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2018 Conferenc

The RAR2018 KRUGER Park, South Africa Conference proceedings, summarize more than a half a century of experience in the usage of Asphalt-Rubber binders as defined by ASTM D6114-97 (2002). However now new products have emerged based on innovative ideas and a more deep understanding on how crumb rubber can be used. Their effect of the functional and structural performance of pavements, properties of mixes and binders is considered.

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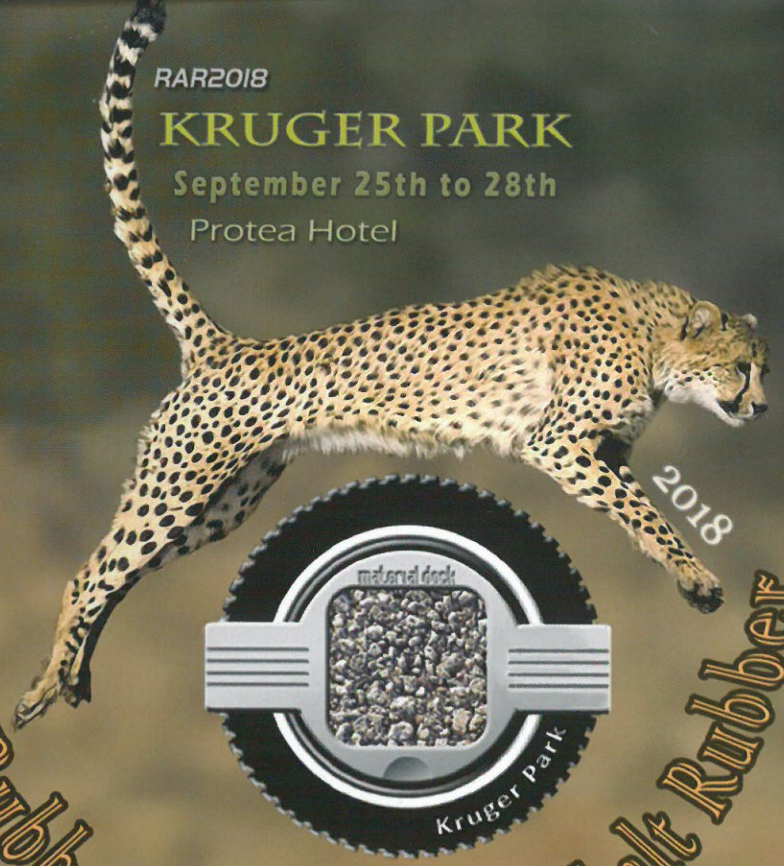
Proceedings
Rubberized Asphalt ◆ Asphalt Rubber
2018

Edited by
Jorge B. Sousa, PhD
George Way, PE
Alex Visser, Prof.

RAR2018
KRUGER PARK
September 25th to 28th
Protea Hotel



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This publication includes all the communications accepted for publication at the Rubberized Asphalt • Asphalt Rubber 2018 Conference that took place in the Kruger National Park, South Africa, 25th to 28th of September, 2018.

Las Vegas, USA, October 2015

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Kruger National Park, South Africa, September 2018

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Synopsis

These Proceedings from the **RAR2018** Conference in Kruger National Park, South Africa, summarized 56 years of research and experience in the use, performance, and properties of Asphalt-Rubber binders and provided much needed vital current and historical information on the product for engineers worldwide. This information has allowed engineers to successfully take advantage of this cost effective, durable and environmentally beneficial material. These proceedings from **RAR2018** will build on the earlier **AR2000, AR2003, AR2006, AR2009, AR2012 and RAR2015** volumes through the latest research and experiences of routine and beginning users throughout the world.

as less splash and spray and quiet less tire/pavement interface noise surface, thin surfaces that save on the quantity of aggregate and thus reduce the amount of CO2 as well as the quantity of energy needed to build a pavement, less tire wear and be helpful to reducing the heat island effect. A fountain head of research papers have evidenced the environmental and sustainability qualities of using GTR in asphalt.

These conferences have documented the cost effectiveness of GTR in asphalt. As the cost of asphalt and other related products have increased in the last 18 years the cost of GTR has remained remarkably relatively constant. In addition new GTR in asphalt products using less GTR, or less heat to make GTR in asphalt, have made the cost effectiveness of GTR in asphalt more attractive.

Beyond the many engineering and environmental qualities documented in all of the conferences there is the human side of the story of GTR in asphalt. This conference would not have come to Africa and specifically South Africa without the good efforts of Professor Alex Visser. Alex has long been a contributor to the rubberized asphalt conferences. He was a presenter at AR2000 and contributor to virtually all the conferences as a presenter, moderator and member of the Technical Committee. His long-standing research efforts regarding recycling tires is in keeping with his countries recognition of the need to support climate change initiatives and a sustainable environment.

In closing, South Africa was selected for this conference because of Alex Visser and the recognition that it was time for the conference to be held on the African continent. The location of the conference is unlike any other in the world, as we share our time at the conference hotel literally observing a world filled with wild animals living all around us, in a setting much like our ancestors observed so very long ago. Africa is where mankind began to move away from the wild and wild animals, and proceeded to advance, it is hoped that this conference can in some ways be a new beginning for rubberized asphalt to continue to advance for the good of mankind and the preserving of nature. Enjoy South Africa, enjoy observing the wild animals and enjoy the conference.

George B. Way, P.E.
Conference Co-Chairman

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Asphalt-rubber mixtures with Warm Mix Asphalt technology and high porosity volcanic aggregates

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ABSTRACT. *Crumb rubber modified (CRM) binders have shown to improve the performance of some bituminous mixtures. In volcanic regions the aggregates are frequently obtained from rocks with a vesicular or scoriaceous structure with high porosity, but the higher absorption, variability and heterogeneous properties make these aggregates marginal and not recommended for structural materials due to the technical specifications. The use of rubber-modified binders in mixtures with these aggregates can contribute to utilize both wastes. However, the production and compaction temperatures of asphalt-rubber mixtures are higher than when using conventional bitumen as the rubber provides a greater viscosity, reducing workability. Consequently, it produces higher energy consumptions and emissions, which compromises its environmental sustainability.*

This study presents the principal engineering properties of low temperature asphalt mixtures with rubber-modified bitumen (asphalt-rubber warm mixes, ARWM) and high porosity vesiculated and scoriaceous basalt. The temperature reduction was carried out *using a liquid surfactant chemical additive in reduced proportion (0.5% by bitumen weight). The results show that with this additive it is possible to lower the production temperatures of the mixtures with asphalt-rubber and porous volcanic aggregates while the mechanical performance is within the specifications for pavements. The results obtained may be extrapolated to other volcanic regions both insular and continental areas where this type of aggregate is commonly found.*

KEYWORDS: Bituminous mixture, Volcanic aggregate, Vesicular basalt, Asphalt-rubber warm mixture (ARWM), Low-temperature mixture, Crumb rubber modifier (CRM), Reclaimed tyre.

1. Introduction

High porosity vesicular and scoriaceous aggregates are the most common lithotypes in volcanic regions. However, the non-cubic particle shape, the higher heterogeneity, alveolar structure and absorption make these aggregates marginal and commonly not recommended for structural materials due to the technical specifications [1].

According to previous studies, bituminous mixtures with crumb rubber modified (CRM) binders have proved the production of paving materials offering enhanced performance and durability [2-5]. They can also offer certain environmental advantages and reduction of traffic noise. Asphalt-rubber (AR), also called "wet process", consist in the blend of asphalt binder and ground recycled tyre rubber powder from scrap end-of-life tyres (ELT) in which the rubber component has reacted in the hot asphalt cement to cause swelling of the rubber particles. Due to the ability of AR to improve the performance properties of some mixtures, the possibility of employing it in paving mixtures with marginal volcanic aggregates has a crucial interest in these regions in order to exploit the local resources and contribute to the environment protection.

However, the production temperatures of asphalt-rubber hot mixtures (ARHM) are usually higher than when using conventional binders as the rubber provides a greater viscosity, reducing workability and as a consequence, decreasing the laying and compaction time. Moreover, it produces higher energy consumptions and emissions, which compromises its environmental sustainability. Thus, AR mixtures must be produced preferably using procedures allowing lower temperatures or warm mix asphalt technologies (WMA).

Some of the most utilized methods to reduce the bitumen viscosity, and so the production temperature generally 20–30 ºC, use different types of microcrystalline waxes [6-8]. However, these additives are expensive as they are required in important quantities, up to 2–4% by weight of bitumen [9].

On the contrary, in this study a tensioactive chemical additive was used in reduced proportion to raise the surfactant capacity of the binder with the aggregates and so coating them at lower temperatures. The laboratory characterization of asphalt-rubber mixes with volcanic aggregates from high porosity vesicular and scoriaceous basalt (6–16% of water absorption) at different low temperatures (mixing between 140 and 170 ºC) is presented in this work. These are called asphalt-rubber warm mixtures (ARWM) throughout this paper. These results are compared to AR mixtures produced at high temperature (mixed at 180 ºC) and also to mixtures with conventional bitumen (at 170 ºC), all of them with the same volcanic aggregates.

2. Experimental

2.1. Materials

290 cylindrical specimens, 44 slab specimens and 50 non-compacted samples, including reference specimens, of semi-dense asphalt concrete for surface courses (AC16 surf S) were produced in the laboratory. This type of bituminous mix was

using a liquid surfactant chemical additive in reduced proportion (0.5% by bitumen weight). The results show that with this additive it is possible to lower the production temperatures of the mixtures with asphalt-rubber and porous volcanic aggregates while the mechanical performance is within the specifications for pavements. The results obtained may be extrapolated to other volcanic regions both insular and continental areas where this type of aggregate is commonly found.

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produced following the Spanish road specifications (PG-3) [10] and is according to the European Standard EN 13108-1.

All the fractions of the aggregate used in the mixtures (10–20, 4–10 and 0–4 mm) where obtained from volcanic rock from the same quarry in Gran Canaria (Canary Islands, Spain). The type of all-in aggregate is a mechanically-crushed vesicular olivinic-piroxenic grey basalt of high porosity, a very common and abundant lithotype of volcanic rock. Table 1 summarizes the main properties and in Fig. 1 a detail may be observed. As mineral filler (# < 0.063 mm), a Portland cement with pozzolanic addition was used. The type of cement was CEM II/B-P 32.5 R, according to EN 197-1.

Figure 1: *Detail of the coarse fraction of the vesiculated and scoriaceous basalt*

These scoriaceous aggregates may be considered marginal according to the technical specifications. The average resistance to fragmentation of the particles (LA = 28 – 29) slightly exceed the standard limits and the high porosity (WA_{24} = 6 – 16%) produces an elevated consumption of binder and energy in order to evaporate water. By contrast, they offer reduced flakiness index (FI) and the resistance to polishing (PSV) usually comply with standard specifications.

The reference mixtures without rubber used a commercial bitumen 35/50 pen (density: 1.042 Mg/m^3; penetration at 25 °C, 100 g, 5 s: 44x10^{-1} mm; softening point: 51.6 °C). The binder of the mixtures with rubber was an asphalt-rubber of the same penetration grade (AR35/50; density: 1.028 Mg/m^3; penetration: 38x10^{-1} mm; softening point: 64.2 °C), produced in the laboratory by adding the crumb rubber modifier (CRM).

The CRM was manufactured by mechanical grinding at ambient temperature (50% from used truck tyres; 50% used car tyres). The thermogravimetric analysis revealed the following composition: 57.41% polymer (rubber), 32.22% carbon black, 6.02% ash and 4.67% plasticizer and additives. A hundred per cent by wt. of CRM passed through sieve 1.0 mm (EN 933-2), 94.1% accumulated of a size smaller than 0.5 mm, 23.7% smaller than 0.25 mm, 3.7% smaller than 0.125 mm and 0.4% smaller than 0.063 mm.

Table 1: *Main properties of the different aggregate fractions. Tests according to European Standards*

	Aggregate fractions			Specified target values according to technical standards [10]
	# 10–20 mm	# 4–10 mm	# 0–4 mm	
% (by wt. of the total aggregate) (*)	20.93	36.27	38.88	—
r_{SSD} (Mg/m^3)	2.63	2.56	2.36	—
r_{rd} (Mg/m^3)	2.35	2.37	2.23	—
WA_{24} (%)	5.8	8.3	15.5	≤ 3 – 3.5 % (recommended for cement concrete); ≤ 6 – 7 % (recommended for recycled aggregates);
FI	6	6	-	≤ 20 – 30 (**)
LA	29	28	-	≤ 20 – ≤ 25 (**)
PSV	60	60	-	≥ 50 – 56 (**)

(*) The total aggregate includes 3.92% of mineral filler (# < 0.063 mm) of Portland cement with pozzolanic addition; (**) Limits of technical specifications depending on the heavy traffic category; (r_{SSD}) Particle density [saturated surface dry] [EN 1097-6]; (r_{rd}) Particle density [dry] [EN 1097-6]; (WA_{24}) Water absorption of particles after 24 hours [EN 1097-6]; (FI) Flakiness index [EN 933-3]; (LA) Los-Angeles coefficient [EN 1097-2]; (PSV) Polished stone value [EN 1097-8].

The surfactant chemical additive (Cecabase RT®) to produce the warm asphalt mixes was supplied by Arkema Innovative Chemistry (France).

2.2. *Instruments*

To produce the AR binder in the laboratory, mixing CRM with hot bitumen: a) disperser unit (IKA Ultra-Turrax T50 digital, with a propeller agitator), 600-15000 rpm; b) oil bath (max. 225 °C, with temperature probe, stability ±1.0 °C) and one-litre metal container.

To make and test the bituminous specimens: a) mixer for bituminous materials (Mecacisa), 60-390 rpm, capacity 30 l, automatic temperature control, stability ±1.0 °C; b) infrared thermometer (Testo 830-T4), range –30 to 400 °C, resolution ±0.1 °C and accuracy ±1.0 °C, previously calibrated; c) digital stem thermometer (Mecacisa), range –50 to 200 °C, resolution ±0.1 °C and accuracy ±1.0 °C, previously calibrated; d) Marshall hammer (Mecacisa) standardized for HMA cylindrical specimens according to EN 12697-30; e) roller compactor machine (Matest) for HMA slab specimens according to EN 12697-33 and ASTM D8079; f) heater-cooler with a capacity of 150 litres with forced air circulation, range 4 to 65 °C, resolution ±0.1 °C and accuracy ±1.0 °C; g) laboratory ovens (Matest), capacity 100 litres, natural convection and thermostatic control up to 250 °C, resolution ±0.1 °C and accuracy ±1.0 °C; h) wheel tracking apparatus (Mecacisa), according to EN 12697-22 and BS 598:110; i) universal testing machine (10 ton), with capacity for dynamic load tests and automatic temperature control; j) glass pycnometers, capacity 1.3 litres, previously calibrated (0.001327 m^3); k) vacuum equipment (Teslar 2-F7) 3.33 Pa, for water saturation in specimen voids.

2.3. Method

Three types of mixtures were made. First, the reference hot mixtures (Ref.HM) with different percentages of conventional bitumen and volcanic aggregates were produced and tested. The bitumen contents were between 5.0% and 7.0% (by total weight of the mix) in order to obtain the optimum that allows fulfilling the technical specifications for roads. These mixtures were made in the laboratory by heating aggregates and bitumen 35/50 pen to 170 °C with 2 minutes in the mixer. The final mixing temperature was between 165 and 170 °C and the compaction temperature ranged between 155 and 160 °C.

Secondly, the reference asphalt-rubber hot mixtures (ARHM) were studied. These were produced with the same aggregate, exactly the same particle size distribution (Fig. 2) and the same binder percentages but using an AR binder of a similar consistence, produced previously in the laboratory by blending CRM and a base bitumen 50/70 pen. This last bitumen allowed obtaining an AR35/50, because the elastomer increased the viscosity and consistency of the resulting binder. To produce the AR35/50 binder, each 50/70 bitumen sample of 600 g was heated at 180 °C and then 10% (by wt. of bitumen) of CRM was added in the blending unit with the oil bath and mixed during 60 minutes at 4000 rpm, maintaining 180 °C. Sufficient homogenization and digestion time and temperature are necessary in order to attain adequate interaction of rubber particles with asphalt, transfer the ultraviolet inhibitors, anti-oxidants and other chemicals in the tyre rubber to the bitumen, including its elastomeric properties, and so produce a reacted AR binder [11, 12].

In the ARHM the heating temperatures of the aggregates and the bitumen (AR35/50) were 180 and 175 °C respectively, being in the mixer unit during 3 minutes. The final mixing temperature was between 175 and 180 °C and the compaction between 165 and 170 °C.

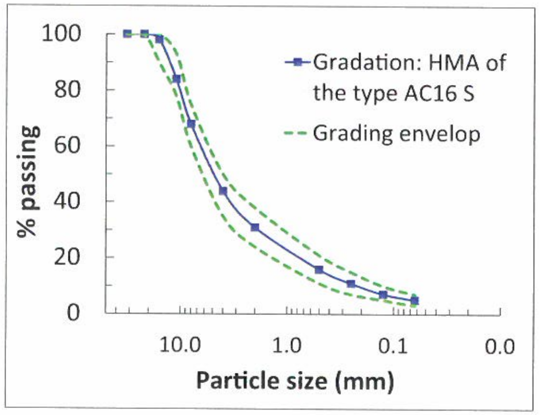

Figure 2: *Aggregate gradation and specified grading envelope for semi-dense asphalt concrete (AC16 S) [10]*

Lastly, the asphalt-rubber warm mixtures (ARWM), with the same aggregates and particle size distribution, were then made with the optimum bitumen percentage obtained for both reference mixtures (6%) and mixing at temperatures between 140 and 170 °C (compacted between 130 and 160 °C) by using the surfactant chemical additive. A 0.5% (by bitumen weight) of Cecabase RT® liquid product was added to the hot bitumen and mixed subsequently for 10 minutes at 4000 rpm at a constant temperature of 185 °C.

The cylindrical specimens (D = 101.6 mm; h = 63.5 mm) were compacted using a Marshall hammer according to EN 12697-30 with 50 or 75 blows/side (depending on the laboratory test). The slab specimens of 300 x 300 x 60 mm were compacted by rolling according to EN 12697-33.

The specimens underwent three series of characterization tests for each type of mixture and bitumen content: a) Volumetric properties of bituminous specimens: bulk density (EN 12697-6, Proced. B: saturated surface dry, and Proced. D: geometric), theoretical maximum density (EN 12697-5, Proced. A: volumetric) and void characteristics (EN 12697-8); b) General and empirical characteristics: water sensitivity (EN 12697-12, by indirect tensile test [EN 12697-23]), wheel tracking test (EN 12697-22, Proced. B: in air, small device, at 60 °C and 10^4 cycles) and Marshall test (EN 12697-34). A total of 384 laboratory specimens and samples were tested, with a total number of 60 tests on the Ref.HM (without rubber), 60 on the ARHM and 32 on the ARWM. When necessary, the different test samples were previously conditioned in a heater-refrigerator during the time required to reach the normalized temperature according to standards and maintained during the test if mandatory.

Figure 3: *Cut section of a cylindrical and a slab specimen of asphalt-rubber warm mixture (ARWM) with vesicular and scoriaceous basalt.*

3. Results and discussion

3.1. Volumetric properties

The bulk densities of the ARWM cylindrical specimens compacted by impact with 75 blows/side decrease when the production and compaction temperatures of the mixtures become smaller (Fig. 4). When they were compacted below 150 °C, these densities resulted lower than the reference ARHM (compacted at 170 °C), though they were higher than the reference conventional mixtures without rubber (Ref.HM, compacted at 160 °C) if the compaction temperature was over 135 °C.

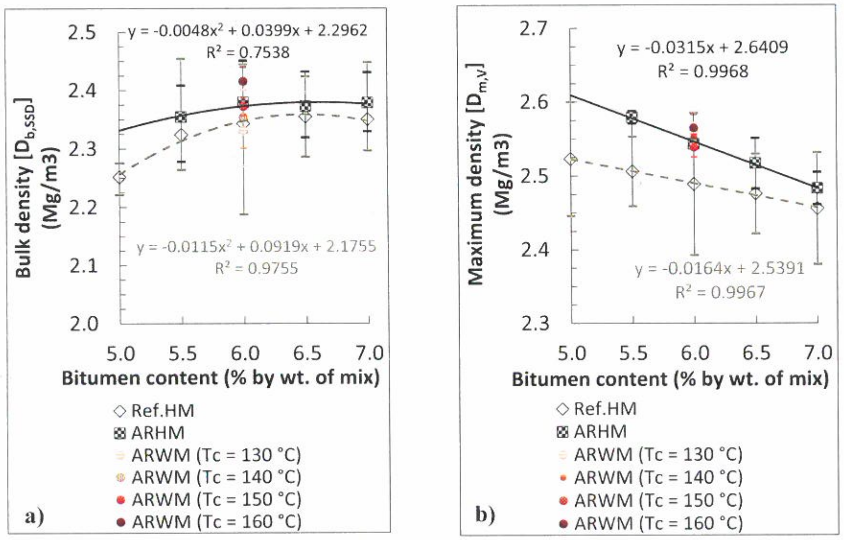

Figure 4: *a) Bulk density of cylindrical specimens compacted by impact with 2x75 blows (Proced. B: saturated surface dry, SSD) [EN 12697-6]; b) Theoretical maximum density (Proced. A: volumetric) [EN 12697-5]*

The air void content (V_m) (Fig. 5) and voids in mineral aggregate (VMA) (Fig. 6a) in the ARWM resulted higher as the compaction temperature decreases. With the ARWM similar or inferior air void contents were obtained to both reference mixtures

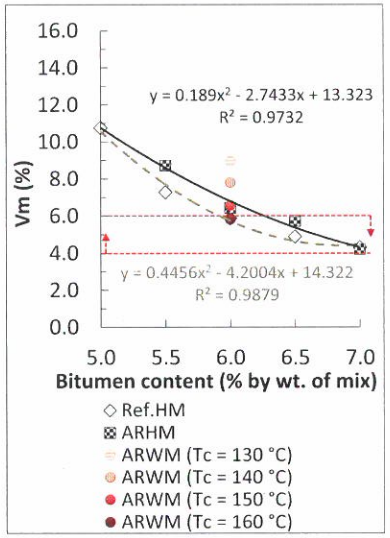

Figure 5: *Air void content in the mixture (by SSD bulk densities [EN 12697-8]). Limits of standard specifications are indicated by horizontal red dotted lines*

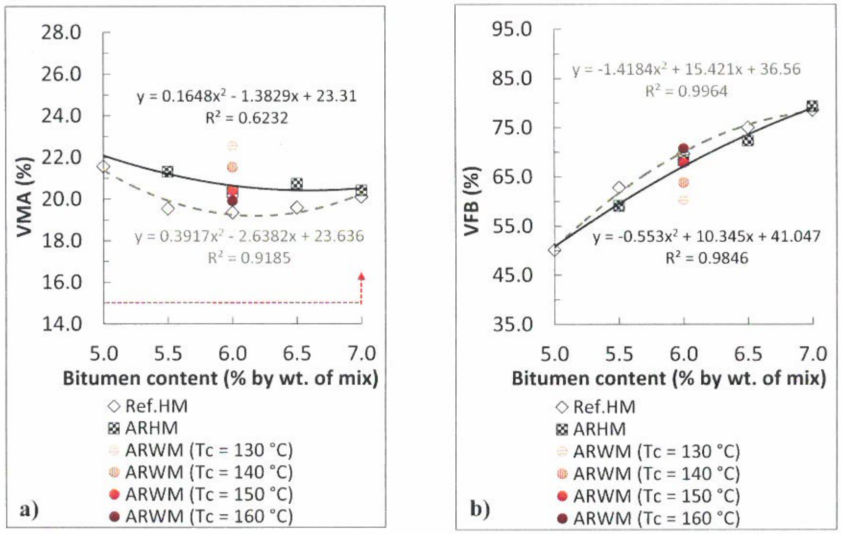

Figure 6: *a) Voids in mineral aggregate. Limits of specifications are indicated by horizontal red dotted lines; b) Voids filled with bitumen. Both calculated by SSD bulk densities [EN 12697-8]*

if compaction temperatures were over 150 °C. Moreover, the void characteristics of the ARWM complied with the specifications of the Spanish standards for roads [10] for compaction temperatures equal or superior to 155 °C. Target values of these volumetric characteristics according to the technical requirements are: $4 \leq Vm \leq 6\%$ and $VMA \geq 15\%$, for cylindrical specimens of AC in surface layers, compacted by impact with 2x75 blows. On Fig. 5 and Fig. 6a, these specified values are highlighted by horizontal red dotted lines.

3.2. Water sensitivity

The indirect tensile strength ratio (ITSR) at 15 °C of the ARWM cylindrical specimens compacted with 2x50 blows clearly reduces with the compaction temperatures (Fig. 7a). However, the technical specifications for roads [10] (ITSR $\geq 85\%$, for AC in surface layers) can be fulfilled if the compaction temperatures are not below 140 °C and the improvement of the ITSR owing to the effect of the asphalt-rubber on these particular mixtures with marginal high porosity aggregates is maintained with all the temperatures studied. Even at 150 °C, the ITSR resulted equal or superior to both reference mixtures (Ref.HM and ARHM).

The indirect tensile resistance of the ARWM water-saturated specimens (72 h at 40 °C) was similar to the conventional hot mixtures without rubber (Ref.HM) if the temperatures were not inferior to 150 °C (Fig. 7b).

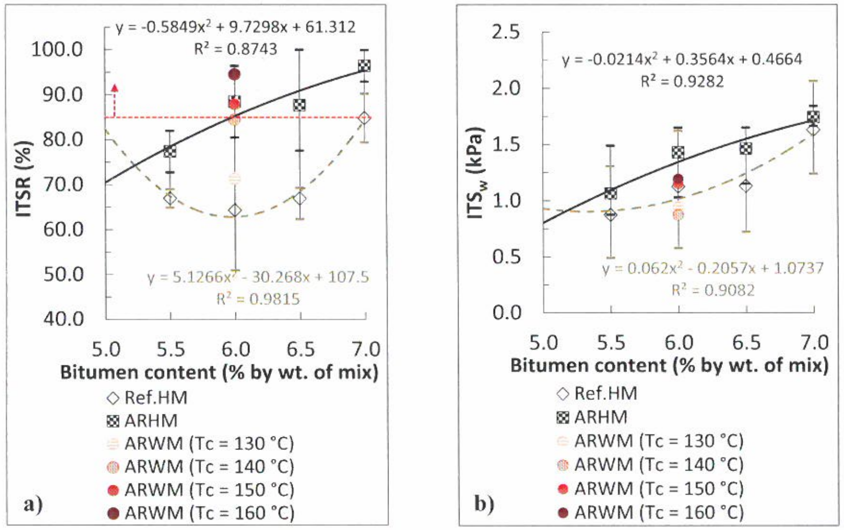

Figure 7: *Moisture sensitivity [EN 12697-12] by indirect tensile test on cylindrical specimens [EN 12697-23] compacted by impact with 2x50 blows: a) Indirect tensile strength ratio. Limits of specifications are indicated by horizontal red dotted lines; b) Indirect tensile strength of saturated specimens*

3.3. Rutting resistance

All the parameters related to plastic deformations on wheel tracking test (wheel-tracking slope of the rut depth, $WTS_{[air]}$, between $5x10^3$ and 10^4 load cycles; rut depth, $RD_{[air]}$, at 10^4 cycles; proportional rut depth, $PRD_{[air]}$, at 10^4 cycles) increased when the production temperatures decreased. However the highest rutting, and so worst performance, was obtained at 140 °C. Consequently, these ARWM only allows compliance to the road specifications ($WTS_{[air]} \leq 0.10$ mm/10^3 cycles; $PRD_{[air]} \leq 5\%$) if the compaction temperature are over 160 °C. Nevertheless, the improvement of the resistance to plastic deformations, compared to the Ref.HM, due to the effect of the asphalt-rubber on these mixtures is maintained with all the working temperatures (Fig. 8).

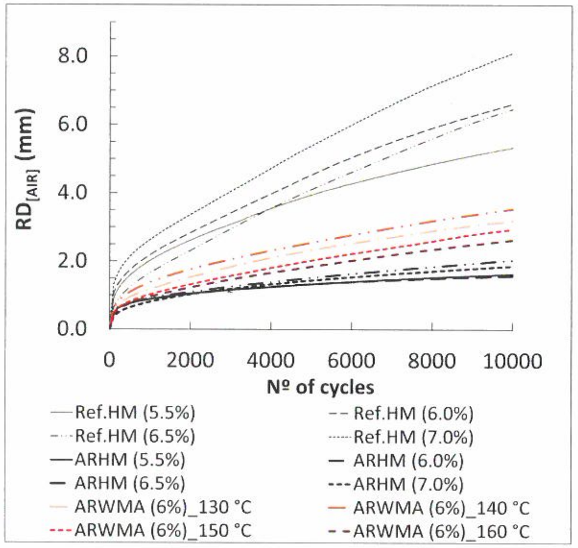

Figure 8: *Rut depth vs. number of load cycles on wheel tracking test (Proced. B: in air, small device, at 60 °C and 10^4 cycles, according to EN 12697-22) for asphalt-rubber warm mixtures (ARWM) at different compaction temperatures. Results are compared to both reference hot mixtures (Ref.HM and ARHM).*

3.4. Resistance to permanent deformations by Marshall test

Marshall tests on cylindrical specimens compacted with 2x75 blows also provided a decreased stability and an increased flow value for the ARWM as the compaction temperature reduced (Fig. 9). In a similar way to the results observed for the wheel-tracking tests, the improvement of the Marshall stability owing to the effect of the asphalt-rubber on these mixtures with marginal porous aggregates is maintained with all the temperatures studied.

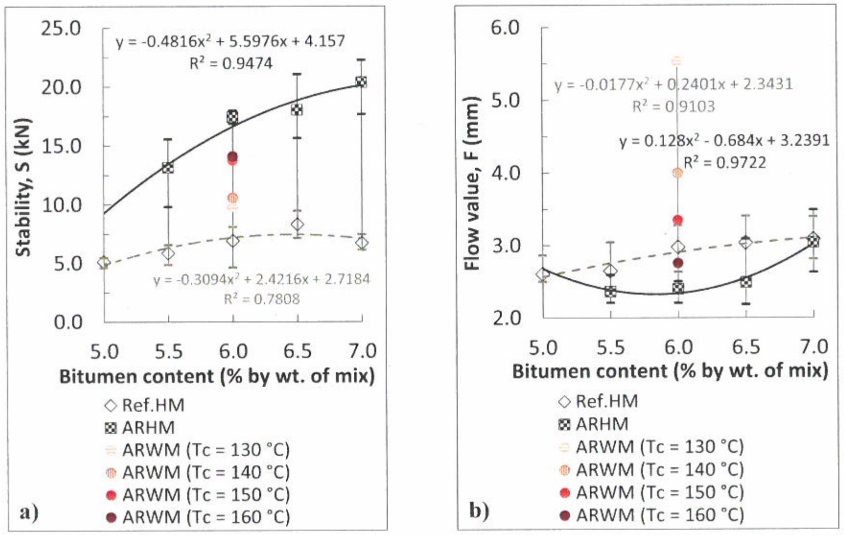

Figure 9: *Marshall stability and flow value of cylindrical specimens compacted by impact with 2x75 blows [EN 12697-34]*

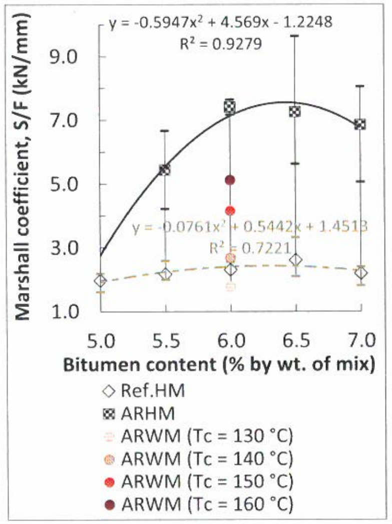

Figure 10: *Marshall quotient of cylindrical specimens compacted by impact with 2x75 blows [EN 12697-34]*

4. Conclusions

The results of this experimental research have shown:

- The bulk densities of the asphalt-rubber warm mixtures (ARWM) decrease as the mixing and compaction temperatures of the mixtures reduce. If they are compacted below 150 ºC, these densities can result lower than the asphalt-rubber hot mixtures (ARHM, compacted at 170 ºC), though they maintain higher than the conventional hot mixtures without rubber (compacted at 160 ºC) if the compaction temperature is over 135 ºC.
- Consequently, the void contents of ARWM increase with the reduction of temperatures. Similar void characteristics were obtained to both reference mixtures if compaction was over 150 ºC, complying with the standard specifications for road surface layers if the compaction temperatures are not below 155 ºC.
- Experimental results proved that ARWM significantly reduce the moisture resistance (ITSR) with the production temperatures. Despite, the ITSR can be maintained over 85% if the compaction temperatures are not below 140 ºC and so fulfil the technical specifications for roads assuring durability. Moreover, the improvement of the ITSR owing to the effect of the asphalt-rubber on these particular mixtures with marginal high porosity aggregates is maintained with all the temperatures studied.
- The resistance to permanent deformations by wheel-tracking test of ARWM also reduces with the production tèmperatures. Consequently, these ARWM only allows compliance to the road specifications if the compaction temperature is over 160 ºC. Nevertheless, the improvement of the rutting resistance due to the effect of the asphalt-rubber is also maintained with all the working temperatures. A similar performance can be observed on Marshall test results.
- In those volcanic areas with a high degree of environmental protection, and therefore impossible to open new quarries, or in countries where technical and economic resources are limited, the use of the marginal local aggregates is an economic, logistic and environmental necessity. Utilizing crumb-rubber modified bitumen from end-of-life tyres in asphalt mixtures with these vesicular volcanic aggregates has proved to be an efficient way to improve the performance of these materials and compensating for the higher amount of bitumen required when using high porosity aggregates.
- By using a reduced percentage of the surfactant additive (0.5% by wt. of binder) it is possible to lower the production and compaction temperatures of the mixtures with asphalt-rubber and porous volcanic aggregates up to a maximum of 10 ºC, while the mechanical performance is within the specifications for surface layers of pavements. This temperature reduction is similar to the increase produced with the asphalt-rubber binder, thus compensating it. However, for bituminous mixtures in base courses or if performance requirements are not so strict, the temperature reduction could reach 25-30 ºC.

These results may be extrapolated to other volcanic regions both islands and continents where these natural aggregates are found in abundance. The proposed methodology could contribute to better development of these regions and extending the durability of asphalt pavements.

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From the two performance studies referred to in this paper and comparison of texture retention, there is enough evidence that bitumen rubber seals, as designed and constructed in South Africa perform at least 70 % better than conventional binders and that due to both elasticity and stiffness, the macro texture on the very high trafficked roads is retained above 1.0mm in excess of 10 years.

6. Way forward

Reasonable confidence exists with temporary revisions of the conversion factors published in TRH3 (2007). However, more research is required to evaluate the short- and longer-term performance to verify or to adjust these conversion factors.

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