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UTILIZATION OF WASTE MATERIALS TO IMPROVE ASPHALT MIXTURES PERFORMANCE

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ABSTRACT

This study aims to develop an innovative bitumen with large quantities of waste materials to improve asphalt mixtures performance. Different amounts of waste motor oil and waste HDPE were added to a new bitumen. The bitumen modified with 10 % of waste motor oil and 5 % of HDPE showed promising characteristics (high softening point temperatures and penetration slightly higher than the conventional bitumen). After the selection of the most promising modified bitumen, three asphalt mixtures were produced with different bitumens (namely conventional bitumen, commercial modified bitumen and the selected modified bitumen). Beyond that, this modified bitumen improved some mechanical characteristics of the asphalt mixture where it was used, in comparison to conventional and modified asphalt mixtures.

Keywords: waste motor oil, waste polyethylene (waste HDPE), modified bitumen, asphalt mixtures performance.

INTRODUCTION

The road paving industry utilizes a large amount of natural resources (like bitumen) for both production and conservation of road infrastructures. As bitumen is one of the most valuable materials used in pavements, there is a concern about minimizing their consumption through the use of waste materials.

Some studies with bio-oil already tried to create new asphalt binders without or only with a lower amount of conventional bitumen (Metwally, 2010). However, it is possible to use modified bitumens with some waste materials that decrease the use of virgin bitumens and significantly improve asphalt mixtures' characteristics (Fuentes-Audén, 2008, Zargar, 2012)

The most used modifiers or additives in road paving industry are polymers, mostly virgin elastomers and plastomers, but more recently other polymers such as for example plastic wastes have also been tested. The plastic wastes can improve the proprieties of the bitumen and, consequently, the performance and durability of the asphalt mixtures and they present environmental and economic advantages (Costa, 2013, Yildirim, 2007). The waste high density polyethylene (HDPE) is available in large amounts, at a low price, because it is present in containers and plastic bottles in large quantities (Casey, 2008). The addition of HDPE to bitumen decreases penetration, increases the softening point temperature and increases the resistance to the variation of temperature (Al-Hadidy, 2009, Hınıslioğlu, 2004).

On the other hand, the waste motor oil is being tested in asphalt mixtures to prevent aging or as bitumen rejuvenator, reducing its viscosity, which results in lower mixing and compaction

temperatures (Lesueur, 2009, Silva, 2012). However, the addition of waste motor oil could reduce the elastic recovery and the resistance to rutting (Jia, 2014).

Thus, the main objective of this study is the development of a new binder that maximizes the use of waste motor oil and waste high density polyethylene (HDPE) and, at the same time, improves the asphalt mixtures behaviour (improves the resistance to rutting and reduces thermal susceptibility and, probably, the cracking resistance at low temperatures (Attaelmanan, 2011)). Thus, bitumen could be partially replaced by waste motor oil and HDPE will improve the mechanical characteristics of the final mixtures.

MATERIALS AND METHODS

The materials used in this study are a conventional bitumen classified as 35/50 pen and a commercial modified bitumen designated Styrelf or Elaster 13/60 (for comparison with the new binders), both from CEPSA Portugal. Besides, the waste materials utilized in this work are a waste motor oil (from heavy vehicles without any kind of treatment) and ground waste plastic (HDPE) with a maximum dimension of 4 mm.

In order to produce the binders that are used in this study, two percentages of waste motor oil (10 and 20 %) and three contents of polymer (2.5, 5 and 10 %) are added to the conventional bitumen, in a high shear mixer at 7200 rpm, for 20 minutes, at temperature of 180 °C. The content of each waste material and their nomenclature are shown in Table 1. The modified binders were characterized by the penetration test (EN 1426 standard), the softening point test (EN 1427 standard) and dynamic viscosity test (EN13302).

Table 1 - Content of each waste material and respective nomenclature of studied binders

Bitumen	Content of motor oil [%]	Content of polymer [%]	Nomenclature
Pen 35/50		0	BO10
	10	2.5	BO10P2.5
		5	BO10P5
		0	BO20
	20	5	BO20P5
		10	BO20P10

After selection of the most promising binders to continue the study, an asphalt mixture was produced with that modified binder and its results were compared to those of asphalt mixtures produced with conventional and commercial modified bitumens. The asphalt mixtures were manufactured with a binder content of 5 % and with production and compaction temperatures of 180 °C and 160 °C, respectively. Furthermore, the selected aggregates are crushed rock aggregates of granite origin, with the exception of filler which origin is limestone. The selected gradation of the aggregates, as well as the lower and upper limit of an AC 14 Surf mixture are presented in Fig. 1.

In order to evaluate the performance of the studied asphalt mixtures, water sensitivity (EN 12697-12 standard), permanent deformation (EN 12697-22 standard) and stiffness modulus (according to EN 12697-26 standard) tests were carried out.

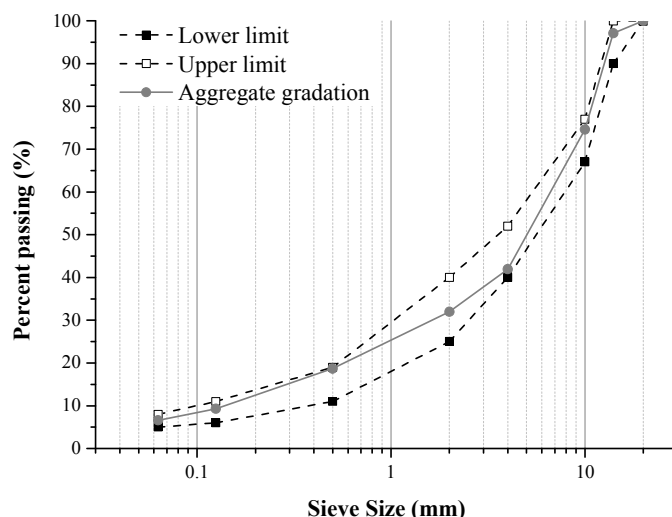


Fig. 1 - Selected gradation and lower and upper limit of an AC 14 Surf mixture

RESULTS

As presented in Fig. 2, the introduction of waste motor oil (in amounts of 10 % or 20 %) into a conventional bitumen (35/50 pen) increased the penetration values, decreased the softening temperatures and did not exhibit any resilient capacity. Furthermore, the increase in the amount of waste HDPE reduced the penetration values and increased the softening temperatures and the resilient capacity. The new modified bitumens with similar or better behaviour comparatively with the conventional bitumen (B) and/or the commercial modified bitumen (Styrelf) are BO10P5 and BO20P10.

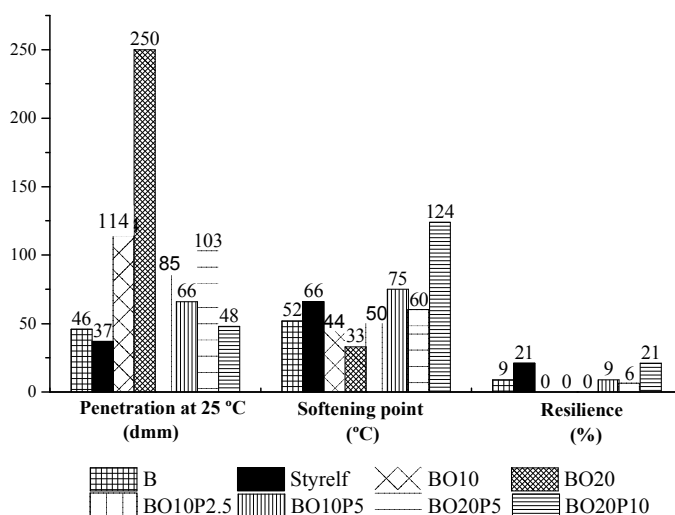


Fig. 2 – Penetration, softening point (R&B) and resilience test results of conventional bitumen and modified bitumens

With regard to the viscosity results (Fig. 3), the modified bitumens using only waste motor oil (BO10 and BO20) showed a lower viscosity than the conventional bitumen. However, the addition of waste HDPE polymer increased the viscosity of all bitumens. In addition, higher

amounts of polymer increased the modified bitumens' viscosity and, for amounts of HDPE equal to 10 %, the modified bitumen BO20P10 showed extremely high viscosity values that make impractical its use in paving industry. In comparison with the conventional bitumen, the modified bitumens with waste motor oil and HDPE presented similar or higher viscosity. When compared with commercial modified bitumen (Styrelf), the modified bitumen BO10P5 showed a similar behaviour, but the viscosity values are slightly lower. In turn, modified bitumen BO20P5 presented higher viscosity values than commercial modified bitumen at higher temperatures.

The dynamic viscosity results also allow to determine the ideal mixing and compaction temperatures according to the viscosity recommended for each case. The ideal viscosity for producing mixtures is about 0.3 Pa.s (horizontal black dotted line in Fig. 3), while the compaction viscosity should be between 2 and 20 Pa.s (horizontal black lines in Fig. 3). Taking this into account, the modified bitumens with waste motor oil and amounts of HDPE equal or lower than 5 % exhibited a mixing temperature under 180 °C (equal or lower than Styrelf). In relation to the compaction temperatures of the modified bitumens with motor oil and HDPE (2.5 % and 5 %), they showed temperatures between those of the conventional bitumen and commercial modified bitumen.

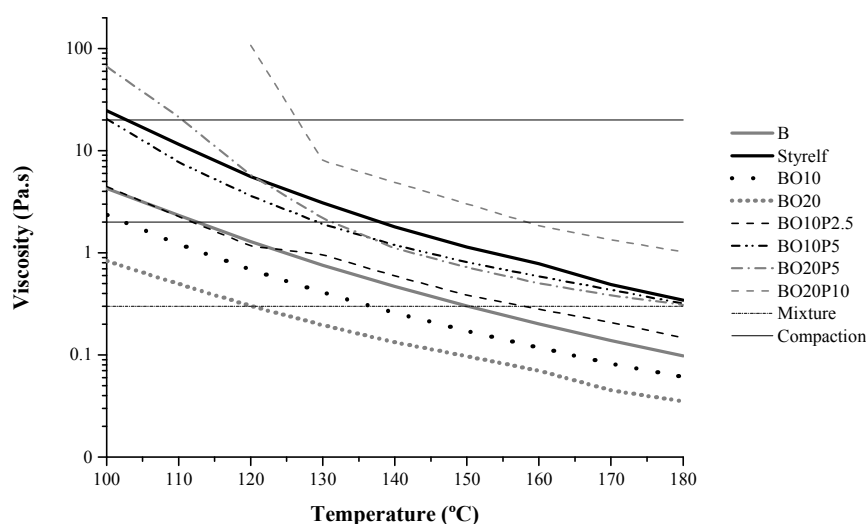


Fig. 3 - Dynamic viscosity test results of conventional bitumen and modified bitumens

After analysis of the previous results, only one of the modified bitumens has the suitable conditions for being used in paving industry. In fact, the modified bitumen with 10 % of waste motor oil and 5 % of HDPE (BO10P5) presented very good properties at intermediate temperatures thanks to slightly higher values of penetration and softening point temperature relatively to conventional bitumen.

Thus, the modified bitumen BO10P5 was selected to evaluate its performance in an asphalt mixture. So, three mixtures were produced, considering the production conditions previously mentioned, as follows:

- Mixture AM-B (conventional mixture with 5 % of a conventional 35/50 bitumen);
- Mixture AM-Styrelf (modified mixture with 5 % of commercial modified bitumen Styrelf) and;
- Mixture AM-BO10P5 (modified mixture with 5 % of modified bitumen incorporating 10 % waste motor oil and 5 % HDPE).

After selecting the asphalt mixtures to be studied, their mechanical behaviour was assessed, namely the water sensitivity, rutting resistance and stiffness modulus results.

The water sensitivity (ITSR) and the air voids content (determined based on EN 12697-8 standard method A) are presented in Figure 4. In turn, the indirect tensile strengths and the deformation at failure of the dry samples can be visualized in Figure 5.

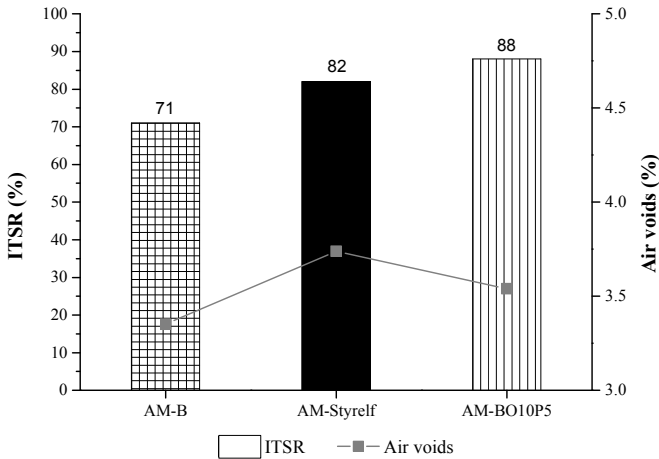


Fig. 4 - Water sensitivity and air voids results of the studied asphalt mixtures

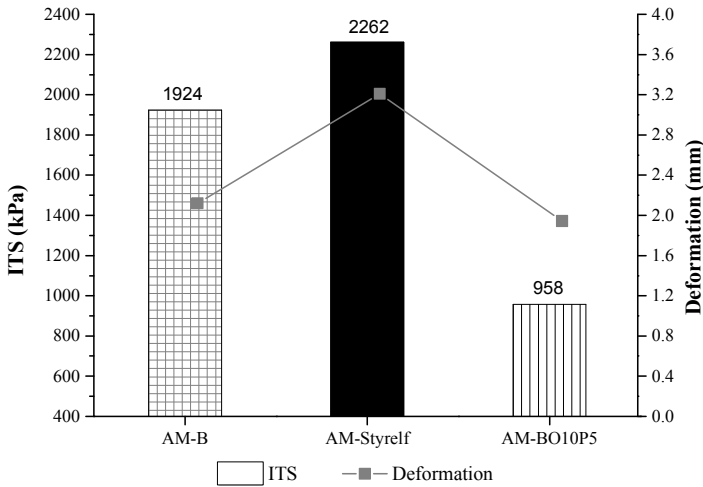


Fig. 5 - Indirect tensile strength and deformation at failure results of the studied asphalt mixtures

All mixtures showed low water sensitivity, with ITSR values always higher than 70 %. Moreover, the mixture with the selected modified bitumen (AM-BO10P5) presented lower water sensitivity than the reference mixtures (mixtures with conventional bitumen and commercial modified bitumen). In relation to the air voids content, the mixture with the selected bitumen presented an air voids value between the mixtures AM-B and AM-Styrelf. Generally, the higher the air void content, the more sensible to water is the mixture. However, in this case the mixture AM-BO10P5 had the best water sensitivity result, although it has not the lowest air void content. This may be caused by a greater bitumen coating on the

aggregates (probably due to the very low viscosity of the waste motor oil), reducing the stripping effect of the water.

In relation to ITS values, the mixture AM-BO10P5 exhibited lower values than the mixtures with commercial modified bitumen and conventional bitumen. This reduced strength value of may be also caused by the presence of waste motor oil as partially substitute of bitumen. On the other hand, the deformation was very similar to that of the mixture with conventional bitumen and lower than that of AM-Styrelf mixture, which allied to the ITS values may indicate that AM-BO10P5 mixture had better flexibility at intermediate temperatures than mixtures AM-B and AM-Styrelf

Then, the resistance to permanent deformation was determined by measuring the rut depth formed by successive passages of a wheel (wheel tracking test). Its evolution with the number of cycles allowed to rank the permanent deformation performance of asphalt mixtures through the wheel-tracking slope in air (WTS_{AIR}) parameter. As can be seen from the Fig. 6, the asphalt mixture with commercial modified bitumen (AM-Styrelf) and the mixture with waste motor oil and HDPE (AM-BO10P5) presented higher resistance to rutting than conventional mixture (AM-B) due to reduced rut depth values. Furthermore, the mixture AM-BO10P5 showed the lowest WTS_{AIR} value, which indicates that this mixture exhibited the best permanent deformation performance. It should also be mentioned that the WTS_{AIR} value of mixture AM-Styrelf is very similar to that of mixture AM-BO10P5.

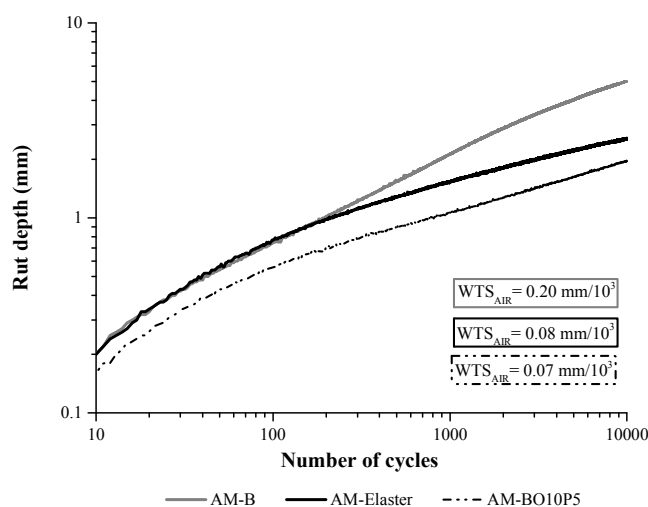


Fig. 6 - Variation of rut depth with the number of cycles for the studied asphalt mixtures

Finally, with regards to stiffness test results, and according to EN 13108-20 standard, this property can be obtained in four point bending loading tests on prismatic specimens (4PB-PR), for a frequency of 8 Hz at a temperature of 20 °C, as presented in Table 2.

Table 2 - Stiffness and phase angle results of the studied asphalt mixtures

Asphalt mixture	Stiffness [MPa]	Phase angle [°]
AM-B	3701	28.2
AM-Styrelf	4460	24.3
AM-BO10P5	2854	25.7

It was concluded that the mixture AM-Styrelf exhibited higher stiffness modulus and lower phase angle values than the mixtures AM-B and AM-BO10P5. Furthermore, the mixture AM-BO10P5 showed the lowest stiffness modulus, which could be caused by the introduction of waste motor oil in the bitumen (because this material greatly increases the penetration of modified bitumen). Nevertheless, this mixture revealed a low phase angle, similar to that of AM-Styrelf. In other words, the developed mixture showed a more elastic behaviour, which associated with the low stiffness of this mixture can indicate a greater flexibility and higher resistance to fatigue.

CONCLUSION

The present study allowed obtaining a modified binder produced with significant quantities of waste materials that shows similar or higher properties than a conventional bitumen and/or a commercial modified bitumen. Although several solutions have been tested, the most viable solution, in terms of characteristics of the bitumen and performance of asphalt mixture was the bitumen with 10 % of waste motor oil and 5 % of waste HDPE.

This modified bitumen showed interesting properties at intermediate temperatures due to the slightly higher values of penetration and softening point temperature than the commercial modified bitumen, while the dynamic viscosity of both bitumens is similar.

Moreover, the asphalt mixture with the selected modified bitumen presented a low water sensitivity and a great resistance to permanent deformation. Although the developed mixture presented lower stiffness modulus comparatively to the other studied mixtures, it also exhibited a low phase angle, which can indicate a greater flexibility and higher resistance to fatigue.

It can be concluded that the performance of the developed asphalt mixtures (incorporating waste motor oil and HDPE) improved some important properties, thus showing the potential of these new environmentally friend solutions to be used in real road pavements.

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