MIXTURES WITH REACTED AND ACTIVATED RUBBER FROM RECYCLED TIRES

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ABSTRACT

The wet method technology of using crumb rubber from recycled tires as a modifier of asphalt (bitumen) binder has been successfully used in crack sealing, spray applications (chip seals) and hot mix asphalt for at least 50 years starting in the 1960's in Arizona and California. The crumb rubber wet process is a practical means of providing environmental, economic, sustainable, and safety of using crumb rubber from recycled tires using the wet method technology widely used in societal benefits. New imaginative and innovative engineering technology concepts have led to the development of a new crumb rubber semi-wet method material. The new semi-wet method employs reacted and activated rubber (RAR). The RAR semi-wet method has demonstrated a product capable matching and surpassing the performance of traditional hot mix asphalt and the traditional crumb rubber method asphalt. Basically, RAR consists of pre-treated and pre-reacted rubber that can be used directly in a mix plant just like a "filler" thus it is easy to handle and requires no special equipment for blending crumb rubber and asphalt and no additional heat source. The RAR dry filler when it meets hot asphalt amalgamates in such a way as to become like the traditional crumb rubber method asphalt rubber. The RAR is superior from the traditional crumb rubber method since it can be used at higher percentages. To ensure the quality and take advantage of the unique nature of RAR new specifications. These specifications encompass a broad range of quality measures to better enable a wide use by road departments. This paper introduces the concept and some experiences of mixes with RAR and presents how the added flexible fatigue resistance of those mixes leads to great environmental benefits. It introduces key concepts that can be the basis of specifications that can be used by road departments to ensure, not only that the crumb rubber is properly reacted and treated, but that the mixes have adequate bitumen and RAR to satisfy flexural/reflective fatigue.

Keywords: reacted and activated rubber, fatigue life, crumb rubber.

1 Introduction

With traffic loading constantly increasing, natural environmental damage never ending and funding for highways static or shrinking government agencies must look for new paving materials such as recycled tire crumb rubber to provide an acceptable functioning highway

network. The primary reason for using recycled tire crumb rubber asphalt binder referred to as Asphalt Rubber (AR) in Hot Mix Asphalts (HMA) is that it provides significantly improved engineering properties over conventional paving grade asphalt (bitumen). Asphalt rubber binders are engineered to perform in virually all climate conditions and traffic. At intermediate and high temperatures, Asphalt rubber binder's are significantly different than those of conventional paving grade asphalts. The rubber stiffens the binder and increases elasticity (proportion of deformation that is recoverable), decreases pavement temperature susceptibility and improves resistance to permanent deformation (rutting) and fatigue.
AR hot mix asphalts proven advantages are clearly enumerated in all seven international Asphalt Rubber conferences from 2000 to 2018 [1,2,3,4,5,6,7] and elsewhere, yet universal practical implementation of this technology has stalled for several reasons. Some reasons of this stagnation are listed as follows:

- The time-consuming wet process method of producing the Asphalt Rubber Binder, involving very high temperature (over 190ºC) and long blending and reaction time (45 min. up to one hour).
- The complexity and cost of the blending unit that must be installed in every asphalt mixing plant.
- The necessity to re-heat the hot asphalt rubber binder after longer rest periods.
- The mis-perception about Asphalt Rubber costs per ton. AR is used in thin appications and the AR cost per square meter is generally less than the cost of other asphalt paving materials.

In view of the proven advantage of AR technology, an effort was made to overcome the main disadvantages listed above. One solution that was found to provide a basis for an innovating and improving Asphalt Rubber is the new "Reacted and Activated Rubber" – RAR which employs the new semi/wet method process.

2 Background

The new type of rubberized asphalt, Reacted and Activated Rubber is referred to as the semi/wet process which combines the strengths of the two processes to create more environmentally friendly and sustainable rubberized asphalt. The original dry and wet process started with many crumb rubber patented products so it is with the semi-wet process. This new semi/wet process, like its predecessors is a patented product [8]. The semi-wet process combines the strengths of both processes. In the semi-wet process the crumb rubber particles are reacted and activated with asphalt binder and a filler to produce a dry powder Figure 1 that can be rapidly and efficiently handled and mixed with the hot aggregate and hot asphalt in the same manner as the dry process. Unlike the dry process no additional mixing or heating equipment is needed, saving significant equipment cost; nor is a premixing reaction time of 45-60 minutes necessary, thus saving energy and reducing CO_2 emissions.

Figure 1: Reacted and Activated Rubber Components and Product Powder.

The environment benefits of placing crumb rubber in pavements using the wet method have been widely demonstrated [9,10,11,12,13,14] showing significant CO_2 reduction by using asphalt rubber thin overlay compared to conventional hot mix overlay. These papers have demonstrated that there are significant energy savings when asphalt rubber wet method is placed in 50 mm overlay instead 100 mm overlay of regular mixes. They have shown that at least for each lb. (0.45 kg) of crumb rubber used in pavements there is a saving of about 200000 BTU (211000 kilo-joules). CALRECYLE reports that annually about 500000 tons (454000 metric tons) of tires are disposed of in California (https://www.calrecycle.ca.gov/tires/overview). This corresponds to about 350000 tons (317000) of crumb rubber that could be use in paving mixes.Since 2005 the California Department of Transportation (Caltrans) has implemented State Law Assembly Bill 338 to incoporate by weight AR in 35% of their HMA mixes, reducing the number of tires placed in landfills and scrap tire piles. However, if the law would require that ALL the California HMA at the city, county and state level use AR an energy benefit that would correspond to the same amount of energy used by about 70% of the households in California per year, based on data from the latest census (https://www.census.gov/quickfacts/CA) and energy consumption per household.
(https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ca.pdf)
Portugal's analysis consisting of 50000 tons (45000 metric tons) of scrap tires in AR daily saved 0.018 euros/KWH, total savings corresponding to 100 million euros annually, or about 50% of the maintenance budget for the public sector roads. These values demonstrate the strong beneficial impacts that policies that would lead to the complete use of annual disposed tires can have on the road construction sector using Reacted and Activated Rubber.

3 Case Studies

The inspiration for the development of RAR began in the Consulpav laboratory in the 2011. By 2015 RAR was commercially produced in Israel on a limited basis. A few test sections of RAR hot mix asphalt gap graded mix were constructed in Israel [15] and later manufacture of RAR was discontinued.A new kind of RAR was invented in 2016 by Consulpav in Portugal. In 2016 a small quantity of RAR produced in Potugal was used in test section demonstration projects [8]. This new process and product were patented in 2017. Later a larger manufacturing facility along with a source of recycle tire rubber was develpoed in Madrid, Spain; named CIRTEC, to make and market Reacted and Activated Rubber product with the trade name RARX™. The commercial production of RARX began in 2017 and increased as more road sections were built, and then complete paving projects of substantial size began to be constructed. From the inspiration in 2011 to the present an amazing total of 4144 lane-km (lanes 1000 m long 3.5 m wide) have been constructed employing RAR in SMA, GAP Graded, OPEN graded and Thin Gap hot mixes. The RARX has been used in spray applications, seal coats and SAMI. It is beyond the scope of this paper to review in detail each project job shown in Table 1, however a few of the more unusual and demanding jobs are reviewed to indicate the RARX very good performance capability have already been reported. The first use of RAR was in Israel. Three short test sections were constructed in 2012 using RAR in an SMA hot mix as a substitute for fibers [16]. Ishai reported on the design and construction of the SMA. The construction using RAR was the same as the routine SMA construction. Performance of the RAR SMA mix was as good as the routine SMA mix. A summary report of several of the trial test sections constructed in the 2012–2015-time frame was prepared in 2018 [16]. The paper shows through Case Studies the research and development efforts in the laboratory and the description of actual constructed road test sections that were monitored for performance in Russia, Israel, Bulgaria, France, Portugal, and Italy. In 2017 a challenging project using RAR in a spray application and thin gap hot mix was constructed in Jakarta, Indonesia. A research study documents results of a first of its kind crumb rubber modified asphalt trial using reacted and activated rubber in Jakarta, Indonesia [17] in both a RAR spray application (SAMI) with a RAR gap graded overlay.

TABLE 1 – List of jobs constructed with RAR around the world

JOB SITE	LOCATION	COUNTRY	YEAR
BULGARIA	Highwasy A-1 Lyubiments	BULGARIA	2013
CHILE		CHILE	2019
COREA DEL SUR		COREA DEL SUR	2017
Lefoll Contractor	secundary roads	FRANCE	2014
ALEMANIA	BAVIERA	GERMANY	2018
AUTOPISTA DE YAKARTA	YAKARTA	INDONESIA	2017
COAL ROADS		INDONESIA	2018
SEVERAL ROADS		INDONESIA	2018
CIRCUNVALACION DE DUBLIN	DUBLIN	IRLANDA	2018
TELAVIV	Quarry Access road	ISRAEL	2012
TELAVIV	Yeheskel Street	ISRAEL	2014
TELAVIV	Salame Street	ISRAEL	2014
Province of Trento	SS421	ITALIA	2013
City of Bussero	Via Primo Maggio	ITALIA	2013
Venio	Viale Cavour Cernusco	ITALIA	2014
Rho	Via Magenta	ITALIA	2013
Trento	SS 12 Freight terminal	ITALIA	2013
ITALIA		ITALIA	2017
AEROPUERTO DE GUADALAJARA	GUADALAJARA	MEXICO	2021
AEROPUERTO DE TIJUANA	TIIUANA	MEXICO	2020
CIRCUNVALACION DE MORELIA	MORELIA	MEXICO	2021
AUTOPISTA PIRAMIDES	PIRAMIDES	MEXICO	2018-2019
BRAGA	Freeway Access ramps	PORTUGAL	2021
BOMBARRAL	Freeway Toll Plaza	PORTUGAL	2015
SAINT PETERSBURG	Ringway South	RUSSIA	2013
SAINT PETERSBURG	Bridge	RUSSIA	2018
ARABIA SAUDI		SAUDI ARABIA	2018-2020
CONSERVACION A-3	MADRID	SPAIN	2020-2021
OPERACIÓN ASFALTO MADRID	MADRID	SPAIN	2020
OPERACIÓN ASFALTO MADRID	MADRID	SPAIN	2020
PLAN ASFALTO FUENLABRADA 2017	FUENLABRADA	SPAIN	2017
SEGOVIA		SPAIN	2020
CARRIL BICI TORREJÓN DE ARDOZ	TORREJON DE ARDOZ	SPAIN	2017
FUERTEVENTURA	FUERTEVENTURA	SPAIN	2019
ZAMORA		SPAIN	2019
AUTOVIA A-68	ZARAGOZA	SPAIN	2020
OPERACIÓN ASFALTO MADRID	MADRID	SPAIN	2020
PLAN ASFALTO DE COSLADA	COSLADA	SPAIN	2019
SEGOVIA	(en blanco)	SPAIN	2020
REFUERZO L-313 GUISSONA	LERIDA	SPAIN	2017
MALLORCA	MALLORCA	SPAIN	2019
PLAN DE ASFALTO DE MALAGA	MALAGA	SPAIN	2018-2019
PLAN DE ASFALTO DE MALAGA	MALAGA	SPAIN	2019-2020
PUERTO DE HUELVA	HUELVA	SPAIN	2020
GRANADA	GRANADA	SPAIN	2020
LA GRANJA	SEGOVIA	SPAIN	2020
OPERACIÓN ASFALTO MADRID	MADRID	SPAIN	2019-2020
PLAN ASFALTO FUENLABRADA 2017	FUENLABRADA	SPAIN	2017
PLAN DE AASFALTO FUENLABRADA	FUENLABRADA	SPAIN	2018
PLAN DE ASFALTO DE MALAGA	MALAGA	SPAIN	2018-2019-2020
ALICANTE	ALICANTE	SPAIN	2018-2020
GRANADA	GRANADA	SPAIN	2019
A-42 PLAZA ELIPTICA	MADRID	SPAIN	2018
OPERACIÓN ASFALTO MADRID	MADRID	SPAIN	2020
SEGOVIA		SPAIN	2018
AEROPUERTO GRAN CANARIAS	GRAN CANARIAS	SPAIN	2019
ALBACETE	ALBACETE	SPAIN	2019
AEROPUERTO DE FUERTEVENTURA	FUERTEVENTURA	SPAIN	2018
CV-35	VALENCIA	SPAIN	2021
PARKING ALEGRA		SPAIN	2021
LLANERA	OVIEDO	SPAIN	2021
PRUEBAS	OURENSE	SPAIN	2018
PLAN ASFALTO DE COSLADA	COSLADA	SPAIN	2018
AUTOVIA A-4	VALDEPEÑAS	SPAIN	2019
SOUTH OF SWEDEN		SWEDEN	2014
VIRGINIA-USA	VIRGINIA	USA	2019
MICHIGAN	MICHIGAN	USA	2018

In 2018 the first example of the use of RAR Thin Gap and Chip Seal coat in the USA was constructed in Kalamazoo, Michigan. The test section construction project and associated research efforts were a combined partnership between Michigan Department of Environmental Quality, Road Commission of Kalamazoo County and Michigan Technical University. A report study on the RAR Thin Gap test section was prepared by Michigan Technical University [18] noting the success of this project. In 2018 Sacyr participated in the use of RARX in the framework of an R&D project called: SILENT RUBBER PAVE in Ireland [19] with Eptisa preparing the final report documenting the success of the project [20]. All these projects are still performing extremely well taking into consideration that those RAR mixes have been placed over very badly cracked pavements and some with extremely poor drainage and under very wet conditions and always with reduced thickness as compared with conventional solutions.

4 Binder Properties

The asphalt rubber (AR) binder has unique properites reported in numerous research studies [21,22,23,24,25,26,27]. Historically AR binders for spray applications and hot mix asphalt contain crumb rubber from 15 to 22% by weight of the binder, whereas RAR asphalt binder can be as much as 40%. Figure 2 shows viscosity at 175° C for AR at 18% rubber versus RAR at 40% binder. The RAR binder pretreated activates instantly in the hot plant and retains its higher viscosity up to two hours. This figure shows hot plant heating is adequate to obtain RAR binder properties without additional preheating or mixing for one hour or more thus saving heating costs and CO_2. Figure 3 shows five different unmodified asphalts PG 64 or PG 70. Adding RAR raises the high temperature PG grade to ultimately PG 120 ensuring greater resistance to rutting.

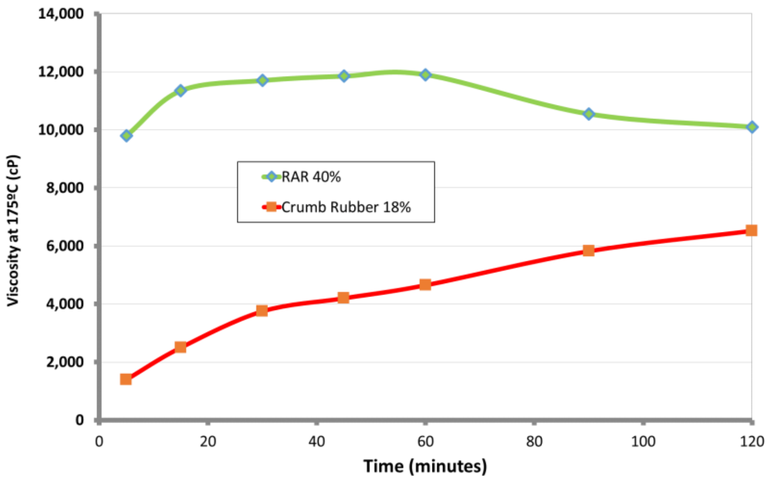

Figure 2: Viscosity 175ºC, asphalt rubber 18% rubber versus RAR binder 40% rubber.

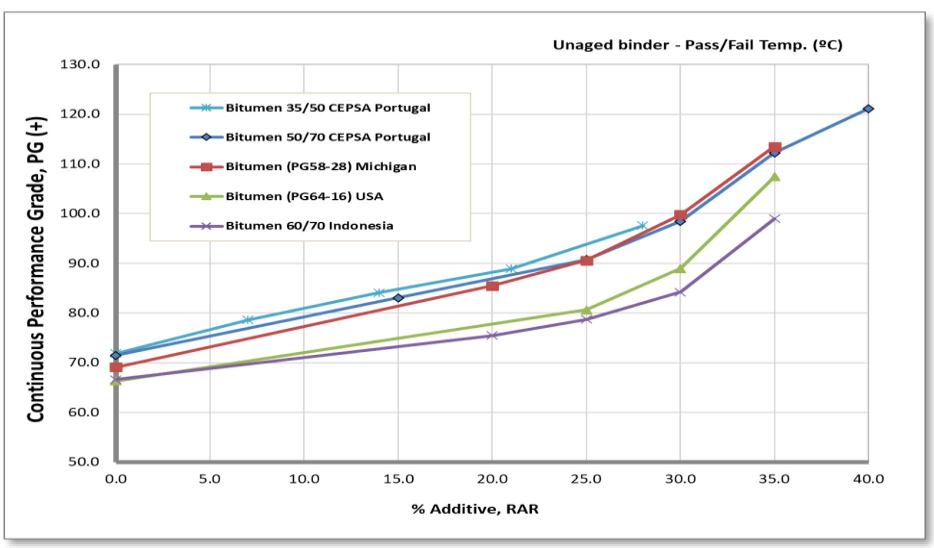

Figure 3: Five different asphalts modified with various percentages of RAR and tested for the high temperature component of the PG grading system.

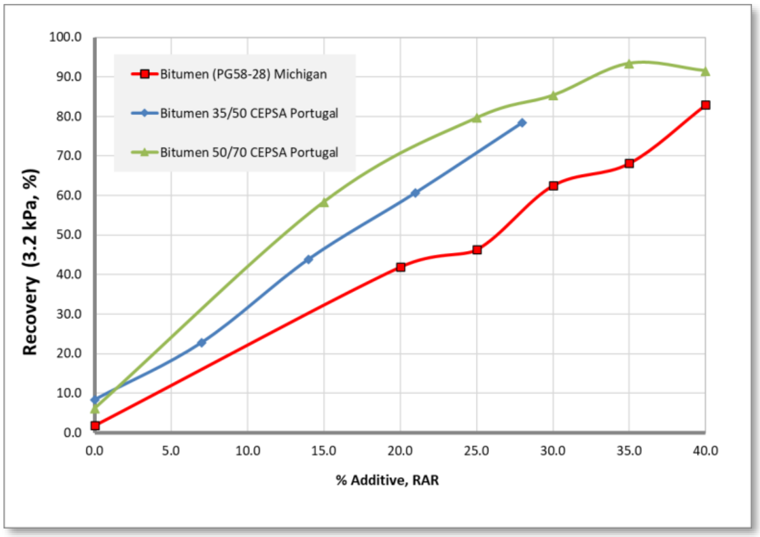

Figure 4: Percentage of recovery for different asphalts modified with various percentages of RAR

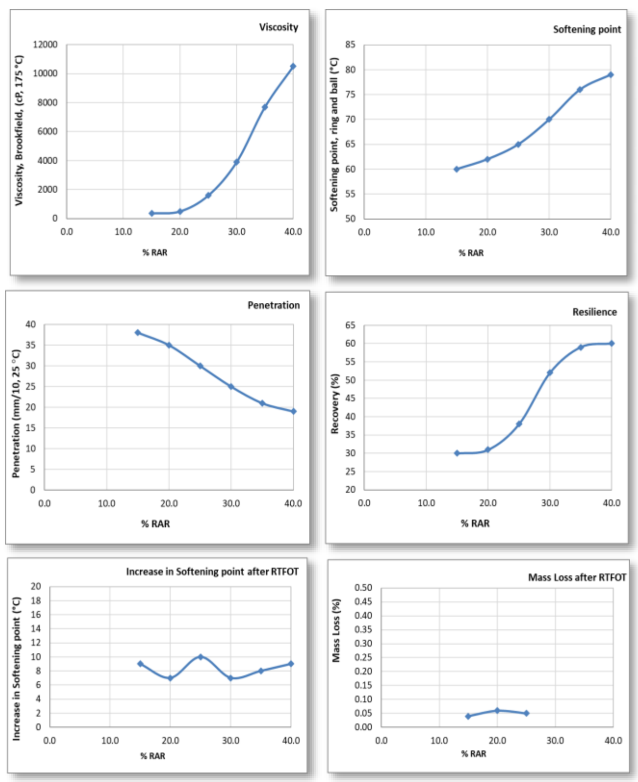

Figure 5: Results of basic and conventional asphalt binder tests.

Figure 4 shows RAR percent recovery increases indicating both rutting resistance and less flexural fatigue cracking. Figure 5 show the results of basic and conventional asphalt binder tests. The Viscosity, Softening Point, Penetration and Resilience (Recovery) tests were conducted on unaged binder at ever increasing percentages of RAR which contribute to reducing the occurrence of rutting in the pavement. Softening Point and Mass Loss were tested after RTFOT aging and evaluated as a function of RAR content in the total combined binder. The increase in softening point with RAR indicates binder stability through the laydown machine and compaction. . The mass loss like the increase in softening point is another measure of the binder stability. These test results indicate the combined RAR binder leads to reducing hot mix rutting and cracking.

5 Mix Properties

There are many RAR properties are relevant for the good performance of asphalt mixes as noted in numerous research studies [28,29,30,31,32,33,34,35,36,37,38]. From rutting resistance, texture depths, moisture resistance and fatigue resistance many others play a role in optimizing mix performance. For RAR mixes rutting performance is satisfactory due to both binder and aggregate properties, texture depth is controlled by aggregate soundness and gradation control and given the high amounts of binder in RAR mixes moisture resistance is regularly high. What really distinguishes RAR mixes is fatigue resistance. The RAR fatigue resistance characteristic is particularly important because RAR mixes are usually placed as a thin overlay and the existing pavement condition is particularly distressed due to a high level of cracking.

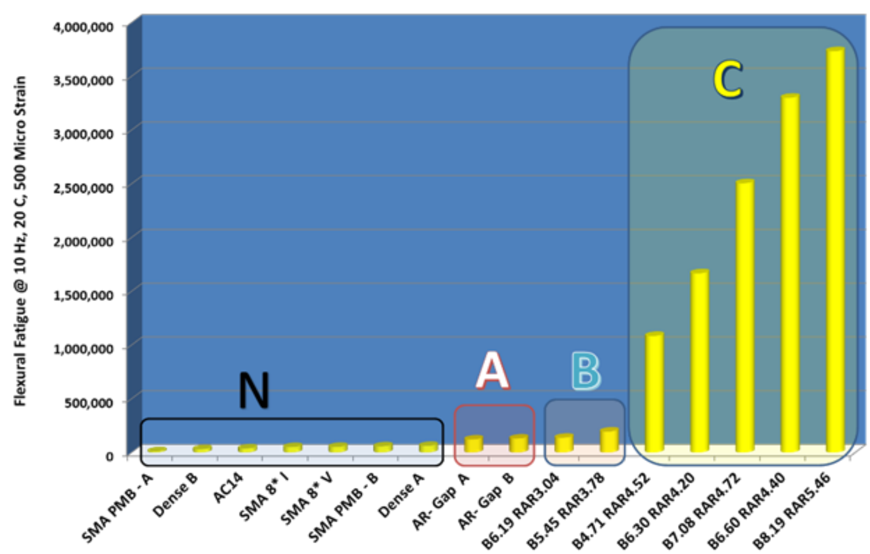

Figure 6: Components/Aspect of Reacted and Activated Rubber.

Figure 6 shows the laboratory testing results of tests performed on various asphalt mixes prepared in the laboratory and tested with the four-point bending beam test and demonstrate greater percent of rubber in the AR and RAR the fatigue life is increased substantially. Figure 7 displays a comparison between the fatigue life four-point bending test results summarized in Figure 6 plotted with the estimated fatigue life values calculated from the Shell equation. The Shell equation estimate is a function of the volume of binder which for this illustration covers a wide range associated with the wide range of weight percent values shown on the x axis. Clearly the Shell equation demonstrates the reasonableness of the premise that as weight percent, i.e., volume percent, increases the fatigue life of the mix increases very dramatically as the four-point bending beam test results indicate.

$$\varepsilon_t = ((0{,}856 \times V_b + 1{,}08) \times E^{-0{,}36} \times N^{-0{,}2})$$

where:

$$V_b = \frac{P_b . G_t}{G_b}$$

ε_t – Tensile extension.
V_b – Non absorbed bitumen percentage by VOLUME of the mix.
E – Bituminous mixture deformability module (Pa).
N – Number of repetitions to failure, i.e. reach 50% moduli reduction.
P_b – Bitumen percentage by weight of the mix.
G_t – Bituminous mixture's specific gravity.
G_b – Bitumen specific gravity at 25ºC.

Figure 8 further amplifies on the reasonableness of greater weight percent, i.e., volume percent, of RAR binder by comparing selected pairs of actual four-point bending beam fatigue lives as illustrated in Figure 5 to the corresponding Shell estimated value. The correlation is remarkably good confirming AR and RAR are acting as a modified asphalt binder not a dry process rubber aggregate. As noted in a 2018 Federal Highway Administration sponsored report [39] the authors reviewed the dry process technology from 1970's to the 2000's. The authors noted that the dry process mixes did not perform to a degree any better than a normal hot mix without rubber and they stated, "*... there is concern that the dry added GTR (Ground Tire Rubber) may lack enough reaction time to provide the desired viscosity increase.*" This statement is in line with reported performance research like that of Juan Gallego [40]. This recognition that dry mixes with a rubber filler are not comparable to the fatigue life of RAR semi-wet process mixes is in keeping with the fatigue life results shown in Figures 6,7 and 8. These findings support the need to incorporate flexural fatigue tests in the required specifications for design and construction control of the RAR mix.

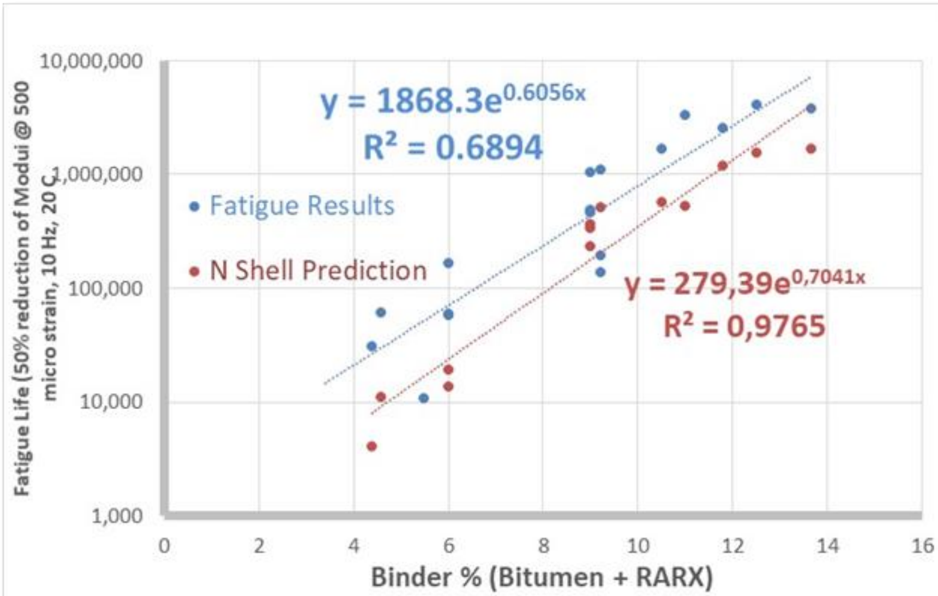

Figure 7: Predicted by Shell equation and actually fatigue results in four point bending testing function of binder %.

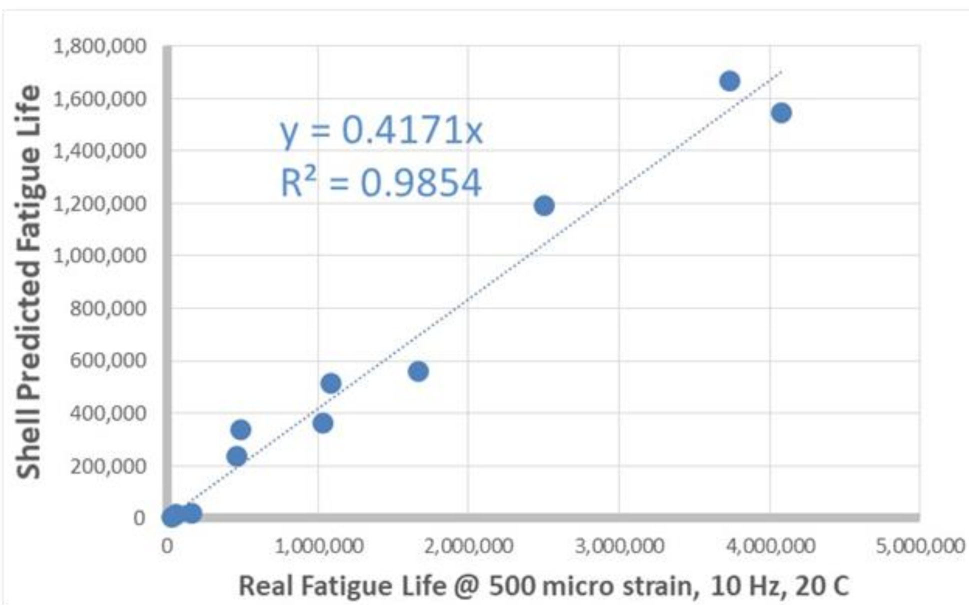

Figure 8: Relationship between fatigue life actually obtained in four-point flexural fatigue testing and predicted by Shell equation.

As previously stated, the RAR designed mixes have good rutting resistance. The RAR fatigue resistance is particularly important because RAR mixes are usually placed as a thin overlay over a cracked pavement. A design method using Falling Weight Deflectometer data derived from field tests and tailored to thin overlay AR mixes placed on badly cracked pavements was reported in 2002 [41]. This method is being fine-tuned for RAR mixes and is presently being validated and will be reported on at the RAR2022 Rubberized Asphalt conference in Malaga, Spain scheduled for June 27-29, 2022 [42].

6 Binder design Specifications

Specific RAR binder specifications are needed to ensure a properly reacted and sufficiently activated binder. Table 2 proposes new specifications to quantify the RAR asphalt binder properties obtained from ASTM tests conducted in the laboratory. The RAR binder is prepared in the laboratory by stirring the two components for five minutes at 175° C at 1200 rpm. The RAR asphalt binder by meeting the specified is suitable for field placement and compaction.

TABLE 2 – Binder specifications using RAR at different percentages levels

Requirements/Properties		Standard reference	Unit	Bituminous binder with a weight ratio of RAR				
				from 18 to 22%	from 25 to 30%	from 30 to 35%	from 38 to 42%	of 40%
Density of the bituminous binder (bitumen + RAR) (a)	at 25°C	ASTM D70 - 18a	Kg/m^3	To be declared	To be declared	To be declared	To be declared	-
Consistency at intermediate service temperature	Penetration at 25°C	ASTM D5 - 20	0,1 mm	> 30	> 20	> 15	> 10	> 10
Consistency at high service temperature	Softening temperature	ASTM D36 – 14	°C	≥ 60	≥ 62	≥ 65	≥ 70	≥ 70
Durability (Resistance to aging - RTFOT at 163°C, ASTM D2872 - 19)	Retained Penetration	ASTM D5 - 20	%	≥ 60	≥ 60	≥ 60	≥ 60	≥ 60
	Increase in softening temperature	ASTM D36 – 14	°C	Class 2 ≤ 10	Class 2 ≤ 10	Class 2 ≤ 10	Class 2 ≤ 10	Class 2 ≤ 10
	Decrease in softening temperature	ASTM D36 – 14	°C	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
	Mass variation (absolute value)	AASHTO T240 ASTM D2872 – 19	%	Class 4 ≤ 0,8	Class 4 ≤ 0,8	Class 4 ≤ 0,8	Class 4 ≤ 0,8	Class 4 ≤ 0,8
Other requirements	Resilience	ASTM D5329	%	≥ 30	≥ 35	≥ 45	≥ 50	≥ 50
	Dynamic viscosity at 175°C after 5 min (VIS 5 min @ 175°C)	ASTM D4402 – 15	MPa.s	≥ 400 < 2000	≥ 1300 < 5000	≥ 3000 < 9000	≥ 5000 < 16000	≥ 5000 < 15000
	Dynamic viscosity at 175°C after 120 min	ASTM D4402 – 15	MPa.s	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C
	Multi Stress Creep Recovery (MSCR) Average recovery at 3.2 kPa	ASTM D7405-20	%	≥ 35	≥ 70	≥ 70	≥ 80	≥ 80
	Flash Point	ASTM D3143 - 19	°C	≥ 235	≥ 235	≥ 235	≥ 235	≥ 235
(a) – The density of the bituminous binder is significantly influenced by the weight ratio of RAR/bituminous binder; its value is indispensable for obtaining the volumetric composition of bituminous mixtures								

7 Mix design Specifications

Table 3 indicates different mixes that can be developed with RAR and recommended percentages to be used in the binder. A properly designed RAR mix should respect the minimum 12-micron film thickness as proposed by [43,44]. Table 4 shows suggested aggregate gradations for the various mixes presented in Table 3.

TABLE 3 – Sample of applicability of different types of mixes with RAR

Bituminous mixture	Abbreviated designation	Maximum dimension of the aggregate (mm)	Layer	Project Layer Thickness (cm)	Binder % RAR (by weight)
Bituminous macadam with added RAR	**MB 20 RAR**	20	Binder, Regularization, Base Courses	5 to 9	10 to 22
SMA bituminous mixture with addition of RAR	**SMA 11 RAR**	11	Wearing Course	3 to 5	25 to 30
Highly discontinued SMA bituminous mixture with the addition of RAR	**SMA 14G RAR**	14	Wearing, Binder, Regularization courses	4 to 8	30 to 35
Super discontinuous SMA bituminous mixture with addition of RAR	**SMA 10S RAR**	10	Wearing course	2.5 to 5	38 to 42
	SMA 8S RAR	8	Wearing Course	2 to 5	38 to 42

TABLE 4 – Sample of aggregate gradation types to be used with RAR

Sieves (mm)	Mix type				
	MB 20 bin RAR	SMA 14G surf RAR	SMA 8S surf RAR	SMA 10S surf RAR	SMA 11 surf RAR
	Cumulative percentage of passed material				
40	–				
31.5	100				
20	90 - 100	100			
16	–	–			100
14	–	90 - 100			
12.5	55 - 85	–	100	100	
11.2					90 - 100
10	–	68 - 83	100	90 – 100 [(a)]	
8			85 - 100	–	55 - 80
6.3	–	43 - 56	50 – 65	45 – 60	
4	30 - 40	24 - 35	28 – 45	12 – 25	18 - 28
2	20 - 30	13 – 21	12 – 25	9 – 15	16 – 25
1	–	–	–	–	–
0.5	8 -18	8 - 13	–	–	8 – 16
0.125	3 - 8	–	–	–	–
0.063	1 - 4	0 - 2	1 - 4	0 - 3	3 – 6
The granulometric composition is obtained from at least three distinct granulometric fractions (a) - If the layer thickness is between 20 and 25 mm the accumulated percentage of the material passed through the 10 mm sieve should be 100%					

Table 5 show proposed ASTM based RAR mix design specifications. It is based on Marshall design procedure and considers laboratory produced specimens using Marshal compactor and using rolling wheel compactor specimens to produce slabs, for wheel tracking testing in the determination of rut resistance, and to be cut into beams for four-point bending beam flexural fatigue testing. Consulpav propose similar field testing to further ensure a high-quality rut resistant, long fatigue life RAR mix is constructed in the field. The draft proposed project quality control specification [45,46] is about 100 pages long is under evaluation and will be made available at the RAR2022 Rubberized Asphalt Conference in Malaga, Spain, June 27-29, 2022.

TABLE 5 – Sample of mix specifications to be expected with different types of mixes with RAR

Requirements and properties		Standard reference	Specific test conditions	Unit	Mix type					
					MB 20 bin RAR MB 20 base RAR MB 20 reg RAR	SMA 14G bin RAR SMA 14G reg RAR	SMA 14G surf RAR	SMA 8S surf RAR	SMA 10S surf RAR	SMA 11 surf RAR
Marshall Characteristics	Stability, max.	ASTM D6927-15	Molding of samples: ASTM D6927 75 Blows	kN	*Smax17,5* (a)	*Smax15* (a)	*Smax15* (a)	*Smax* 15	To be declared	*Smax* 17,5 (a)
	Stability, min.			kN	*Smin10*	*Smin7,5*	*Smin7,5*	*Smin* 7,5	*Smin* 8	*Smin* 7,5
	Deformation, max.			mm	F5	F5	F5	F5	F5	F4
	Deformation, min .			mm	F3	F3	F3	F3	F3	F2
	Marshall Quotient			kN/mm	*Qmin2,5*	*Qmin* 2	*Qmin* 2	To be declared	To be declared	*Qmin* 3
Voids in the aggregate mixture (VMA), min.		ASTM D2726-05	ASTM D2726 - 05 - Calculated based on maximum theoretical gravity (b) - determined according to ASTM D2041 in water and in gravity (c)	%	VMA*min15*	VMA*min19*	*VMAmin19*	VMA*min24*	VMA*min25*	VMA*min14*
Porosity, Vm		ASTM D2726 - 05	ASTM D2726 - 05 - Calculated based on maximum theoretical gravity (b) - determined according to ASTM D2041 / in water and in gravity (c)	%	Vmin3,*0* - V*max6,0*	Vmin3,*5* - V*max6,5*	Vmin3,*5* - V*max6,5*	Vmin1,*5* - V*max3,5*	Vmin3,*0* - V*max5,5*	Vmin2,*0* - V*max5,0*
Percentage of binder by ignition		ASTM D 6307	Determined for the optimum percentage of binder of the mixture under study (opt) and for another four percentages of binder: opt-1%; opt-0.5%; opt+0.5%; opt+1% (e)	%	To be declared	B*min9,0* (d)	B*min9,0* (d)	B*min11,5* (c)	B*min11,0* (c)	B*min8.0* (d)
Conserved Resistance Index (IRC) in Marshall compression tests, min.		MIL-STD-620A	Molding of samples: ASTM D6927 75 Blows	%	80	80	80	90	90	80
Resistance to Permanent Deformation ("Wheel- tracking")	Deformation rate WTS_{AR}	ASTM D8292 - 20	Small equipment, procedure B, air conditioning, test temperature 60ºC	mm/10^3 load cycle	0.08	0.08	0.08	0,09	0,08	0.09
	Maximum rut depth, PRD_{AR}			%	6	6	6	6	6	6
Fatigue strength (Number of cycles, min.)		ASTM D7460 - 08	Tests with frequency of 10 Hz, temperature of 20ºC and maximum extension of 500 x 10^{-6}; result is the average value of three samples	Load cycles	$4,0 \times 10^4$	$3,0 \times 10^5$	$3,0 \times 10^5$	$1,5 \times 10^6$	$1,2 \times 10^6$	$2,0 \times 10^5$
Percentage of bituminous binder (bitumen + RAR), min.		-	-	%	B*min5,3* (d)	To be declared	To be declared	To be declared	To be declared	To be declared
Weight ratio of RAR in the bituminous binder		-	Weight percentage of RAR in the bituminous binder (bitumen + RAR)	%	18 to 22	30 to 35	30 to 35	38 to 42	38 to 42	25 to 30
Water sensitivity, ITSR, min		ASTM D6931 - 17	Molding of samples: ASTM D6927 - 75 blows, test temperature: 15ºC	%	$ITSR_{75}$	$ITSR_{90}$	$ITSR_{90}$	$ITSR_{90}$	$ITSR_{90}$	$ITSR_{90}$
Bitumen drain-down, max		ASTM D6390 - 11	Schellenberg test in glass beaker	%	-	0.3	0.3	0.3	0.3	0.3

(a) - For granitoids and aggregates from rocks with a predominance of silica in their composition, the maximum stability should be 21 kN.

(b) - Calculated for the optimal percentage of binder in the mixture under study.

(c) - For the molding of the samples, the impact compactor with 75 blows is used, in accordance with the ASTM D6927 standard.

(d) - This value corresponds to the lowest percentage of bituminous binder to be used in the manufacture of the bituminous mixture - to be considered for the starting point of the Marshall test - from which 4 more bituminous mixtures will be manufactured, with five percentages of bituminous binder, with successive increments of 0.5% of bitumen.

(e) - for each percentage of binder, the declared value corresponds to the average value of at least three tests.

8 Conclusion

For more than 60 years asphalt rubber wet method technology has been successfully used around the world and particularly in California and Arizona. There also has been widely documented the environmental benefits of paving solutions using asphalt rubber wet method. This paper brings such beneficial attributes to light showing how Reacted and Activated Rubber enhances several of the reported environmental advantages.

More than 4000 lane-km have been paved with several types of mixes using a binder composed of unmodified bitumen and reacted and activated rubber. Some of those mixes have been in place for more than nine years still exhibiting great performance even when placed over highly damaged pavements.

It is one key objective of this paper to present the overall performance of RAR hot mixes and to identify the key aspects that lead to the successful implementation of RAR asphalt binders, namely the great elastic behavior imparted by the addition of the reacted and activated rubber.

The second key objective is put a spotlight on the kinds of specifications that need to be included in road departments specifications to ensure not only that the RAR placed in the mix contains properly reacted rubber but also that the rutting resistance; and most particularly the fatigue resistance of the RAR mixes is properly characterized by requiring four-point bending beam flexural test results at 500 micro strain, 10 Hz and 20 ºC.

Properly designed RAR mixes can have flexural fatigue lives more than 100 times higher than conventional mixes with highly beneficial cost-effective solutions. Furthermore, the very high PG grade of these RAR mixes increase the likelihood that the mixes will not be subjected to permanent deformation.

With the ever present environmental need to reduce carbon footprint; paving solution mixes with high RAR contents stand out as the likely candidates for widespread applications on private and public road networks.

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