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The effects of laboratory ageing on rheological and fracture characteristics of different rubberised bitumens

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HIGHLIGHTS

- The rheological and fracture properties of aged rubberised bitumen were studied.
- Pre-treatment with Sasobit has detrimental effect on fracture properties of binders.
- Glover-Rowe parameter of aged rubberised bitumens was improved.
- CTOD was sensitive and consistent to the effects of ageing.

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ABSTRACT

Ageing of bituminous materials can result in loss of the durability of a flexible pavement. Using rubberised bitumens can enhance pavement performance while at the same time it solves a serious waste disposal problem. Combining Warm Mix Asphalt (WMA) additives with rubberised bitumens reduces the difficulties associated with the production of asphalt mixtures using this modified binder. This work was conducted to study the effect of ageing using fundamental parameters based on performance, i.e., CTOD and Glover-Rowe parameters have been related to pavement cracking. Different unmodified bitumens and rubberised bitumens were short-term aged using the Thin Film Oven Test (TFOT) and long-term aged using the Pressure Ageing Vessel (PAV). The rheological and fracture properties of the binders were studied before and after laboratory ageing. The results indicated that rubberized bitumens are more resistant to laboratory ageing. However, the pre-treatment with Sasobit® seemed to be detrimental when the materials were evaluated based on their fracture properties. The results also showed that base bitumen properties can affect the ageing mechanism of rubberised bitumens. Using softer bitumen could produce rubberised bitumens with superior anti-ageing properties when the analysis is based on linear viscoelastic properties using the Glover-Rowe parameter. However, these improvements were significantly reduced after ageing when the analysis is based on fracture properties.

1. Introduction

The main factors that affect the durability of asphalt pavements are ageing and moisture damage with ageing generally stiffening the binders and making them less ductile [1]. This stiffening can reduce the ability of the pavement material to dissipate the stresses generated from low-temperature contraction and expansion, and/or heavy traffic loads leading to deteriorating performance of the pavement and increasing the cost of maintenance. Ageing also affects the cohesive properties of binders and the adhesion at the binder and aggregate interface. In general, ageing can be attributed to the oxidation, as well as loss of some of light oils, that occurs at elevated temperatures during asphalt mixture production (short-term ageing). This is followed by oxidation that continues after placing the asphalt materials in the pavement (long-term ageing). Additional elements that may contribute to ageing include molecular structuring over time (steric hardening) and actinic light (primarily ultraviolet radiation, particularly in arid conditions) [1].

The changes in the rheological properties of Recycled Tyre Rubber Modified Bitumen (RTR-MBs) after laboratory ageing have been investigated by many researchers [2–5]. The relative degree of change in the rheological properties of RTR-MBs has been shown to vary depending on ageing conditions, rubber content, rubber particle size and the source of base bitumen. One such study by

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Huang [5] has investigated the effect of long-term oxidative ageing for modified binders manufactured using different rubber contents and bitumen types. The results from this research indicated that the addition of a lower rubber percentage (5% by bitumen mass) to a bitumen that has high sulphur and asphaltene content, resulted in a higher phase angle at the same oxidation viscosity which could be translated into better long-term fatigue performance.

In another study by Ghavibazoo et al, the addition of higher rubber concentration (20% by bitumen mass) improved low-temperature properties (higher m-value and lower stiffness) after oxidative ageing in comparison to 0 and 10% rubber concentration [2]. The effects of ageing on rubberised binders have also been studied by means of dynamic mechanical analysis (DMA) [4]. These analyses have shown that ageing increased the viscous behaviour for the rubber modified binders compared to the base bitumen behaviour which showed an increase in the elastic components with ageing.

The increase in the viscous behaviour, within the polymer dominant DMA response areas (high temperatures and low frequencies) after ageing has been attributed to a dissolution of the rubber network structure and a reduction in the size of rubber particles [4]. This increase in viscous behaviour is considered to be beneficial for the long-term durability of flexible pavements. Increasing the rubber dissolution due to the effect of ageing has also been shown to enhance the ageing characteristics of binders by lowering the hardening and carbonyl formation rates [6]. Also, some of the rubber compounds, such as carbon black, have antioxidant characteristics that can improve the ageing resistance of rubberised bitumens [3].

Rubberised bitumens are normally very viscous at high temperatures. Therefore, higher operating temperatures are required in order to handle those kinds of binders during asphalt mixture production. This leads to increased energy consumption and emissions as well as health and safety issues for workers. Only a few studies have considered adding WMA additives to rubberised bitumens to potentially reduce the need for these elevated temperatures. The inclusion of WMA additives in rubberised bitumen have shown improved workability and handling using reduced mixing and compaction temperatures [7–10].

In this study, the rubberised bitumens containing standard tyre rubber and pre-treated tyre rubber with WMA additives were evaluated before and after laboratory ageing. Dynamic Mechanical Analysis (DMA) was used to evaluate the viscoelastic properties while the Essential Work of Fracture (EWF) was used to evaluate the fracture properties of materials. In terms of the fracture testing, the Double Edge Notched Tensile (DENT) test was chosen due to its ability to evaluate the resistance of binders to fracturing when subjected to high levels of strain and yielding. Although previous studies dealing with ageing of rubberised bitumens have not investigated the fracture properties of these binders, evaluating the fracture properties has been shown to be a promising approach for developing performance-related characterization of bituminous binders [11].

2. Materials

2.1. Base bitumens

Two different grades of base bitumens were chosen; a ‘soft’ bitumen with a penetration of 200 dmm and a ‘hard’ base bitumen with a penetration of 40 dmm. The ‘soft’ bitumen is labelled S and the ‘hard’ bitumen is labelled H throughout the paper. Other rheological characteristics are shown in Table 1. The large differences in their grades were used to identify how the base bitumen can influence the interaction with crumb rubber and ageing mechanisms.

Table 1
The characterisations of base bitumens.

Ageing states	*Index*	*Binder “S”*	*Binder “H”*
Unaged binder	Penteration @25 °C, 0.1 mm	200	40
	Softening point °C	37.0	51.4
	Rotational viscosity, Pa.s @135 °C @160 °C	0.192 0.065	0.474 0.170
	Asphaltenes content	4.2%	15.2%
	$G^*/\sin\delta$ @ 60 °C & 1.59 Hz, kPa	0.615	1.95
TFOT aged residue	$G^*/\sin\delta$ @ 60 °C & kPa	1.256	7.70
TFOT + PAV aged residue	$G^*.\sin\delta$ @ 20 °C & kPa	1050	10,027

2.2. Crumb rubber

Two types of recycled rubber, termed as N and W were used in the study. The standard crumb rubber, N, is a recycled crumb rubber obtained from used truck and passenger car tyres and ground using ambient grinding. On the other hand, the recycled crumb rubber, W, was obtained from 100% used truck tyres and cryogenically ground. The crumb rubber W was also pre-treated with an oil and Fischer–Tropsch (FT) wax component. The oil can help to decrease the movement of lighter fractions of the bitumen into the rubber particles and thus could decrease the impact of initial ageing (stiffening of the base bitumen). The FT-wax in W enables a reduction in production temperature while maintaining sufficient workability and compactability. The same materials were also used in previous research studies [12]. Fig. 1 shows different images of the recycled crumb rubbers taken using the Scanning Electronic Microscope (SEM).

2.3. Rubberised bitumen

The rubberised bitumens were prepared using the wet process. The base bitumen was first preheated to 180 °C before gradually adding the crumb rubber. The rubber content was set to be 18% by mass of the base bitumen. A Silverson L4RT high shear laboratory mixer was used to blend the materials. The blending of base bitumen and rubber particles continued at 180 °C for two hours and at 3000 rpm. The processing conditions were adopted from previous studies that dealt with the optimisation of mixing conditions [13,14]. High shear mixing has been adopted by various researchers and it has shown to produce rubberised binders with superior rheological properties compared to standard (low shear) mixing [5,15–18].

3. Experimental programme

3.1. Ageing processes

The base bitumens and rubberised ones were aged in the laboratory using the thin film oven test (TFOT) for the short-term ageing and using the pressure ageing vessel (PAV) for the long-term ageing. In the TFOT, 50 g of the binders were poured into steel pans so that the binders have an approximately 3.2 mm film thickness. The materials in the stainless pans were then conditioned at 163 °C for 5 h in a standard TFOT oven. The TFOT was preferred rather than the rolling thin film ovens test (RTFOT) because of concerns over the rubberised bitumens not uniformly covering the interior walls of the RTFOT glass containers during the ageing process and also having the RTR-MBs rolling out of the containers during