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Towards storage-stable high-content recycled tyre rubber modified bitumen

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HIGHLIGHTS

- A Liquid Rubber (LR) is presented as solution to overcome common issues of asphalt rubber binders.
- LR-bitumen blends are manufactured at several temperatures and with various modifier contents.
- High temperature rheology, service temperature properties and storage stability are assessed.
- Analysis includes a comparison with a neat bitumen and a SBS modified bitumen.
- Results show that liquid rubbers could represent a breakthrough within the bitumen industry.

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ABSTRACT

The addition of crumb rubber particles as bitumen modifier can be currently considered as a well-established alternative to conventional polymers for bitumen modification. However, Recycle Tyre Rubber (RTR) modified binders still present drawbacks such as poor mix workability and hot storage stability. Within this study the authors try unlocking the full potential of devulcanised tyre rubber-heavy oils blend, named Liquid Rubber (LR), by exploring the possibility of tailoring recycled polymer modified bitumen with unconventional high-content of RTR and designed to overcome the above mentioned technological problems of RTR modified bitumen while keeping its advantages. Results show that LR-bitumen blends incorporating up to 30% RTR in weight of total binder clearly improves useful temperature interval of base bitumen by maintaining solubility values allowing them to be considered stable at hot-storage temperature. Furthermore, the LR modifier allows reducing usual manufacture temperatures up to 30 °C by providing superior low and intermediate temperature rheology, however high service temperature properties are improved only at low strain.

1. Introduction

Bitumen modification has been carried out during decades in order to enhance performance of conventional binder for asphalt mixtures. Traditionally, synthetic polymers of different nature and functionality are used to enhance the resistance to the main distresses affecting asphalt mixtures by increasing their useful temperature interval (UTI) [1]. However, environmental concerns and economical savings opportunities have promoted the use of recycled modifiers for bitumen. In particular, Recycled Tyre Rubber (RTR) has been widely studied due to the high saving of landfill space that its use implies and because of the good performance it has shown as bitumen modifier [1–4].

When RTR is used as a modifying agent for bitumen, it is called crumb rubber modifier (CRM), while the method of modifying bitumen with CRM before being incorporated into the mixture is referred to as the Wet Process [5]. Bitumen – CRM interaction is material-specific and depends on a number of basic factors, including processing variables (such as temperature, time and applied shear stress), base binder properties (such as source and eventual use of oil extenders) and CRM properties (such as source, processing methods, particle size and content in binder) [6–9].

Depending on the adopted processing system and on the selected materials, the Wet Process leads to two different technologies which main distinction is based on rotational viscosity of the resulting rubberised binder at high temperature. On one hand, Wet process–high viscosity is the traditional and more widely used technology obtained with mainly physical modification process based on the swelling of 0–2 mm CRM, reaction

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temperatures between 160 °C and 260 °C, reaction time varying from 45 min up to few hours and usually low shear processing [9]. The final product allows obtaining a rubberised asphalt mix with benefits that are basically linked to the binder's increase in elasticity and viscosity at high temperatures [10,11]. Rubberised asphalt mixtures obtained with this technology showed longer lasting performance compared to the conventional ones [12,13]. However, these materials require an accurate blend design and non-conventional continuous agitation during hot storage to keep the RTR particles uniformly distributed. Moreover, they could present several operative drawbacks such low workability, poor binder storage stability and the fumes it emits during the paving process due to high operative temperatures (even 180 °C).

The second technology is known as Wet process–No agitation and aims at producing CRM bitumen not occurring in phase separation of the modifier from the binder during storage or transportation. For this purpose, CRM has to be fully digested/dissolved into the bitumen without leaving visibly discrete particles. This process prevents the constant agitation needed in Wet Process-High viscosity and improves particles distribution and hot storage stability of blends. The idea behind Wet-process-No agitation binders is therefore obtaining a technology more similar to polymer modified bitumen rather than the above mentioned Wet Process-High Viscosity. Some successful no-agitation wet process technology, such as terminal blends, are already used however they still need to be manufactured at refineries and do not allow achieving the superior performance provided by both the conventional wet process and polymer modification [5].

The objective of this paper is to investigate the feasibility of unlocking the full potential of a liquid polymer that has the potential to allow bitumen technologist to manufacturing in-house storage-stable rubberised bitumen with very high-content of RTR. The above mentioned liquid polymer was provided by innovator LLC and is named Liquid Rubber (LR). LR is actually a family of semi-solid/fluid materials composed by a very high-percentage of RTR plus other oils. In the recent past some LR was used in concrete [14] as well as bitumen modifier by Fini et al. [15] who tested blends of bitumen and 15% LR showing that it can enhance its low-temperature characteristics but adversely affects the base bitumen elasticity and thus its resistance to rutting. This investigation goes a step further and investigates the potential of maximising the re-use of RTR in bitumen modification by incorporating LR as modifier in proportions from 5% to 60%. The experimental programme consisted in monitoring high temperature rheology (Rotational viscosity) at different temperatures, as well as assessing service temperature rheological and performance-related properties of the blends. At last, solubility tests have been performed to estimate the behaviours of the blends during hot storage. In order to have a direct feel of the level of modification obtained by using several concentration of LR, the measured properties have been compared with those of the base bitumen as well as with a Styrene-Butadiene-Styrene Modified Bitumen (SBS-MB) currently used for asphalt mixtures.

2. Materials and methods

2.1. Materials

In this study the LR, an innovative modifier incorporating 50% RTR and 50% oils, is blended with a 40/60 bitumen in different proportions from 5 to 60% of the final binder. Liquid Rubber is a technology supplied by Innovators LLC in USA and obtained with a proprietary process composed from a digestion tank, a main reactor and a cooling unit. In the first two tanks the #8 (2.36 mm) fibre and glass free RTR is subjected to a process of devulcanisation and mixed with heavy oils derived from petroleum and/or soy. The process is customisable, allows having control of the off gases, and has a production rate of 12–25 Gal/h of LR. The end product is a sticky visibly homogeneous fluid that varying the composition and processing conditions

Fig. 1. Liquid Rubber (LR) aspect.

can have different viscosities (Fig. 1). No other details of the production process have been disclosed to the authors.

As mentioned earlier, two different binders were considered as references for the comparison of LR and bitumen blends, namely: conventional 40/60 penetration grade bitumen (40/60 bitumen) and SBS-polymer modified binder (SBS-MB). Conventional properties of these binders are shown in Table 1. The LR is a modifier not a bitumen and therefore it was decided not to perform its conventional characterisation. Instead a complete rheological characterisation of the high-temperature viscosity (Fig. 2) and intermediate-temperature rheology (Fig. 5) was carried out. Fig. 2 reports the high-temperature viscosity of the LR and the reference material. A significant non-Newtonian behaviour of LR was detected during the test within the temperature range 135 °–200 °. For this reason, all measurements are referred to a speed of 100 rpm in the rotational viscometer. As a result LR presents viscosity values that are higher than the control binders at all considered temperatures.

2.2. Methods

2.2.1. LR-bitumen blends' manufacture and high-temperature rheology

Rotational viscosity was the physical parameter controlled during the modification process. Therefore, as starting point, rotational viscosity tests build-up by

Table 1
Properties of conventional bitumen and SBS-M.

	40/60 bitumen	SBS-MB
Penetration at 25 °C (dmm) – EN 1426	46	87
Softening Point (°C) – EN 1427	50.8	103

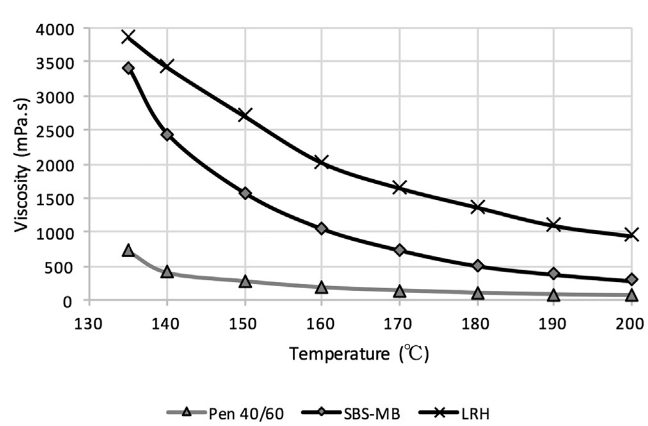

Fig. 2. Rotational viscosity at 100 rpm of the reference materials vs. temperature.