Performance evaluation of Warm-Mix Asphalt Mixture with terminal blend bitumen

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Abstract

Over the last few years there has been a growing concern for environmental issues, resulting in a demand for scaling down fossil fuels consumption, and subsequent reduction of greenhouse emissions, one of the main challenges of modern society. It is in this context that warm-mix asphalt mixtures appear. Due to lower production and compaction temperatures, these mixtures have lower energy consumption and therefore lower environmental impact.

Currently, for these mixtures to be accepted it is necessary to prove that their performance is better or equaly good to that of the equivalent conventional mixtures. Therefore, this dissertation aims to study the performance of a warm mix asphalt mixture with terminal blend bitumen and provide a comparative analysis of their performance against an equivalent conventional asphalt mixture.

The mixtures in study are of type AC 14 Surf 35/50 (BBr) and their performance was evaluated through the execution of laboratory tests. Initially, the Marshall study was carried out to determine the optimum bitumen percentage, and subsequently, water sensitivity (ITSR), stiffness, resistance to fatigue and wheel tracking tests were performed.

The results obtained proved that the performance of bituminous mixture with conventional bitumen is generally better. However, there is no reason to prevent the use of tempered bitumen in terms of saving energy resources and therefore it being more environmentally friendly, or even using this type of mixture in cooler climatic conditions, taking advantage of its lower compaction temperatures.

Key words: Road pavements, modified bitumen, Hot Mix Asphalt, Warm Mix Asphalt, performance.

1. Introduction

Over the last few years the growing concern for environmental issues, has required a reduction of fossil fuels consumption and subsequent reduction of greenhouse gas emissions. In response to these concerns, the Kyoto Protocol established some goals, in particular, it called for the reduction of greenhouse gases emissions. These goals motivated the development of alternative technologies in many sectors, such as construction and, more specifically, the field of road infrastructure.

Road pavements have a life cycle that can be divided into four stages - production, construction, maintenance and demolition. The production of bituminous mixtures is the phase that represents greater environmental impact (Park et al., 2003), therefore, in order to mitigate the negative impacts of this stage, warm mix asphalt (WMA) emerge.

These mixtures can keep good workability and similar mechanical behaviour as that of the conventional hot mix asphalt (HMA) but are produced and compacted at lower temperature (100 to 140^{o}C) which results in a lower fuel consumption and consequently results in less greenhouse gases (GHG) emissions.

This dissertation aims to study the performance of a warm mix asphalt mixture with terminal blend bitumen and provide a comparative analysis of its performance against an equivalent conventional asphalt mixture based on laboratory tests.

2. Warm Mix Asphalt with special Binders

2.1. Initial Considerations

Road pavements are traffic support structures, their main function is to ensure a rolling surface that allows vehicles to circulate comfortably and safely. Two types of quality should be required: functional quality, related to the comfort and safety of users, and structural quality, related to pavement capacity to withstand loads. (Branco et al, 2011)

Road pavements are multi-layered systems, formed by several layers supported in the foundation (Branco et al, 2011) and can be classified according to the type of materials and the deformability in rigid, semi-rigid and flexible.

Flexible pavements are the type of pavements most used in Portugal, presenting the upper layers – surface course and regularization course, formed by bituminous mixtures, followed by one or two layers of granular material - base course and sub-base (Branco et al, 2011).

2.2. Bituminous Mixtures

The bituminous mixtures used in the surface and regulation courses, are composed by aggregates, bitumen and air, the intrinsic characteristics and the relative proportions of these materials dictate the properties of each mixture (Neves, 2010). Based on production and compaction temperatures, bituminous mixtures can be classified as cold, half-warm, warm or hot.

Cold mixtures are obtained at room temperature and use bituminous emulsions or bitumen foam as binder agents (Vaitkus, 2009). Thus, the reduction of bitumen viscosity is not achieved by increasing the temperature but by emulsifying it with water using emulsifiers.

Half-warm mixtures are obtained at temperatures below 100 ° C. The aggregates are heated to temperatures between 60 and 100°C and the mix may be produced, for example, with bituminous emulsion or foamed bitumen.

Warm Mix Asphalt are obtained at temperatures between 100 and 140^{o}C, and use bitumen as binder, which is only possible with the incorporation of additives which allow this reduction temperature either during production phase or during compaction.

Hot Mix Asphalt are manufactured at elevated temperatures, between 150 and 180°C because the binder is conventional bitumen. This increase in temperature implies a very high energy and fuel consumption causing a higher emission of gases into the atmosphere.

2.3. Warm Mix Asphalt

These mixtures have become important since the 1990's to address environmental concerns due to their lower production and compaction temperatures.

2.3.1. Warm Mix Asphalt technologies

WMA's production technologies can be divided into three groups - organic additives, chemical additives and bitumen foam production.

Organic additives are, in general, waxes that can be added to the blend or binder and enable a temperature reduction of 20-30°C (EAPA 2010). These waxes cause a decrease in the binder viscosity that remain during the production and compaction process, crystallizing with the cooling of the pavement, giving it an increase in stiffness and a higher resistance to deformation (Barbosa, 2012).

The chemical additives act as surfactants, acting at the level of the bitumen/aggregate interface favouring the coating, even at low temperatures (Hurley and Prowell, 2006). This type of additives allow reducing the production and compaction temperatures by about 20 to 30°C (EAPA 2010).

The production of bitumen foam has two variants: foamed bitumen by water injection and foamed bitumen with synthetic or natural minerals. In either case, the process consists of the expansion of the bitumen, increasing its volume and decreasing viscosity, making it possible to mix at room temperature and humidity. Furthermore, the bitumen regains the initial conditions by gradually lowering the acquired volume. This process allows a reduction in temperature between 20 and 30 ° C in the case of water injection and in the case of synthetic or natural minerals reductions of 30°C are achieved (EAPA 2010).

2.3.2. Benefits of Warm Mix Asphalt

Warm Mix Asphalt offer economic, environmental and social benefits at short, medium and long term.

The decrease in production temperature results in a reduction in fuel consumption, with reductions of around 28˚C being estimated to result in savings of approximately 11% (Prowell and Hurley, 2012). This reduction also leads to a decrease in the amount of gases produced and released into the atmosphere which must be added to the reduction of emissions due to the reduction of consumption. Because they are less polluting mixtures, it is possible to bring plants closer to the urban centers and significantly improve working conditions, since the workers are less exposed to pollution and can work at more pleasant temperatures.

In addition to the ecological benefits, they also offer greater speed in opening to traffic, the possibility of transport over longer distances, without compromising the workability (Capitão et al, 2012), and the greater ease of application in time or cold zones due to the decrease of the cooling rate.

In terms of performance, these mixtures, due to lower production temperatures, reduce the oxidation and consequent aging and hardening of bitumen, increasing fatigue resistance and long term durability of the pavement (Newcomb, 2007).

The temperature decrease allows for the incorporation of higher reclaimed asphalt pavements percentages, due to the reduction of binder viscosity and aging, thus guaranteeing an increase in fatigue life and reducing cracking problems (Prowell and Hurley, 2012). Besides the environmental advantage, less use of virgin materials results in lower costs.

It is also worth mentioning that in the case of cold bituminous mixtures, certain tempered mixtures showed better performance due to the better and more efficient bitumen/aggregate interface (Capitão et al, 2012).

2.3.3. Drawbacks of warm mix asphalt

As expected, this type of mixture also has some drawbacks and, because of their recent appearance, there are some concerns regarding their implementation. Some examples are the possible presence of residual water in the mixing and paving phase due to the incorporation of water at the beginning of the production, which can cause peeling problems and premature pavement settlement and the different behavior that mixtures incorporating organic additives may have, comparing to hot mixing, due to the crystallization of waxes which tends to increase bitumen viscosity and stiffness (Zaumanis, 2010). On top of that it is important to consider that the reduction of the cost for using less fuel does not necessarily lead to a reduction in the overall cost of production because the use of additives to reduce the production temperature represents an addition to the overall cost which may not be advantageous. The same can be said of gas emissions.

2.4. Performance Evaluation of Bituminous Mixtures

The bituminous mixtures, before being implemented, must be tested in order to ensure that the mechanical and safety requirements imposed by the competent authorities are complied with. Therefore, several tests are carried out to evaluate the main characteristics that influence the mechanical behaviour of the bituminous mixtures.

2.4.1. Bitumen characterization tests - Ring and ball and Penetration

The ring and ball and penetration tests are bitumen characterization tests and provide results regarding the softening point and the penetration of the bitumen, respectively.

The penetration test is developed according to EN 1426 (CEN_a, 2007) and consists in releasing a clean needle touching the surface of the sample in a thermostatic bath (zero penetration point) and recording the value obtained.

The ring and ball test is developed according to EN 1427 (CEN_b, 2007) and consists in heating, in thermostatic bath, two sets of steel balls and rings with bitumen, initially at the same temperature. The test ends when the bitumen of each ring and ball assembly touches the bottom and the temperature indicated by the thermometer for each set is recorded.

2.4.2. Marshall Test

The Marshall test is developed according to the norm EN 12697-34 (CEN_a, 2004), and it is executed with an equipment that incorporates the stabilizer of Marshall. The aim of the test is to determine the stability and deformation of the specimens through the action of a constant speed load with the final objective of defining the optimum percentage of bitumen to be incorporated in each bituminous mixture. The test requires the production of 4 cylindrical specimens for each percentage of bitumen to be considered. Each set of specimens is physically characterized first, heated in a thermostatic bath and then placed one by one on the stabilometer where the load is applied. Based on the results and the values obtained in the physical characterization the optimum percentage of bitumen to be incorporated is determined.

2.4.3. Water sensitivity test

The water sensitivity test is performed according to NP EN 12697-12 (IPQ, 2008) and intends to evaluate the susceptibility of bituminous mixtures to the presence of water. In order to carry out this test, it is necessary to compress 6 cylindrical specimens for each mixture. All specimens are volumetrically characterized according to standards and later divided into two groups - wet and dry - of three specimens each, according to their dimension and density, and are stored under different circumstances as explained in the standard.

The test consists of compressing the specimen by applying a diametrical load at constant speed until it reaches the peak of load and the physical rupture of the specimen. At the end of the test the type of rupture and the state of the aggregates at the surface are registered and the ITS_d, ITS_w and ITSR are calculated.

2.4.4. Stiffness Test

The Stiffness test aims to obtain the stiffness module, which depends on weather conditions and traffic speed. Thus, the test consists in subjecting a specimen to the application of a sinusoidal cyclic load on certain conditions of temperature, frequency and mode of loading.

The temperature strongly influences the type of elastic, viscous or viscoelastic behaviour of the materials.

The frequency of load application is intended to simulate the traffic actions on the pavement. The standard proposes the use of frequencies between 0.1 and 50Hz, and dictates that test specimens should not be subjected to more than 3000 cycles.

Finally, regarding the charging mode, it is possible to choose between controlled strain or controlled tension.

The test is performed according to EN 12697-26 (CEN_b, 2004), where eight types of tests are defined, which differ according to the shape of the test pieces, the equipment used and the load configuration.

2.4.5. Fatigue Resistance Test

The fatigue resistance test aims to evaluate the fatigue resistance of the test specimens in terms of the maximum strain supported by them in each load cycle. The test is performed in accordance with EN 12697-24 (CEN_c, 2004) and uses four point bending equipment. The test takes place at 20 ° C and consists of the application of a sinusoidal load until it reaches 50% of the initial stiffness modulus, which is considered a breaking point, determining the number of loading cycles to which the specimen is submitted until it reaches that rupture.

The most common charging frequency in this type of test is 10 Hz, since the frequency is the inverse of the charging time, this frequency represents a mean traffic flow velocity of about 60 km/h, according to the Van der Poel (Shell, 2015).

2.4.6. Wheel Tracking Test

The wheel tracking test aims to evaluate the resistance to permanent deformation and is performed according to EN 12697-22 (CEN_b, 2003) in 6 possible ways, using different types of equipment and packaging.

The test requires the production of two parallelepiped specimens with approximately 400x300x60 mm3, according to EN 12697-22 (CEN_b, 2003), and consists of measuring the rut depth formed after successive passages of a load on the specimen at constant temperature. Depending on the type of procedure chosen, a number of parameters are obtained, namely, the mean proportional rut depth (PDR), mean rut depth (RD) and the parameters necessary to calculate wheel tracking slope (WTS).

2.4.7. Texture Testing - Sand Patch and British Pendulum

The Sand Patch and British Pendulum tests evaluate the macro and micro texture of the pavement, respectively.

The macro texture is a parameter that promotes fast drainage, improving contact and reducing the possibility of aquaplaning. This parameter is evaluated by the sand patch test, carried out in accordance with EN 13036-1 (CEN, 2010), which consists in spreading a known volume of sand/glass microspheres onto a pavement surface, creating a patch that is measured and allow the calculation of the average sand height.

The micro texture allows for the characterization of a surface in terms of roughness, being the main one responsible for the resistance to skidding. This parameter is evaluated by the British Pendulum Test, carried out according to EN 13036-4 (CEN, 2011). The rubber surface of the pendulum sliding on the pavement simulates the behaviour of a vehicle, at a speed of 50 km/h, stopping on a wet surface. The result obtained with this test is the PTV - Pendulum test value, which indirectly represents the longitudinal friction (Menezes, 2008).

3. Laboratory evaluation and analysis of results

The objective of the present dissertation is to evaluate, based on a laboratory study, the performance of a Warm-Mix Asphalt Mixture with terminal blend bitumen (CEPSASFALT BT 35/50 additives) against a traditional binder (CEPSASFALT BT 35/50). To this end, all the fundamental tests to the analysis of the mechanical behaviour of bituminous mixtures with these binders were performed.

From this point on, the traditional mixture is referred to as MR and the warm-mix asphalt mixture with terminal blend bitumen as MV.

3.1. Characterization of the components

The penetration and ring and ball tests were performed on the terminal blend bitumen and those results were compared with the traditional bitumen data sheet. The properties of bitumen are presented in Table 1.

Table 1 - Properties of bitumen under study

	BT 35/50 (MR)	BT 35/50 (MV)
T_{prod} (°C)	160 – 165	130 – 140
T_{lig} (°C)	160 – 165	130 – 140
T_{Comp} (°C)	150 – 160	110 – 130
Pen^{25} (mm)	45	45
T_{ab} (°C)	51.6	50.1
IPen	-1.00	-1.45

The mixtures in study are, according to norm NP EN 13108-1 (IPQ, 2008), the type AC14 surf binder (BBr) and their grade composition results from the combination of granular materials of granitic origin in the ratio indicated in Table 2.

Table 2 - Granulometric composition of the aggregate

Aggregates	Percentage (%)
Gravel 10/20	42
Gravel 4/10	28
Sand	30

3.2. Marshall Study

The Marshall test was performed with 5 different bitumen percentages, according to what is mentioned in 2.4.2.. The specimens were physically characterized first and then submitted to the test. Thanks to the characterization and the obtained results (Table 3) it was possible to determine the optimum percentage of bitumen to be adopted – 4.5%.

Table 3 – Characterization of specimens and results of the Marshall test

B (%)	ρ_{bssd} (kg/m³)	η (%)	VMA (%)	S (KN)	F (mm)
4,0	2344,97	6,49	15.61	12,19	5,43
4,5	2335,92	6,97	17.19	14,39	5,15
5,0	2345,32	6,15	17.56	10,02	5,62
5,5	2380,15	3,61	16.34	10,75	6,20
6,0	2386,92	2,91	16.84	10,52	6,68

3.3. Water sensitivity test (ITSR)

This test was performed according to 2.4.3. and based on the average of the results obtained for the *wet* group (ITS_w) and for the *dry* group (ITS_d) the Indirect Tensile Strength Ratio (ITSR) was determined for each mixture (Table 4).

Table 4 - Results obtained in the water sensitivity test

	ITS_w (kPa)	ITS_d (kPa)	ITRS (%)
MR	7,770	11,476	68
MV	5,125	10,100	51

The results obtained showed that resistance to water action is higher for MR (ITSR - 68%) by about 30%. It can be said that the decrease in resistance to the action of water in the MV mixture is likely due to the lower production and compacting temperatures of the specimens, which result in a lower efficiency for the bitumen-aggregate adhesion. However, as the MR result is not very high either and the fact that fractured surfaces of the specimens are identical for the respective groups of both mixtures, there may be aggregate-bitumen affinity grounds that may be responsible for these results.

3.4. Stiffness Test

The stiffness test, in this dissertation, was performed according to 2.4.4. and by using the four-point bending test, where the prismatic specimen is placed on four supports that prevent the vertical displacement allowing free horizontal translation and rotation. This equipment is inserted in a climatic chamber and connected to a load application system through the internal supports that allow the automatic acquisition of the test parameters.

The test was carried out at 20 ° C, controlled extension with a maximum strain amplitude of 50 µm/m (because there was a need to preserve the integrity of the test pieces), and it was decided to use the frequencies 1Hz, 3Hz, 5Hz, 10Hz, 20Hz, 30Hz and 1Hz again, for a total of 700 cycles. The average module values obtained for each type of mixture and frequency tested are shown in Table 4.

Table 5 -Average values of MR and MV deformability modules by frequency

Frequency (Hz)	MR (Mpa)	MV (Mpa)
1	3014	3017
3	4224	4471
5	4687	5049
10	5351	5881
20	6183	6811
30	6556	7258
1	2891	2931
Average	**4701**	**5060**
Standart Deviation	**1331**	**1587**

The analysis of Table 4 allows to state, by comparison and analysis of the overall average, that the MV mixture presents better behaviour to deformability for all frequencies tested. However, the overall standard deviation shows that the MR presents less variability in the results obtained.

3.5. Fatigue Resistance

The test was performed according to 2.4.5, and in this case, for controlled extension tests, the breaking criterion adopted was the reduction of the initial deformability modulus to 50% of its value. According to the standard, at least three extension levels must be defined, 6 test pieces being tested for each extension level. Thus, the 18 specimens of each bituminous mixture were tested for the 150 µm/m, 250 µm/m and 350 µm/m extensions at the recommended temperature (20°C) and frequency (10 Hz).

The values of the overall average and standard deviation, by extension, are presented in the Table 6 and the fatigue laws obtained according to those results, by linear regression, are shown in Figure 1.

Table 6 - Statistical parameters, by extension, of fatigue test

	MR		MV	
Strain (µm/m)	**Average**	**Std. Deviation**	**Average**	**Std. Deviation**
150	3 405 408	1 861 921	439 765	285 224
250	128 499	117 014	50 689	17 253
350	29 178	15 225	10 595	4 681

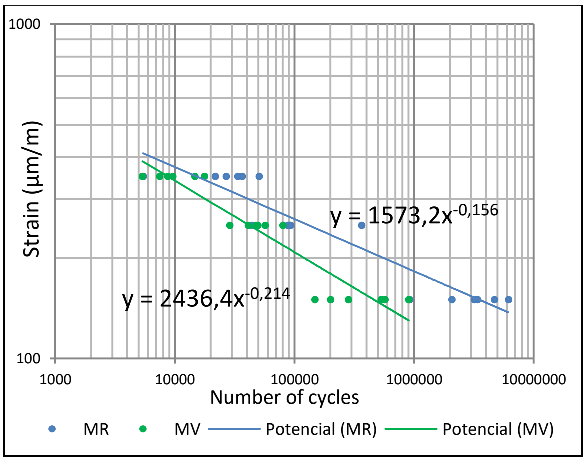

Figure 1 – Fatigue laws obtained for MR and MV

In Table 7 the parameters (a, b) obtained in the linear regressions and the values of ε_6 (level of extension which the material will support 10^6 cycles) are presented.

Table 7 – Fatigue test results

Mixture	a	b	ε_6 (µm/m)
MR	1573.2	-0.156	182
MV	2436.4	-0.214	127

The analysis of the results make possible to conclude that, although the results obtained for the MV are not out of the ordinary and do not rule out the possibility of using this mixture, the results obtained for the MR are superior, which translates in a higher fatigue resistance.

3.6. Wheel Tracking Test

The wheel tracking test was performed as described in 2.4.6., adopting procedure B, which consists in applying 10,000 load cycles to a minimum of 2 specimens. The test ends after that number of cycles or when a depth of 20 mm is reached. For air-conditioned specimens, the results obtained are the wheel tracking slope (WTS_{AIR}), the mean proportional rut depth (PRD_{AIR}) and the mean rut depth (RD_{AIR}) of the 2 specimens.

The test was performed at 60°C, the suggested temperature by EN 12697-22 (CEN_b, 2003), and the results are shown in Table 8.

Table 8 - Results obtained in wheel tracking test

	RD_{AIR} (mm)	PRD_{AIR} (%)	WTS_{AIR} (mm/10^3cycles)
MR	1,9	3,1	0,041
MV	3,9	6,4	0,137

Analysing the results and the graph evolution (Figure 2), it is possible to affirm that the values obtained, in terms of settlement, for the MV mixture are close to double of the values obtained for the MR. This difference may be due to the fact that the bitumen softening temperature is close to 50°C, causing the resistance to permanent deformation to depend essentially on the aggregate arrangement of each specimen.

Although MR offers a better resistance to permanent deformation, it should be noted that the results of both blends are within the acceptable range and are good options for surface course.

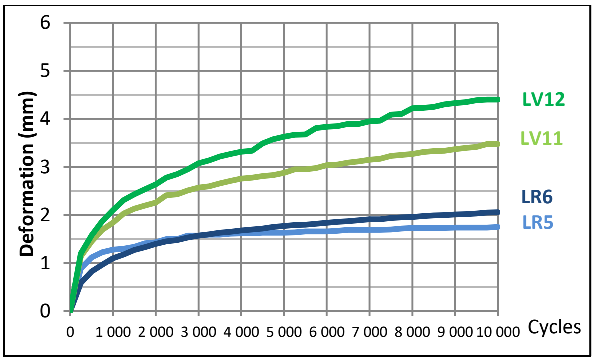

Figure 2 – Evolution of Wheel Tracking for mixtures MR (LR5 and LR6) and MV (LV11 and LV12)

3.7. Sand Patch and British Pendulum

The sand patch test was performed as described in 2.4.7. and the results of the average sand heights (h_m) created on the 12 slabs are given in Table 9.

The results of this test make it possible to understand what type of application the pavement in question is best suited for. Based on these results it is possible to state that both mixtures have a macro-texture that can be implemented in any type of track.

The British pendulum test was performed as described in 2.4.7 and 5 repeats were made for each slab, the average values obtained for each mixture are shown in Table 9.

The reference value for the results obtained in this test, according to EP, 2014, is 0.55 PTV therefore, it can be concluded that although the results are superior for the MV mixture, any of the mixtures under study presents quite satisfactory results.

Table 9 – Sand patch and british pendulum results

	Average h_m (mm)	Average PTV
MR	1.14	0.85
MV	1.31	0.92

4. Conclusions

The Marshall study was performed to determine the optimum percentage of bitumen to be used in the mixtures - 4.5%. This percentage was used to produce all of the following samples.

The water sensitivity test (ITSR) performed showed that MR is less susceptible to water than MV although both mixtures have shown sensitive behaviour.

The stiffness test results showed that MV has, on average, 10% bigger stiffness modules than MR for the 10Hz frequency.

The fatigue resistance test showed that MR has a much better performance than MV, which is evidenced by the rather higher ε_6 value obtained (about 40%).

The wheel tracking results were quite good for both mixtures, although, for a low level of deterioration, MR showed better behaviour, showing lower rut depth and deformation velocity evolution than MV.

The results of the sand patch and British pendulum tests were similar for both mixtures, meeting the references that the specifications indicate.

Overall, MR showed a more robust behaviour, however, from the standpoint of performance, there is nothing to prevent the use of tempered bitumen in terms of saving energy resources and therefore being more environmentally friendly (less pollution and less emissions to cause greenhouse gases). Plus, MV can also be used in cooler weather conditions by taking advantage of its lower compaction temperatures.

However, according to the manufacturer and supplier of bitumen, the market price of the modified bitumen is about 5% more expensive than the traditional one, so a solution of this kind must be accompanied by greater imposition from the governmental tutelage of this sector, otherwise the most environmentally friendly solutions will find it difficult to impose themselves.

Finally, it should be noted that the conclusions drawn are subject to certain limitations, namely that the composition of the terminal blend bitumen is not known, the need to perform field tests and the possibility of carrying out a more elaborate laboratory analysis that could be extendible to other types of mixtures. Only by overcoming those limitations would it be possible to understand the true potential of this type of mixtures and understand which are more effective in terms of production, implementation, performance and life cycle.

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