap tire rubber plant which is presently owned by CRM, Inc [11].

6. Rubber Pavements Association

Following the repeal of Section 1038 and the AR patents expiration in 1995 the AR industry needed to re-group. In 1997 a new organization was formed with the name of Rubber Pavement Association (RPA). The RPA is a 501(c) 6, non-profit association composed of members that supply ground tire rubber, contractors that produce AR binder and/or hot mix, engineers, academics, government agencies, consultants and equipment suppliers [12]. The RPA provides information library consisting of various reports on the manufacturer and use of AR.

7. RPA TAB Background

The Rubber Pavements Association (RPA) Technical Advisory Board (TAB) was formed in 1997. The TAB is composed of many distinguished experts in the pavement and hot mix asphalt field, Figure 6. These experts represent a broad knowledge of hot mix asphalt (HMA) design, construction and maintenance. Those persons serving on the TAB include people from the HMA construction industry, state and federal Departments of Transportation, consultants and University Professors. Serving on the TAB is voluntary and members receive no honorarium for their time. Figure 4 gives the current active members of the TAB.

Figure 6. *TAB Members*

The purpose of the TAB is to advise the RPA Executive Board about future research needs to further the technical knowledge about asphalt rubber, its practical usefulness and benefit. From the recommendation of the TAB the Executive Committee decides upon the funding to support the proposed research effort. The following is a brief summary of the major research sponsored and substantially funded by the RPA based upon the recommendations of the TAB. As a result of the TAB's efforts a considerable body of research and research related work has been conducted. The following is a list of this work;

8. Research Studies and Reports

- "Life Cycle Costs For Asphalt-Rubber Paving Materials," study by Drs. Gary Hicks and Jon Epps [13]
- Development of a Mechanistic Overlay Design Method Based on Reflective Cracking Concepts," by Drs. Jorge Sousa and Jorge Pais, Richard Stubstad and George Way [14]
- "The Aging and Fatigue Behavior of Asphalt Rubber Mixes," by Dr. Lufti Raad [15]
- "Asphalt Rubber Design And Construction Guidelines," by Dr. Gary Hicks [16]
- "Quality Control For Asphalt Rubber Binders And Mixes," by Dr. Gary Hicks [17]
- "Evaluation of Caltrans Modified Binder (MB) Specification," by Dr. Gary Hicks [18]
- "Evaluation of Asphalt Rubber Pavements in Texas," by Maghsoud Tahmoressi [19]
- "The Arizona Asphalt-Rubber Project Review Part 1," by Doug Carlson and Gene Morris [20]

Other Related Research Activities

The TAB has drafted numerous ASTM Standards including the following shown in Figure 7. The TAB has contributed to four AR International Conferences, AR2000 in Portugal [21], AR2003 in Brazil [22], AR2006 in California [23] and AR2009 in China [24].

TAB ASTM Activities

Standards Developed

ASTM 6114 Asphalt-Rubber Specification
ASTM 6932 Open-Graded Friction Course Design & Construction
ASTM 7064 Open-Graded Friction Course Mix Design
ASTM 7584 Asphalt-Rubber Cape Seal
Newly developed Standard
ASTM 7741 Test Method for Measurement of Apparent Viscosity of Asphalt-Rubber or Other Asphalt Binders by Using a Rotational Hand Held Viscometer

Figure 7. *TAB ASTM Standard*

8. Closure

The RPA continues to contribute to the AR industry. The RPA is a vibrant organization which has helped to document AR's numerous benefits both mechanical (cracking and rutting) and environmental (noise, energy and CO_2). Besides members across the United States it has members around the world, Figure 8. The story of AR began on or about the year 1965 with the simple goal of developing a maintenance patching material to hold together old crack pavements long enough to allow for the future overlaying or reconstruction of the pavement. In the intervening 45 plus years its use has grown an expanded into a myriad of areas and now is a routine seal coating and paving material in Arizona, California, Texas and Florida. Useful products from adding scrap tire crumb rubber to pavements will continue to be developed because pavements that last longer, use less material and need less maintenance will always be in demand.

Figure 7 - *RPA Members Worldwide*

8. Acknowledgement

Thanks to Gene Morris for his notes on the AR history.

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