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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

2018

Rubberized Asphalt ◆ Asphalt Rubber

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Jorge B. Sousa, PhD
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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

Edited by

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RAR2018 - 7th Asphalt Rubber, International Conference, Kruger National Park, South Africa, September 25-28, 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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Marginal high porosity volcanic aggregates in asphalt-rubber hot mixes

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ABSTRACT. *In volcanic territories the high porosity vesicular and scoriaceous aggregates are the most common lithotypes: in the Canary Islands these make up over 72% of the economically exploitable rock masses. However, owing to the excessive heterogeneity and property variability, to the alveolar structure, and to the particle shape, the standard specifications consider these aggregates as marginal materials and certain properties of asphalt mixtures containing them usually offer inferior performance. In a similar way, the waste from used tyres has also created an important environmental issue in these island territories with natural areas of great value and therefore utilization in situ becomes vital. In this sense, the use of crumb rubber from reclaimed tyres as a modifier of the asphalt binder can contribute to the production of bituminous mixtures with enhanced performance. In this study the results of the main properties of hot asphalt mixes with crumb rubber modified bitumen (asphalt-rubber hot mixtures, ARHM) and volcanic aggregates from high porosity vesiculated and scoriaceous basalt (6 - 16% of water absorption) are presented. These are compared to the mixtures produced with conventional bitumen and the same volcanic aggregates. The results show a considerable improvement of most of the properties of these particular mixtures thanks to the use of an*

asphalt-rubber binder. This enables compliance with the standard specifications for paving and ensures longer durability. More specifically, the use of asphalt-rubber offered superior resistance to water action by 10–24%, improved stability between 145–198% and a reduction of rutting deformations by 198–280% (depending on the bitumen content). The results obtained may be extrapolated to other volcanic regions both islands and continents where these natural aggregates are found in abundance.

KEYWORDS: *Bituminous mixture, Volcanic aggregate, Vesicular basalt, Scoriaceous basalt, Asphalt-rubber hot mixture (ARHM), Crumb rubber modifier (CRM), Reclaimed tyre*

1. Introduction

In volcanic territories the high porosity vesicular and scoriaceous aggregates are the most common lithotypes: in the Canary Islands these make up over 72% of the economically exploitable rock masses. However, the principal drawbacks of these aggregates are [1]: a) excessive heterogeneity and property variability (Fig. 1); b) the alveolar structure, which is very porous and made up of non-prismatic particles (Fig. 2), results in a high level of absorption, with a higher consumption of binder and energy to evaporate water. Consequently, the standard specifications consider these aggregates as marginal materials and certain properties of asphalt mixtures containing them usually offer inferior performance. However, very few studies have exclusively used marginal volcanic aggregates in bituminous mixtures [2-4], and there are no studies regarding the performance of asphalt mixes with vesicular and scoriaceous volcanic aggregates of high porosity as the main mineral aggregate, even though these are the most abundant. Moreover, the technical regulations do not usually include specifications adapted to the singularities of this material.

In a similar way, the waste from end-of-life tyres (ELT) has also created an important environmental issue in these island territories with natural areas of great value (over 40000 tonnes in the Canary Islands during 2016 with a population of over 2 million) and therefore utilization in situ becomes vital. In this sense, the use of crumb rubber from reclaimed tyres as a modifier of the asphalt binder (CRM) has proved the production of paving materials offering enhanced performance and durability [5-8]. Asphalt-rubber (AR), also called "wet process", consist in the blend of asphalt binder and ground recycled tyre rubber powder from scrap ELT in which the rubber component has reacted in the hot asphalt cement to cause swelling of the rubber particles.

In this study the characterization of hot asphalt mixes with crumb rubber modified bitumen (asphalt-rubber hot mixtures, ARHM) and volcanic aggregates from high porosity vesicular and scoriaceous basalt (6 - 16% of water absorption) is presented. These results are compared to the mixtures produced with conventional bitumen and the same volcanic aggregates.

2. Experimental

2.1. Materials

219 cylindrical specimens, 32 slab specimens and 38 non-compacted samples, including reference specimens, of hot mix asphalt (HMA) of the type semi-dense asphalt concrete for surface courses (AC16 surf S) were produced in the laboratory, with contents of bitumen between 5.0% and 7.0% (by total weight of the mixture). This type of bituminous mix was produced following the Spanish road specifications (PG-3) [9] and is according to 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. 2 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.

Table 1. *Main properties of the different aggregate fractions*

	Aggregate fractions		
	# 10–20 mm	# 4–10 mm	# 0–4 mm
% (by wt. of the total aggregate) (*)	20.93	36.27	38.88
Particle density: r_{SSD} [EN 1097-6] (Mg/m³)	2.63	2.56	2.36
Particle density: r_{rd} [EN 1097-6] (Mg/m³)	2.35	2.37	2.23
WA_{24} [EN 1097-6] (%)	5.8	8.3	15.5
FI [EN 933-3]	6	6	—
LA [EN 1097-2]	29	28	—
PSV [EN 1097-8]	60	60	—

(*) The total aggregate includes 3.92% of mineral filler (#<0.063 mm) of Portland cement with pozzolanic addition; (r_{SSD}) Particle density [saturated surface dry]; (r_{rd}) Particle density [dry]; (WA_{24}) Water absorption of particles after 24 hours; (FI) Flakiness index; (LA) Los-Angeles coefficient; (PSV) Polished stone value.

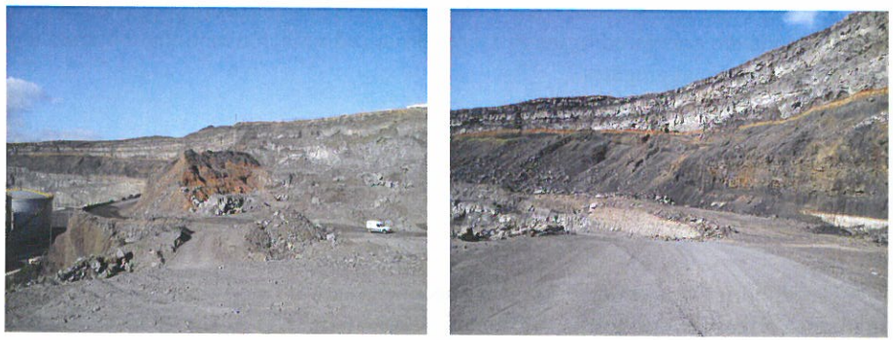

Figure 1: *Quarry with different volcanic lithotypes, showing the heterogeneity and variability of volcanic rocks*

Figure 2: *Detail of the coarse fraction of the vesiculated and scoriaceous basalt*

The reference mixtures used a commercial bitumen 35/50 pen (density: 1.042 Mg/m³; penetration at 25 ºC, 100 g, 5 s: $44x10^{-1}$ mm; softening point: 51.6 ºC). The binder of the mixtures with rubber was an asphalt-rubber of the same penetration grade (AR35/50; density: 1.028 Mg/m³; penetration: $38x10^{-1}$ mm; softening point: 64.2 ºC), produced in the laboratory by adding the crumb rubber modifier (CRM). As for the CRM, it was manufactured by mechanical grinding at ambient temperature (50% from used truck tyres; 50% 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. 100% 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% <0.25 mm, 3.7% <0.125 mm and 0.4% <0.063 mm.

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 ºC, 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 ºC, 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

Two types of mixtures were produced. First, the reference hot mixtures (Ref.HM) with volcanic aggregates and percentages of conventional bitumen 35/50 from 5.0% to 7.0% were produced and tested. Secondly, the AR hot mixtures (ARHM) were studied. These were produced with the same aggregate and exactly the same particle size distribution (Fig. 3), the same binder percentage but using an AR 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, so that the ultraviolet inhibitors, anti-oxidants and other chemicals in the tyre rubber are transferred to the asphalt, including its elastomeric properties, giving a reacted AR binder of higher consistency.

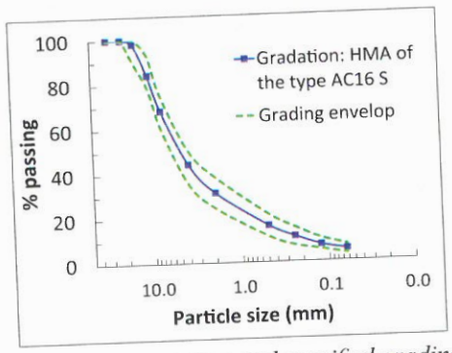

Figure 3: *Aggregate gradation and specified grading envelope for semi-dense asphalt concrete (AC16 S) [9]*

The Ref.HM mixtures were produced in the laboratory by heating aggregates and bitumen 35/50 pen to 170 °C with 2 minutes in the mixer. The final temperature in the mixer was between 165 and 170 °C and compaction temperature ranged between 155 and 160 °C. Due to the greater viscosity of the rubber, in the ARHM the heating temperatures of the aggregates and the AR35/50 bitumen were 180 and 175 °C respectively, being in the mixer unit during 3 minutes. The final temperature in the mixer was between 175 and 180 °C and compaction between 165 and 170 °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.

Figure 4: *Cut section of a cylindrical specimen of asphalt-rubber (AR) mixture with vesicular and scoriaceous basalt*

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 289 laboratory specimens and samples were tested, with a total number of 60 tests on the Ref.HM (without rubber) and 60 on the ARHM. 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.

3. Results and discussion

3.1. Volumetric properties

The bulk densities of the ARHM cylindrical specimens compacted with 75 blows/side are slightly superior (0.8–1.6%) to the Ref.HM with conventional bitumen (Fig. 5), with any bitumen content studied. The highest bulk densities were obtained with similar binder contents in both types of mixtures (6.5–7% of bitumen by total wt. of mix).

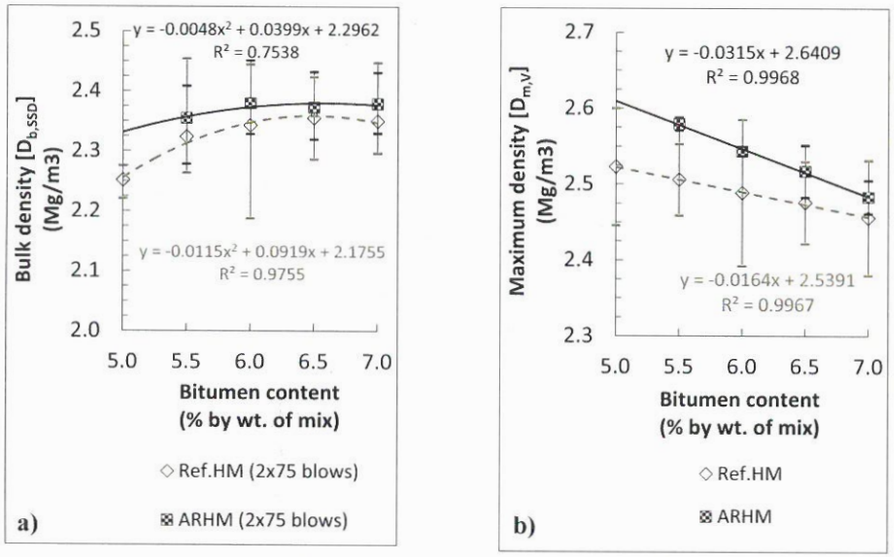

Figure 5: *a) Bulk density (Proced. B: saturated surface dry, SSD) [EN 12697-6]; b) Theoretical maximum density (Proced. A: volumetric) [EN 12697-5]*

Air void content (V_m) and voids in mineral aggregate (VMA) in the ARHM were always slightly superior (V_m differences between 0.1–1.4%) than the Ref.HM (Fig. 6 and Fig. 7a), for the same compaction energy (2x75 blows), although the bulk densities of ARHM also resulted higher. This is due to the higher theoretical maximum densities of the ARHM (Fig. 5b) for all bitumen contents (1.1–2.9% superior). Void characteristics, both ARHM and Ref.HM, complied with the specifications of the Spanish standards for roads [9] ($4 \leq V_m \leq 6\%$ and VMA $\geq 15\%$, for AC in surface layers, specimens compacted by 2x75 blows) for bitumen contents greater than 6–6.3%, what it shows the great absorption of these volcanic aggregates.

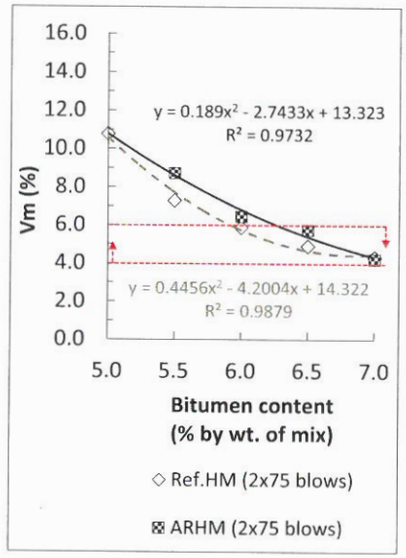

Figure 6: *Air void content in the mixture (by SSD bulk densities [EN 12697-8]). Limits of standard specifications are indicated by horizontal red dotted lines*

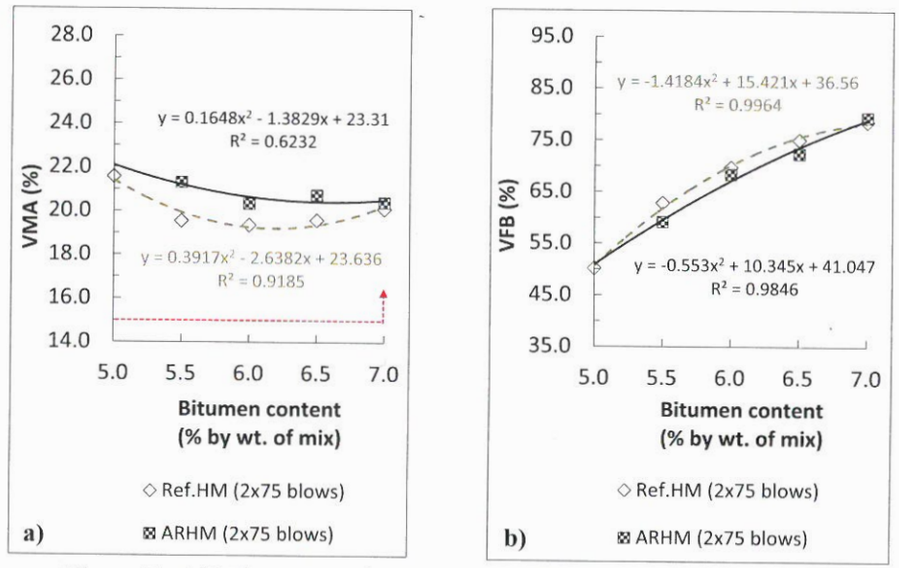

Figure 7: *a) Voids in mineral aggregate (Limits of standard specifications are indicated by horizontal red dotted lines); b) Voids filled with bitumen. Both calculated by SSD bulk densities [EN 12697-8]*

3.2. *Water sensitivity*

Indirect tensile resistance at 15 ºC of water-saturated cylindrical specimens (72 h at 40 ºC; compacted with 2x50 blows) of ARHM was always superior (6.8–28.8%) to the Ref.HM, for all the bitumen contents studied (Fig. 8b), being similar for dry specimens. This result proves the higher resistance to water action than the use of AR produces in mixtures with marginal volcanic aggregates of high porosity and reflects in the increase of ITSR (10.4–24.1%) (Fig. 8a). Consequently, the ARHM can fulfil the road specifications (for AC in surface layers: ITSR ≥ 85%) if bitumen content is higher or equal to 6%.

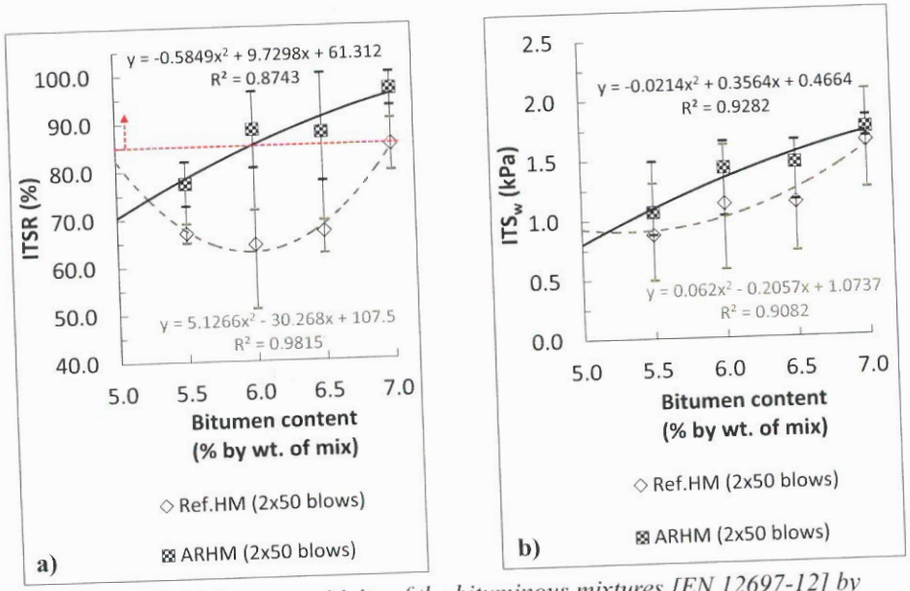

Figure 8: *Moisture sensitivity of the bituminous mixtures [EN 12697-12] by indirect tensile test on cylindrical specimens [EN 12697-23]: a) Indirect tensile strength ratio (Limits of specifications are indicated by horizontal red dotted lines); b) Indirect tensile strength of saturated specimens*

3.3. *Rutting resistance*

Better resistance to permanent deformation on wheel tracking test (proced. B: in air, small device, at 60 ºC and 10^4 cycles, slab specimens compacted with metallic roller) of the ARHM with respect to the Ref.HM even is more remarkable (Fig. 9). The wheel-tracking slope of the rut depth ($WTS_{[air]}$ between $5x10^3$ and 10^4 load cycles) decreased by 322.8–546.0%. The rut depth ($RD_{[air]}$ at 10^4 cycles) decreased by 197.7–279.6%, and the proportional rut depth ($PRD_{[air]}$ at 10^4 cycles) by 6.2–10.4%.

These results offer an important practical application: the use of AR as a binder for mixtures with marginal aggregates considerably improves resistance to plastic deformation owing to the elastic properties of the rubber. This allows compliance to the road specifications ($WTS_{[air]} \leq 0.10$ mm/10^3 cycles; $PRD_{[air]} \leq 5\%$), which does not occur with the Ref.HM, remaining outside the regulation requirements with any of the binder percentages studied.

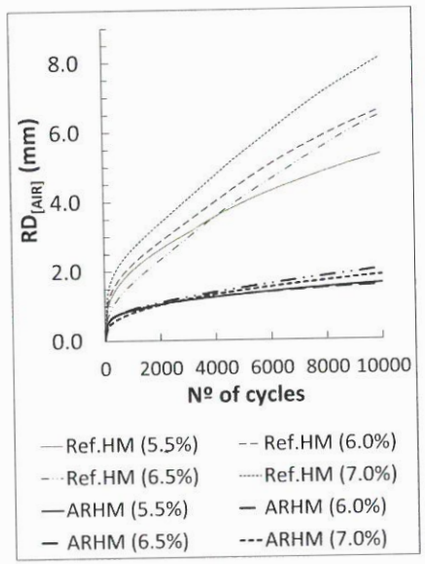

Figure 9: *Rut depth vs. number of load cycles on wheel tracking test for mixtures with different bitumen contents (Proced. B: in air, small device, at 60 ºC and 10^4 cycles) [EN 12697-22]*

3.4. *Resistance to permanent deformations by Marshall test*

Marshall tests on cylindrical specimens compacted with 2x75 blows also provided an increased stability for the ARHM between 145.0 and 197.6% (depending on binder percentage, as Fig. 10a shows). The Marshall flow value was reduced by 0.2–19.4% (Fig. 10b). Consequently, an increase of the Marshall quotient between 162.8 and 242.0% was obtained. (Fig. 11).

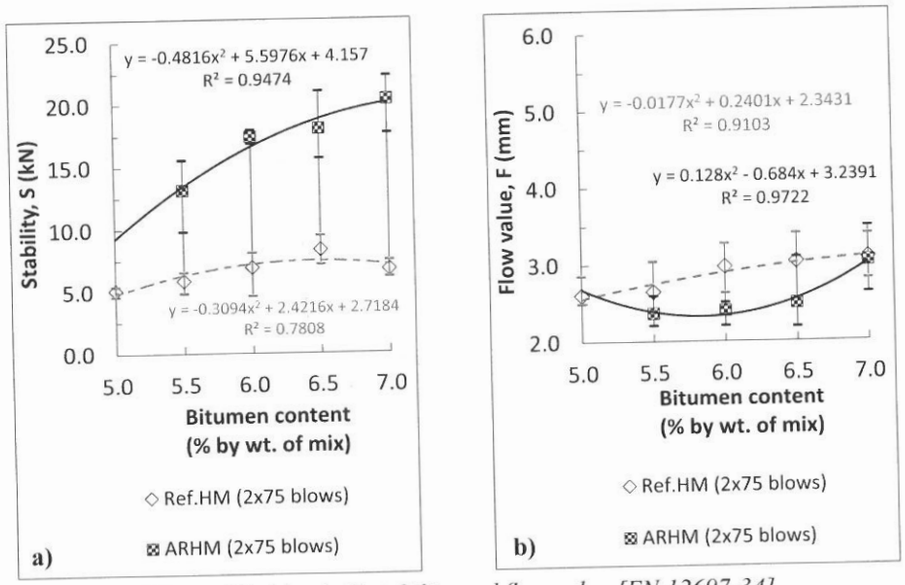

Figure 10: *Marshall stability and flow value [EN 12697-34]*

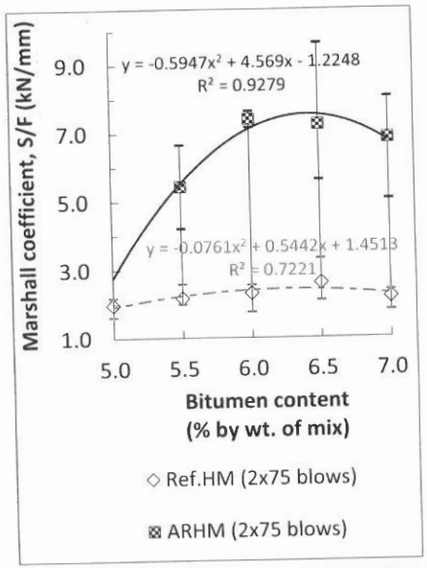

Figure 11: *Marshall quotient [EN 12697-34]*

4. Conclusions

The results of this experimental research have shown:

- Bulk densities of the asphalt-rubber (AR) mixtures proved to be similar or slightly superior (but differences in any case lower than 1.6%) to the reference mixtures with conventional bitumen. The highest bulk densities were obtained with 6.5–7.0% of bitumen by total weight of mix, being similar binder contents in both types of mixtures.
- Although the bulk density of AR mixes resulted slightly higher, the air void content and voids in mineral aggregate in the AR mixtures turned out to be also superior. Nevertheless, this difference was always inferior to 1.4% and is explained by the higher theoretical maximum densities of the AR mixtures for all the bitumen contents (1.1–2.9% superior). Void characteristics of AR mixtures complied with the specifications for road surface layers if bitumen contents were greater than 6–6.3% (by wt. of mix), showing the great absorption of these volcanic aggregates.
- Experimental results proved that AR mixtures significantly improve the moisture sensitivity with respect to conventional mixtures. The indirect tensile strength ratio (ITSR) on cylindrical specimens of AR mixtures increased by 10.4-24.1% (depending on the bitumen content). ITSR fulfilled the road technical specifications for bitumen contents equal or superior to 6% (by wt. of mix).
- Resistance to permanent deformations by wheel-tracking test of AR mixtures outstandingly improves compared to conventional mixtures. The slope of the rut depth (in air, at 60 °C, between $5x10^3$ and 10^4 cycles) decreased by 322.8–546.0%. The rut depth decreased by 197.7–279.6%, and the proportional rut depth by 6.2–10.4%, and so complied with paving specifications.
- In a similar way, Marshall tests showed an increment of stability (145.0–197.6%), a reduction of Marshall flow value (0.2–19.4%) and, consequently, an increase of the Marshall quotient (162.8–242.0%) in the case of AR mixtures.

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, allowing fulfil the standard specifications for pavements. In addition, it can compensate for the higher amount of bitumen required when using high porosity aggregates. The results obtained 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.

5. References

[1] M.A. Franesqui, F. Castelo-Branco, M.C. Azevedo, P. Moita. Construction experiences with volcanic unbound aggregate in road pavements. In: Volcanic Rock Mechanics. Olalla et al. (Eds.). Taylor & Francis Group, London (2010) 241-247. http://www.crcnetbase.com/doi/abs/10.1201/b10549-36

[2] R.P. Faustino, M.J. O'Connell, N.R. Valencia, W. Ford. Making effective use of volcanic ash in road-building in the Philippines. In: Proceedings of the Eastern Asia Society for Transportation Studies 5 (2005) 868-76.

[3] J.A. Naji, I.M. Asi. Performance evaluation of Asphalt Concrete mixes containing granular volcanic ash. J. Mater. Civ. Eng. 20 (2008) 754-61. https://doi.org/10.1061/(ASCE)0899-1561(2008)20:12(754)

[4] H. Akbulut, C. Gurer, S. Cetin. Use of volcanic aggregates in asphalt pavement mixes. Proceedings of the Institution of Civil Engineers-Transport 164 (2011) 111-123. https://doi.org/10.1680/tran.2011.164.2.111

[5] S. Lee, C.K. Akisetty, S.N. Amirkhanian. The effect of crumb rubber modifier (CRM) on the performance properties of rubberized binders in HMA pavements. Constr. Build. Mater. 22 (2008) 1368-1376. https://doi.org/10.1016/j.conbuildmat.2007.04.010

[6] S. Huang, A.T. Pauli. Particle size effect of crumb rubber on rheology and morphology of asphalt binders with long-term aging. Road Materials and Pavement Design 9 (2008) 73-95. https://doi.org/10.1080/14680629.2008.9690108

[7] D.Y. Kebria, S.R. Moafimadani, Y. Goli. Laboratory investigation of the effect of crumb rubber on the characteristics and rheological behaviour of asphalt binder. Road Materials and Pavement Design 16 (2015) 946-956. https://doi.org/10.1080/14680629.2015.1042015

[8] P.S. Wulandari, D. Tjandra. Use of crumb rubber as an additive in asphalt concrete mixture. Procedia Engineering 171 (2017) 1384-1389. https://doi.org/10.1016/j.proeng.2017.01.451

[9] Spanish Ministry of Infrastructures. Spanish Specifications for Roads and Bridges (PG-3, Art. 542, Art. 543). Orden FOM/2523/2014. Madrid, Spain, 2014 (in Spanish).

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

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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Danie Erasmus

8. References

COLTO – Committee of Land Transport Officials-South Africa, Standard Specifications for Road and Bridge Works for State Road Authorities, 1998.

Hanson, F.M. 1935. Bituminous surface treatment of rural highways. Conference of NZ, Society of Civil Engineers 1934-35.

Henning, TPF, Costello, SB and Watson,TG. A review of the HDM/dTIMS pavement models based on calibration site data, research report 303, Land Transport New Zealand, Wellington, New Zealand. 2006

Jooste K and Van Zyl GD. 2010. The use and performance of bitumen rubber in spray seals for holding actions in RSA. 2nd International Spray Seal Conference, Melbourne, Australia.

Renshaw RH, Kleyn EG and Van Zyl GD.1991. The performance of bitumen rubber binders. The South African Bitumen and Tar Association. Proceedings of Modified Binder Seminars. South Africa

Renshaw R.H., Strauss P.J., Kleyn E.G., Review of the performance of a Bitumen Rubber over a six-year period, Proceedings of the 5th Conference on Asphalt Pavements for Southern Africa, Swaziland, 1989.

Sabita, Technical Guidelines: The use of Modified Bituminous Binders in Road Construction, TG 1, Third Edition, Southern African Bitumen Association (Sabita), 2015.

Semmelink, C.J., A Rational Design Approach for Single and Double Surfacing Seals Based on the Modified Tray Test, Transportation Research Record 1106.

South African National Roads Agency (SANRAL). 1998. Design and construction of surfacing seals. (Technical recommendations for highways; TRH3). Pretoria. South Africa.

South African National Roads Agency (SANRAL). 2007. Design and construction of surfacing seals. (Technical recommendations for highways; TRH3). Pretoria. South Africa.

TMH1: Standard Methods of Testing Road Construction Materials, COLTO, South Africa, 1986.

TMH9: Manual for Visual Assessment of Road Pavements. COTO Committee Draft, May 2016.

Transvaal Provincial Administration: Roads Department. Seal work manual, Pretoria, South Africa, 1991.

Van Zyl GD and Jenkins K. 2015. Overview of Long Term Seal Performance. CAPSA, Sun City, South Africa.