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# BENEFITS OF INCLUDING HOT MIX RECYCLED MATERIALS IN PAVEMENT DESIGN

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## ABSTRACT

Pavement recycling is becoming more acceptable among the available techniques for pavement maintenance/rehabilitation. It is based on sustainable development, by reusing materials reclaimed from the pavements and reducing the disposal of asphalt materials.

Based on the results obtained from laboratory tests carried out on two bituminous mixtures, one of which including 50% of recycled asphalt, some simulations were made for the design of a pavement where those mixtures would be used as a bituminous base. The aim of this investigation was to assess the benefits of using recycled materials, taking into account environmental and economical advantages.

The results of pavement design were obtained using the linear elastic theory in BISAR (the structural analysis software developed by Shell). Fundamental properties of the mixtures analysed in this study were obtained from laboratory tests, which were carried out to determine their stiffness modulus and their resistance to fatigue and permanent deformation.

With the results obtained from the pavement design, the cost savings of using recycled materials were quantified.

## KEYWORDS

Flexible Pavements, Recycled Mixtures, Mechanical Characterisation, Cost Savings

## 1. INTRODUCTION

Nowadays, there are several concerns regarding the disposal of waste materials and its impact in the environment. Therefore, its elimination (and any by-products) passes through the optimization of their use in the industrial processes. Existing deteriorated material can be reused; its characteristics can be rehabilitated, recycled and improved. The old material can be used in the same application that it was initially used for, or as part of a new material [1].

Bituminous mixtures obtained from hot recycling of flexible pavements can perform as well as new hot mixtures, provided that recycled materials are correctly characterised and the final mixture is properly designed.

Potter and Mercer [2] carried out a study including several trials on public roads and full-scale accelerated load testing facilities. They have evaluated the performance of recycled materials used in the construction of sections of these trials. One of the main conclusions of the study was that the performance of the recycled materials was as good as that of equivalent conventional materials.

Another investigation [3] included the determination of the mechanical properties of hot bituminous mixtures after the incorporation of reclaimed material in different percentages (0, 30, 50 and 70%). In that study, no clear correlation was found between the percentages of recycled material and the properties of the resulting mixture. Therefore, given an adequate mix design, the amount of recycled material to be included depends upon other factors, related to the material itself, the type of plant used and even economic and ecological policies.

In this study, it was decided to use 50% of reclaimed material in one of two bituminous mixtures, in order to assess their mechanical properties and determine the cost savings of using the recycled mixture as an alternative to a conventional bituminous mixture (made of 100% new materials) in pavement design.

The environmental benefits of the recycled mixture are obvious, since it reduces the need for new materials at the same time it reduces the amount of waste materials to be disposed. Therefore, only the economic benefits will be quantified in this paper.

This study includes a hypothetical pavement structure, typical for low traffic volume roads, comprising granular materials in the lower layers and bituminous materials as surfacing. The studied mixtures are intended to be used as a bituminous base, overlaid by a new surface course. Thus, two alternatives were used: (i) conventional pavement with new materials on both top layers; (ii) recycled pavement using 50% of reclaimed material in the bituminous base. Figure 1 represents schematically the pavement structure analysed.

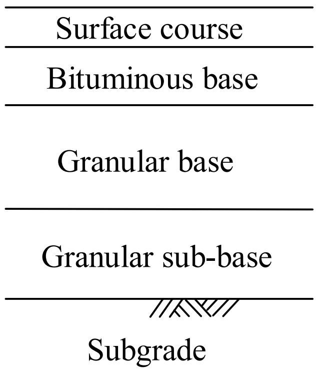

Figure 1 – Idealised pavement structure used in the design simulations

## 2. MATERIAL CHARACTERISATION

The reclaimed material used in this study was obtained from a section of the Principal Itinerary 5 (IP5), between Angeja and the Motorway A1, and comprised only old bituminous materials from the surface course and binder course. The material was previously used [4] in a study where it has been characterised, in terms of its physical properties.

The residual bitumen content of the reclaimed asphalt was determined using the Ignition Method (ASTM D6307), on three samples. The results are presented in Table 1 and the average bitumen content is 5.1%.

Table 1 – Percentage of bitumen determined by the Ignition Method [4]

| Sample | Mass of the sample $M_t$ (g) | Mass of bitumen $M_b$ (g) | Percentage of bitumen $P_b$ (%) |
|---|---|---|---|
| RBM-01 | 3173.0 | 160.0 | 5.04 |
| RBM-02 | 3406.0 | 174.6 | 5.13 |
| RBM-03 | 3318.0 | 171.1 | 5.16 |

After the incineration of the bitumen, the aggregate remaining (representing 94.9% of the reclaimed material) was subjected to a grading characterisation and it was observed, from two different samples, that the material was homogeneous. In Table 2 and Figure 2 the grading of the aggregate present in the Reclaimed Bituminous Material (RBM), and the grading limits specified by the Portuguese Road Administration [5] for a bituminous mixture to be used in a base layer, less than 10 cm thick, can be observed.

Table 2 – Gradation of the aggregate of the RBM and grading specification

| Sieve size ASTM | Percentage Passing (%) | |
|---|---|---|
| | RBM | SPECIFICATION |
| 25.0 mm (1”) | 100 | 100 |
| 19.0 mm (3/4”) | 100 | 95 – 100 |
| 12.5 mm (1/2”) | 96 | 60 – 91 |
| 9.5 mm (3/8”) | 87 | 51 – 71 |
| 4.75 mm (# 4) | 66 | 36 – 51 |
| 2.00 mm (# 10) | 46 | 26 – 41 |
| 0.425 mm (# 40) | 24 | 11 – 25 |
| 0.180 mm (# 80) | 15 | 5 – 17 |
| 0.075 mm (# 200) | 8.0 | 2 – 8 |

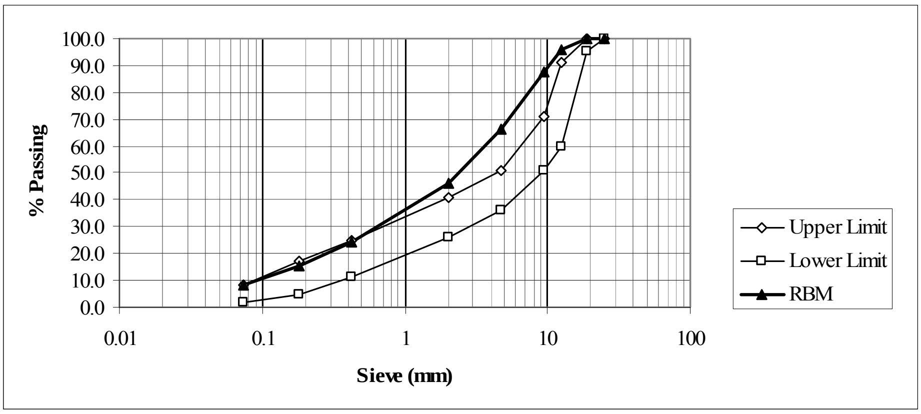

Figure 2 – Gradation Curve of the RBM and grading specification

## 3. CHARACTERISATION OF THE FINAL MIXTURES

The new binder used in this study was a 50/70 pen bitumen, both for the conventional and for the recycled mixture, since it is the penetration grade most commonly used in Portugal. For the recycled mixture, the percentage of bitumen was determined by Equation 1 [6]. The final percentage of bitumen in both mixtures was set to be 5.0%.

$$p_{NB} = p_{FB} - R_R \times p_{RB} \qquad (1)$$

where: $R_R$ – recycling ratio;
$p_{RB}$ – percentage of bitumen in the RBM;
$p_{FB}$ – percentage of bitumen in the Final Mixture;
$p_{NB}$ – percentage of new bitumen added;

Regarding the aggregate present in the reclaimed material, it is important to mention that the size of some particles was reduced by the milling operation. In addition, the reclaimed material was obtained from surface and binder courses, which includes smaller aggregate sizes. Therefore, it was necessary to correct the grading of the aggregate in the final mixture by adding a coarser aggregate.

The percentage of new aggregate used to correct the grading of the reclaimed material was obtained from Equation 2 and its gradation was determined taking into account the grading of the aggregate in the RBM, so that the aggregate of the final mixture would meet the specifications (Figure 3).

$$p_{NA} = p_{FA} - R_R \times p_{RA} \qquad (2)$$

where: $R_R$ – recycling ratio;
$p_{RA}$ – percentage of aggregate in the RBM;
$p_{FA}$ – percentage of aggregate in the Final Mixture;
$p_{NA}$ – percentage of new aggregate used for the correction of the grading;

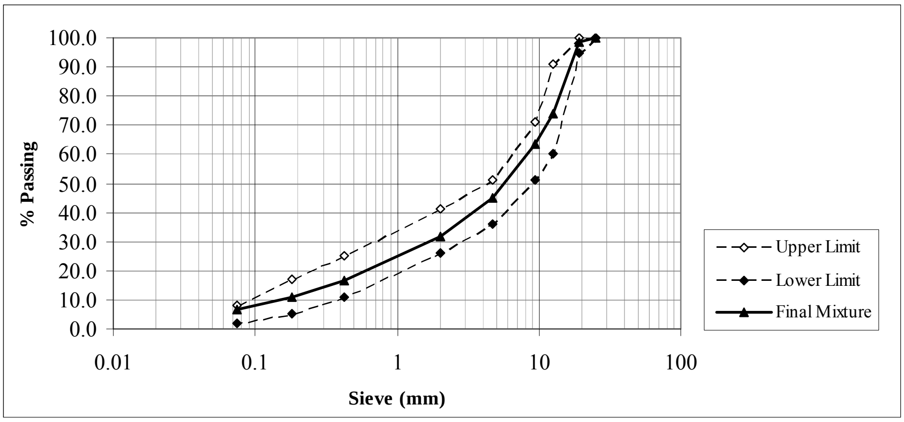

Figure 3 – Aggregate of the final mixture meeting the grading specification

The aggregate used in the conventional mixture was the same as that used as the additional aggregate in the recycled mixtures. Its gradation was established to meet the grading specifications, as close as possible to the gradation of the recycled mixture. The curve obtained is presented in Figure 4.

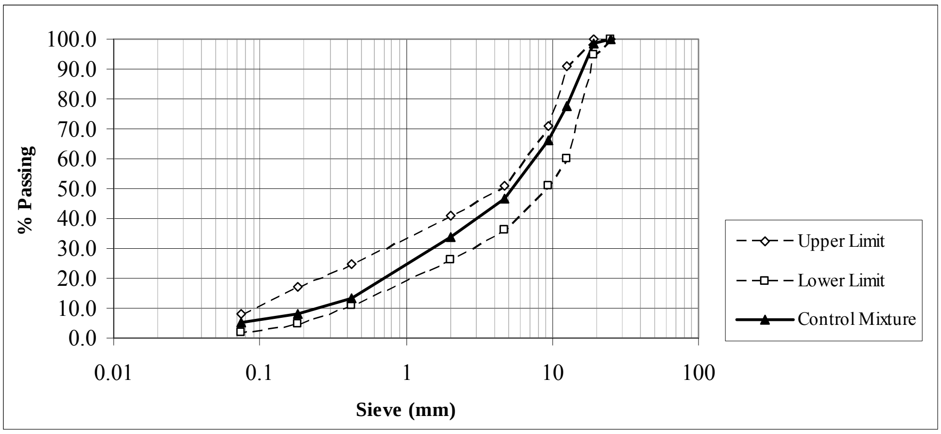

Figure 4 – Aggregate of the conventional mixture meeting the grading specification

## 4. LABORATORY TEST RESULTS

The laboratory tests carried out in this investigation were performed using laboratory prepared specimens, obtained from slabs, including several beams and cores to be used, respectively, in four point bending tests and in the repeated simple shear test at constant height (RSST-CH). The first type of tests is used to determine the stiffness modulus and fatigue life and the second is used to determine the resistance to permanent deformation.

Some tests were also carried out to determine the bulk density of both mixtures. The results obtained for the bulk density (ASTM D1188 – 96) are presented in Table 3, for both the conventional and the recycled mixture.

Table 3 – Bulk density of the studied mixtures

| Mixture | Bulk Density (g/cm$^3$) |
|---|---|
| Conventional | 2.413 |
| Recycled | 2.415 |

The four point bending tests were carried out at 20 ºC. This temperature was chosen, as it is a typical value for the design temperature in the north of Portugal. Figure 5 represents the average stiffness modulus for the studied mixtures, as a function of the frequency of load application.

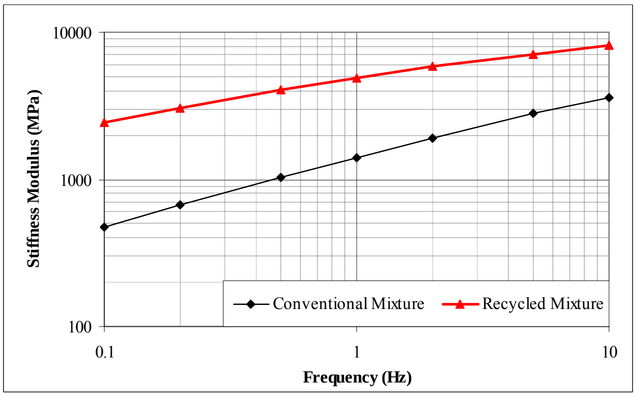

Figure 5 – Stiffness Modulus of the studied mixtures at 20 ºC

From the previous figure it is possible to see that the stiffness modulus of the recycled mixture is two to five times higher than that of the conventional mixture. The reason for that is the harder bitumen resulting from the blend of the recycled bitumen with the new bitumen.

The results obtained in the four point bending tests to determine the fatigue life of both mixtures are presented in Figure 6. The tests were carried out in controlled strain at 10 Hz, loading the specimens with a sinusoidal waveform.

The conventional mixture shows a better fatigue resistance, as was expected, since the bitumen present in the mixture is softer.

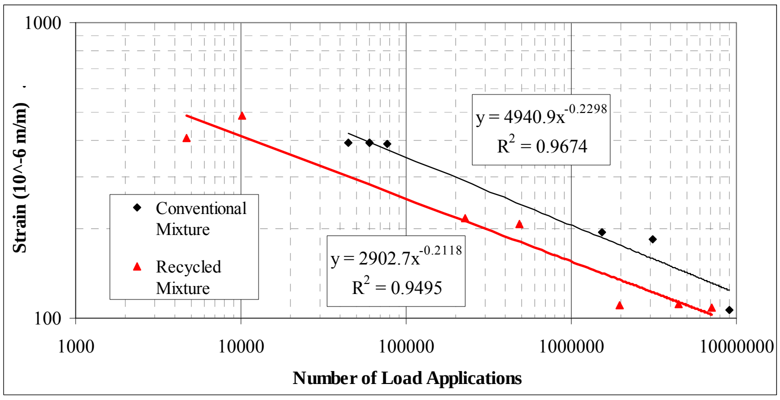

Figure 6 – Fatigue life of both mixtures obtained at 20 ºC & 10 Hz

The RSST-CH tests, used to determine the resistance to permanent deformation of the mixtures, were performed at 50 ºC to simulate the bitumen behaviour in the hot days of the year, showing low viscosity and making the mixtures more susceptible to deform. At the same time, using a high temperature, it is possible to decrease the duration of the tests. The resistance to permanent deformation of the mixtures is defined as the number of Equivalent Standard Axles (ESALs) correspondent to the number of load applications in the RSST-CH to obtain a specified rut depth. This test was carried out according to the procedure specified in [7] and [8]. The results of the tests are shown in the Figure 7.

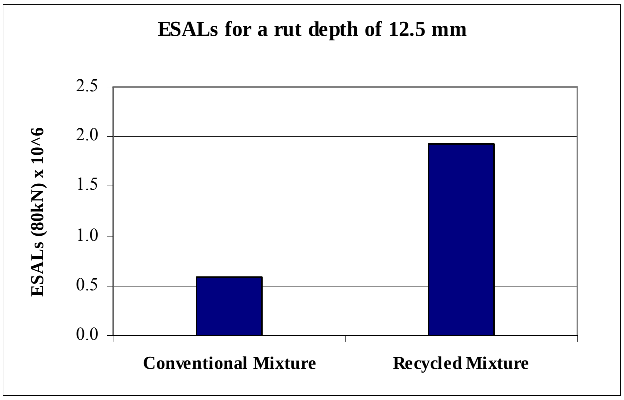

Figure 7 – Resistance to permanent deformation of the studied mixtures

The resistance to permanent deformation of the recycled mixture is much higher than the conventional mixture. Once again, this can be explained by the bitumen type present in the recycled mixture, which is harder than the bitumen in the conventional mixture, resulting in a mixture with higher stiffness modulus and more resistant to permanent deformation.

## 5. PAVEMENT DESIGN STUDY

In the pavement design study, two alternatives were considered: (i) determine the thickness of the bituminous base for the two studied mixtures with a surface course thickness of 50 mm; (ii) determine the thickness of the base for a 40 mm surface course.

The thickness of the granular layers was established to be of 250 and 150 mm respectively for the base and sub-base. Regarding the mechanical properties of the materials used in the various layers, they were assumed for the granular materials and, for the bituminous materials, the results from the laboratory tests have been used. In Table 4, a summary of the values used in the design can be observed.

Table 4 – Material properties of pavement layers

| Layer | Thickness (mm) | Stiffness Modulus (MPa) | Poisson's Ratio |
|---|---|---|---|
| Surface course | 50 | 3600 | 0.35 |
| Bituminous base | To be determined | 3600/8000 | 0.35 |
| Granular base | 250 | 200 | 0.3 |
| Granular sub-base | 150 | 100 | 0.3 |
| Subgrade | n.a. | 70 | 0.4 |

From the previous table it can be seen that the stiffness values used for the two bituminous mixtures were obtained from the results of the laboratory tests corresponding to the frequency of 10 Hz. Thus, the conventional mixture has a stiffness value of 3600 MPa while the stiffness value of the recycled mixture is of about 8000 MPa. The Poisson's Ratio has been assumed according to the type of material used in each layer.

The most important parameter in pavement design is the expected life of the pavement being designed. In this study, it was decided to use, as the expected life, the number of equivalent standard axles (ESALs) resulting from the permanent deformation results obtained in the laboratory tests. Thus, based on the results presented in Figure 6, the value of 0.6 million ESALs was chosen, since it is the maximum expected life for the conventional mixture (also used in the surface course) before it starts to show excessive rutting. Since the recycled mixture shows a higher expected life when the permanent deformation is concerned, this can already be seen as a benefit of using recycled mixtures in pavement design.

Once the expected life of the pavement was defined, the next step was to define the design criteria, normally accepted as the permissible tensile strains at the bottom of the bituminous base, to delay the appearance of cracking, and the permissible vertical compressive strain at the top of the subgrade, in order to avoid the failure of the pavement at the foundation.

The permissible tensile strain ($\varepsilon_t$) for each mixture was obtained from the fatigue results presented in Figure 6, for 0.6 million ESALs. Therefore, for the conventional mixture the value obtained was 232 $\mu\varepsilon$ and for the recycled mixture 173 $\mu\varepsilon$, according to the fatigue resistance of each mixture. To determine the permissible compressive strain at the top of the subgrade, the TRRL model [9] has been used. This model is presented in Equation 3 and the value obtained for 0.6 million ESALs was 515 $\mu\varepsilon$.

$$\log N = -7.21 - 3.95 \log \varepsilon_z \qquad (3)$$

where: N – no. ESALs;
$\varepsilon_z$ – permissible vertical compressive strain at the top of the subgrade;

After defining the design criteria, several simulations were carried out, using BISAR software, in order to determine the minimum necessary thickness of the bituminous base to accomplish the permissible strains. This procedure was repeated for both alternatives studied (according to the surface course thickness). The results obtained are presented in Table 5.

Table 5 – Results obtained from the pavement design study

| | Alternative 1 | | Alternative 2 | |
|---|---|---|---|---|
| | Conventional mixture | Recycled mixture | Conventional mixture | Recycled mixture |
| Surface course thickness (mm) | 50 | | 40 | |
| Bituminous base thickness (mm) | 65 | 55 | 75 | 65 |
| $\varepsilon_t$ ($\mu\varepsilon$) | 226 | 170 | 226 | 170 |
| $\varepsilon_z$ ($\mu\varepsilon$) | 406 | 413 | 406 | 408 |

In economic terms, the benefits of using recycled materials in pavement design can be determined by quantifying the savings per square metre in terms of the amount of new material used in the layer. Thus, the savings for each alternative were calculated based upon the density of each mixture (Table 3) and the percentage of new bitumen and aggregate in the mixture (Equations 1 & 2). The results are presented in Table 6.

Table 6 – Savings obtained with the recycled mixture on both alternatives per m$^2$

| | Alternative 1 | | Alternative 2 | |
|---|---|---|---|---|
| | Conventional mixture | Recycled mixture | Conventional mixture | Recycled mixture |
| Amount of bituminous mixture (kg) | 157 | 133 | 181 | 157 |
| Amount of bitumen (kg) | 7.85 | 3.26 | 9.05 | 3.85 |
| Amount of aggregate (kg) | 149.15 | 67.16 | 171.95 | 79.28 |
| Bitumen savings (%) | 0 | 58.5 | 0 | 57.5 |
| Aggregate savings (%) | 0 | 55.0 | 0 | 54.0 |

As can be observed in the previous table, for both alternatives, the costs of applying a recycled mixture as a base course were reduced by more than half, when compared with the cost of applying a new bituminous mixture with the same expected life.

## 6. CONCLUSIONS

Based on the results presented in this paper, the main conclusion to highlight is the fact that it is possible to substitute a new bituminous mixture by a recycled mixture (with up to 50% reclaimed material) without compromising the behaviour of the pavement, in terms of fatigue and permanent deformation, for the same expected life. In addition, for the type of pavement and Recycling Ratio used in this study, savings over 54% were determined in the amount of new materials to be used.

It must be underlined that a high amount of reclaimed material was used to characterise the recycled mixture. This is only possible to implement if the right batch plant is available. Nevertheless, the study shows that some amount of investment in the right technology pays very well.

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