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Effect of incorporating different waste materials in bitumen

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Abstract

The increasing environmental concern about waste materials and the necessity of improving the performance of asphalt mixtures prompted the study of incorporating different waste materials in conventional bitumen. The reuse of waste materials can present benefits at an environmental and economic level, and some wastes can be used to improve the pavement performance. Thus, the purpose of this study is to evaluate the incorporation of different waste materials in bitumen, namely waste motor oil and different polymers. In order to accomplish this goal, 10% of waste motor oil and 5% of polymers (high density polyethylene, crumb rubber and styrene-butadiene-styrene) were added to a conventional bitumen and the resulting modified bitumens were characterized through basic and rheological tests. From this work, it can be concluded that the incorporation of different waste materials improves some important properties of the conventional bitumen. Such improvements might indicate a good behaviour at medium/high temperatures and an increase of fatigue and rutting resistance. Therefore, these modified bitumens with waste materials can contribute to a sustainable development of road paving industry due to their performance and environmental advantages.

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Keywords: Modified bitumen; binder properties; waste materials; waste motor oil; polymers.

1. Introduction

The main problems of asphalt mixtures are rutting and cracking mainly due to the thermal susceptibility and ageing of conventional bitumen [1]. Besides these problems, the increasing traffic volume and loads applied in road pavements could compromise the durability and performance of asphalt mixtures [2,3]. Such factors demonstrate the need of developing binders with improved characteristics in comparison with those of conventional bitumens, or in other words, modified bitumens. The mostly used modifiers or additives in road paving industry are polymers [4]. The polymers decrease the thermal susceptibility and permanent deformation, and increase the resistance to cracking of asphalt mixtures, thus expanding the

bitumens' durability and operating temperatures range [5]. The polymer modified bitumens typically have higher elastic response, cohesion, ductility, softening point temperature and viscosity than conventional ones [6,7].

Although polymers are used in small amounts in modified bitumen (the typical percentage is 5% to 6% [5]), the utilization of virgin polymers in bitumen modification has a high cost. Consequently, it is crucial to find an alternative for these virgin polymers, namely by using waste polymers. In fact, the characteristics of a bitumen modified with waste polymers is similar to those obtained when using virgin polymers, and the first solution presents economic and environmental advantages [3]. Some examples of waste polymers already used are ethylene-vinyl acetate (EVA), high and low density polyethylene (HDPE and LDPE) and crumb rubber. The HDPE is found in packages and plastic bottles and it increases significantly the stability and

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durability of asphalt mixtures [8,9]. In turn, the crumb rubber, from used tires, is a waste of fast accumulation and it is difficult to eliminate. When added to bitumen, the crumb rubber decreases the permanent deformation, cracking and reflective cracking [10]. These different waste materials present environmental and economic benefits, and they can improve asphalt mixtures' performance.

Even though the used styrene-butadiene-styrene (SBS) was not a waste material, this polymer is probably one of the most used and suitable for modifying bitumens [1,11]. The SBS improves elastic response and increases rutting and cracking resistance [12]. Moreover, the bitumen modified with this polymer presents lower penetration values and higher softening temperatures [4,13].

Another waste material which can be used as additive in asphalt mixtures is waste motor oil. It is typically used as rejuvenator in recycled asphalt mixtures to restore the initial properties of the aged bitumen of the reclaimed asphalt pavement, namely by adding volatile fraction or maltenes. The motor oil also reduces the bitumen viscosity and the mixing and compaction temperatures [14]. Furthermore, waste motor oil could add value to paving industry if it was used as a partial substitute of bitumen [15].

The aim of this study is to evaluate the effect of incorporating waste materials (waste polymers and motor oil) in bitumen through basic and rheological characterization tests. These modified bitumens with waste materials should be compared to a conventional bitumen and a commercial modified bitumen, in order to identify possible improvements in their behaviour.

2. Materials and Methods

2.1. Materials

The waste materials used in this study were the high density polyethylene, crumb rubber and the motor oil. In addition to these materials, a conventional bitumen and one of the most common polymers applied in paving industry, the SBS, were also utilized.

As regards to the polymers used, the HDPE and SBS were supplied by *Gintegral* and *Indústria Invicta*, respectively, both with a maximum dimension of 4 mm. Moreover, the crumb rubber supplied by *Recipneu* has a dimension of 0.18 to 0.60 mm. In order to obtain the melting and/or glass transition temperatures of the different polymers, differential scanning calorimetry (DSC) tests were performed. The sample of polymer was heated in a range of temperatures of -60°C to 160°C , with a heating rate of $10^{\circ}\text{C}/\text{min}$. The HDPE presented a melting temperature

of 131°C and the SBS a glass transition temperature of 74°C . It should be noted that the equipment used (DSC-Diamond Pyris) does not allow to achieve temperatures below -60°C , which made some of the glass transition temperatures impossible to obtain. In fact, the glass transition temperatures of HDPE, crumb rubber and the butadiene block of SBS were impossible to obtain because their values were typically lower than -60°C [16-18].

The thermal behaviour of the waste motor oil, obtained from heavy vehicles without any kind of treatment, was evaluated with the dynamic viscosity test [19], and is presented in Fig. 1. As expected, the waste motor oil exhibited a very low viscosity, between 0.1 and 0.005 Pa s, over the test temperature range of 30 to 180°C .

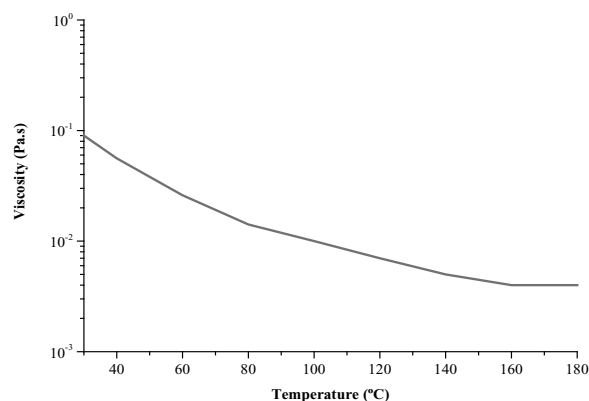


Fig. 1. Dynamic viscosity of the waste motor oil.

The conventional bitumen, used as base and control material in this study, presents a penetration of 46 dmm, a softening temperature of 52°C and a resilience of 9%. Concerning the commercial modified bitumen Elaster 13/60, also used as a control material, it presented a penetration of 37 dmm, a softening temperature of 66°C and a resilience of 21%. Both bitumens were supplied by CEPISA Portugal.

2.2. Methods

The production of the modified bitumens was carried out in two phases: 1) firstly, by adding waste motor oil and different polymers (high density polyethylene, styrene-butadiene-styrene and crumb rubber) to the conventional bitumen, using a low shear mixer, in order to obtain an initial blend at a temperature of 180°C ; 2) then, those initial blends were placed in a high shear mixer at 7200 rpm, at 180°C , for additional 20 min, in order to grind the polymers and obtain a homogeneous polymer modified binder.

The bitumen was modified with a percentage of 5% of each of the three different polymers, since that is the typical percentage of polymer used in the paving industry. The waste motor oil was applied in an amount of 10% taking into account that the maximum percentages already used in recycling mixtures were less than 7%. The amount of this waste was slightly increased in order to obtain a more sustainable solution without severely reducing the rut resistance of the new binder. It should be noted that one of the samples was modified only with waste motor oil for comparison reasons. Thereby, the conventional and modified bitumens were entitled as follows:

- Conventional bitumen 35/50 – “B”;
- Commercial modified bitumen – “Elaster 13/60”;
- B + 10% Motor oil – “BO10”;
- B + 10% Motor oil + 5% HDPE – “BO10H5”;
- B + 10% Motor oil + 5% SBS – “BO10S5”;
- B + 10% Motor oil + 5% Crumb rubber – “BO10R5”.

All new modified bitumens, as well as the conventional and commercial ones, were characterized by performing basic and rheological tests.

The basic tests included the penetration at 25°C test [20], the softening point test by the ring and ball method [21], the resilience test [22] and the dynamic viscosity test [19].

In relation to the rheological characterization, it comprised the assessment of the rheological properties, based on EN 14770 standard [23], and the Multiple Stress Creep Recovery test, according to AASHTO TP 70-11 [24]. The rheological properties (the complex shear modulus and phase angle) were obtained for a range of frequencies between 100 and 0.01 Hz at temperatures of 30, 45, 60, 70 and 80°C. In turn, the Multiple Stress Creep Recovery test allows to obtain the percentage recovery and non-recoverable creep compliance of a modified bitumen, for different stress levels, such as 25, 50, 100, 200, 400, 800, 1600 and 3200 Pa, at the higher performance grade temperature needed in Portugal (in this case 64°C).

3. Results

3.1. Basic characterization

As indicated in Fig. 2, the introduction of waste motor oil in a conventional 35/50 pen grade bitumen increases the penetration value, reduces the softening

point temperature and does not change the resilient capacity of the base bitumen. Then, after introduction of different polymers in the BO10 material, the penetration values decreased and the softening point temperatures and resilient capacity increased. In comparison with the control materials (bitumens B and Elaster 13/60), the bitumens modified with HDPE (BO10H5) and SBS (BO10S5) had higher penetration values, but the softening point temperatures were similar or higher than that of Elaster 13/60. This indicates that these new binders produced with waste materials may have a good behaviour at medium/high temperatures. Regarding the resilient capacity, the bitumen modified with SBS (BO10S5) was the only one presenting a better behaviour than the commercial modified bitumen. The bitumen modified with 5% of crumb rubber (BO10R5) presented a high penetration value, but the softening point temperature and resilience capacity were similar to those of bitumen B. Despite this, higher amounts of crumb rubber waste could be used in bitumen (more than 20%, according to the Portuguese specifications), which can improve the binder properties and will certainly present huge economic and environmental advantages.

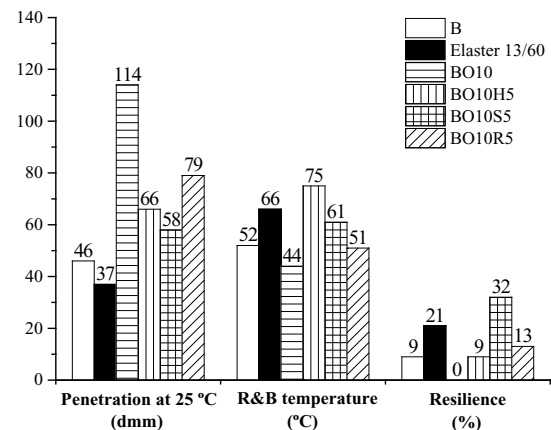


Fig. 2. Penetration, softening point (R&B) and resilience test results of conventional, commercial modified and several modified bitumens developed in this study.

The viscosity results presented in Fig. 3 show that the addition of waste motor oil reduces the bitumen’s viscosity, as expected. However, after introducing polymers in the mixture of bitumen and waste motor oil, the viscosity increases and becomes similar to that of the commercial and conventional bitumens (depending on the polymer used). The bitumen modified with crumb rubber (BO10R5) exhibited viscosity values similar to those of the conventional bitumen (B), while the bitumens modified with SBS (BO10S5) and HDPE (BO10H5) presented clearly higher viscosity values, similar to those of the

commercial bitumen (Elaster 13/60). At temperatures below 120°C, the bitumen modified with SBS (BO10S5) showed the highest viscosity of all binders studied, but at higher temperatures the new bitumens are less viscous than the commercial bitumen.

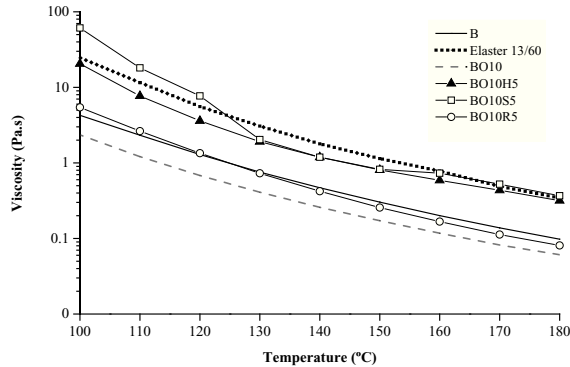


Fig. 3. Dynamic viscosity results of the conventional, commercial modified and several modified bitumens developed in this study.

3.2. Rheological characterization

The rheological proprieties of the several bitumens studied are presented in Figs. 4 and 5, respectively the complex shear modulus and the phase angle.

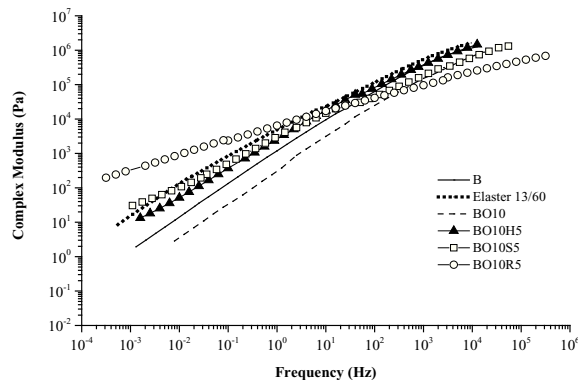


Fig. 4. Complex modulus of conventional, commercial modified and several modified bitumens developed in this study.

Again, as expected, the addition of waste motor oil to the conventional bitumen decreased its complex modulus. In turn, the complex modulus increased after the introduction of polymers. In general, it was observed that the commercial modified bitumen (Elaster 13/60) exhibited higher stiffness modulus values than the new modified bitumens produced with waste motor oil and polymers, except for very low frequencies and high temperatures where the asphalt BO10S5 (with SBS) presented a higher stiffness modulus. Furthermore, in comparison with the conventional bitumen (B), the new modified bitumens

BO10S5, BO10H5 and BO10R5 presented higher complex modulus for a large range of temperatures and frequencies.

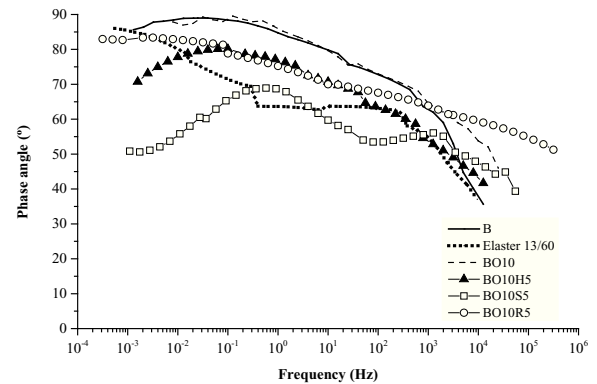


Fig. 5. Phase angle of conventional, commercial modified and several modified bitumens developed in this study.

However, at very high frequencies and low temperatures, the complex modulus of the new modified bitumens tends to become similar or smaller than that of the conventional bitumen (B). This might indicate that modified bitumens are stiffer than the conventional bitumen at higher temperatures, but they have a similar stiffness at low temperatures. This is interesting, because bitumens cannot be very stiff at low temperatures in order to avoid a brittle behaviour associated with thermal cracking problems. Finally, the obvious lower slope of the complex modulus curve of bitumen BO10R5 (with crumb rubber) may be related with a very low susceptibility of this bitumen to frequency and temperature changes, making this material an interesting solution for regions with very high thermal amplitudes.

As far as bitumens' phase angle assessment is concerned, all modified bitumens with waste motor oil and polymers showed lower phase angles, in a wide range of frequencies, when compared with conventional bitumen (B). These lower phase angle values occurred because the polymers increased the elastic component of the modified bitumens' stiffness. Although it is more difficult to compare the new bitumens with the commercial modified bitumen (Elaster 13/60), it is apparent that in general the bitumen modified with SBS is the only one with phase angle values lower than those of Elaster 13/60. Lastly, it was observed that the phase angles of the bitumen modified only with waste motor oil (BO10) are quite similar to those of the conventional bitumen.

The Multiple Stress Creep Recovery test results are presented in Fig. 6. According to standard AASHTO TP 70-11 [24], the non-recoverable creep compliance (J_{nr}) measured in this test is an indicator of the

resistance of a bitumen to permanent deformation under repeated loads. Thus, according to this test, the modified bitumen with 10% of waste motor oil and 5% of SBS (BO10S5) showed the best rut resistance performance due to the clearly lower non-recoverable creep compliance values, which are even lower than those of Elaster 13/60. The non-recoverable creep compliance values of modified bitumen BO10H5 (HDPE) are lower than those of conventional bitumen (except for higher stresses), but higher than those of Elaster 13/60. The modified bitumens BO10 and BO10R5 exhibited very high J_{nr} values, which may indicate a lower rut resistance.

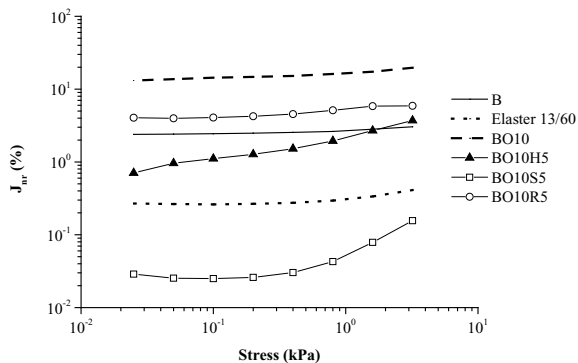


Fig. 6. Non-recoverable creep compliance of conventional, commercial modified and several modified bitumens developed in this study.

4. Conclusion

In this study it was concluded that large quantities (15%) of waste materials can be incorporated in a conventional bitumen because those wastes notably improve some properties of the bitumen, namely the softening point temperature, resilience and viscosity. Moreover, some of these new modified bitumens with waste motor oil and polymers have properties similar to those of a commercial modified bitumen, being an alternative to the present solutions for road paving. The modified bitumens with HDPE and SBS showed low phase angles and high stiffness modulus values at medium temperatures, as well as low non-recoverable creep compliance values, which might indicate high resistance to fatigue cracking and rutting, respectively. Therefore, these new bitumens can clearly contribute to a sustainable development of road paving industry, by combining very good performance for road use with economic and environmental advantages.

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