Development of new asphalt mixture ThinGap 9.5 mm with Reacted and Activated Rubber

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ABSTRACT. *The objective of this study was to develop a mix, named herein ThinGap 9.5 mm, with reacted and activated rubber (RAR), with identical or superior performance attributes of a normal asphalt rubber gap graded mix to resist surface torsional forces but that could be used in very thin lifts just like an Open Graded Asphalt rubber mix.*

It was also an objective of the study to insure that reflective cracking resistance was maximized without compromising rut resistance. This objective was achieved after a guided trial an error process that led to the optimization of a gradation that could incorporate about 9.5% to 10% binder content, of which about 45% would be RAR.

It was demonstrated that the asphalt mixtures ThinGap 9.5 mm with RAR used in this study, exhibit an excellent rut resistance, fatigue lives about one hundred times those of regular mixes, all without decreasing water resistance, or Cantabro wear.

KEYWORDS: *ThinGap, RAR, Reacted, Activated, Rubber, Fatigue, rut resistance, water resistance, ITS resistance, Cantabro.*

1. Introduction

The objective of this study was to develop overall limits of target composition (grading envelope) for a new asphalt mixture, named herein ThinGap 9.5 mm with a reacted and activated rubber (RAR) material as previously reported (Sousa, 2013A and 2013B). Furthermore, for the final overall mixture performance was evaluated using some performance related tests such as fatigue, permanent deformation, indirect tension strength, etc.

The study was carried out by CONSULPAV, and the samples tested were mixed using Portuguese aggregates and 35/50 bitumen grade normally used in Portugal, and plus 40 % and 45 % (by weight of the binder) of RAR.

Figure 1 shows the composition of the 8 asphalt mixtures produced and analysed in this study.

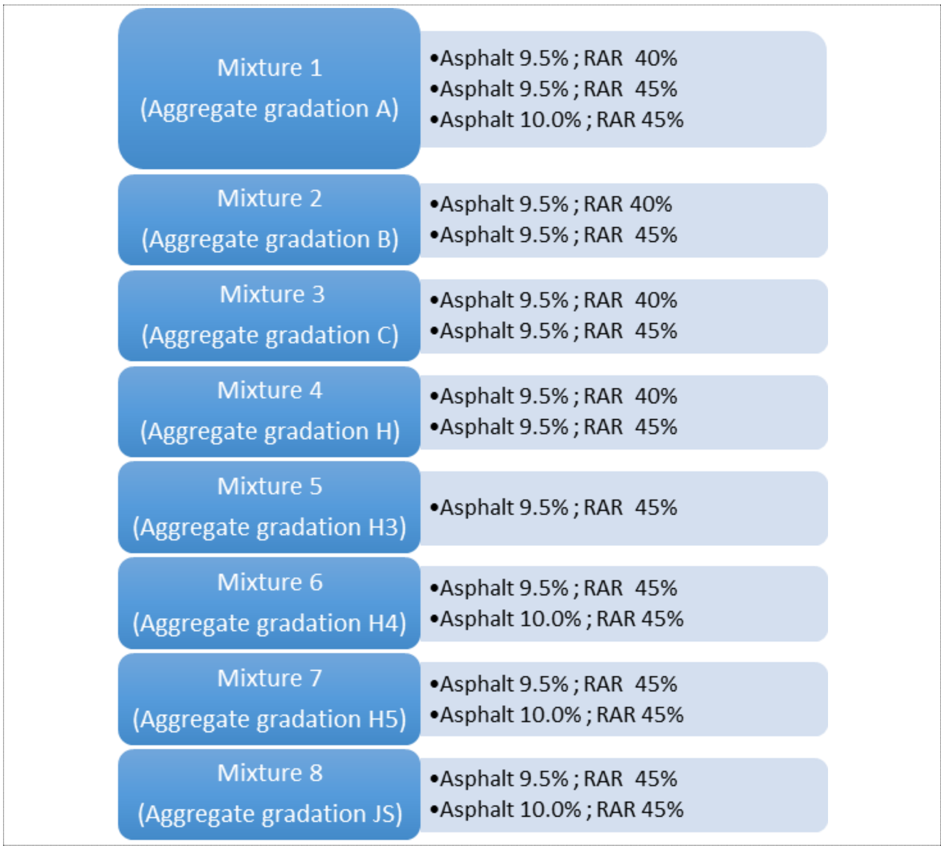

Figure 1 – *Composition of the asphalt mixtures produced with RAR*

2. Materials

The original binder used in the production of the bitumen with RAR was a 35/50 penetration grade bitumen according to European standard EN 12591:2000 supplied by CEPSA. This bitumen was modified with 40% or 45% of RAR (placed directly in the mix). Figure 2 and 3 shows the effect the addition of RAR has on the ring and ball, and resiliency of the binder properties. It is clear that the added percentages of RAR lead to very clear improved binder properties.

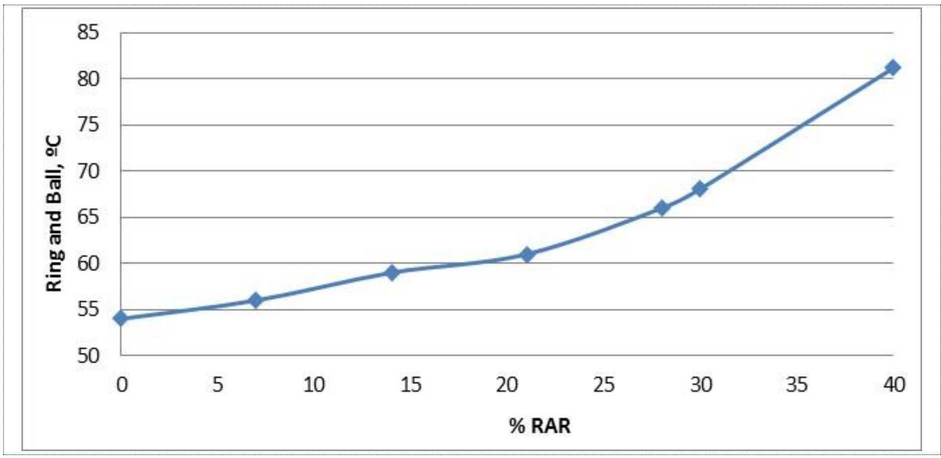

Figure 2 – *Ring and ball behaviour for bitumen with RAR*

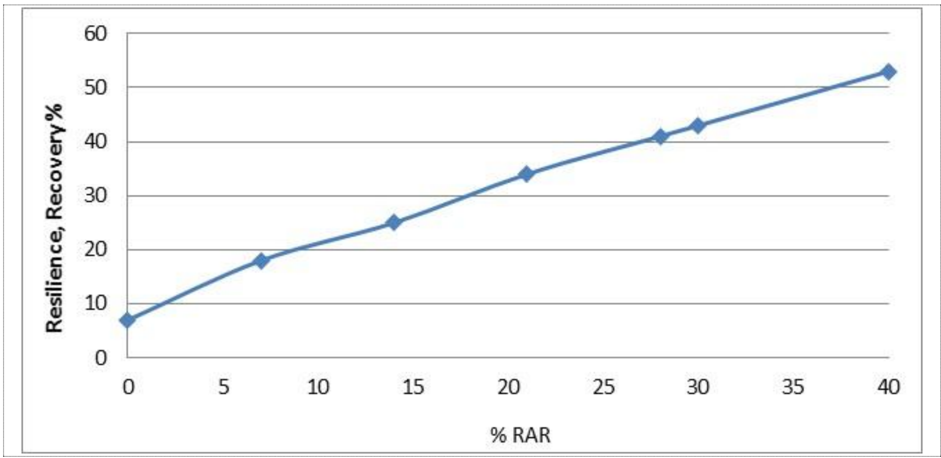

Figure 3 – *Resilience recovery for bitumen with RAR*

RAR is composed of soft asphalt cement (bitumen), fine crumb tire rubber (usually #30 mesh) and fillers blended at optimized proportions and temperatures.

On the series of tests reported herein two percentage of RAR, by weight of the binder, were used, namely 40% and 45%. However, regarding an improvement of the mixture performance, the final overall limits of target composition defined for the new asphalt mixture were based on mixtures with 45 % of RAR.

The aggregates used in this study were supplied by Quarry of Benafessim in Montemor-o-Novo, Portugal. To define the overall limits of target composition (grading envelope) for a new asphalt mixture, four different fractions of aggregates were used (0/4 mm, 1/4 mm, 4/6 mm, 6/10 mm).

Figure 4 shows the aggregate gradations used in the asphalt mixtures to define the overall limits of target composition (grading envelope) for the ThinGap 9.5 mm gradation.

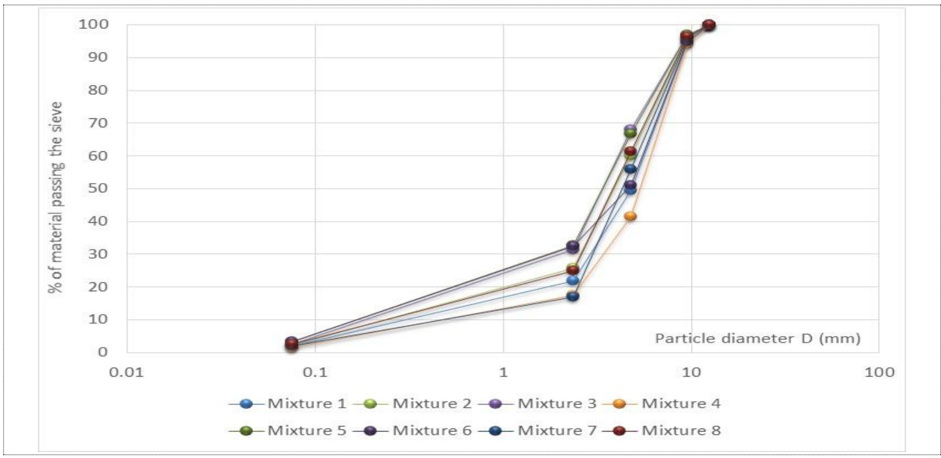

Figure 4 – *Final aggregate gradations*

Figure 5 shows the relative percentages of different aggregate sizes as compared with the two other well know and used gradations, GAP Graded and OPEN Graded. The ThinGap mixture with RAR has lower percentages of coarse aggregates comparing to the gap and open graded mixture. The thinner aggregate part of the envelope grading, the ThinGap mixture have a higher percentage of fine aggregate and filler compared to a gap and open graded mixture.

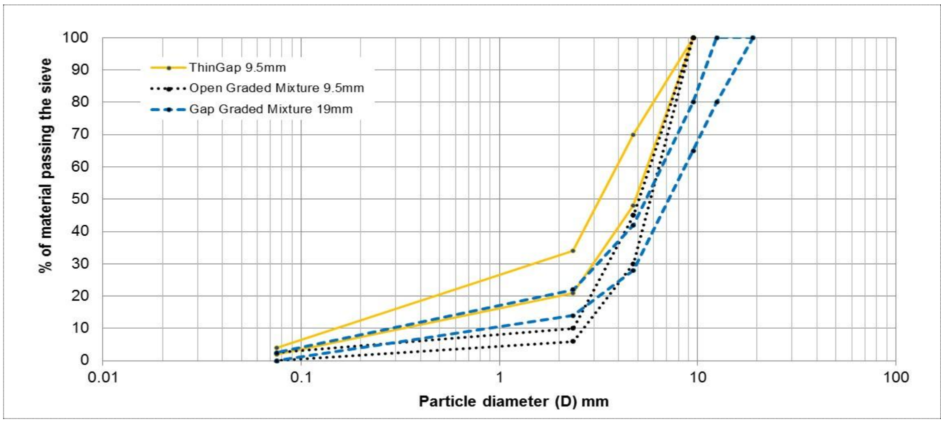

Figure 5 – *Differences between grading envelopes used for a open graded, gap graded and a ThinGap mixture with RAR*

3. Marshall Mix design

3.1. *Optimum asphalt binder content determination*

- Compacted ThinGap 9.5 mm mixtures should have air voids (porosity) between 2.5% and 5%;
- Preparation a series of initial samples, each at different asphalt binder contents. Three samples were made for each percentage of binder presented in Figure 1;
- Compaction of these trials mixes using the Marshall drop hammer. This hammer is specific in the Marshall Mix design method. Marshall specimens were compacted with 75 blows on each side for all mixes;
- Density evaluation; Maximum Theoretical Density (MTD) Rice test;
- Test the samples in the Marshall testing machine for stability and flow. This testing machine is specific to the Marshall mix design method;
- Select the optimum asphalt binder content, according to: Stability, Flow, Density (MTD) Specific Gravity, Air Voids, Voids in the Mineral Aggregate (VMA).

3.2. Marshall results

Table 1 and Figure 6 present the results obtained in the Marshall studies in the mixtures. It must be noted that these mixes were compacted after one hour in the oven at 180ºC.

Table 1 – *Results for Marshall test*

Mixture	Sample	MTD, Rice Bituminous Mixture Gravity (g/cm^3)	Bulk of samples without parafilm (g/cm^3)	Porosity of samples (%)	Stability (N)	Flow (mm)	VMA (%)
1	A1	2.408	2.281	5.3	10 849	2.8	25.2
	A2		2.278	5.4	10 015	2.9	25.3
	A3		2.271	5.7	9 700	3.3	25.5
		Average:	**2.277**	**5.5**	**10 188**	**3.0**	**25.4**
2	B1	2.408	2.263	6.0	10 226	3.0	25.3
	B2		2.263	6.0	9 520	2.5	25.3
	B3		2.243	6.9	8 192	2.6	26.0
		Average:	**2.256**	**6.3**	**9 313**	**2.7**	**25.5**
3	C1	2.412	2.211	8.4	9 220	3.1	27.2
	C2		2.189	9.3	8 015	2.6	27.9
	C3		2.189	9.3	7 298	2.5	27.9
		Average:	**2.196**	**9.0**	**8 178**	**2.7**	**27.7**
4	H1	2.408	2.205	8.4	6 406	2.0	27.2
	H2		2.197	8.8	6 906	3.1	27.5
	H3		2.189	9.1	7 123	3.6	27.7
		Average:	**2.197**	**8.8**	**6 812**	**2.9**	**27.5**
5	H3-1	2.401	2.215	7.8	7 494	2.5	26.6
	H3-2		2.158	10.1	6 673	4.1	28.5
	H3-3		2.231	7.1	6 678	1.5	26.1
		Average:	**2.201**	**8.3**	**6 948**	**2.7**	**27.1**
6	H4-1	2.404	2.295	4.6	10 068	2.5	24.1
	H4-2		2.279	5.2	9 379	2.6	24.6
	H4-3		2.304	4.1	11 868	2.6	23.8
		Average:	**2.293**	**4.6**	**10 438**	**2.6**	**24.2**
7	H5-1	2.406	2.298	4.5	11 732	3.4	24.1
	H5-2		2.285	5.0	9 297	3.1	24.5
	H5-3		2.296	4.6	10 734	3.0	24.2
		Average:	**2.293**	**4.7**	**10 588**	**3.1**	**24.3**
8	JS1; JS4	2.410	2.321	3.7	10 803	3.3	24.3
	JS2; JS5		2.308	4.3	10 254	3.1	24.8
	JS3; JS6		2.297	4.7	9 782	3.1	25.1
		Average:	**2.308**	**4.2**	**10 279**	**3.2**	**24.7**

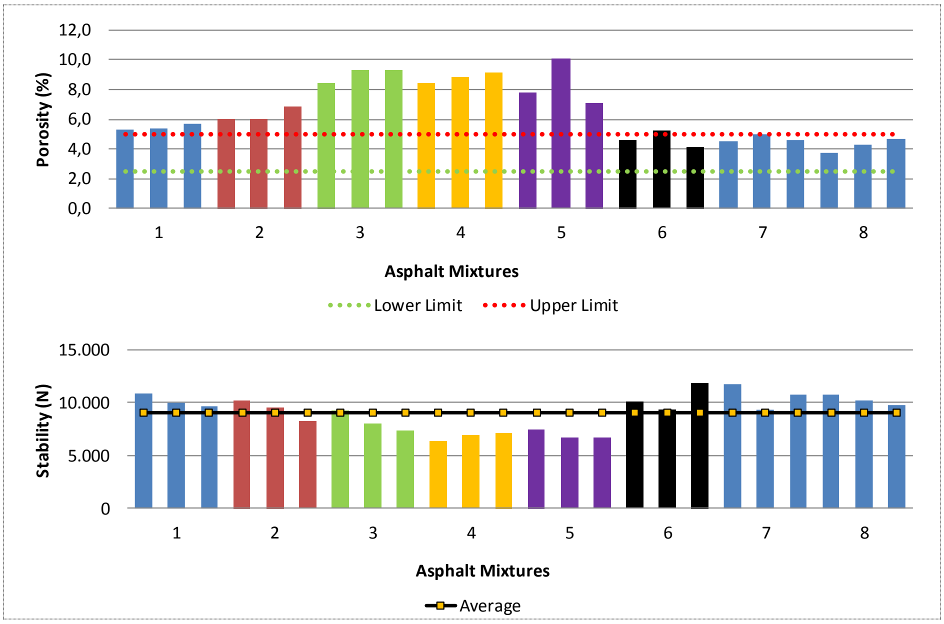

Figure 6 – *Results for Marshall test*

According to Table 1 and Figure 6 it's possible to conclude that only mixture 1, 6, 7 and 8 have porosity according to the interval defined initially for this type of mixture (2.5% to 5%). The results also show that this four mixtures present the higher values of Marshall Stability, always above the average value obtain for all the mixtures evaluated. It's also possible to see that mixture 7 (10 558 N) and mixture 6 (10 438 N) are the mixtures with the higher Marshall Stability.

Regarding that the compacted ThinGap 9.5 mm mixture should have porosity between 3 % and 6 %, mixtures 1, 6, 7 and 8 were chosen for further evaluation (permanent deformation, fatigue, water sensibility).

To evaluate the sensibility of the ThinGap 9.5 mm to the percentage of bitumen, in the further evaluation of the permanent deformation, fatigue and water sensibility was made for mixtures with the optimum percentage of bitumen (9.5%) and plus 0.5% of bitumen (10.0%).

4. Performance evaluation

4.1. *Permanent deformation resistance*

Evaluation of permanent deformation in slabs of asphalt under the action of a loaded wheel as it moves along its surface. The test is conducted in controlled temperature chamber at a relatively high temperature (60°C), considered representative of conditions of service in unfavorable situations. The evaluation of the permanent deformation of the asphalt mixtures was carried out through wheel-tracking tests, according to the test procedure described in the Spanish standard NLT 173/00 (Spanish Norm).

Table 2 presents the results obtained in the ThinGap (mixtures 1, 6, 7 and 8) slabs permanent deformation tests. In the tests asphalt mixtures slabs were compacted with 9.5 % of asphalt and 10.0 % of asphalt (with 45 % of RAR).

Table 2 – *Results of the permanent deformation resistance tests obtain for mixture 1, 6, 7 and 8*

Asphalt Mixture	**% Bitumen**	**Specific Bituminous Mixture Gravity (g/cm^3)**	**Bulk of Samples without parafilm (g/cm^3)**	**Porosity of samples (%)**	**Deformation (mm)**	**Difference on deformation from 9.5% to 10.0% of bitumen (mm)**
1	9.5	2.408	2.295	4.7	1.88	0.27
	10.0	2.392	2.291	3.7	1.61	
6	9.5	2.404	2.328	6.4	1.34	-0.22
	10.0	2.446	2.323	5.4	1.56	
7	9.5	2.406	2.316	3.8	1.67	-0.23
	10.0	2.391	2.303	3.7	1.90	
8	9.5	2.410	2.330	3.4	1.20	-0.32
	10.0	2.395	2.329	2.8	1.52	

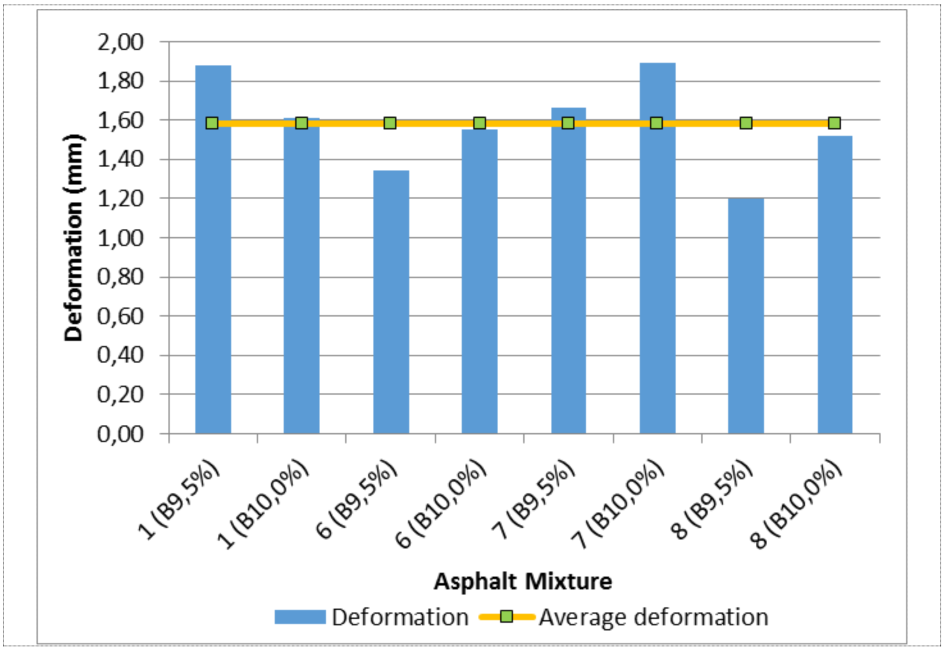

Figure 7 – *Results of the permanent deformation resistance tests (Rutting – deformation 120 min)*

From the test results presented in Table 2 and Figure 7 it is possible to conclude that all the mixtures evaluated reveal an excellent permanent deformation resistance, exhibiting an average value of 1.58 mm, nerveless it's possible to see that mixture 8 (1.20 mm) and mixture 6 (1.34 mm) are the mixtures with the higher permanent deformation resistance.

Table 2 shows that the mixtures studied have an extremely high interlock between the aggregates, resulting in a slightly increase of deformation between the mixtures with optimum percentage of bitumen and the same mixtures with an increase of 0.5 % of bitumen. Mixture 6 and mixture 7, and mixture 8 show an increase of only 0.22 mm and 0.23 mm, and -0.32 mm respectively. Nevertheless, mixture 8 had the highest increase of permanent deformation; it still continues to have a deformation of only 1.52 mm for 10.0 % of bitumen.

The ThinGap mixtures developed present higher resistance to permanent deformation than the best mixes ever tested for rut resistance by Consulpav generally obtained for mixtures with high rut resistance as SMA mixtures with fibers as shown in Figure 8.

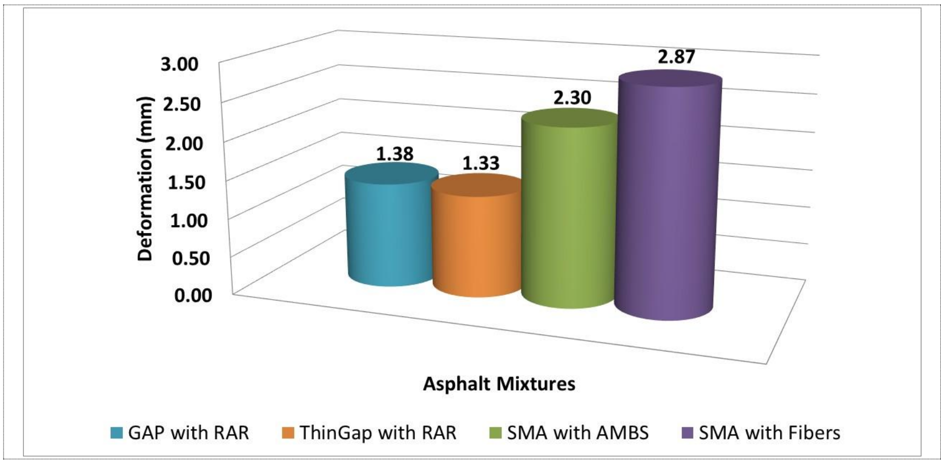

Figure 8 – *Results of the permanent deformation resistance tests with different types of bituminous mixtures (Rutting - deformation 120 min)*

For the further tests, only mixture 6 (with 9.5 % and 10.0 % of bitumen) was evaluated regarding that this mixture represents proximally the mean aggregate gradation for the aggregate envelope developed for the ThinGap mixture regarding mixtures 6, 7 and 8.

4.2. *Fatigue*

The methodology adopted in this study for the preparation of bituminous mixing and compaction is the one that has been used by the laboratory of CONSULPAV in many other studies of this nature. This methodology is based on the standard AASHTO PP3-94D (Standard Practice for Hot Mix Asphalt Preparing Specimens by Means of the Rolling Wheel Compactor).

To study the mechanical behavior of bituminous mixtures CONSULPAV has an adopted the latest and the most advanced technology in the area of fatigue tests as recommended by SHRP A-003A. This allows in particular for the test to be conducted based on pure bending prismatic beams where loads are applied at four points.

The evaluation of the fatigue behaviour of the asphalt mixtures was carried out through four points bending fatigue tests, with controlled strain, applying a 10 Hz sinusoidal load, at 500 micron in strain (displacement) and 20 ºC, according to the test procedure described in the European standard EN 12697-24.

Only mixture 6 with 9.5 % of asphalt and 10.0 % of asphalt (both with 45 % of RAR) was evaluated, the average fatigue life is presented in Figure 9 and Figure 10.

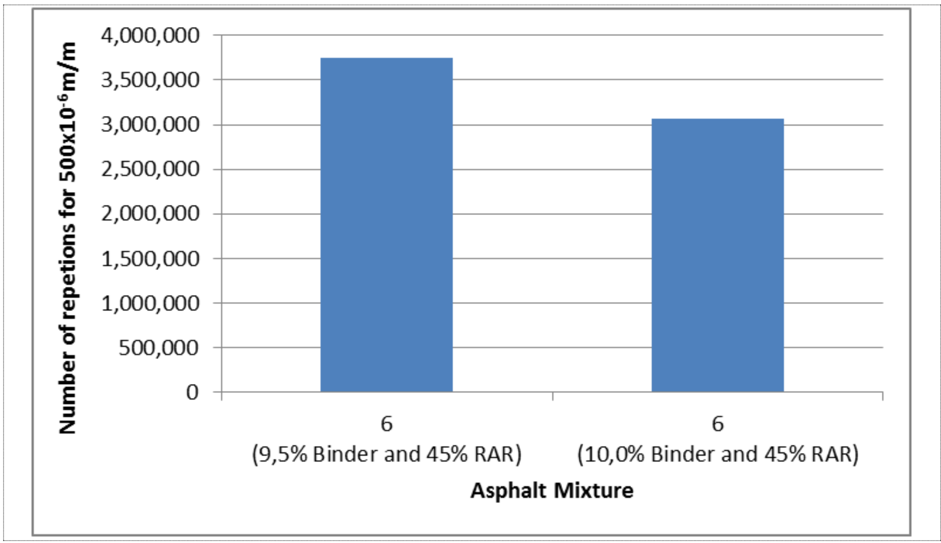

Figure 9 – *Results of the fatigue resistance tests (Average fatigue life)*

From the test results presented in Figure 9 it is possible to conclude that the mixtures evaluated reveal a very good fatigue resistance, exhibiting an average number of repetitions above $3x10^6$ for a strain equal to $500x10^{-6}$. The ThinGap mixtures presented higher resistance to fatigue than the generally obtained for mixtures with high fatigue resistance as Asphalt Rubber mixtures as previous studied, also shown in Figure 10. It can be noticed that ThinGap mixes with 45% RAR have fatigue lives about 100 times that of conventional mixes. The moduli of these mixes is the same as regular gap graded mixes about 4000 MPa to 4500 MPa at 20ºC and 10 Hz.

According to the results obtain (Figure 11) is also possible to conclude that a decrease in the asphalt mixture porosity (porosity) corresponds to an increase in the fatigue life. Similar results for dense hot mix asphalt mixtures were obtained in the WesTrack study (Epps, 1997). Also in the Australian study (Austroads, 1999) as showed in Figure 12.

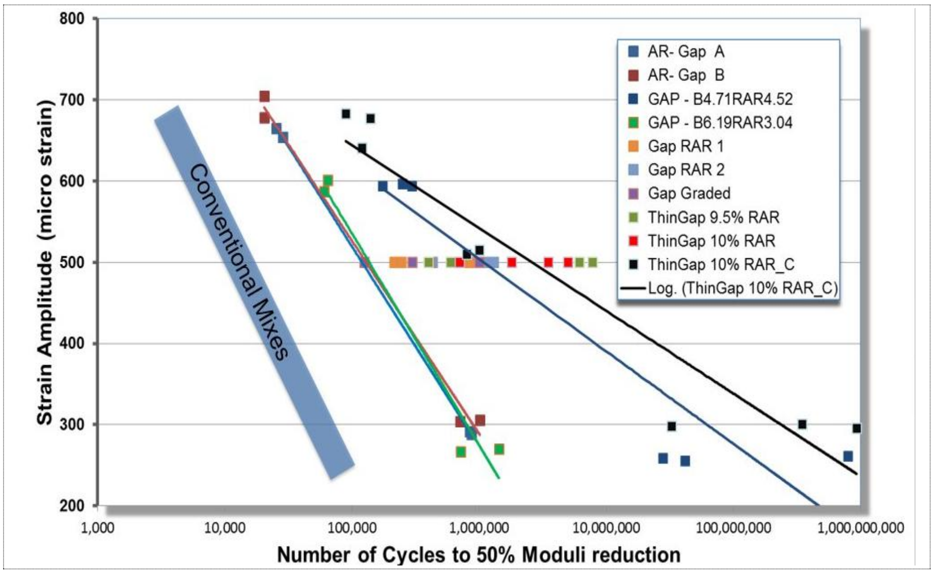

Figure 10 – *Fatigue life at 10 Hz, 20ºC and 500µ strain for different types of bituminous mixtures*

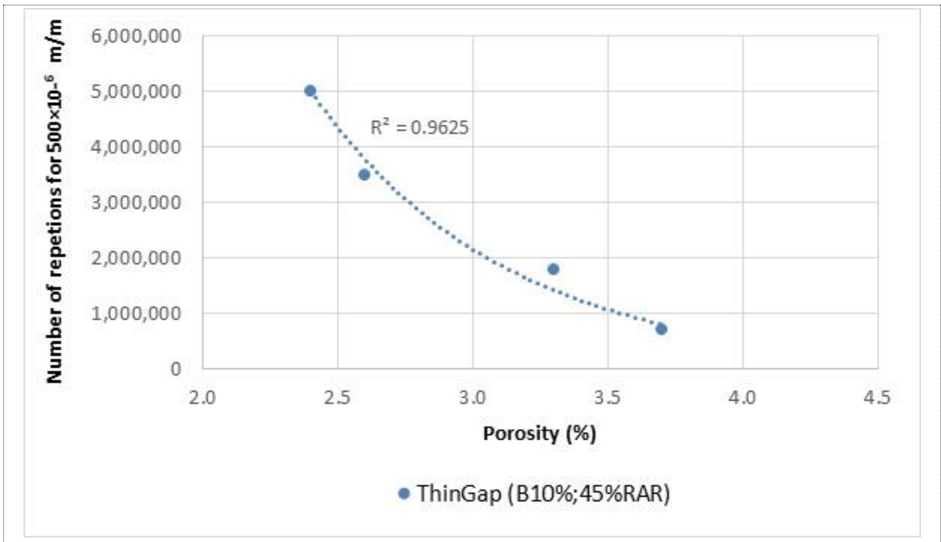

Figure 11 – *Fatigue life versus asphalt mixture porosity*

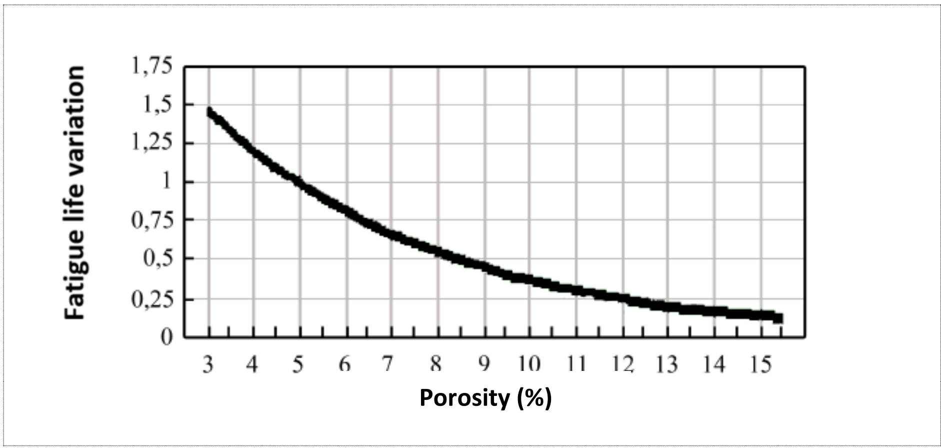

Figure 12 – *Fatigue life for dense graded hot mix versus asphalt mixture air voids (Austroads, 1999) (Austroads, 1999)*

4.3. *Cantabro test*

Cantabro test is used to determine the abrasion loss of compacted hot-mix asphalt specimens. This test procedure measures the wear of compacted specimens utilizing the Los Angeles Abrasion machine. The percent of weight loss (Cantabro loss) is an indication of wearing course durability and relates to the quantity and quality of the asphalt binder. The percentage of weight loss is measured and reported. The test specimen was placed in the Los Angeles testing machine (not including the steel balls). The Los Angeles machine tumbled the specimen at speed of 30 to 33 revolutions per minutes for 300 revolutions**.** The loose material broken off the test specimen was discarded.

The test was conducted under the Standard NLT 362/92 (Spanish Norm).

Table 3 – *Cantabro results (Mixture 6 – 9.5%) – Dry and Wet*

Mixture 6 – 9.5%, 45% RAR						
Samples	**TG1**	**TG2**	**TG3**	**TG4**	**TG5**	**TG6**
Air Voids (%)	7.1	5.0	5.5	6.1	5.9	6.0
Density (g/cm^3)	**2404**					
Results	**CANTABRO**					
	DRY			WET		
	5.9	6.0	5.8	6.0	7.5	6.3
	Average=	**5.9 %**		**Average=**	**6.6 %**	

Table 4 – *Cantabro results (Mixture 6 – 10.0%) – Dry and Wet*

Mixture 6 – 10.0%, 45% RAR						
Samples	**TG31**	**TG32**	**TG33**	**TG34**	**TG35**	**TG36**
Air Voids (%)	3.7	2.8	3.2	3.2	3.6	3.1
Density (g/cm^3)	**2388**					
Results	**CANTABRO**					
	DRY			WET		
	2.8	2.2	1.3	2.1	2.5	1.9
	Average=	**2.1 %**		**Average=**	**2.2 %**	

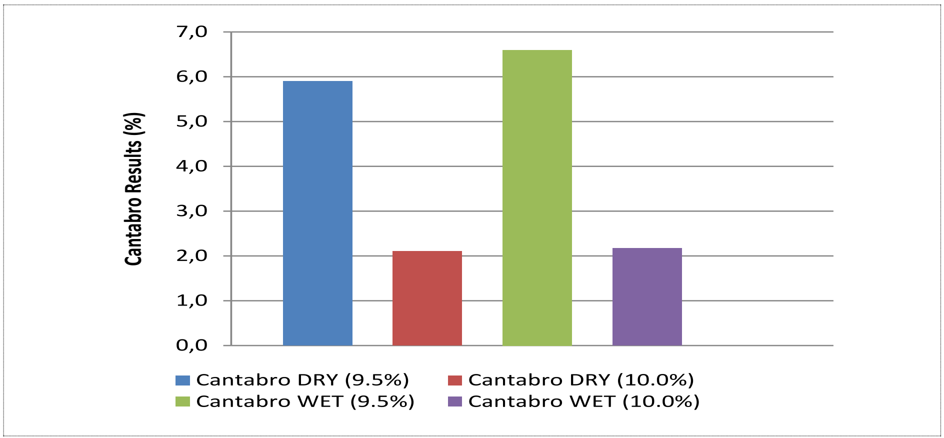

Figure 13 – *Graphic results of Cantabro Test (Average – 3 samples)*

As can be seen through the graphic results (Figure 13), the mixture 6 with 9.5% and 10.0% shows very good results. It is significant that there is no difference between wet and dry results.

4.4. *Indirect Tensile Strength*

A cylindrical specimen is loaded diametrically across the circular cross section. The loading causes a tensile deformation perpendicular to the loading direction, which yields a tensile failure. The test was conducted under the Standard ASTM D6931. ITS tests were made by leaving the mixtures for two hours in the oven, at 180ºC, before compaction. These tests were made using 45% of RAR. The results obtained can be seen in Table 5 and Table 6. As these tables show the mixture 6 with 9.5 % and 10.0 % has expected good results with a ITS between 88.3 % and 101.9 %, respectively.

Table 5 – *ITS results (Mixture 6 – 9.5%)*

Mixture 6 – 9.5%, 45% RAR						
Samples	**13**	**14**	**15**	**16**	**17**	**18**
Air Voids (%)	3.8	3.9	4.7	4.5	4.3	4.2
Density (g/cm^3)	**2404**					
Results	**ITS**					
	DRY			WET		
	Indirect tensile strength (kPa)			**Indirect tensile strength (kPa)**		
	1524	1522	1371	1275	1270	1355
	TSR: 88.3 %					

Table 6 – *ITS results (Mixture 6 – 10.0%)*

Mixture 6 – 10.0%, 45% RAR						
Samples	**TG25**	**TG26**	**TG27**	**TG28**	**TG29**	**TG30**
Air Voids (%)	2.5	3.2	2.5	3.3	2.9	2.8
Density (g/cm^3)	**2388**					
Results	**ITS**					
	DRY			WET		
	Indirect tensile strength (kPa)			**Indirect tensile strength (kPa)**		
	1269	1264	1253	1299	1261	1297
	TSR: 101.9 %					

4.5. *Water sensitivity*

The evaluation of the reduction in Marshall Stability resulting from the action of water on compacted asphalt mixtures (index of retained stability) was carried out through Marshall Tests, according to the test procedure described in the American Military standard ML-STD-620A.

Table 7 – *Water sensitivity results (Mixture 6 – 9.5%)*

Mixture 6 – 9.5%, 45% RAR						
Samples	**TG7**	**TG8**	**TG9**	**TG10**	**TG11**	**TG12**
Air Voids (%)	4.0	4.1	4.2	4.3	4.2	4.8
Density (g/cm^3)	**2404**					
Results	**Water Damage Resistance**					
	DRY			WET		
	Stability (N)			**Stability (N)**		
	9670	10854	10540	9100	8931	9716
	AVG=	10355		AVG=	9249	
	Flow (mm)			**Flow (mm)**		
	2.5	2.6	2.6	2.4	2.5	3.0
	Average=	2.6		Average=	2.6	
	WDR:			**89.3 %**		

Table 8 – *Water sensitivity results (Mixture 6 – 10.0%)*

Mixture 6 – 10.0%, 45% RAR						
Samples	**TG19**	**TG20**	**TG21**	**TG22**	**TG23**	**TG24**
Air Voids (%)	3.4	3.3	3.0	2.9	2.7	2.8
Density (g/cm^3)	**2388**					
Results	**Water Damage Resistance**					
	DRY			WET		
	Stability (N)			**Stability (N)**		
	9349	8996	8131	8677	7538	11477
	AVG=	8825		AVG=	9231	
	Flow (mm)			**Flow (mm)**		
	3.0	3.5	3.0	2.5	2.5	3.5
	Average=	3.2		Average=	2.8	
	WDR:			**104.6 %**		

As can be seen through the results presented in Table 7 and Table 8, the mixture 6 with 9.5% and 10.0% shows as expected good results with a water sensitivity between 89.3% and 104.6%, respectively. Obviously, it is not to be expected an improvement of properties under moisture action. The values above 100% are due to random errors but they indicate that not much damage is indeed present.

5. Performance Design Prediction

This new ThinGap mixture could be effectively used to control reflective cracking in a similar manner as GAP Graded overlay do. Current design procedure make accommodations for reduce thicknesses when high binder contents with high rubber contents are used in mixes in Arizona and California. To investigate the relative performance on actual pavement designs the fatigue properties of ThinGap with about 45% RAR content were introduced in the reflective design methodology developed for RPA and reported in Sousa (2002). Figure 14 compares the design chart of dense mixes, Gap graded asphalt mixes and ThinGap. It is very likely that even more reduced thicknesses can be achieved using this high crumb rubber content mixes.

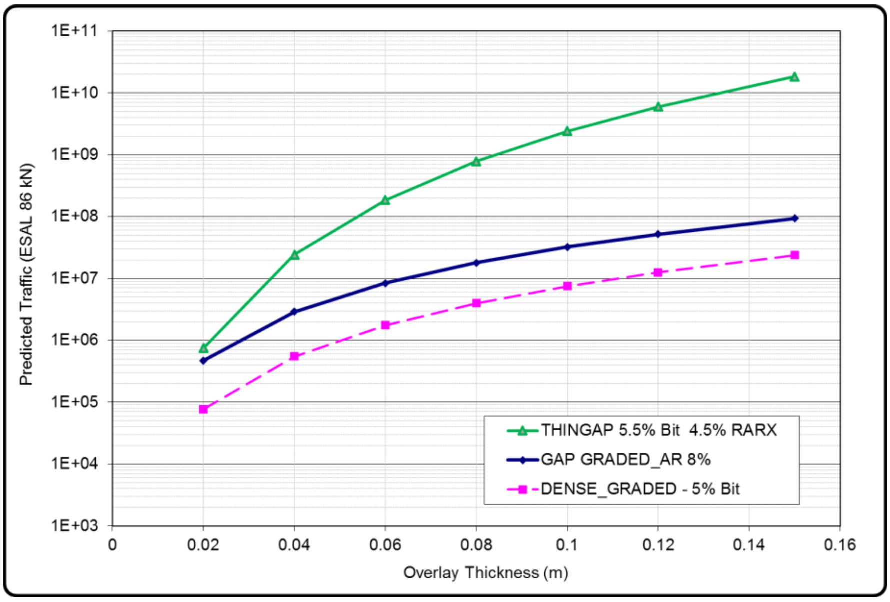

Figure 14 – *Design Chart comparing the reflective cracking life of an overlay function of their thicknesses for ThinGap, GapGraded and Dense mixes*

6. Case study – In main highway in Portugal

The ThinGap mixture have been recently applied in the toll of a main highway in Portugal (Figure 15). The mixture used is being used as a case study in Portugal. The Thingap had 5.5% bitumen and 4.5% RAR by weight of the mix.

Figure 15 – *Aerial view of the toll of the main highway in Portugal*

Figure 16 shows a general view of the surface of the ThinGap mixture.

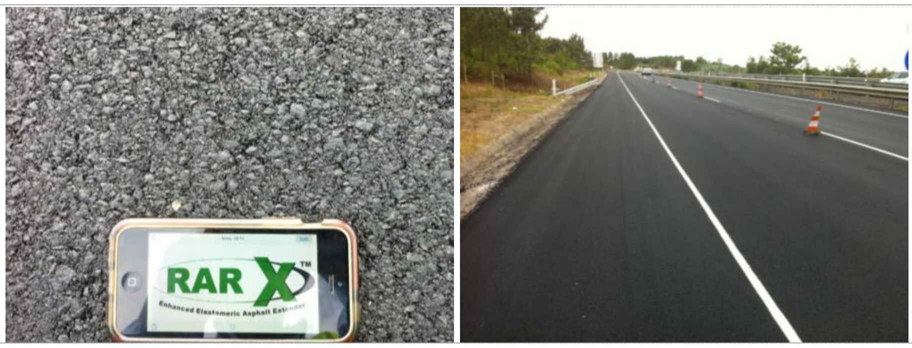

Figure 16 – *View of the ThinGap applied*

Friction tests with the ASFT equipment were carried out one day after the mixture have been applied in the pavement. The tests were made at a speed of 65 km/h for wet condition. The results present in Figure 17 show a very high friction value of 0.73 (mean value). For example, the existing open graded mixture, already applied a few years ago has a mean friction value of 0.68. These results show that the use of Thingap with high percentages of RAR promotes improved friction in wet condition.

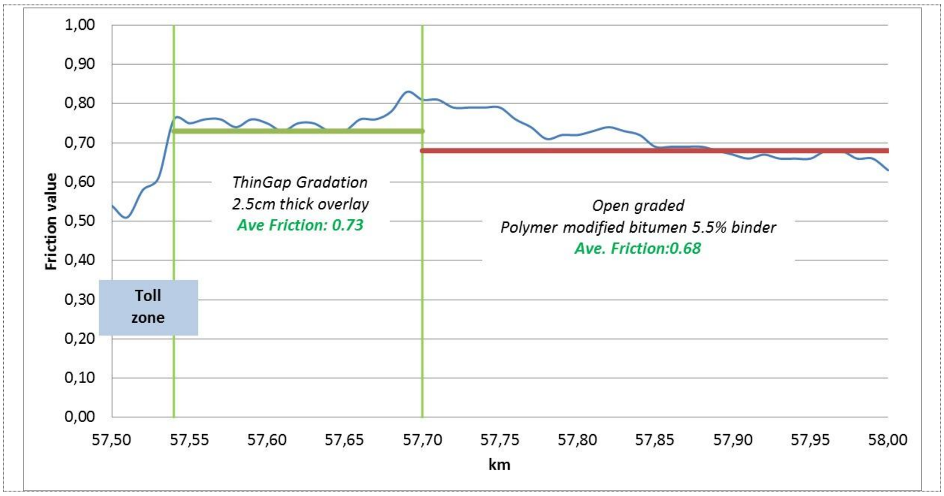

Figure 17– Friction test results for ThinGap used in a main Highway in Portugal

6. Conclusions and final remarks

A new mix was developed as part of this research effort. It was specifically designed to maximize the amount of RAR possible to place in a mix. The objective was to develop with identical or superior performance attributes of a normal asphalt rubber gap graded mix to resist surface torsional forces, but that could be used in very thin lifts like an Open Graded Asphalt rubber mix. It was also an objective of the study to insure that reflective cracking resistance was maximized without compromising rut resistance.

It was demonstrated that the asphalt mixtures ThinGap 9.5mm with RAR used in this study, exhibit an excellent rut resistance, actually the very best rutting resistance ever observed in a mix tested in Consulpav. The fatigue life is about 100 times that of regular mixes. This is attributed to the very high recovery encountered on the binder where 45% is replaced with RAR (lower percentages RAR can be used). No decrease of water or moisture resistance of observed as indicated by ITS or moisture sensitivity tests. The Cantabro wear was also incredible low even in a wet condition. Additionally to the present study, torsional recovery was also evaluated in Sousa *et al*. (2015). The results show that in generally the mixture ThinGap with

RAR shows a better elastic recovery for 35 ºC, when compared with other asphalt mixtures (dense, gap-graded, open-graded and SMA).

According to this study ThinGap 9.5 mm with RAR can be used with the following overall limits of target composition (grading envelope) as shown in Table 9. The mix design process is absolutely identical to that of a Marshall Mix design for an Arizona Asphalt Rubber GAP Graded mix except that the gradation used is the proposed above. It is very likely that no other additives are needed to guard against water damage but for particular sensitive aggregates, the normal additives could be added.

Table 9 – *Overall limits of target composition (grading envelope) for the ThinGap 9.5 mm with RAR*

Sieve size (mm)	Lower limit	Upper limit
9.5	100	100
4.75	48	70
2.36	21	34
0.075	2.0	4.0

With such high degree of rut resistance and the fact that most binder is not included in the RAR it is possible to decrease the air void content requirement to 2.5 to 5.0%. The crack resistance benefits of lowering air void content are hugely beneficial.

These types of asphalt mixtures with RAR can provide a very interesting alternative to other types of mixtures used in pavement rehabilitation works, both from environmental and from the economical point of view. With this new mix type the layer thicknesses can be as low as 16 mm and as high as 75 mm. As such ideal to place over even or un-even highly cracked pavements to extend their life, provide an excellent riding surface that it is also one of the least noise generating surfaces (Biligiri *et al*. 2015).

The extremely high fatigue resistance (when well compacted) of about 100 times that of regular paving mixes is without parallel in the industry. This was achieved by maximizing the crumb rubber (RAR) content in the binder making the binder virtually elastic (i.e. minimizing the viscous component). With 38 to 45% RAR content on 10% binder content the actual crumb rubber content is about 29.75% by the weight of the binder and about 3% by weight of the mix. As such this is most likely to be one of the most environmental friendly mixes ever created given that overlay thickness reductions to about 25 to 30% of actual dense graded thickness appears to be very probable.

6. References

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