INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Study of the Performance of Alternative Materials in Road Paving

The case of Warm Mix Asphalt

Maria Cristina Alves

Abstract: The growing concern over the reduction of emissions and energy savings has led to the development of new paving technologies that are environmentally friendly. The use of Warm Mix Asphalt (WMA) is an example of the industry's efforts toward improvement. Due to the decrease of the temperature during the production and compaction, WMA mitigates its impact on environmental pollution, energy consumption and worker exposure to gases. This work has the aim to make a comparative analysis of the performance, in laboratory, of one Hot Mix Asphalt (HMA) mixture produced at conventional temperatures (between 140 and 150 °C), and a warm mixture of the same type produced with three different WMA production techniques, such as the introduction of additives (Sasobit and Rediset) that allow manufacturing and compacting the mixture at lower temperatures, between 100 and 120 °C. To prove that WMA performance is similar to the HMA, some laboratory tests were run, such as a Marshall Study, Water sensitivity and Wheel Tracking. The results obtained show that the behavior of WMA is similar to HMA and proved the good performance capabilities of WMA mixtures.

Keywords: Road Pavements, Hot Mix Asphalt (HMA), Warm Mix Asphalt (WMA), Additives, Performance

1. Introduction

Over the past years, after the adoption of the Kyoto protocol, the concern about environmental issues has been increasing in various construction sectors, since it is necessary to reduce greenhouse gases emissions into the atmosphere. In the domain of road infrastructure this issue has also been very present, and in recent years, technologies have been developed to reach the goals defined in environmental terms. In this context, arises Warm Mix Asphalt (WMA), which is a process that consists in the manufacture and compaction of bituminous mixtures at lower temperatures (between 100 and 120°C). Reducing production and placement temperatures will provide several benefits, including reduced emissions, fumes, odors and a cooler work environment.

A WMA production technique is the introduction of additives in the bituminous mixture (Silva et al., 2010). The additive is incorporated during the manufacturing stage, causing a decrease in the binder viscosity, allowing the production, application and compaction of the asphalt at lower temperatures (Redondo et al., 2010). WMA presents a similar performance to Hot Mix Asphalt (HMA), sometimes even better. The performance of this type of mixtures results of several factors. The fact that the mixture presents good workability allows to achieve a higher density, which in, the long run, reduces the hardening of the bitumen and prevents water infiltration. The lower production temperatures also decrease the aging of the bitumen in the production phase, which improve the characteristics of thermal resistance and fatigue (EAPA, 2010).

So that these mixtures can be accepted and be used, it is necessary to prove that its performance is similar to HMA. The objective of this work is to analyze and compare the performance of three WMA mixtures and one HMA mixture, all of the same type. This investigation includes laboratory tests such as a Marshall Study, Water Sensitivity and Wheel Tracking.

2. Generalities about Warm Mix Asphalt

The bituminous mixtures are, generally, constituted by a set of granular materials, called aggregates, and a hydrocarbon binder, the asphaltic bitumen. These components are dosed and mixed in a plant. The mixture is subsequently carried, spread and compacted forming a pavement layer.

The bituminous mixtures can be classified in several ways, one of which is made according to the temperature range of production in central and fuel consumption. In Figure 1 is the classification used to the bituminous mixtures depending on the production temperature in central and fuel consumption.

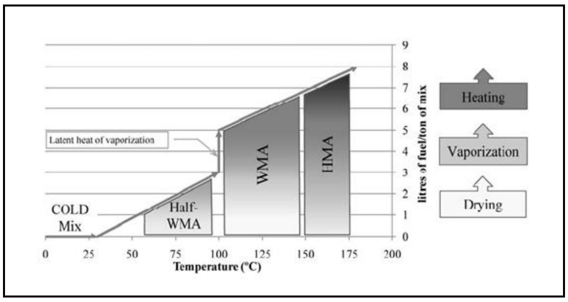

Figure 1 - classification used to the bituminous mixtures depending on the production temperature in central and fuel consumption (Olard & Noan, 2008)

In the case of WMA, the mixture is produced at a temperature approximately between 120 and 140°C (Vaitkus et al., 2009). The production of bituminous mixtures in this range of temperatures is possible with the introduction of additives in the mixtures. The additives are agents from different sources that allow the reduction of the production and compaction temperature, without compromising the performance of the pavement (Silva et al., 2010).

2.1 Benefits of WMA

The use of WMA brings many benefits and advantages at different levels. At an environmental level, WMA generates an evident reduction in emissions, which arises due to the lower production and compaction temperature of the mixtures. Some reports refer that the use of WMA generates a saving of 20 to 35% of fuel (D'Angelo et al., 2008). Regarding the paving, the fact that it is possible to execute a pavement at lower temperatures, brings several advantages making WMA production technologies very attractive. It is possible to pave at lower temperatures also ensuring the desired density, as well as transport the mixture at bigger distances than usual and still ensure workability for the application and compaction with less effort. At a social level, it was proved that decreasing the production and compaction temperatures of the mixture, gases emissions and the fumes are also reduced, providing more safety and better work conditions to the workers, as well as a better environmental quality for the society. The fact that it is provided more comfort and better work conditions to the workers, promotes an increase of the productivity in the application of the mixtures (D'Angelo et al., 2008). At an economical level there is a reduction in the energy costs resulting from the reduction of the fuel consumption.

2.2 Usual Compositions for WMA Production

In general there are four WMA technologies that are used in the world:

- Foaming bitumen technology, where foaming is caused by water. The foaming of bitumen is caused by spraying water into hot bitumen or by mixing the wet sand into asphalt mix. Some of the products used in this technology are WAM Foam, Terex WMA System, Double-Barrel Green, LEA – Low Energy Asphalt, LT Asphalt, LEAB and Ultrafoam GX.
- Foaming bitumen technology where foaming is caused by natural or synthetic zeolite injection into asphalt mixture during mixing process. Some of the

products used in this technology are Aspha-Min, Advera WMA Zeolite and Natural Zeolite.

- Organic additives for the reduction of bitumen viscosity. The additives are injected into the asphalt mixer together with the aggregates and the bitumen. Some of the products used in this technology are Sasobit, Asphaltan B and Licomont BS 100.
- Chemical additives for the reduction of bitumen viscosity. The additives are injected into the asphalt mixer together with the aggregates and the bitumen. Some of the products used in this technology are Rediset, Cecabase, Interlow T, Evotherm and Revic (Vaitkus et al., 2009).

In the present work the additives used were Sasobit and Rediset. Moreover cellulose fibers known as Viatop were used. Thus, it was carried out a detailed analysis only about these components.

Sasobit is a Fischer-Tropsch (F-T) or synthetic wax produced by the heating of coal or natural gas with steam, in the presence of a catalyst (Chowdhury & Button, 2008). This additive causes a decrease in the binder viscosity in the manufacture process and during the mixture application.

Rediset consists of a combination of chemical and organic surfactants which modify the rheology of the binder. It contains no water, so the surfactants enhance the involvement of the aggregates' surface with the binder, through an "active adhesion", and the remaining components of the additive reduce the binder viscosity (Prowell & Hurley, 2008).

Viatop consist of cellulose fibers coated with bitumen by means of a special production process. The addition of Viatop allows stabilization of the mixture and the pavement has also a high deformation resistance and a long life period (J.Rettenmaier & Söhne).

2.3 Characterization Studies of WMA

A laboratory study was conducted by the University of Minho, School of Engineering to evaluate the performance of WMA. The tests were run in two mixtures of the same type, AC 14 Surf 50/70 with syenitic and limestone aggregate. The difference was that one was a WMA mixture with the additive Sasobit and the other was a HMA control mixture. A Marshall design was done to obtain the optimum binder content, that was 5%, according to the Portuguese specifications. Then after the selection of the additive content (2 and 4%), the mixing and compaction temperatures were defined. The results showed that Sasobit allows a reduction of 10°C in the mixing temperature. After that, were carried out compactability, water sensitivity and wheel tracking tests. The comparison between the voids content of the HMA control mixture and those of the WMA mixture produced with Sasobit, and compacted at different temperatures, allowed to conclude that it is possible to reduce the mixing temperature up to 20°C. Regarding the remaining tests, the values of the water sensitivity test (ITSR) were lower than expected, which can be related to the aggregate adhesion, however the wheel tracking results were similar and within the expected values. Thus it is possible to conclude that WMA show a good performance (Ferreira, 2009).

A research report written by the University of California described a laboratory testing study that compared the performance of a control mix, produced and compacted at conventional temperatures, with a WMA mixture containing Rediset, produced and compacted at approximately 35°C lower than the control. The mixtures analyzed were of the same type, PG 64-10, which is equivalent to AC 20 Base 60/70, with granitic aggregate. The voids content were similar to both mixtures. In the Hamburg Wheel Track the results and trends indicated similar performance between the two mixtures. Thus, it is possible to conclude that the use of Rediset in WMA mixtures, produced and compacted at lower temperatures, does not significantly influence the performance of the asphalt concrete when compared to control specimens, produced and compacted at conventional HMA temperatures (Jones et al., 2010).

3 Experimental Study

In this work an experimental study is developed with the objective of evaluating the performance of four bituminous mixtures. In Figure 2 is a Flow Chart explaining the experimental work that will take place and the outputs that result from it.

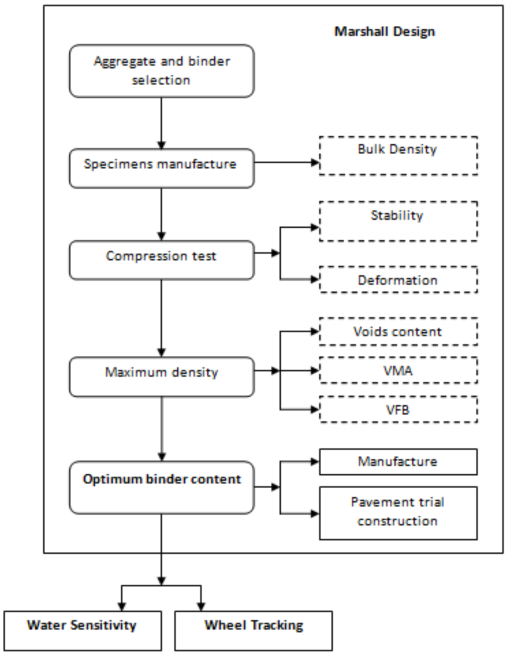

Figure 2 – Flow Chart explaining the experimental work that will take place and the outputs that result from it (adapted from Picado Santos, 2010).

3.1 Materials Characterization

One of the mixtures was a conventional HMA produced by the Tecnovia S.A. company while the other three were WMA mixtures with the same composition but with additives. One was with Sasobit, another with Rediset and the last one was with the additive Rediset and the fibers Viatop. The mixtures were of type AC 20 Base 35/50 with limestone aggregate. In Table 1 is referred the designation of the analyzed mixtures, used from now on.

Table 1 – Designation of the analyzed mixtures

Designation	Mixture	Type	Additive
M0	HMA	AC 20 Base 35/50	-
M1	WMA	AC 20 Base 35/51	Sasobit
M2	WMA	AC 20 Base 35/52	Rediset
M3	WMA	AC 20 Base 35/53	Rediset and Viatop

The characteristics of the aggregates are presented in Table 2 and in Figure 3.

Table 2 – Properties of the aggregates used in the studied mixtures (Tecnovia S.A., 2011)

Properties	Aggregate 10/20 mm	Aggregate 4/10 mm	Sand 0/4 mm
Flakiness Index (%)	12	13	-
Methylene Blue	-	-	0.2
Los Angeles Abrasion (%)	-	-	-
Particle Density (g/cm^3)	2.66	2.67	2.63
Water Absorption (%)	1.0	1.0	1.2

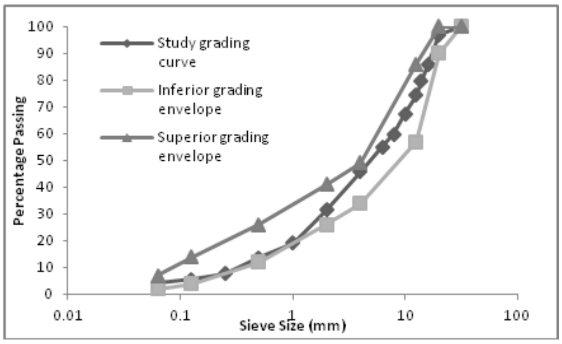

Figure 3 – Placement of the grading curve in the spindle of the standard EN 13108-1:2008

Based on the mixtures aggregate grading, it was determined the proportion of the granular materials to be adopted, in order to obtain a mixture of aggregates adjusted, as well as possible, to the grading spindle defined in the standard EN 13108-1 (CEN, 2006) The grading curve that best fits, presenting a regular shape, is the one that results from the combination of aggregate percentage presented in Table 3.

Table 3 – Percentage of aggregates used in the studied mixture (Tecnovia S.A., 2011)

Aggregate	Percentage
Aggregate 10/20 mm	32
Aggregate 4/10 mm	20
Sand 0/4 mm	48

Regarding the content of the additive, in the mixture M1, was added a proportion of Sasobit of about 4% by weight of the bitumen, in the mixture M2 it was added about 2%

by weight of the bitumen of Rediset, and in the mixture M3 was added about 1.5% and 5% by weight of bitumen of Rediset and Viatop, respectively.

3.2 Marshall Design

The Marshall method was carried out according to the EN 12697-34 (CEN, 2004) and started with the manufacture of the specimens. In the WMA mixture the aggregates were heated at 120°C, then the additive was added at 25°C and finally the bitumen at 160°C. All the components were mixed and afterward the specimens were compacted at 100°C with 75 blows in each face. The specimens were demoulded ensuring that they were cool. After a wait of at least 4 hours the bulk density of each specimen was determined in accordance with EN 12697-6 (CEN, 2003). Then the maximum density test was executed and all the volumetric characteristic of the Marshall specimens were calculated (voids content, VMA and volume of bitumen and aggregates). At last, all specimens were tested by using the Marshall test procedure, registering the stability and deformation values obtained from the test.

This procedure, as referred, was performed on the three WMA mixtures; and for each mixture were produced 20 specimens, 4 for each binder content. The binder contents were 3.5%, 4.0%, 4.5%, 5.0% and 5.5%.

In the HMA mixture the specimens were manufactured at 150°C and compacted at 140°C. Nevertheless, it was not necessary to produce specimens with this mixture and assess its characteristics because the Tecnovia S.A. company yielded a report with all data of the HMA mixture, corresponding to the Marshall test.

The optimum binder content of a bituminous mixture is determined calculating the average of the corresponding percentage of the maximum stability, maximum bulk density and the average value of the air voids limits.

However, it was found that some of the values obtained in the Marshall test, for the WMA mixtures, did not followed the normal trend, which makes it difficult to determine the optimum binder content. Therefore, it was decided to proceed the studies adopting, for the three WMA mixtures, the same optimum bitumen content as the conventional HMA mixture, ie 4.5%.

3.3 Water Sensitivity Test (ITSR)

The water sensitivity test was executed in accordance with EN 12697-12 (CEN, 2008). The specimens were prepared and compacted as in the Marshall test, with 75 blows in each face, a diameter of 100 mm and a height of 63.5 mm. The WMA specimens were produced at 120°C and compacted at 100°C while the HMA specimens were at 150°C and compacted at 140°C.

Six specimens were prepared for each, which were divided in two subsets having approximately the same average length and average bulk density. The two groups of specimens were conditioned in different environments, dry and wet with the application of vacuum. Finally, the indirect tensile test was performed on each specimen (compression test) and the indirect tensile strength ratio was determined.

3.4 Wheel Tracking Test

The determination of the resistance to permanent deformation was carried out using the wheel tracking test in accordance with the standard EN 12697-22 (CEN, 2003).

For each mixture two specimens were prepared. The mass of the bituminous mixture, previously calculated, was introduced in the mould with dimensions of 300 x 400 x 60 mm. The specimens were compacted using a roller compactor in accordance with the standard EN 12697-33 (CEN, 2003). After a period of conditioning at 60°C the wheel tracking test was performed. The test was carried out according to procedure B of EN 12697-22 (CEN, 2003), using a small size device, at a temperature of 60°C. The tracking continued until 10 000 load cycles have been applied. The susceptibility of the mixtures to deform was assessed by measuring the rut depth (RD_{AIR}) and the Wheel Tracking Slope in air (WTS_{AIR}).

The values of the main characteristics obtained from the laboratory tests executed in this study are presented in Table 4.

Table 4 – Results obtained from the laboratory tests performed in the present study

Properties	M0	M1	M2	M3
Bitumen Content (%)	4.5	4.5	4.5	4.5
Voids Content (%)	4.2	5.4	4.9	5.4
VMA (%)	14.4	15.5	14.9	15.4
Bulk Density (kg/m^3)	2394	2310	2299	2284
Stability (kN)	12.2	11.1	10.8	11.3
Deformation (mm)	3.65	4.3	4.61	5.06
ITSR (%)	73.8	42.4	49.0	47.6
RD_{AIR} (mm)	7.8	2.2	3.4	6.1
WTS_{AIR} (m/10^3)	0.33	0.06	0.10	0.23

4 Discussion

4.1 Marshall Design

In Figure 4 there is a comparative graph of the four analyzed mixtures, referring to the bulk density.

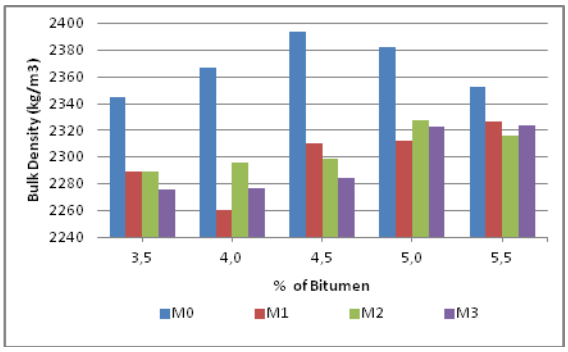

Figure 4 – Bulk Density of the analyzed mixtures

The graph shows that the bulk density of the Control mixture (M0) is higher than the WMA mixtures, which can be justified with the temperature reduction in both manufacture and compaction stage. It is important to refer that the specimens for the Marshall study were produced manually, making it difficult to maintain a constant temperature. After mixing at 120°C, the specimens were cooled down until they have reached 100°C, in order to be compacted. Thus, given the laboratory conditions, it is likely that the compaction has been carried out at a temperature slightly below 100°C, which justifies the decrease in the bulk density of the WMA mixtures. A variation of just 1°C in the compaction stage has a considerable influence in the obtained results.

In Figure 5 and in Figure 6 there is a comparative graph of the four analyzed mixtures, referring to the voids content and the voids content in the mineral aggregate (VMA), respectively.

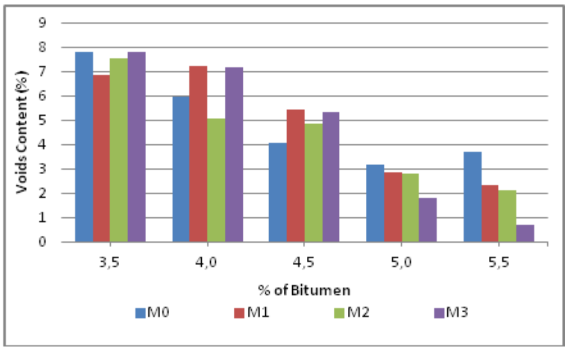

Figure 5 – Voids Content of the analyzed mixtures

Figure 5 shows that for 3.5% of bitumen, the voids content of WMA is similar to that of the Control mixture, for 4.0 and 4.5 % of bitumen the voids content of WMA is higher than in the mixture M0 and finally, for 5.0 and 5.5 % of bitumen the voids content of WMA is lower than in mixture M0.

Regarding the VMA, it can be seen in Figure 6 that the Control mixture has higher values than those of the WMA mixtures, for the percentages of bitumen of 3.5, 5.0 and 5.5. In the two remaining percentages of bitumen, the values are similar, except in the WMA mixture M2.

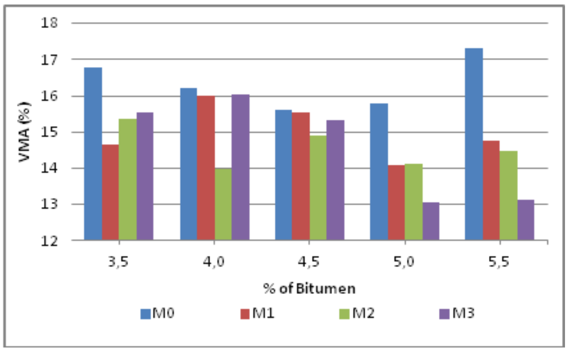

Figure 6 – Voids Content in the Mineral Aggregate of the analyzed mixtures

In Figure 7 and in Figure 8 there is a comparative graph of the four analyzed mixtures, referring to the stability and deformation, respectively.

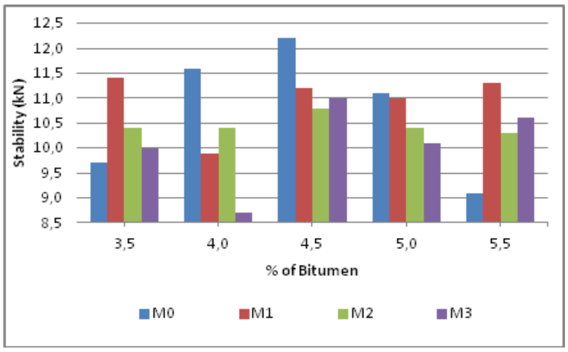

Figure 7 – Stability of the analyzed mixtures

As it can been observed in Figure 7, the stability of the WMA mixtures did not follow the expected trend. Typically, as in the Control mixture, for the lower percentage of bitumen, the stability is more reduced, increases until reaching a peak and returns to decrease, with the increase of the amount of bitumen. In the WMA mixtures, this process was not observed. The stability remained sensibly constant, reaching in most of the cases 10 kN.

Concerning the deformation, the values obtained for the WMA mixtures were higher than those for the Control mixture, and as the stability, did not follow the expected trend, ie, they did not increase with the increase of the amount of the bitumen, as it happens in the Control Mixture. This fact was already expected since the bulk density of the WMA mixtures was reduced.

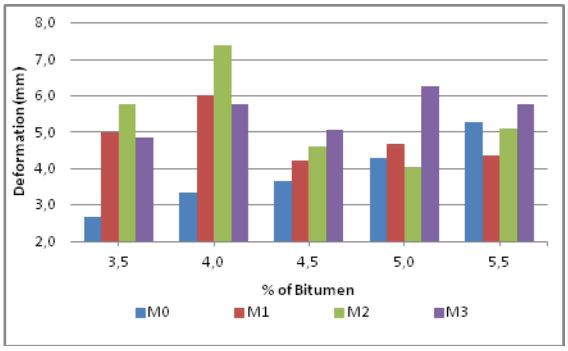

Figure 8 – Deformation of the analyzed mixtures

As already mentioned, the results obtained for the WMA mixtures in the Marshall study did not follow the normal trend, making it difficult to determine the optimum bitumen content. Therefore, since the optimum bitumen content set to Control mixture was 4.5% and for this content the WMA mixtures presented good values of stability, voids content and VMA, the studies were continued with an optimum binder content of 4.5%.

So that bituminous mixtures can be applied on road pavements it is necessary that both the asphalt and its components meet certain requirements. In Portugal, these requirements are usually expressed in the Technical Specifications from the national company Estradas de Portugal SA (EP). Thus, a verification of the requirements will be done of the mixtures analyzed for the base layer. In Table 5 are indicated the limits of the asphalt properties defined in the Technical Specifications from EP (EP, 2009). In Table 6 are presented the values of the characteristics of the bituminous mixtures analyzed, obtained in the Marshall study, which are highlighted in bold those that do not meet the limits imposed by the Technical Specifications from EP.

Table 5 – Limits of the asphalt properties, for the base layer, defined in the Technical Specifications from EP (EP, 2009)

Tests			**Standards**	**Limit Values defined by EP**
Voids Content		V_m	EN 12697-8	3 -6 %
VMA		VMA_{min}	EN 12697-8	> 14 %
Marshall	Stability	$S_{min/max}$	EN 12697-34 and 30	7 - 15 kN
	Deformation	$F_{min/max}$		2 - 4 mm
	Quotient	Q_{min}		> 2 kN/mm

Table 6 – Validation of the results of the analyzed mixtures, obtained in the Marshall study

Properties	**M0**	**M1**	**M2**	**M3**
Bitumen Content (%)	4.5	4.5	4.5	4.5
Voids Content (%)	4.2	5.4	4.9	5.4
VMA (%)	14.4	15.5	14.9	15.4
Stability (kN)	12.2	11.1	10.8	11.3
Deformation (mm)	3.65	**4.3**	**4.61**	**5.06**
Quotient (kN/mm)	3.34	2.58	2.33	2.23

Analyzing the above table it is verified that all the properties satisfy the limits imposed by the Technical Specifications from EP, except the deformation.

However, it is important to refer that the presented deformation is not the adjusted deformation, so if those values had been obtained, it is probable that the results would have been within the limits, since it is an adjusted deformation.

The presented results indicate that, regarding the volumetric and mechanical properties evaluated in the Marshall study, the performance of the WMA mixtures is similar to the Control mixture.

4.2 Water Sensitivity Test (ITSR)

In Figure 9 there is a comparative graph of the four analyzed mixtures, referring to the indirect tensile strength ratio (ITSR).

Figure 9 evidences that the ITSR of the WMA mixtures is relatively lower than that of the Control mixture, which means that, in the WMA mixtures, a decrease has occurred in the moisture resistance. This fact can have occurred due to the small dimensions of the specimens, the low temperatures that may have caused a reduction in the bulk density and another arrangement in the voids content, and eventually the connection aggregate-bitumen that was not successful.

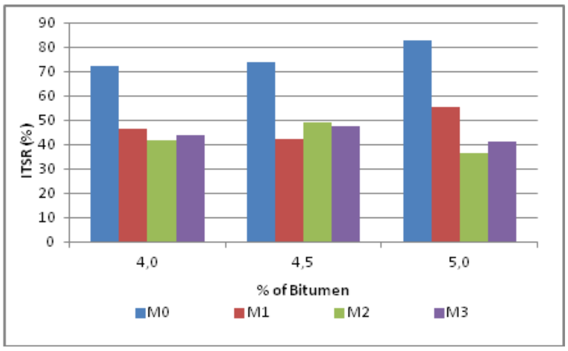

Figure 9 – Indirect Tensile Strength Ratio of the analyzed mixtures

4.3 Wheel Tracking Test

In Figure 10 there is a comparative graph of the four analyzed mixtures, referring to the rut depth.

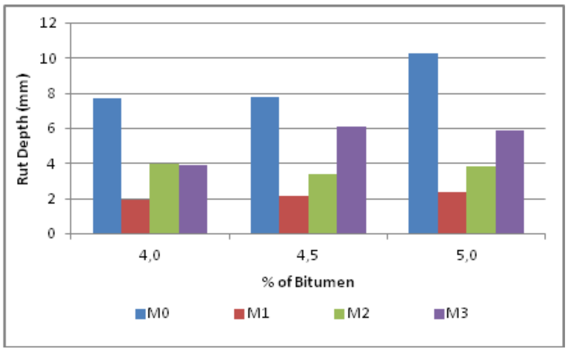

Figure 10 – Rut Depth of the analyzed mixtures

The wheel tracking test, one of the most representative tests of the mechanical performance of bituminous mixtures, demonstrated that WMA mixtures have a greater resistance to permanent deformation. It appears that, especially in the WMA mixture M1, the additive Sasobit gave a better fitting of the aggregate skeleton in the mixture, leading to a lower rut depth. The remaining WMA mixtures also presented a good resistance to permanent deformation when compared to the Control mixture. Therefore, it can be concluded that, on the subject of resistance to permanent deformation, WMA mixtures present an improvement over the Control mixture.

4.4 Economical Analysis

This section summarizes the costs associated with the production of the analyzed mixtures, in order to verify if WMA mixtures are, in fact, a competitive product, when compared to HMA mixtures.

It is expected that, when concerning costs, both reductions and increases can occur. As for what regards the reductions, the most important factor contributing to this is the lowering of the production temperature, once it requires less fuel to heat the aggregates and the bitumen. The lower production temperatures cause less wear on the production plant, which also means an economic advantage. On the other hand, WMA present new costs that may arise from: the cost of the additives, the modification of the production plant and the cost of licenses for the application of WMA technologies. Thus, depending on the interaction of these factors, it is expected that the final costs of the production of WMA are similar to HMA (EAPA, 2010).

In Table 7 are indicated the costs of most of the necessary components for the production of the analyzed mixtures, for the optimum bitumen content, which are: the binder, the additives, the aggregates and the fuel. The unit costs of these components were supplied by the company Tecnovia and the representative company of the additives and fibers in Portugal.

Table 7 – Total production costs of the analyzed mixtures

Properties	M0	M1	M2	M3	
Bitumen Content (%)	4.5	4.5	4.5	4.5	
Cost of Bitumen 35/50 (€/ton mix)	25	25	25	25	
Cost of Additives (€/ton mix)	-	3.58	2.7	2.01	2.7
Cost of Aggregates (€/ton mix)	3.76	3.76	3.76	3.76	
Cost of Fuel (€/ton mix)	4.2	2.1	2.1	2.1	
Total Costs (€/ton mix)	33	34	34	36	

The results demonstrate that the cost of HMA is similar to WMA, since the additional cost of the additives is compensated by the reduction in the fuel consumption. The WMA mixtures M1 and M2 have a difference in costs of 3%, from the HMA mixture; while the WMA mixture M3 has a difference of 9%. However, as previously referred, despite the economic costs of WMA are not an evident advantage when compared to HMA, WMA presents relevant benefits such as the reduction of greenhouse emissions into the atmosphere and the improvement of workers safety and comfort conditions during paving.

5 Conclusions

In this section are presented the main conclusions based on the results presented in this paper and on their analysis.

The results obtained in the Marshall study, for the WMA mixtures, did not allow reaching clear conclusions, since the obtained values did not follow the normal trend, making difficult the determination of the optimum bitumen content. Thus, the study was proceeded with the optimum binder content set for the Control mixture, ie, 4.5%. However, it was observed that, for the adopted optimum binder content, the WMA mixtures were within the limits defined by the Technical Specifications from EP, which validates its performance and indicates its similarity to the HMA.

The results obtained in the water sensitivity test demonstrated that WMA, due to the lower production and compaction temperatures, loses ability to resist to moisture.

The wheel tracking test proved the good mechanical performance of WMA, once the resistance to permanent deformation was evidently superior then in the HMA.

The cost analysis of the analyzed mixtures showed very similar values for both WMA and HMA mixtures, which makes WMA a very attractive product.

Finally, it is possible to conclude that the objectives of the present study have been achieved, provided by laboratory testing, that WMA presents a similar performance to HMA, demonstrating that these ‘new’ mixtures can be an effective solution in road paving, with the addition that it brings several environmental, social and economic benefits.

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