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# A MECHANICAL ANALYSIS OF ASPHALT RECYCLED MIXTURES PRODUCED WITH HIGH RECYCLING RATES

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## ABSTRACT

In this work four asphalt mixtures were compared in terms of mechanical characteristics. One of the mixtures (control mixture) was used as a reference to the study of three mixtures produced with reclaimed asphalt pavement (RAP). One of the recycled mixtures incorporated 30% of RAP and the other two were produced with 50% of RAP. The effect of using a rejuvenator additive (3% rejuvenator) was also evaluated in one of the mixtures with 50% of RAP.

***Keywords:*** Recycling, reclaimed asphalt, rejuvenator additive.

## INTRODUCTION

Recycling is nowadays a main concern to the society, and industries are facing the need to make some efforts to turn their products more environmentally friendly. In terms of road pavements, a number of new ideas have emerged in order to preserve natural resources and the use of reclaimed asphalt pavement (RAP) has become a very common practice (Dinis-Almeida et al., 2012). Normally the use of RAP in asphalt recycling means the addition of this materials to new asphalt mixtures, maintaining the function of the RAP components, but can be also used as unbounded material where the function of the materials were not maintaining (EAPA, 2005).

Recently, a considerable number of authors have tested different solutions to incorporate the highest amount of RAP possible (Kaksonen, 2000, Widyatmoko, 2008, Su et al., 2009, Celauro et al., 2010, Valdés et al., 2011, Shu et al., 2012, Silva et al., 2012).The percentage of RAP used in the mixtures have a significant importance to choose the recycling procedure that the industries will use. High percentages of RAP can reduce the costs of the material but will demand higher asphalt plant modifications, which increase the production indirect costs (Oliveira et al., 2012, Silva et al., 2012).

In this article, the characteristics of four mixtures were tested in terms of water sensitivity, fatigue cracking resistance and stiffness modulus. In terms of resistance to permanent deformation only three mixtures were tested, once the mixture with 30% of RAP was not prepared on time for the results to be presented in this paper. The objectives of this study are the evaluation of the influence of incorporating different RAP percentages and the use of 3% rejuvenator in one of the mixtures allowed understanding the influence of that type of additives in mixtures with high percentages of RAP.

## MATERIALS AND METHODS

### Materials

The reclaimed asphalt pavement (RAP) used in this study has been obtained from milling off the surface layer of a highway pavement and was separated into fine and coarse fractions by an aggregate classifier with a mesh of 10 mm.

The virgin aggregates used comprised granite coarse material and limestone filler. This type of aggregates was selected because they are the type of aggregates readily available in the region and because they are of the same type of aggregate of the RAP material.

The virgin bitumens used were a 70/100 and a 50/70 pen grade bitumen, the first one was used in the mixtures with RAP, to soften the aged bitumen present in the RAP and the second was used to the control mixture.

The rejuvenating agent used is a commercial product, referred by the Reseller Company as an antioxidant, plasticizer, rejuvenating, hydrating, thinner and dispersant. It is known as Iterlene ACF 1000. The amount of additive (3%) applied in the mixture was selected according to a previous study by Abreu et al. (2013) where the percentage of 2% showed unsatisfactory results and for that reason the option for 3% of additive has been taken.

### Methods

The asphalt mixtures used in this study have been produced in the laboratory, taking into consideration the existence of two fractions of RAP. The fine fraction was maintained at ambient temperature and the coarse fraction was heated up to the same temperature of the virgin aggregates. The Control mixture was produced only with virgin aggregates and with the 50/70 pen bitumen. The other mixtures were produced with the 70/100 pen bitumen. The mixture with 3% rejuvenator was produced with the incorporation of 50% RAP although it is only mentioned as the mixture with 3% rejuvenator.

The assessment of the water sensitivity is obtained by measuring the indirect tensile strength (ITS) on specimens kept dry at 20+/-5ºC, according to EN 12697-23 and specimens kept in water (ITSw) at 40+/-1ºC over a period of 68 to 72h, according to EN 12697-12. After 68 to 72 hours under the conditions of preparation described, the two groups of samples are placed at a temperature of 15ºC two hours before the test. Following the determination of the ITS of each specimen, it is possible to calculate the average value of each group and the indirect tensile strength ratio (ITSR), which corresponds to the ratio between the ITS of the wet group (ITSw) and of the dry group (ITSd) of specimens. The air voids content of the specimens was also assessed because they have a significant influence on the water sensitivity performance of asphalt mixtures.

The stiffness modulus and the fatigue tests carried out in the present work consist in supporting a prismatic specimen in four points and applying a sinusoidal load in the two central points, bending the specimen in a similar way of that imposed by the vehicles in a pavement layer. In the stiffness modulus tests, the specimens are not damaged and are submitted to a frequency sweep load at 0.1, 0.2, 0.5, 1, 2, 5, 8 and 10 Hz, according to the EN 12697-26 standard. In order to obtain a characterization of the mixtures in a wider range of testing conditions, the tests were repeated for different temperature conditions (0, 10, 20 and 30 ºC) but the results present are expressed for a master curve at 20 ºC. The fatigue resistance test was carried out according to the EN 12697-24, for the test temperature of 20ºC and with a frequency of 10 Hz in controlled strain.

For this study, the rut resistance was assessed in a laboratory scale, with the Wheel Tracking Test (WTT), whose parameters are defined on the EN 12697-22 standard: test temperature, 60ºC, load 70 N, test frequency 0.44 Hz and with 10000 loading cycles. For understanding the characteristics of the mixture, at the end of the test, the information about the Wheel Tracking Slope (WTSAIR), the Proportional Rut Depth (PRDAIR) and the maximum Rut Depth (RDAIR) is determined for each slab.

## RESULTS

Water sensitivity is a very important characteristic of asphalt mixtures because it provides information about the behaviour of the mixture in contact with water, a measurement of the durability of the mixture. The results of water sensitivity and indirect tensile strength are presented in Table 1, which can be related with the air void content.

Table 1 - Water sensitivity test results

| | Control Mixture | 30% RAP | 50% RAP | 3% Rejuvenator |
|---|---|---|---|---|
| **ITSR (%)** | 94% | 94% | 92% | 90% |
| **ITSd (kPa)** | 2850 | 2900 | 3228 | 2400 |
| **Air void content (%)** | 3.4 | 3.5 | 3.2 | 2.3 |

Taking into account the Specification limits for the air void content (3% – 5%), it's possible to see that the control mixture and the mixtures without additive fulfil the specification. However the mixture with 3% rejuvenator has an air void content below the lower limit value, which can be justified by the use of an additive that improves the workability of the mixture. Because of that, a decrease in the production temperatures of the mixtures with that additive could be used without compromising the air voids content of the mixture. In terms of indirect strength the values are very similar and the increase of that value in the mixtures with RAP can be attributed to the presence of the aged bitumen who is a component of the RAP. The efficiency of the rejuvenator incorporation was proven by the reduction of the indirect strength. In terms of water sensitivity, the mixtures with better results are the control mixture and the mixture with 30% RAP but all the mixtures have shown very interesting results.

The resistance to permanent deformation, also known as rut resistance, can be expressed by the parameters presented in Table . The results show that the difference between the three mixtures are not so significant but, as expected, the mixture with RAP and without additive has the best result, due to the presence of the aged bitumen which reduces the susceptibility of the mixture to permanent deformation. The mixture with 3% Rejuvenator has a smaller resistance to permanent deformation which can be justified by the bitumen rejuvenation.

Table - Results from the Wheel Tracking Test

| | Control Mixture | 50% RAP | 3% Rejuvenator |
|---|---|---|---|
| **Average thickness (mm)** | 42.2 | 41.6 | 41.8 |
| **Wheel tracking slope (WTSAIR) (mm/$10^3$ cycles)** | 0.05 | 0.03 | 0.07 |
| **Proportional Rut Depth, max. (PRDAIR) (%)** | 5.0 | 4.7 | 6.2 |
| **Rut Depth, max. (RDAIR) (mm)** | 2.1 | 2.0 | 2.6 |

Figure 1 presents the evolution of the rut depth against the number of cycles throughout the WTT tests. It can be observed that both the control mixture and the mixture with 50% RAP show a very similar behaviour along the time. The mixture with 3% rejuvenator showed a slightly higher susceptibility to permanent deformation, even though the final result can still be considered very good.

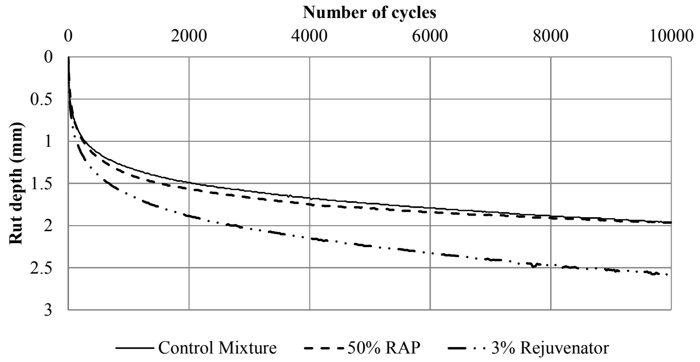


Fig. 1 - Evolution of the rut depth during the Wheel tracking tests

To analyse the performance of the mixtures when subjected to repeated traffic loads the other important characteristic that should be analysed is the fatigue cracking resistance. The results obtained in the four-point bending tests can be plotted in a graph and this property can be expressed by a fatigue life equation (Fifure 2).

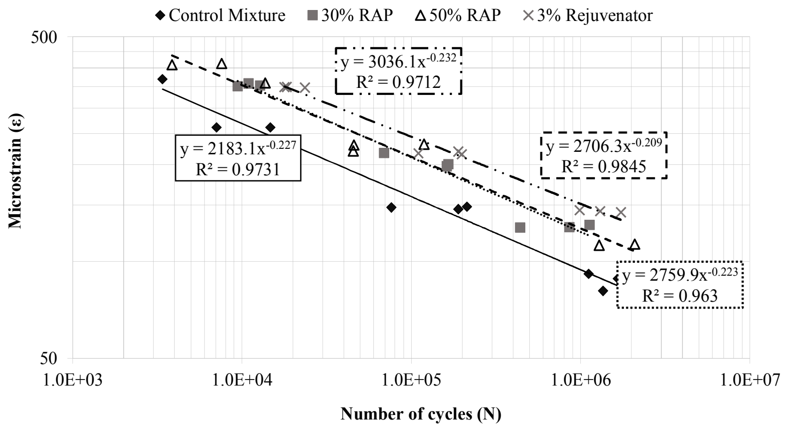


Fig. 2 - Fatigue life equations of the mixtures studied tested at 20 °C

Based on the fatigue life equation, it is possible to conclude that the mixture with 3% rejuvenator presents a longer fatigue life in comparison to the others mixtures. On the other hand it is possible to conclude that the control mixture has the worst result in terms of fatigue cracking resistance. The main variables for assessing this property ($N_{100}$ – number of cycles that the mixture can withstand before failure at a tensile strain level of $100\times10^{-6}$; $\varepsilon_6$ – tensile strain that causes a fatigue resistance of 1×106 cycles) were estimated from the fatigue life equations and are presented in Table 3.

Table 3 - $N_{100}$ and $\varepsilon_6$ parameters estimated from the fatigue life equation

| | $N_{100}$ | $\varepsilon_6$ |
|---|---|---|
| **Control Mixture** | 4.16E+05 | 78.5 |
| **30% RAP** | 2.07E+06 | 119.28 |
| **50% RAP** | 2.46E+06 | 123.34 |
| **3% Rejuvenator** | 6.22E+06 | 148.26 |

The parameters obtained for the three mixtures with RAP are higher than the parameters to the control mixture. Between the mixture with 30% RAP and the mixture with 50% RAP the parameters are very similar, although the mixture with a higher RAP content seems to perform better than that only 30% RAP. The parameters of the mixture with 50% RAP and

3% rejuvenator are significantly higher than the other mixtures, highlighting the role of the rejuvenating agent in improving the fatigue life resistance of the recycled asphalt mixture.

Based on the different testing temperatures used in the stiffness modulus tests, it was possible to represent the master curves for complex modulus, phase angle, storage modulus and loss modulus characteristics (Figure 3).

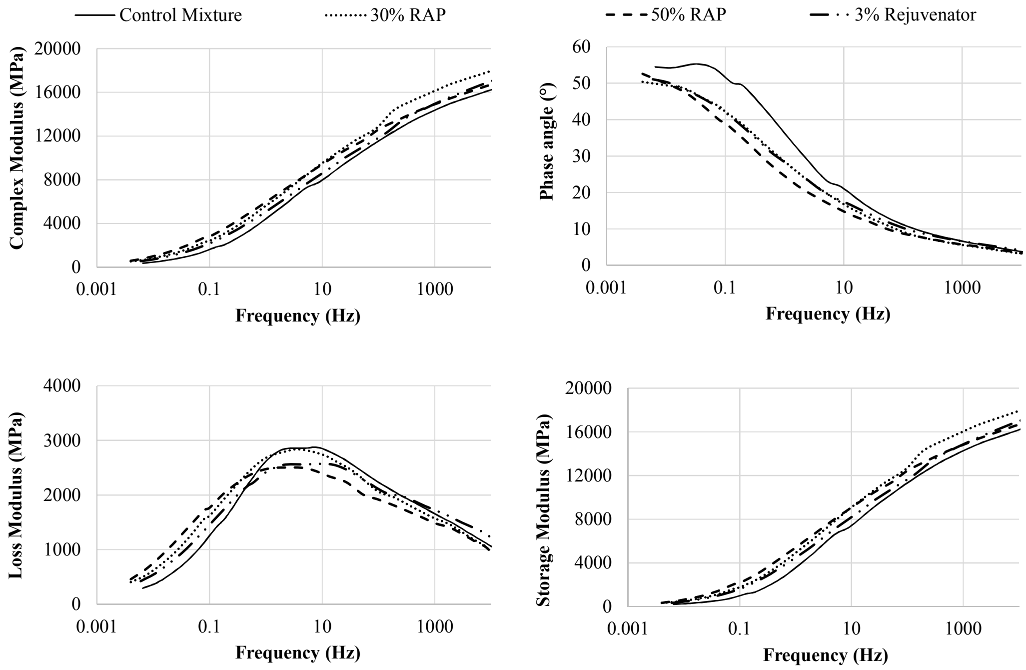


Fig. 3 - Master curves of the mixtures for a reference temperature of 20 °C

The incorporation of RAP increased the complex modulus of the mixtures and decreased the phase angle. This is caused for the presence of the aged binder in the RAP material, which makes the final mixture stiffer. The results of the complex modulus also confirm the effectiveness of the rejuvenator. In fact, the incorporation of the rejuvenator turned the results of the control mixture and of the mixture with 3% rejuvenator very similar.

## CONCLUSIONS

The results presented on this study confirmed the possibility to incorporate high percentages of reclaimed asphalt pavement in new asphalt mixtures and confirmed the efficiency of using rejuvenating agents in recycled mixtures with high RAP contents.

The incorporation of higher percentages of RAP cause an increase on the stiffness modulus of asphalt mixtures. This increase makes the mixtures normally more fragile, which can conduct to worse performances when applied in roads with high levels of traffic. Because of that, some sort of additive may be necessary in order to reduce the stiffness modulus of the mixtures and improve the fatigue cracking resistance. The rejuvenator used in this study prove to be efficient in making the mixture less fragile and consequently with better results in terms of fatigue cracking resistance.

The incorporation of a rejuvenator can be associated to an increase in the production costs but the possibility to incorporate higher percentages of RAP with identical or even improved results, in comparison to a conventional mixture, is benefic both in economic and environmental terms, due to the decrease in the need for new materials. Other important aspect is the possibility to reduce the production temperature of the mixtures incorporating a rejuvenator, due to the softening effect on the RAP aged binder, but this needs more further investigation that could not be included in the present paper.

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