Warm Mix Recycled Asphalt – a sustainable solution

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A B S T R A C T

The environmental issues raised over recent years, mainly the lowering of fuel consumption and the consequent emission of polluting gases, have led to a bigger concern with the environment. As a response to such concern, the asphalt road industry has developed warm mix asphalts. These are part of a set of new technologies that are being developed in order to reduce both the energy consumption and the gas emissions into the atmosphere, by lowering the mixing temperature. On the other hand, the incorporation of Reclaimed Asphalt Pavement (RAP) in these mixtures aims to improve sustainability by reducing the production of waste and the consumption of natural resources. The warm mix asphalt with RAP are environmentally friendly mixtures and have social, environmental and economic benefits in the production and application of asphalt mixtures. Thus, the main aim of this paper is to produce a comparative study of the mechanical behaviour of warm mix asphalt and of conventional hot mixtures. We also intend to study the applicability of these mixtures with and without incorporation of RAP. Initially, the optimal bitumen content for each mixture was determined and fundamental properties were calculated. The tests performed were the stiffness test by indirect tension to cylindrical specimens, water sensitivity and resistance to fatigue by four-point bending test on prismatic shaped specimens. The findings have confirmed the advantages and demonstrated good performance of warm mix asphalt compared to conventional hot mixtures. The result of the stiffness modulus to the mixture with RAP, of 4750 MPa, is very close to the hot mixture. The water sensitivity for the hot mixture and warm mixture is the same, of 97%, and the fatigue resistance of the three mixtures in analysis is very similar. However, it was also found that these mixtures require an increased care during the production and application phases, in particular as far as the temperature control is concerned.

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1. Introduction

The production of hot mix asphalt is responsible for a large consumption due to the heating of its components (aggregates and binder). This energy is spent on the burning of fossil fuels and the consequent greenhouse gas emissions (Carvalho and Barreno, 2013; Park et al., 2003; Rubio et al., 2013). The implementation of the Kyoto Protocol in 2005, which has been extended until 2020, aims to have the signatory countries undertaking measures to reduce those atmospheric emissions. Thus, new manufacturing techniques of conventional mixtures have been developed, and the decrease of the temperature of manufacture plays an important role as far as reaching these goals is concerned (Capitão et al., 2012; D’Angelo et al., 2008; EAPA, 2010; Oliveira et al., 2013). Since the late 20th century, studies with warm mix asphalt have been made and they have been evolving to the present day (Kheradmand et al., 2014; Prowell et al., 2008; Rubio et al., 2012; Zaumanis, 2010). The production of these mixtures occurs between 110 °C and 140 °C, thus allowing a reduction of approximately 40 °C when compared to the hot mix asphalt (Capitão et al., 2012; Carvalho and Barreno, 2013; EAPA, 2010), as illustrated in Fig. 1.

On the other hand, besides wanting to decrease the temperature in the production of bituminous mixtures, it is also intended that these are reusable (Reyes-Ortiz et al., 2012). The resources that make the mixtures, aggregates and binder, are natural and therefore limited. Asphalt mixtures are 100% recyclable. In Europe, every year there are about 50 million tons of RAP produced, which can be reused in the production of new bituminous mixtures. Germany, the Netherlands and Sweden are the countries that incorporate the largest percentages of RAP in Europe in the production of hot and warm mix asphalt, (EAPA, 2014). Other materials have been studied

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This paper aims to contribute to a better knowledge of the addressed mixtures, since the success of this technology depends on their performance. Thus, the experimental study aimed to evaluate the performance of the warm mix asphalt, with or without RAP, when compared to the hot mix asphalt, at a level of resistance to fatigue by making a four-point bending test. Initially, the particle size distributions of aggregates were studied and the amount of optimum bitumen content to the three mixtures produced was determined. The study also presents the indirect tension to cylindrical specimens and water sensitivity tests. This research aims to deepen the knowledge about the warm mix asphalts, contributing to a more significant dissemination and application of such asphalts on the pavements.

2. Experimental programme

The experimental programme was developed in two phases. In the first phase presents the materials characterization tests used in bituminous mixtures. In the second phase the mechanical characterization tests carried out were the stiffness by indirect tension to cylindrical specimens, water sensitivity and resistance to fatigue by four-point bending test on shaped prismatic specimens.

2.1. Materials

2.1.1. Bitumens

In the present study both mixtures with conventional bitumen 35/50, and mixtures containing warm bitumen BT 35/50 were produced. Warm bitumen is specially formulated in order to reduce both manufacturing and application temperatures, without losing their mechanical characteristics. Depending on the type of additive used, its rheology can vary in relation to conventional bitumen. For example, the use of waxes implies changing the viscosity of bitumen, which becomes inferior to the one of the conventional bitumen, whenever temperatures are above 100 °C. The viscosity increases at below 100 °C, giving origin to bitumen with a higher softening point. There are other types of additives (surfactants), which work by reducing the surface tension at the interface aggregate/binder and that do not alter the rheology of the binder, in accordance with standard EN 12591 (Carvalho and Barreno, 2013]. In this study the warm bitumen with this type of additives was used.

The characterization of bitumen was based on the penetration test (EN 1426) and on the softening point (EN 1427), which led to the results on Table 2. The warming temperatures of the components, of the mixture and of the compaction define the differences between the two types of binders. In Table 2 it is possible to see a clear reduction of approximately 40 °C in these temperatures as far as the warm bitumen is concerned.

2.1.2. RAP characteristics

The RAP used in the mixture WMA was obtained from milling pavement of a highway (A23). This material was solely obtained from the surface course thus ensuring it was homogeneous. It is composed by aggregates that maintain their original properties and bitumen which presents an advanced state of ageing due to the environmental conditions it has been subjected over the years.

The extraction of aged bitumen was performed by centrifuge extractor method, according to EN 12697-1, testing 5 samples which confirm a good homogeneity of the RAP material. Their characterization resulted in an average content of 5.0% aged bitumen, a penetration of 11 × 10^-1 mm and a softening point of 82.6 °C. These results showed the bitumen of RAP quite aged with a low penetration and a high softening point.
made: the stiffness by indirect tension to cylindrical specimens, know the asphalt mixtures performance the following tests were out to assess the optimal percentage of bitumen. Then, in order to

2.2. Methods

results that may be observed in Tables 3 and 4.

Asphalt with 30% RAP (WMRA 30). The particle size distribution of (HMA), a Warm Mix Asphalt (WMA) and a Warm Mix Recycled

Barreno (2013) in Spain. The analysis of the RAP after extraction of the results of this study with those made by Carvalho and

envelope resulted from the intention to have a comparative analysis asphalt mixtures applied in surfaces course. The choice of this en-

2.2.1. Determination of the optimum bitumen content

The obtaining of the optimum bitumen content was achieved through an initial estimation of the bitumen content to be added to the mixtures. For HMA and WMA mixtures the estimate was based on the Equation (1).

where is the estimated percentage of bitumen in relation to the total mass of the mixture (%), is the percent of mineral aggregate retained on 2.36 mm sieves (%), is the percent of mineral aggregate passing the 2.36 mm sieve and retained on the 75 μm sieve (%), is the 0.15 for 11–15% passing 75 μm sieve, 0.18 for 6–10% passing 75 μm sieve, 0.20 for 5% or less passing 75 μm sieve. is the percent of mineral aggregates passing on 75 μm sieves (%) and is the 0–2% absorption factor of aggregates, in the absence of information is used.

For the WMRA 30 mixture, since it contains RAP, the estimate of the bitumen content was based on the Equation (2), which calculates the new bitumen content (). For the calculation of the , we have used the expression related to the final binder penetration test on prismatic shaped specimens.

Fig. 2. RAP and aggregates grading curves.

Table 3

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>% passing</th>
<th>HMA and WMA</th>
<th>WMRA 30</th>
<th>AC 16 Surf D</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>100</td>
<td>99</td>
<td>90–100</td>
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</tr>
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<td>8</td>
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<td>64–79</td>
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<td>4</td>
<td>48</td>
<td>48</td>
<td>44–59</td>
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<td>2</td>
<td>30</td>
<td>31</td>
<td>31–46</td>
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</tr>
<tr>
<td>0.500</td>
<td>17</td>
<td>19</td>
<td>16–27</td>
<td></td>
</tr>
<tr>
<td>0.250</td>
<td>13</td>
<td>14</td>
<td>11–20</td>
<td></td>
</tr>
<tr>
<td>0.063</td>
<td>7</td>
<td>7</td>
<td>4–8</td>
<td></td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>HMA and WMA</th>
<th>WMRA 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic lime</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Stone dust</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>Gravel 3/6</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Gravel 5/15</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>RAP</td>
<td>–</td>
<td>30</td>
</tr>
</tbody>
</table>

2.1.3. Determination of particle size distribution

The natural aggregates used in the production of bituminous mixtures were granites of different fractions (stone dust, gravel 3/6 and 5/15). In addition all mixtures incorporated hydraulic lime.

The determination of the particle size distribution and of the RAP was performed according to the sieving method, EN 933-1 standard. The series of sieves used were in accordance with the Spanish road administration (Dirección General de Carreteras, 2011), corresponding to a grading envelope AC 16 Surf D, for asphalt mixtures applied in surfaces course. The choice of this envelope resulted from the intention to have a comparative analysis of the results of this study with those made by Carvalho and Barreno (2013) in Spain. The analysis of the RAP after extraction of aged bitumen and of the natural aggregates is presented in Fig. 2.

In this study three mixtures were produced, a Hot Mix Asphalt (HMA), a Warm Mix Asphalt (WMA) and a Warm Mix Recycled Asphalt with 30% RAP (WMRA 30). The particle size distribution of the mixtures are inserted in the envelope AC 16 Surf D, with the results that may be observed in Tables 3 and 4.

2.2. Methods

This section first presents a preliminary study which was carried out to assess the optimal percentage of bitumen. Then, in order to know the asphalt mixtures performance the following tests were made: the stiffness by indirect tension to cylindrical specimens, water sensitivity and resistance to fatigue by four-point bending test on prismatic shaped specimens.

2.2.1. Determination of the optimum bitumen content

The obtaining of the optimum bitumen content was achieved through an initial estimation of the bitumen content to be added to the mixtures. For HMA and WMA mixtures the estimate was based on the Equation (1).

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Pb = 0.035 × a + 0.045 × b + K × p200 + F

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Pb = 0.035 × a + 0.045 × b + K × p200 + F

(1)
Table 5: Results of the WMRA30 bitumen content.

<table>
<thead>
<tr>
<th>Equation used</th>
<th>Different values</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3)</td>
<td>( p_{enB} = 30 \times 10^{-1} \text{ mm} ); ( p_{enF} = 11 \times 10^{-1} \text{ mm} ); ( TRb = 31% )</td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td>( TR = 30%; PbN = 5.0%; TRb = 31% ); ( PbF = 4.9% )</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>( PbA = 4.9%; PbN = 5.0%; TR = 30% ); ( PbF = 3.4% )</td>
<td></td>
</tr>
</tbody>
</table>

\[
TRb = \frac{TR \times PbF}{PbR}
\]

where \( PbN \) is the new bitumen content (%), \( PbR \) is the bitumen content (final binder) of recycled asphalt mixture (%), \( PbF \) is the RAP bitumen content (aged binder) (%), \( TR \) is the rate of recycling (%), \( p_{en} \) is the final binder penetration of recycled mixture (%), \( TRb \) is the bitumen recycling rate (%) determined by Equation (4), \( p_{en} \) is the RAP aged bitumen penetration and \( p_{enB} \) is the new bitumen penetration.

The value of \( 30 \times 10^{-1} \text{ mm} \) has been adopted as the penetration final binder \( (p_{enF}) \) of the recycled mix since that is the usual value. Table 5 presents the sequence of equations used and the new bitumen content \( (PbN) \) to be added to the WMRA30 mixture.

Thus, using Equation (1) resulted different bitumen content of 4.9%, 5.4% and 5.9% for the production of HMA and WMA mixtures. For the WMRA30, the bitumen content obtained was of 3.9%, 4.4% and 4.9%. The determination of the bitumen content for each mixture was based in both Portuguese and Spanish road administrations (Estâncias de Portugal, 2012; Dirección General de Carreteras, 2011). The parameters evaluated were the porosity (EN 12697-8) and the Marshall test (EN 12697-34).

There were produced 27 cylindrical test specimens with approximately 100 mm in diameter and variable height, three for each bitumen content for all the bituminous mixtures, according to the particle size composition of Table 4. The aggregates, the RAP and the bitumen 35/50 were preheated at \( +155 \text{ °C} \) for the HMA, for WMA and WMRA30 with bitumen BT 35/50 was preheated at \( +125 \text{ °C} \). The compaction of specimens was held with an impact compactor, applying 50 blows on each side of the specimens. The temperature of compaction was \( +155 \text{ °C} \) to the HMA, for WMA and WNRA30 was \( +115 \text{ °C} \). The specimens were tested after 36 h curing at room temperature and 50 min in immersion in water bath at \( 60 \text{ °C} \).

The results of porosity, VMA (voids content in the mineral aggregate), VFB (voids in the mineral aggregate filled with binder), bulk density, stability and flow Marshall are represented in Table 6. In the same table there are the ranges related to the specifications requirements. After analysis of the achievement of the results obtained, it appears that the optimum bitumen content to the HMA is 5.4%, for WMA is 4.9% and for WMRA30 is 4.4%.

2.2.2. Stiffness

The stiffness modulus of asphalt mixtures is one of the most important properties for the design of flexible pavements. The test applying Indirect Tension to Cylindrical Specimens (IT-CY) took place according to EN 12697-26:2004, using the Nottingham Asphalt Tester (NAT).

The production of cylindrical specimens of mixtures was made according to the study presented in Table 4. Three specimens were made for each of the optimum bitumen content of the three bituminous mixtures, as in the Marshall test.

The test was performed in tension controlled conditions by evaluating the deformation. Considering that the specimen performance is elastic and linear, the material is homogeneous and isotropic, the Poisson’s ratio is constant and known (assuming 0.35 for a temperature of 20 °C). In this study the rise-time used was 124 ms.

The stiffness modulus is determined by the application of repeated 5 loads, preceded by a pre-loading of 10 repetitions of load, which has the function of adjusting the load application system to the specimen.

2.2.3. Water sensitivity

The evaluation of water sensitivity is important, because this property is directly related to the performance and durability of mixtures during the life of the pavement. The characterization of water sensitivity of bituminous mixtures was performed according to standard EN 12697-12:2003. The production of cylindrical specimens of mixtures was made according to the study presented in Table 4. Three specimens were made for each of the optimum bitumen content of the three bituminous mixtures, as in the Marshall test. A set of cylindrical test specimens is divided into two equally sized subsets and conditioned. One subset is maintained dry (dry specimens) at 20 °C temperature, while the other subset is saturated (wet specimens) and stored in water at 40 °C over a period of 68–72 h.

However, the standard indicates that wet specimens are previously subjected to vacuum in water at 20 °C and kept for 30 min under an absolute pressure of 6.7 kPa. After removing the specimens from the water bath at 40 °C, they were subjected to a water bath at 15 °C for 2 h. The dry specimens, after being kept at 20 °C, were placed in a dry environment at 15 °C for another 2 h.

Then, the two groups of specimens were tested for indirect tensile strength according to the procedure of EN 12697-23:2003. Compression testing machine is capable of applying loads to specimens at a constant rate of deformation of 50 mm/min. From this test results the Indirect Tensile Strength Ratio (ITSR) according to EN 12697-12 standard and Tensile Strength Indirect (ITS) according to EN 12697-23 standard.

2.2.4. Resistance to fatigue

The fatigue resistance is an essential mechanical property in bituminous mixtures, because fatigue is one of the most frequent mechanisms of degradation of pavements. It turns out that over time there is a decrease in the performance and in the resistance capacity of the pavement materials, and these depend on factors that are directly responsible for their degradation (traffic loading and climate conditions), and for the mixtures production quality or for the pavement construction quality.

The characterization of the resistance to fatigue in this study has been carried out according to the standard EN 12697-24:2004, Annex D – four-point bending test on shaped prismatic specimens.

The prismatic specimens resulted from execution and two compaction slabs for each mixture, produced in the laboratory, according to the composition study of Table 4. The manufacture and compaction of slabs temperatures were the same as already mentioned in the execution of the Marshall specimens. The compaction of slabs was performed with the vibratory roller. These slabs were afterwards cut, resulting in a total of 36 beams with dimensions of 40 cm in length and 5 cm in width and height.

The specimens remained at 20 °C temperature during 28 days, being the test performed with the same temperature and frequency of 10 Hz. The laboratory tests can be done in different conditions: controlled stress or controlled strain. Controlled stress is commonly used in the evaluation of bituminous layers of great thickness. Controlled strain is used to evaluate layers of small thickness as in the case of mixtures used in the surface courses. The range of extension values were of 200 and 400 μm, applied by a sinusoidal loading with no resting period. In controlled extension tests, the
initial stiffness modulus was measured after 100 cycles of load application and it is taken as a reference to determine the moment of specimens rupture, corresponding to a reduction of stiffness to half of its initial value.

The fatigue laws obtained result from the relationship between the extension imposed and the number of load application, when the breaking criterion is reached. These laws resulted in a curve obtained by Equation (5).

\[ \varepsilon_f = a \times N^b \]

where \( \varepsilon_f \) is the tensile strain applied to the mixture (\( \mu m \)), \( N \) is number of cycles corresponding to the failure of the mixture for a strain, \( a \) and \( b \) are laboratory determined coefficients.

The evaluation of fatigue resistance also includes the determination of two important parameters: \( \varepsilon_6 \) that is the strain level corresponding to a fatigue resistance of 1 million cycles and \( N_{100} \) is the number of cycles corresponding to a tensile microstrain of 100.

3. Results and discussion

3.1. Stiffness

The 9 cylindrical specimens produced were tested after a day of curing at 20 °C temperature, which produced the results presented in Table 7 related to the average of the three specimens for each bituminous mixture. It is observed that the HMA showed the greatest stiffness modulus, followed by WMRA30, where the WMA obtained the smallest value.

The reason why the WMA showed a weaker stiffness than the WMRA30 was because this mixture contained 30% RAP which presented an aged bitumen with a lower penetration.

3.2. Water sensitivity

The results of the water sensitivity test are presented in Fig. 3, corresponding to the average of the three cylindrical test specimens belonging to each group. The Spanish road administration (Dirección General de Carreteras, 2011) refers to an ITSR value bigger than 85% for HMA applied in surface courses. All mixtures meet this value. The WMRA30 presents a final value of 100% and the mixture density does not allow water penetration in the specimen.

3.3. Resistance to fatigue

Fatigue resistance results of the WMA and WMRA30 at 20 °C are presented in Fig. 4. In the same figure are also presented the results of conventional mixture (HMA) in order to evaluate the difference between two mixtures.

Analysing the results, the HMA presents a bigger fatigue resistance than the other two mixtures. However, these are very close to the number of cycles obtained for both extensions. The WMA, compared with HMA, reveals a number of very similar cycles for the extension of 200 \( \mu m \). However, to the extension of 400 \( \mu m \) this mixture displays values under the expected. The WMRA30 presents a number of cycles very similar to the other two mixtures, resembling with HMA for the extension of 400 \( \mu m \), revealing a better fatigue performance than WMA. A bigger fatigue resistance of WMRA30 is due to the fines that are presented in RAP because of the milling process. This fatigue resistance improvement of recycled mixtures resulted in the coating by the aged bitumen.

The parameters, \( N_{100} \) and \( \varepsilon_6 \), specified in EN 12697-24 and presented in Table 8, should be used to evaluate the studied mixtures fatigue performance.

\( N_{100} \) is bigger for the WMA, followed by the HMA, reaching a number of cycles of over 200 million and 100 million, respectively. The WMRA30 obtained the smallest value of \( N_{100} \), but it was considered a satisfactory value. Since this mixture has a higher stiffness compared with WMA, the less flexibility is justified around 15%.

The HMA showed the largest \( \varepsilon_6 \). The bituminous mixtures with warm bitumen presented similar values. These results are almost the same as the conventional mixture.

The fatigue laws allowed the correlation coefficients (\( R^2 \)) above 92% for the three mixtures and observed that the HMA has a bigger correlation coefficient than the other mixtures.

3.4. Discussion

This article shows that the WMA, with or without RAP, is an innovative technology and it can be used in real pavements. These mixtures mechanical performance proved to be comparable with conventional HMA, as it can be seen in the stiffness modulus and fatigue resistance. Recently, different solutions of warm mix asphalt incorporating RAP have been studied (Dinis-Almeida et al., 2012a; Guo et al., 2014; Sengoz and Oylumluoglu, 2013) aiming to put this technology into practice. However, it is still necessary to conduct more studies in order to improve the bituminous mixtures performance and contributing to a sustainable solution.
When comparing the results of $\varepsilon_6$ with those obtained by Carvalho and Barreno (2013) in experiences carried out in Spain (Table 9), HMA with bitumen 35/50 has a superior extension relating to the HMA with bitumen 50/70. The same happens with the WMA with bitumen BT 35/50 relating to WMA with bitumen BT 50/70. It is important to point out the differences in the bitumen and the content used. In addition, the compaction method used was different in the laboratory and in Spain. Other aspects, such as the test conditions are also relevant to the results obtained. Highlighting these distinctions, theoretically, it would be expected that the mixtures with 35/50 or BT 35/50 bitumen obtained $\varepsilon_6$ lower values than the mixtures with bitumen 50/70, because that bitumen has lower penetration.

The WMA presented a bigger fatigue performance than the HMA. It is also observed that the incorporation of RAP in these mixtures is an advantage, since it maintained the mechanical properties and saved natural resources.

### 4. Conclusions

This study evaluated the mechanical performance of the WMA and the recycled WMA, i.e. the asphalt mixtures produced at lower temperatures and with incorporation of RAP. It enabled to prove the equivalent performance of these mixtures with the conventional, which occupy a preferential place in the road construction. The warm bituminous mixtures have a special interest, not only in road industry but also in a global scale, since they present a set of advantages for the environment. These mixtures usage as recycling technique constitutes one valid alternative in the pavements rehabilitation. However, further research is necessary to evaluate the mixtures performance.

Overall, the mechanical performance assessed in this study for the WMA is very similar to the HMA mixtures. The HMA mixture reveal to have a higher stiffness modulus than the WMA. The WMRA30 has a higher stiffness modulus than the WMA due to the presence of the aged bitumen which has lower penetration. The water sensitivity of the HMA and the WMA is the same. However, this test was showed insufficient to assess the sensitivity of the mixture with RAP.

The fatigue resistance of the WMA and the WMRA30 is slightly lower than the conventional. The $N_{100}$ is bigger for the WMA, because the law of fatigue presented itself with lower slope and the $\varepsilon_6$ is bigger for the HMA.

It should be noted that the mixture produced with RAP did not contain any additive to improve the aged bitumen performance. Even tough, the mixture performance with RAP proved to be very satisfactory.

In this study, the compaction temperature of bituminous mixtures is an important factor to ensure a good performance. It was also confirmed that the incorporation of RAP in these mixtures is an asset, since it maintained the mechanical properties relating to conventional mixtures and saved natural resources.

The WMA, with or without the incorporation of RAP, gathered a set of advantages and combined with a good fatigue performance, inserted one of the techniques with a growing potential in the following years. They presented also a good alternative in the rehabilitation of the road pavements concerning environmental, social and economic aspects.

### References


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**Table 8**

<table>
<thead>
<tr>
<th>Bituminous mixtures</th>
<th>a</th>
<th>b</th>
<th>$R^2$</th>
<th>$N_{100}$ (cycles)</th>
<th>$\varepsilon_6$ ((\mu)m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA (35/50)</td>
<td>4124.8</td>
<td>-0.198</td>
<td>0.96</td>
<td>1.44E + 08</td>
<td>268</td>
</tr>
<tr>
<td>WMA (BT 35/50)</td>
<td>2054.1</td>
<td>-0.157</td>
<td>0.92</td>
<td>2.29E + 08</td>
<td>235</td>
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<tr>
<td>WMRA30 (BT 35/50)</td>
<td>6457.3</td>
<td>-0.239</td>
<td>0.95</td>
<td>3.74E + 07</td>
<td>238</td>
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</table>

**Table 9**

<table>
<thead>
<tr>
<th>Bituminous mixtures</th>
<th>$R^2$</th>
<th>$\varepsilon_6$ ((\mu)m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA (50/70)</td>
<td>0.89</td>
<td>113</td>
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<tr>
<td>WMA (BT 50/70)</td>
<td>0.90</td>
<td>134</td>
</tr>
</tbody>
</table>


