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Original Research Paper

Influence of mineral fillers on the rheological response of polymer-modified bitumens and mastics

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ABSTRACT

The rheological properties of the bituminous components (bitumen and bituminous mastic) within asphalt mixtures contribute significantly to the major distresses of flexible pavements (i.e. rutting, fatigue and low temperature cracking). Asphalt mixtures are usually composed of mastic-coated aggregates rather than pure bitumen-coated aggregates. The purpose of this study is to investigate the effects of mineral fillers on the rheological behaviour of several polymer-modified bitumens (PMBs) through laboratory mixing. A neat bitumen and two types of polymers (elastomeric and plastomeric) were used to produce PMBs, and two fillers with different minerals (limestone and basalt) were selected to obtain mastics. The dynamic shear rheometer (DSR) and bending beam rheometer (BBR) were used to characterize the rheological properties of PMBs and mastics. In particular, multiple stress creep recovery (MSCR) tests were performed to evaluate the rutting potential at high temperatures, whereas BBR tests were carried out to investigate the low temperature behaviour of these materials. BBR results for unmodified mastics show that the increase of stiffness is similar regardless of the filler type, whereas results for polymer-modified mastics indicate that the degree of stiffening depends on the combination of filler/polymer types. MSCR results show that adding filler leads to a reduced susceptibility of permanent deformation and an enhanced elastic response, depending on the combination of filler/polymer types. Overall results suggest that a physical–chemical interaction between the filler and bitumen occurs, and that the interaction level is highly dependent on the type of polymer modification.

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1. Introduction

The rheological properties of the bituminous components of asphalt mixture contribute significantly to the major distresses of flexible pavements. In particular, bitumen and mineral fillers create a blend known as bituminous mastic that, depending on its nature and composition, significantly influences the durability of pavement asphalt layers.

Playing a dual role in asphalt mixture, the filler is a mineral aggregate that fills the interstices between larger aggregates. It provides a higher number of contact points and, when mixed with bitumen, improves bitumen consistency by enhancing the bonds between larger aggregate particles. Presently, asphalt mixture should be considered a mixture comprising mastic-coated aggregates rather than pure bitumen-coated aggregates (Wang et al., 2011).

The main effect of mineral filler is to stiffen the bitumen, consequently to improve the asphalt mixture's mechanical properties. The stiffening effect of the mastic controls the mixture performance from the construction stage through the entire service life of the pavement. During transportation and paving processes, poor stiffness within the mastic can cause drain-down problems, whereas excessive stiffness may lead to compaction difficulties and workability reduction (Brown et al., 2009). The mastic stiffness affects the ability to resist permanent deformation at high temperatures, fatigue life at intermediate temperatures and cracking resistance at low temperatures (Airey et al., 2006; Johnasson and Isacsson, 1998; Wang et al., 2011).

The stiffening effect of mineral fillers on bitumen has been extensively investigated by many researchers (Faheem et al., 2008; Faheem and Bahia, 2010; Grabowski and Wilanowicz, 2008; Harris and Stuart, 1995; Kim et al., 2003; Liao et al., 2012; Wang et al., 2011). These studies show that the filler volume concentration and physical properties, such as size distribution, shape, texture, void space and surface area, of mineral fillers, along with the physical–chemical interaction between the filler and bitumen, affect the stiffness of the mastics. According to Buttlar et al. (1999), the behaviour of mastics can be divided into three reinforcement mechanisms: volume-filling reinforcement (i.e. the presence of a rigid inclusion in a less rigid matrix causes the stiffening effect), physical–chemical reinforcement (the stiffening is caused by interfacial effects between the bitumen and filler particles), and particle-interaction reinforcement. The last mechanism has a limited role in the stiffening effect of the filler and is usually considered negligible (Shashidhar and Romero, 1998). Furthermore, laboratory investigations based on rheological measurements show that mastics can be considered thermorheologically simple linear viscoelastic materials (Anderson and Goetz, 1973), and the mechanical influence of fillers can be assessed through a viscoelastic analysis of the mastics (Kim and Little, 2004; Underwood and Kim, 2015).

Given the fundamental role of mastics in asphalt mixtures, their mechanical characterization is essential in improving the understanding of asphalt mixture performance with respect to common asphalt pavement distresses. This paper presents a laboratory investigation on different bituminous mastics using a rheology-based approach. In particular, the study investigates the effects of fillers with different mineralogy on the high and low temperature behaviour of both neat and polymer-modified bitumens (PMBs). Specifically, the use of both elastomeric and plastomeric polymers allowed the effects of the filler/polymer type combination on the rheological properties of the mastics to be evaluated. This line of research was chosen because current studies mostly focus on filler properties and place less importance on the polymer modification of bitumens.

2. Laboratory investigation

2.1. *Materials*

A neat bitumen, selected as the reference bitumen, was used to produce two PMBs by adding 2 types of polymers to the same content. Subsequently, the neat bitumen and PMBs were used to produce 6 mastics by adding 2 types of fillers, which were dosed at a constant filler/bitumen ratio according to the identification codes summarized in Table 1.

The neat bitumen was a 70/100 penetration-grade bitumen from an Italian oil refinery. Regarding the production of PMBs, a radial styrene-butadiene-styrene (SBS) polymer containing 30% styrene with a density of 0.94 g/cm^3 and polyolefin (PO) polymer containing an ethylene and propylene blend with a density of 0.94 g/cm^3 were selected as modifying agents. The two different types of polymers (elastomer and plastomer) were selected because of their different reinforcement mechanisms within bitumen. The polymer content adopted for the PMBs was 4% of the base bitumen's weight.

All modified bitumens were produced in the laboratory using a ROSS high-shear mixer operating at a rotation speed of 3000 rpm at 180 °C for 3 h. Initially, 700 g of bitumens in a 1000 mL cylindrical can were heated to a fluid condition. Upon reaching 180 °C, the polymer was added slowly to the bitumen to prevent any polymer separation during the mixing process. Table 2 shows the physical properties of the neat and polymer-modified bitumens.

The two natural fillers with different minerals (i.e. basalt and limestone) were selected and consisted of particles passing the 0.063 mm sieve. Table 3 lists some basic properties of the fillers.

Table 1 – Codes for bitumens and mastics.

Polymer type	Polymer content (%)	Bitumen code	Mastic code	
			Basalt filler	Limestone filler
No polymer	–	B_Neat	M1_Unmodified	M2_Unmodified
SBS	4	B_SBS4	M1_SBS4	M2_SBS4
PO	4	B_PO4	M1_PO4	M2_PO4