Study of the performance of bituminous mixtures for paving with recycled crushed concrete incorporation

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EXTENDED ABSTRACT

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1. Introduction

In Portugal and other countries, the road network is essential to the economic development, representing the main transport infrastructure of people and goods (Branco, Pereira, & Picado Santos, 2006).

In order to promote sustainable development and reduce energy consumption associated to the production of bituminous mixtures began to be developed techniques for reducing manufacturing temperatures and application of bituminous mixtures. Some of them involving the modification of bitumen properties used (Martinho, 2014).

In Portugal the construction industry deals annually with thousands of tons of materials. Part of which ends up being classified as Construction and Demolition Waste (C&DW). There are huge amounts of waste that requires a solution which allows to promote a sustainable construction industry in Portugal (Pereira et al., 2004).

The C&DW appears as possible materials to be incorporated in bituminous mixtures. One of these materials is the recycled crushed concrete that was the selected material to be studied in this dissertation. The importance of this issue is based on the fact that there aren’t any specifications for the incorporation of this type of material to be applied in asphalt layers.

The objective of this dissertation is the study of the performance of warm mix asphalt (WMA) for paving with high rate incorporation of C&DW. In particular, it is intended to study the phenomenon of interaction paving bitumen with recycled aggregates from crushed concrete. In order to achieve the objective were developed experimental tests of characterization and assessment of the feasibility to apply recycled crushed concrete as aggregate for WMA which help to understand some aspects such as the interaction of recycled aggregates with the binder and its behavior under dynamic loading conditions.

Incorporating recycled aggregates of C&DW as a part of bituminous mixtures has been the subject of some national and international studies. In Portugal there are some academic studies in this area. One of which is the study of (WMA) incorporating industrial by-products (Martinho, 2014) which serves as a comparison for some results of this dissertation. The author studied bituminous mixtures with different compositions. The WMA was produced with traditional bitumen which additive was applied in the mixing phase. The aggregate was composed by recycled crushed concrete aggregate in the amount of 60% of the total mass of the aggregate in addition to natural aggregate. For comparison values were also produced hot mix asphalt (HMA) only with natural aggregate.
2. Materials and methods

2.1. Materials

Since the mid-90s a set of techniques to reduce the energy involved and the temperature of production and compaction of Hot Mixtures Asphalt (HMA) have been studied and developed. As a result of this development emerged the Warm Mixtures Asphalt (WMA) (EAPA, 2014).

According to Ferreira et al. (2009) and CEPSA (2016a), these mixtures have the following main benefits: reduction in fuel consumption; reduction of emissions in production process; ensure a better workability and compaction at lower temperatures; the production and conventional applications because there is no need to adapt the bituminous plant; have the same quality compared to HMA.

Usually, WMA resulting from the addition of additives which are pre-mixed with the hot bitumen. However, the additives can also be added to the mixture in the mixing container after addition of the bitumen. The study of this dissertation tried to overcome this additional step of adding additives manually. WMA was produced from bitumen with additives added at the factory suitable for the production of such mixtures.

Currently, there are a set of European standards that define requirements for HMA: the EN 13108 whose properties are characterized by test methods described at EN 12697. These were the rules followed for the assessment of WMA. Currently there are no Portuguese specifications (with the name “Caderno de Encargos Tipo Obra” (CETO) (Estradas de Portugal, 2014a)) related to the WMA. For this reason, the study followed the specifications of HMA to apply in base course layers.

Among the types of paving bitumen, this dissertation used a 35/50 bitumen CEPSA (CEPSA, 2016b) indicated for WMA which complies with the specifications of the standard EN 12591. It differs from traditional bitumen used to produce the HMA because the additives were pre-mixed in manufacture so that it can be used in WMA.

Regarding the natural aggregates, CETO defines the requirements/properties to be satisfied. The mixtures used limestone aggregates and they were formulated with 33% (relative to the total mass of the aggregate) of 10/20 natural aggregate, 5% of 4/10 natural aggregate and 2% of 0/4 natural aggregate.

The C&DW are a considerable part of solid waste. As a C&DW the concrete represents the most significant component between the construction materials (Arabani et al., 2013). The dissertation evaluated the incorporation of Recycled Crushed Concrete (RCC) corresponding to 60% of the total mass of aggregate. This aggregate had a particle size of 0/20 mm.

To perform the sieve analysis of aggregates used in the production of the WMA was followed the procedure set out in EN 933-1 which resulted in the particle size distribution curve represented in Figure 1.
2.2. Methods

For the formulation of WMA, similar procedures for HMA formulation were followed. It was used the Marshall mix design method.

The experimental study was organized in four phases: geometric characterization of the aggregate; physical characterization of the aggregate; formulation of bituminous mixtures and determination of their void characteristics; performance tests of bituminous mixtures.

For each of these phases, it was followed the procedures according to the standards as shown in Table 1.

Table 1 - Organization of experimental study

<table>
<thead>
<tr>
<th>Characterization</th>
<th>Properties</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical</td>
<td>Particle size analysis</td>
<td>EN 933-1</td>
</tr>
<tr>
<td>Physical</td>
<td>Affinity between aggregate and bitumen</td>
<td>EN 12697-11</td>
</tr>
<tr>
<td></td>
<td>Laboratory mixing</td>
<td>EN 12697-35</td>
</tr>
<tr>
<td></td>
<td>Specimens preparation</td>
<td>EN 12697-30</td>
</tr>
<tr>
<td>Mixture design</td>
<td>Bulk density</td>
<td>EN 12697-6</td>
</tr>
<tr>
<td></td>
<td>Maximum density</td>
<td>EN 12697-5</td>
</tr>
<tr>
<td></td>
<td>Void characteristics</td>
<td>EN 12697-8</td>
</tr>
<tr>
<td></td>
<td>Stability and Deformation - Marshall Test</td>
<td>EN 12697-34</td>
</tr>
<tr>
<td></td>
<td>Specimens prepared by roller compactor</td>
<td>EN 12697-33</td>
</tr>
<tr>
<td>Performance tests</td>
<td>Permanent deformation – Wheel Tracking Test</td>
<td>EN 12697-22</td>
</tr>
<tr>
<td></td>
<td>Water sensitivity</td>
<td>EN 12697-12, 12697-23</td>
</tr>
</tbody>
</table>

3. Results and discussion

3.1. Initial considerations

During the presentation of the results, some comparisons with studies carried out by other authors were made. In particular, comparisons were made with some results of WMA M08, M09, M23 and M25 samples produced by Martinho (2014). They all contained 4.5% of bitumen. 60% by weight of aggregate was composed by RCC with the same origin of the aggregate used in this study. 40% of the aggregate was composed by natural limestone aggregate from the same source of the present
work. M09 and M23 mixtures contained 2% (relative to the mass of the binder) of chemical additive Rediset. M08 and M25 mixtures respectively contained 4% and 3% of organic additive Sasobit.

For M08 and M09 mixtures produced in the first phase of work were proceeded to a formulation mix design for the percentages of 3.5%, 4.0%, 4.5%, 5.0% and 5.5% of bitumen. These specimens were analyzed and so defined the composition of the mixtures to formulate for performance testing. It was used the same RCC from this work in order the results can be directly comparable. However, in order to make a comparative study regarding the mixtures performance tests, it was decided to also make an analysis of the M23 and M25 mixtures, made after determining the optimal percentage of bitumen, corresponding to 4.5% and formulated with RCD added from a different source.

3.2. Affinity between aggregate and bitumen

The results of tests to determine the affinity between aggregate and bitumen are represented in Figure 2.

![Figure 2 - Affinity between aggregate and bitumen results](image)

The results of tests performed with natural aggregate show that the introduction of Rediset and Sasobit modifiers in the mixture led to better results compared with results of bitumen with additives added at the factory.

The analysis of all the tests for different types of aggregate and bitumen show small differences. At the last rolling time, bitumen coverage is around 50%.

Although the results of tests performed with RCC show the lowest values, this difference is not significant because the results were obtained recurring to a visual inspection which is quite subjective.

The decrease of bitumen coverage was gradually and approximately constant throughout the test. This situation is assumed as a positive aspect because there was no great loss of connection between bitumen and aggregate in the early hours of the test.

In conclusion, the both types of aggregate exhibit the same behavior in terms of affinity with the bituminous binder. In this terms, the RCC discloses a performance which makes it feasible for incorporation into bituminous mixtures.
3.3. Marshall mix designed method

3.3.1. Void characteristics

The bulk densities of the specimens produced with the WMA are shown on Figure 3 and the results of maximum density are shown on Figure 4.

![Bulk density results](image1)
![Maximum density results](image2)

Figure 3 - Bulk density results
Figure 4 - Maximum density results

The results show that WMA lead to lower values of bulk density and maximum density than the WMA of reference.

The results of the porosity and voids in the mineral aggregate (VMA) are shown respectively on Figure 5 and Figure 6.

![Porosity results](image3)
![VMA results](image4)

Figure 5 - Porosity results
Figure 6 - VMA results

Regarding porosity, the results indicate that the increasing amount of bitumen leads to a decrease of the mixture porosity. It appears that to values of 4.5% of bitumen the mixtures have porosity values within the limits defined by CETO. For larger percentages than 4.5% of bitumen, the results are so low and away from the lower limit 3.0%.

The results of VMA do not reveal any trend. For all values of bitumen percentage, the mixtures have similar values and below the minimum limit.
3.3.2. Marshall stability and deformation

Marshall test results are shown below with the respective values of Marshall stability and Marshall deformation.

From the data obtained after the formulation of the bituminous mixtures, the Marshall methodology allow to extract some conclusions about their behavior.

It appears that for smaller values of the percentage of bitumen the mixtures have more stability and less deformation.

For stability, almost mixtures comply with the limits specified by CETO. The only exception is the mixture containing 5.5% of bitumen that does not meet the minimum value of stability ($S_{\text{min}} = 7.5$ kN).

As for the deformation only mixing with 3.5% of bitumen complies with the specified maximum ($F_{\text{max}} = 4.0$ mm). All mixtures meet the maximum limits of stability and minimum deformation specified for these parameters ($S_{\text{max}} = 15.0$ kN and $F_{\text{min}} = 2$ mm).

Regarding the Marshall quotient, it appears that an increase in the amount of bitumen led to the decrease in the value of this quotient. Almost mixtures do not accomplish the minimum limit specified ($S/F_{\text{min}} = 2$ kN/mm). The mixture with 3.5% of bitumen is the only exception.

In conclusion, using as criteria the fulfillment of the values specified in the CETO, we decided to formulate a mixture with percentage of bitumen between 3.5% and 4.0%.

For the performance comparison between formulated WMA and the WMA of reference the results are not very conclusive. Although the WMA have lower stability, they also have lower deformation values than the WMA of reference, with exception for the amount that corresponds to 4.5% of bitumen. In this case the chart shows that it has a higher deformation value.
3.3.3. Optimum asphalt binder content

To evaluate the optimum asphalt binder content it is necessary to determine the bitumen percentage value corresponding to maximum stability (3.85 kN), maximum bulk density (4.70 kg/m³) and the average value of porosity limits (3.90%). The value of the optimum asphalt binder content is the average of these values and it corresponds to 4.15%.

This value corresponds to a 4.75 mm of deformation and 12.9% value of VMA. Both values do not fall within the limits specified by CETO which are 4.75 mm for maximum deformation and 14.0% for minimum value of VMA. As this specification was not designed to evaluate the recycled aggregate, the failure to comply with these values does not imply necessarily a bad performance. Therefore, it’s necessary to evaluate the mixture through performance tests.

The analysis of the results of different void characteristics of the mixtures, deformation and Marshall stability concluded that the amount of 3.7% of bitumen is the best to comply with the limits specified by CETO. However, this value is lower than the calculated value of optimal asphalt binder content. Initially it was decided to advance to test mixtures formulated with 3.7% and 4.5% of bitumen because it was predicted that the low value of 3.7% of bitumen could compromise the performance of the mixture.

3.4. Performance tests

3.4.1. Water sensitivity

Performance tests included the water sensitivity of the specimens with 3.7% and 4.5% of bitumen. In order to obtain a comparison, test specimens were prepared with an amount of bitumen corresponding to 4.5% and made with only natural aggregate. The specimens were divided into dry and wet subsets.

CETO does not specify any requirement for water sensitivity results. It only indicates that the indirect tensile strength ratio (ITSR) value must be declared at the characterization of the bituminous mixture. However, the ASTM D 4867/D 4867-M04 (ASTM International, 2004) states that a bituminous mixture must have a value of this property at least 80%.

The results of the water sensitivity test are shown on Table 2 and comparison values on Table 3.

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Bitumen %</th>
<th>Subset</th>
<th>ITS (\mu) (kPa)</th>
<th>ITSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural and recycled</td>
<td>3.7%</td>
<td>Wet</td>
<td>625.4</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry</td>
<td>2227.3</td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td>4.5%</td>
<td>Wet</td>
<td>985.3</td>
<td>47.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry</td>
<td>2096.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Water sensitivity results

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Bitumen %</th>
<th>Subset</th>
<th>ITS (\mu) (kPa)</th>
<th>ITSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M23</td>
<td>4.5%</td>
<td>Wet</td>
<td>1093.4</td>
<td>84.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry</td>
<td>1289.6</td>
<td></td>
</tr>
<tr>
<td>M25</td>
<td>4.5%</td>
<td>Wet</td>
<td>1548.8</td>
<td>82.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry</td>
<td>1670.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Water sensitivity values of WMA of reference
The results of the water sensitivity tests of RCC specimens and natural aggregate specimens led to ITSR values that are lower than the reference values which demonstrates that the bituminous mixtures studied have a low performance in the presence of water.

The type of failure of the all specimens is categorized as "combination" because they had a limited break line and larger deformed areas close to the loading strips. In the end of tests, the surfaces of aggregates mainly were broken.

Regarding the comparison between the two tested bitumen percentages, it was concluded that 3.7% of bitumen leads to very low ITSR values. Consequently, it reveals a lower performance compared to the specimens with 4.5% of bitumen. Therefore, 4.5% of bitumen was the percentage of bitumen used to formulate mixtures for performance tests. This percentage corresponds to a reasonable situation expected for this type of mixtures and it is corroborated by the results of Martinho (2014).

To clarify the obtained results and to confirm if the bitumen used was the cause of these results, tests were made to specimens with natural aggregates with 35/50 bitumen suitable for HMA.

The results of the water sensitivity test of HMA specimens made only with natural aggregate are shown on Table 4.

<table>
<thead>
<tr>
<th>Bitumen %</th>
<th>Subset</th>
<th>ITSm (kPa)</th>
<th>ITSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5%</td>
<td>Wet</td>
<td>623.3</td>
<td>47.3</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1316.4</td>
<td></td>
</tr>
</tbody>
</table>

The results for specimens with the traditional bitumen and only composed by natural aggregate proved to be similar to the results of WMA specimens made with the same type of aggregate. In terms of water sensitivity, the recycled aggregate has a similar performance compared to natural aggregate. However, this performance proves to be unsatisfactory for both formulated mixtures. In the presence of water both types of specimens lose about half of their indirect tensile strength resistance and show a ITSR value half about the specified in the US standard.

Although the results showed very low ITSR values, the fact that the study focused in bituminous mixtures for use in base course layers decreases the importance of the outcome.

3.5. Permanent deformation

The test results are shown on Table 5 and Figure 10.

<table>
<thead>
<tr>
<th>Slab number</th>
<th>RD_{AIR} (mm)</th>
<th>PRD_{AIR} (%)</th>
<th>WTS_{AIR} (mm/10^3 cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Partial</td>
<td>Average</td>
<td>Partial</td>
</tr>
<tr>
<td>1</td>
<td>9.28</td>
<td>18.71</td>
<td>20.50</td>
</tr>
<tr>
<td>2</td>
<td>11.01</td>
<td>22.28</td>
<td>0.772</td>
</tr>
</tbody>
</table>
By analyzing the Figure 3 it is concluded that initially there was a huge increase of the deformation due to densification of the bituminous layer caused by repeated load application. In a second phase there was a lower rise of the deformation due to increase of deformation resistance caused by the contact between the aggregates. Both slab tests finished to 10000 load cycles without mean rut depth exceeds 20 mm.

For the comparison were added the results of the HMA M26. This mixture was made with 4.5% of bitumen and only with natural aggregates. All the results are shown on Figure 11.

The results show that WMA studied present medium values compared with two types of reference WMA. The WMA reveals better performance compared to M23 mixture (with Rediset additive) and worst performance compared to M25 mixture (with Sasobit additive). However, the M23 mixture presents a barely acceptable behavior in relation to this test.

Compared to the mixture containing only natural aggregate, WMA studied exhibited high values for the three parameters. This fact indicates that the incorporation of RCC causes a decrease in permanent deformation performance.

4. Conclusions

The purpose of this work was to study the performance of paving bituminous mixtures with incorporation of RCC from C&DW for asphalt base layers. In particular, it was intended to study the phenomenon of interaction paving bitumen with recycled aggregates from crushed concrete. For that, bituminous mixtures were formulated with RCC as aggregate, in replacement of the natural origin aggregate in the amount of 60%, intended asphalt base layers (AC 20 base) and with a 35/50 warm bitumen.

The experimental work had included geometric, physical, mechanical and chemical characterization of the aggregates. For the formulation of the bituminous mixtures it was followed the empirical Marshall method widely used in Portugal.

In order to analyze the feasibility of the incorporation of RCC, performance tests were carried out: the determination of the water sensitivity, the resistance to permanent deformation. Throughout the dissertation, the experimental procedures used are described in detail.
The results from the experimental tests were discussed and compared to previously activities performed by other authors in order to achieve a better understanding of the observed behavior. It is concluded that the recycled concrete does not meet all the specifications for the aggregates to be used in base course layers. However, RCC reveals an identical performance when compared to the natural aggregate in some tests. RCC is a material with potential for future use in paving.

5. References


CEPSA. (2016b). "CEPSASFALT 35/50 BT".


