ASPHALT MIXTURES PRODUCED WITH 100% RECLAIMED MATERIALS

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ABSTRACT
The environmental and economic benefits of using Reclaimed Asphalt Pavement (RAP) material in hot mix asphalt (HMA) applications could be pushed up to the limit, by producing totally recycled HMAs (100% RAP), but the performance of this alternative must be satisfactory. In fact, these mixtures could possibly present a lower performance due to the behaviour of the aged binder, which loses its lighter fractions with time. In order to improve the mixture properties, a binder rejuvenator should be used. Thus, in the present study, the utilization of a used motor oil as a rejuvenator was evaluated. This would allow the modification of the aged binder, restoring some of its original properties and promoting an adequate performance of the mixture.
The optimal amount of oil was determined by conventional bitumen tests, using the achievement of a bitumen with a penetration grade above, as the selection criterion for the definition of the amount of oil.
Once the amount of rejuvenator (oil) was defined, laboratory specimens were prepared and tested for water sensitivity, permanent deformation, stiffness and fatigue, in order to confirm that the totally recycled mixture will perform as good as a conventional mixture used for comparison purposes.

Keywords: Asphalt recycling; Binder rejuvenation; 100% RAP; Asphalt mix performance

INTRODUCTION
In order to contribute towards a sustainable development, Road Authorities are beginning to adopt alternative materials to be applied on their infrastructures. Furthermore, the rehabilitation of the existing pavements is also being more often considered in a closed cycle, where the old material (usually know as Reclaimed Asphalt Pavement, RAP) is seen as a product for the new layers, rather than a waste material [1]. Several studies have been carried out in the past [2, 3, 4] with high content of recycled asphalt (up to 60%), which is mainly limited by practical issues related to the production of the mixtures in the asphalt plant.
According to Riebesehl and Nölting [5], the environmental and economic benefits of using RAP in hot mix asphalt (HMA) applications could be pushed up to the limit, by producing totally recycled HMAs (100% RAP). However, in order to assure that this type of mixture can be seen by the Road Authorities as a true alternative, its performance must be as good as that of conventional mixtures. In fact, these mixtures may present a lower performance due to the loss of the lighter fractions of the aged binder. In order to improve the mixture properties, a rejuvenator has to be used.
Rejuvenation of bitumen is simple in principle, consisting on the replacement of the oils lost during the aging process, and on the rebalancing of the bitumen composition. However, this is not generally possible, as it would require sophisticated extraction, testing and remodelling of the binder in the road pavement [6]. The used oil was selected for this study because a similar material has already been used as rejuvenator in previous studies [7]. In addition, it would allow the recycling of asphalt mixtures with exclusive use of reclaimed materials, which is the main objective of this study.

MATERIAL CHARACTERISATION

In the present study, RAP material was used as the main component of the mixture. However, since the binder usually present in this type of material is too hard for a conventional bituminous mixture, a used oil was also used to rejuvenate the binder and improve its properties. In order to determine the amount of additive that should be added to the mixture (to improve its properties), a new binder (10/20 pen grade), with properties similar to those of the RAP binder (penetration of 10 x 0,1 mm) was used in this particular part of the study, as it would be impracticable to extract the necessary amount of aged binder from the RAP to run the series of tests.
The optimum amount of additive that should be used was determined by means of conventional bitumen tests. The criterion used was the obtainment of a bitumen of a higher penetration grade (in this case, the bitumen should reach a 20/30 pen grade, since it was previously classified as a 10/20 pen bitumen). The penetration and ring and ball test results are shown in Fig. 1.

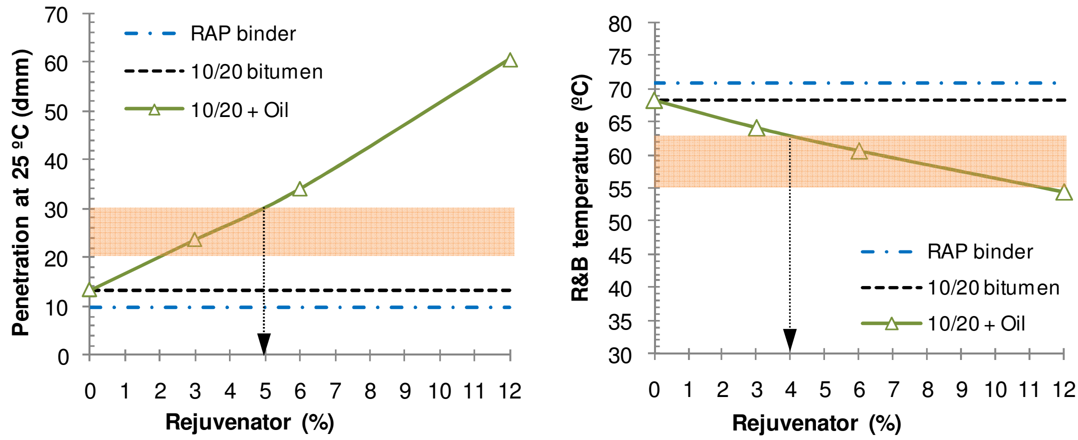

Fig. 1 – Penetration and softening point (R&B) test results of bitumen with different percentages of rejuvenator

As presented in Figure 1, the minimum amount of rejuvenator necessary to modify the aged binder and achieve a 20/30 penetration grade (corresponding to the shaded areas, as specified in EN 12591) was 5%. This was the additive content used in the remainder of the study.
The grading of the RAP material was evaluated according to EN 933-1 standard. The RAP material was also incinerated, according to the EN 12697-39 standard, in order to burn the bitumen and to evaluate the grading of the aggregates constituting the RAP (according to the EN 12697-2), so as to determine whether it fits within the grading envelope of a conventional surface course mixture (AC 14 surf), as illustrated in Fig. 2.

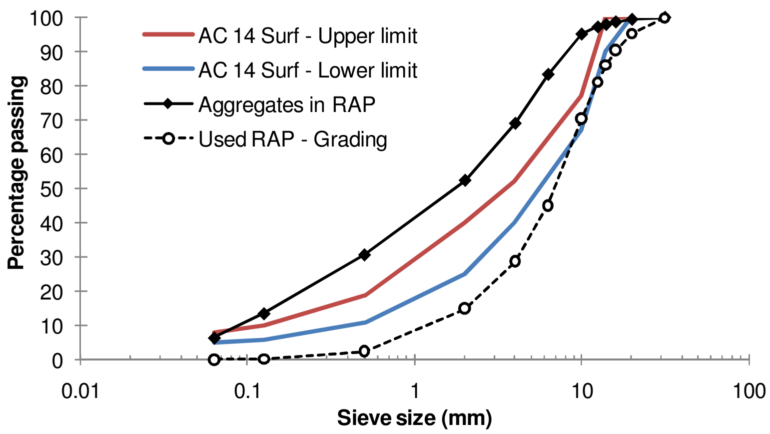

Fig. 2 – RAP and its aggregates grading curves outside AC 14 surf envelope

The RAP aggregates have an excess of fines and a low percentage of coarse material. This is due to the milling process or the wearing of the surface layer from which the RAP was extracted. Excessive fines may cause permanent deformation problems, although this is not expected in this study because the binder of the RAP is very hard, increasing the rutting resistance. Thus, the influence of failing to meet the aggregates grading envelope on the performance of the mixture needs to be verified.

PERFORMANCE OF STUDIED MIXTURES

In order to confirm that the totally recycled mixture will perform as good as a conventional mixture, water sensitivity, permanent deformation, stiffness modulus and fatigue tests were performed on both mixtures and the results are presented below.

Water sensitivity

The evaluation of the water sensitivity is essential when studying asphalt recycled mixtures, since this property is directly related to the performance and durability of these materials during the road pavement life. The evaluation of this property is determined in Europe by the EN 12697-12 standard. According to this standard, two groups of three specimens are tested for the indirect tensile strength (ITS) after a different conditioning period. In that period, one group is kept dry and the other is immersed in water, in order to determine the influence of the water on the weakening of the bond between aggregates and binder and, consequently, on the strength of the mixture.
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 the dry group (ITSd) of specimens. In the present study, the indirect tensile test was carried out according to the EN 12697-23 standard, after a volumetric characterization of the specimens (to determine the voids content, which significantly influences the results), as presented in Fig. 3.

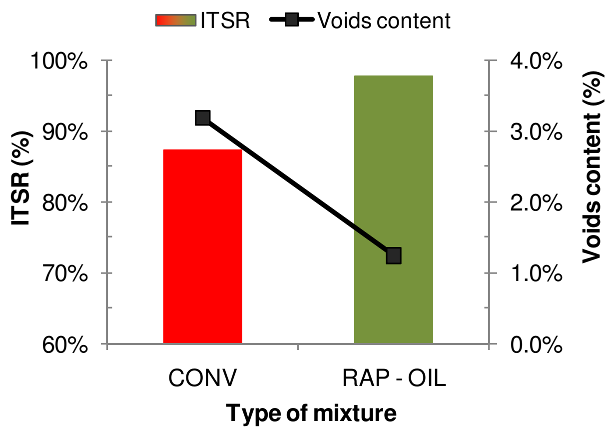

Fig. 3 – Results water sensitivity tests (ITSR vs. air voids content)

Overall, it was found that both mixtures had very good water sensitivity results, although the conventional mixture (produced with a 35/50 pen grade bitumen) was slightly more sensitive to the presence of water (lower ITSR due to its higher voids content). The recycled mixture with incorporation of a rejuvenator (RAP - OIL) showed a better performance (durability), mainly due to the low volume of voids, which in turn is related to the high amount of fines previously mentioned.

Permanent Deformation

The rut resistance of asphalt mixtures may be assessed, in comparative terms, by the analysis of wheel tracking test results, plotted in a graph deformation vs. number of cycles. Fig. 4 represents the results of the recycled mixture and a conventional mixture produced with a 35/50 pen bitumen.

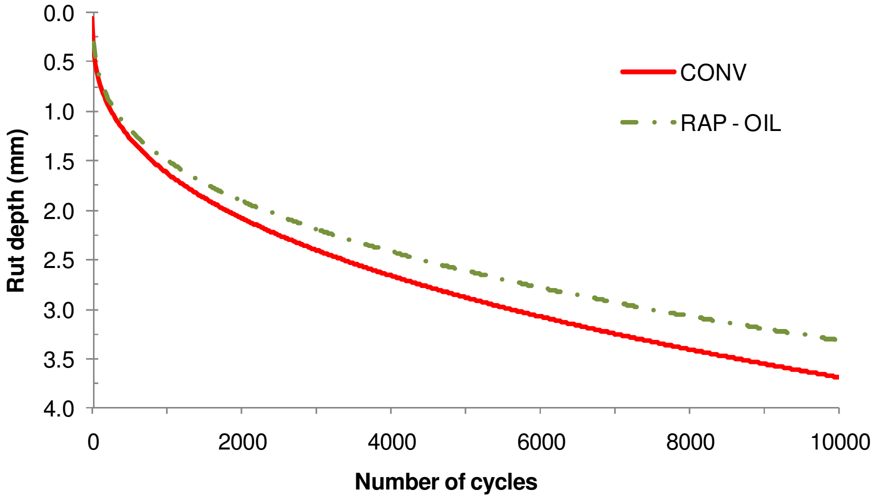

Fig. 4 – Wheel tracking tests results of both mixtures carried out in air, at 50 ºC

The permanent deformation performance of both mixtures is similar, as can be observed from Fig. 4, although the 100% recycled mixture still showed a slightly better behaviour. One of the main parameters used to assess the rut resistance of bituminous mixtures is the wheel tracking slope (WTS_{air}) measured between the 5000^{th} and the 10000^{th} cycles. In this study, the recycled mixture presented a WTS_{air} of 0.14 [mm/10^3 cycles] while the conventional mixture used for comparison presented a WTS_{air} of 0.16 [mm/10^3 cycles].

Stiffness Modulus

The stiffness modulus and phase angle were obtained using the four-point bending beam test, with a repetitive sinusoidal loading configuration, as specified in the EN 12697-26 standard. A frequency sweep (0.1 to 10 Hz) test was used to determine the response of the material to different loading frequencies. The tests were carried out at 20 ºC and the results are presented in Fig. 4.

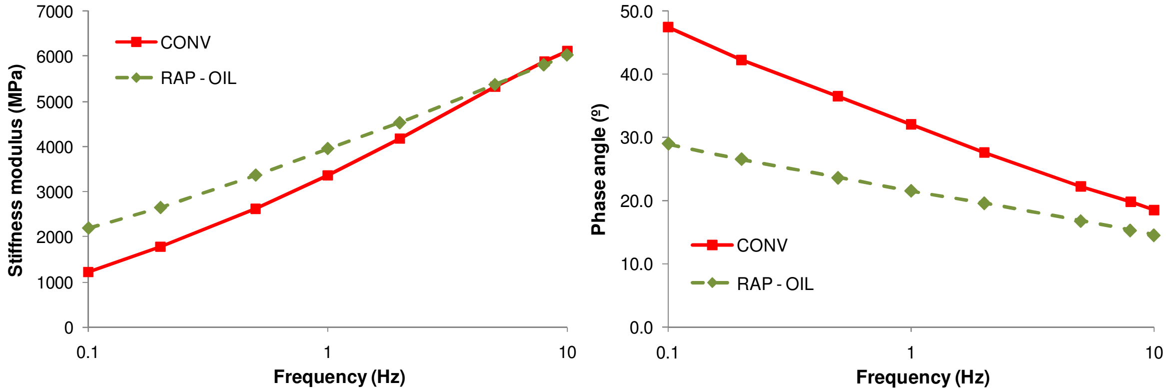

Fig. 5 – Stiffness modulus and phase angle for different frequencies at 20 ºC

As can be observed in Fig. 5, the recycled mixture is less susceptible to the loading frequency which is typical of mixtures with aged binders, since the stiffness modulus variation is smaller than in the case of the conventional mixture and the phase angle is significantly lower than that of the conventional mixture, for any frequency tested. These results are in accordance with those obtained in the rut resistance tests, where the recycled mixture has shown a good performance, even at a high temperature (which is equivalent to lower frequencies in the stiffness modulus tests).

Fatigue Cracking Resistance

The fatigue life equations at 20 ºC of the conventional AC 14 Surf 35/50 (CONV) and the 100% recycled (RAP - OIL) mixtures are presented in Fig. 6, in order to evaluate the difference between the fatigue resistance of totally recycled and "new" asphalt mixtures.

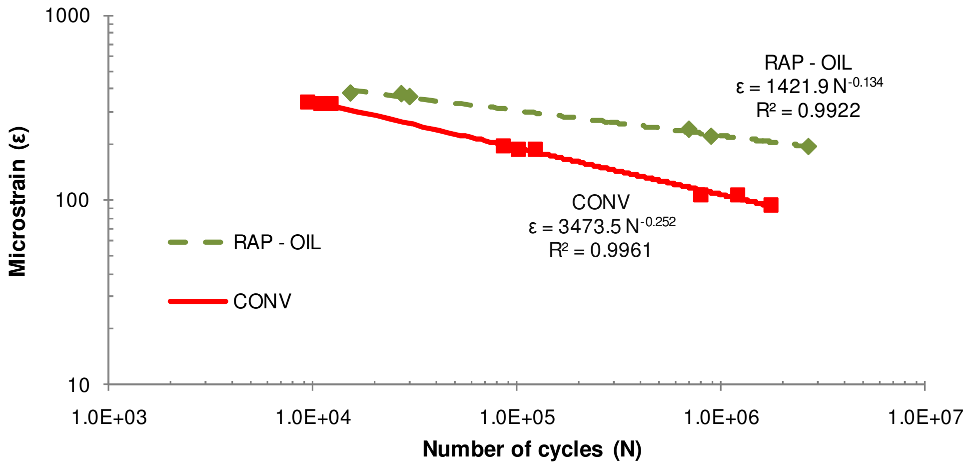

Fig. 6 – Fatigue cracking resistance of both mixtures assessed at 20 ºC

Based on the results presented in Fig. 6, it was possible to conclude that the recycled mixture presented a better performance than the conventional mixture.
The high fatigue resistance of the 100% recycled mixture can result from its high content of fines (the quantity of mastic filling material increases), which are present in the RAP due to the milling operation of the bituminous mixture from the road pavement. This fact could also have led to rutting problems if the hardened bitumen of the recycled mixtures was not so stiff. This unexpected high fatigue resistance result has already been noted by other authors [8], who concluded that the aged binder in RAP formed a stiffer layer coating the RAP aggregate particles. This layered system helped to reduce the stress concentration within the mixtures and the aged binder mastic layer was actually serving as a cushion layer in between the hard aggregate and the soft binder mastic.
The parameters specified in EN 12697-24 (N_{100} and ε_6), which are normally used to evaluate the fatigue performance of bituminous mixtures, were estimated from the fatigue life equations of Fig. 6 and are presented in Table 1.

Table 1 – N_{100} and ε_6 parameters estimated from the fatigue life equations

Asphalt mixture	N_{100} [No. cycles]	ε_6 [10^{-6}]
RAP - OIL	3.78E+08	222.1
CONV	1.30E+06	106.8

As previously mentioned, the rejuvenators increase the fatigue life of recycled mixtures due to the combined effect of the reduction on the penetration grade of the binder and the slight increase on the binder content of such mixtures. In this case, those factors associated with a higher content of fines greatly enhanced the flexibility of the recycled mixture, thus increasing the fatigue cracking resistance of the mixture.

CONCLUSIONS

The main conclusions that can be drawn from this study of an innovative mixture, totally recycled from old and distressed road pavement materials, are the following:

- The content of rejuvenator (OIL) was defined by the minimum amount that could change the grade of the aged binder from 10/20 to 20/30 pen grade (this was assessed by means of penetration and softening point tests), resulting in an optimum content of 5%;

- All properties of the 100% recycled mixture evaluated in this work (water sensitivity, rutting resistance, stiffness and fatigue resistance) showed better results than those of a conventional asphalt mixture, and this surprisingly good result could be a consequence of the higher content of fines and the higher stiffness of the binder, associated with the increased flexibility given by the rejuvenator;
- The performance based analysis carried out in this work may be used to obtain and validate the composition of 100% recycled mixtures that can be implemented in real pavements, even without complying with the empirical specifications (e.g., grading envelope) usually applied in road pavement works;
- In summary, the "total recycling" technology can be used to produce mixtures with a performance as good as conventional asphalt mixtures, provided that adequate storing and handling conditions are assured during the production stage.

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