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Study of the effect of four warm mix asphalt additives on bitumen modified with 15% crumb rubber

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HIGHLIGHTS

- The four organic additives studied reduces the viscosity of a binder modified with 15% rubber.
- The theoretical reduction of the manufacturing temperature is smaller in bitumen with 15% rubber than in pure binders.
- Additives into the binder modified with 15% rubber causes the penetration to decrease and the softening point increase.
- It was not possible to clearly establish the effect of the organic additives on the elastic recovery test.
- The force-ductility test at 25 °C does not seem to be reliable due to the rubber particles that produce premature breakage.

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ABSTRACT

Due to a growing concern over global warming, the bituminous mixture industry is making a constant effort to diminish its emissions by reducing manufacturing and installation temperatures without compromising the mechanical properties of the bituminous mixtures. The use of mixtures with tyre rubber has demonstrated that these mixtures can be economical and ecological and that they improve the behaviour of the pavements. However, bituminous mixtures with a high rubber content present one major drawback: they require higher mixing and installation temperatures due to the elevated viscosity caused by the high rubber content and thus they produce larger amounts of greenhouse gas emissions than conventional bituminous mixtures.

This article presents a study of the effect of four viscosity-reducing additives (Sasobit®, Asphaltan A®, Asphaltan B® and Licomont BS 100®) on a bitumen modified with 15% rubber. The results of this study indicate that these additives successfully reduce viscosity, increase the softening temperature and reduce penetration. However, they do not have a clear effect on the test for elastic recovery and ductility at 25 °C.

1. Introduction

In recent years, environmental protection, energy savings and sustainable development have become important global themes. In road construction, new technologies such as warm-mix asphalt (WMA) and mixes with crumb rubber have been actively developed to promote energy savings and protect the environment.

Crumb rubber has been being used as an environmentally-friendly material which produces pavements with good mechanical behaviour, reduces the noise caused by traffic as well as road maintenance costs, while increasing the life of the pavement [1–4].

However, the manufacture of asphalt rubber mixes requires that manufacturing temperature be increased to 180 °C [5–10], as the rubber lends a greater viscosity to the binder, thus making the bitumen more sensitive to decreases in temperature [11]. From a technical point of view, various solutions have been proposed in order to reduce manufacturing temperatures. One such solution is warm-mix asphalt, which allows for a reduction in manufacturing and installation temperatures by reducing the viscosity of the bitumen using organic and chemical additives or foaming processes [12–14].

If warm-mix technology is applied to rubberised bitumen, mixes with good properties could be produced at a lower cost and with less environmental impact. Although there are numerous studies of warm-mix bitumen, very few have considered bitumen and warm-mixes with tyre rubber [15–17].

This article presents the results of tests for dynamic viscosity, softening point, penetration, ductility at 25 °C and elastic recovery on bitumen modified with 15% rubber and the corresponding control binders. 0%, 2% and 4% of four viscosity reducing additives were added to the mixtures.

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2. Materials and test programme

2.1. Materials

2.1.1. Asphalt binder

The net binder used in this study is a B 50/70 (50/70 × 10^{-1} mm of penetration), an asphalt bitumen which allows the manufacture and installation of asphalt mixes at normal temperatures. To this bitumen 15 wt.% of rubber was added in order to obtain a rubber-modified bitumen with increased viscosity. Table 1 indicates the basic specifications of these two binders; 'B' refers to the B 50/70 bitumen and 'B + 15% R' to the B 50/70 bitumen to which 15 wt.% of crumb rubber was added.

The asphalt bitumen was also subjected to a fractionation analysis as specified in the NLT 373/94 standard [18]. The results can be seen in Table 2.

2.1.2. Crumb rubber modifier (CRM)

The CRM used in this study was produced by mechanical shredding at ambient temperature by the Renecal company (Guardo, Spain). To ensure that the consistency of the CRM was maintained throughout the study, only one batch of crumb rubber was used. The gradation of the rubber used in this study is provided in Table 3.

50% of the rubber comes from lorry tyres and the remaining 50% from car tyres. A thermogravimetric analysis was completed on a TGA/SDTA 851 thermobalance and the results can be seen in Table 4.

2.1.3. Additives

The organic additives used in this study are Sasobit®, Asphaltan A®, Asphaltan B® and Licomont BS 100®. Organic or wax additives are used to achieve temperature reductions by reducing the viscosity of the binder. Studies show that these waxes can reduce the viscosity of a bitumen, thereby allowing asphalt mixes to be manufactured at lower temperatures [13].

Sasobit® is a Fischer–Tropsch (F–T) wax which is produced by treating hot coal with steam in the presence of a catalyst. It is a long-chain aliphatic hydrocarbon wax with the melting range between 85 °C and 115 °C, high viscosity at lower temperatures and low viscosity at higher temperatures [19,20]. Asphaltan A® is a Montan wax obtained by solvent extraction of certain types of lignite or brown coal; its effect on asphalt is similar to that of F–T waxes. Asphaltan A® melts at 125 °C [21,22]. Asphaltan B® is a refined Montan wax blended with a fatty acid amide. Its melting point is between 82 and 95 °C [20]. Licomont BS 100® is a fatty acid amide; these waxes are manufactured synthetically by reacting amines with fatty acids [20,23]. Licomont BS 100® melts between 141 °C and 146 °C [13].

Table 1
Specifications of the B 50/70 bitumen without rubber and with 15 wt.% of rubber.

	Unit	B	B + 15% R
Penetration (25 °C)	0.1 mm	55.4	36.2
Softening point	°C	51.1	71.3

Table 2
Fractionation analysis of the B 50/70 bitumen.

Fractionation analysis	B 50/70
Asphaltenes (%)	13.8
Saturates (%)	9.7
Naphthene–aromatic (%)	48.5
Aromatic–polar (%)	28.0

Table 3
Crumb rubber gradation.

Sieve (mm) (UNE 933-2)	Accumulated (%)
2.0	100.0
1.5	100.0
1.0	100.0
0.50	94.1
0.250	23.7
0.125	3.7
0.063	0.4

Table 4
Thermogravimetic analysis of crumb rubber.

TGA	Rubber
Plasticiser + additives (%)	4.67
Polymer (rubber) (%)	57.41
Carbon black (%)	32.22
Ash (%)	6.02

2.2. Production of rubberised warm asphalt binders

2.2.1. Equipment

The production equipment consisted of an oil bath with a maximum temperature of 225 °C, a mixer with a maximum velocity of 15,000 rpm fitted with a propeller agitator and a one-litre metal container for mixing. The oil bath is equipped with a temperature probe that can be introduced into the mixing receptacle, allowing the temperature of the binder to be controlled with precision.

2.2.2. Production protocol

750 g of each bitumen sample was prepared. First, the bitumen was heated to 140 °C. Then, the viscosity-reducing additive was introduced and the bitumen was mixed for 15 min at 4000 rpm, ensuring that the additive was properly integrated into the binder. Afterward, the mixture was heated to 190 °C and the rubber added. Lastly, the mixture was blended for 30 min at 2000 rpm and then for another 45 min at 1000 rpm, always at a temperature of 190 °C. Upon completion of this process, the bitumen was ready to be tested.

3. Results and discussions

3.1. High-temperature viscosity

Each rubberised warm-mix asphalt binder was tested using a Brookfield rotational viscometer. The viscosity was measured over the widest possible temperature range in order for the decrease in viscosity – caused by the incorporation of the additive – to be observed at different temperatures. The standard used in this test is UNE-EN 13302:2010 (Bitumen and bituminous binders – determination of dynamic viscosity of bituminous binder using a rotating spindle apparatus) [24]. The results of the tests are summarised in Figs. 1–9.

As can be observed in Fig. 1, the addition of 15% crumb rubber to the B 50/70 bitumen increases the viscosity and, consequently, the manufacturing and compaction temperatures are increased. This is one of the major drawbacks of rubber-modified bitumen.

Fig. 2 exhibits the influence of the Sasobit® additive on the dynamic viscosity of a bitumen without rubber.

F–T waxes such as Sasobit® have fusion points between 85 and 115 °C [13]. It can be seen that beyond 100 °C a change occurs due to the fact that, as the Sasobit® melts, the viscosity decreases. In the end, the 4% Sasobit® curve remains below the 2% curve.

The introduction of the Asphaltan A® additive (Fig. 3) produced a decrease in viscosity. It can be observed that the change was produced between 110 and 115 °C, as the fusion point of this additive is at 125 °C [21,22]. The 4% viscosity curve remains slightly below the 2% curve.

With the Asphaltan B® (Fig. 4), the change in viscosity was produced between 90 and 100 °C, as this type of wax has a lower fusion point than F–T waxes [13]. It can be observed that the 4% viscosity curve remains below that of the 2% mixture.

The effect of the Licomont BS 100® (Fig. 5) on the viscosity of the bitumen is the same as that described in the previous cases, save that the decrease occurred at a higher temperature – above 120 °C – as this type of wax has a higher fusion point [20,23].

Figs. 6–9 show the influence of the additives on bitumen with 15% rubber. It can be seen that, with all of the additives, the viscosity of the bitumen with rubber decreases in proportion to the additive content, indicating that each one has the potential to reduce the mixing and compaction temperatures of asphalt rubber hot mixes.

The viscosity of the rubberised bitumen containing Sasobit® (Fig. 6) decreases in proportion to the quantity of the additive. The viscosity is lowest when the Sasobit® content is 4%.