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Shear rheology and microstructure of mining material-bitumen composites as filler replacement in asphalt mastics

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HIGHLIGHTS

- Magnetite powder can be added to asphalt mixes as filler replacement.
- Shear rheology of magnetite-bitumen composite mastic was evaluated.
- Micro structure of magnetite-bitumen samples was investigated.
- Temperature and loading time susceptibility of composite mastics was reduced.
- Stiffness and elastic response at high temperature of composite mastics was improved.

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ABSTRACT

Magnetite is a mineral that occurs in many types of igneous rock and can be found in large quantities in fluvial and marine environments. It can also be extracted by reprocessing of existing mine tailings. In this paper, magnetite supplied from two different mining sites was evaluated as a substitution of natural limestone filler in asphalt mix design. Magnetite and limestone fillers were added to the bitumen according to three filler/bitumen ratios to form composite asphalt mastics.

Rheology of the mixes was analysed to study the effects of magnetite as potential filler in asphalt pavement applications and comparisons were made with natural limestone filler-based mastics. In addition, particle size analysis, scanning electron microscope, Cryo-SEM and energy dispersive X-ray spectroscopy, were conducted to comprehensively characterize the composite mixes.

Results showed that the addition of magnetite-based ferromagnetic filler in asphalt mix design represents a suitable way to recycle this material, which is available in large quantities in many countries. In addition, ferromagnetic particles could also be exploited for induction or microwave healing of asphalt cracks as demonstrated by recent studies.

Viscoelastic properties of the bituminous mastic are improved by reducing the mastic's temperature and loading time susceptibility; stiffness and elastic behaviour at high temperature was also improved hence potentially increasing resistance to permanent deformation.

1. Introduction

Asphalt mastic is the combination of bitumen and filler material when mixed in due proportion; its mechanical and rheological (time-temperature dependency) behaviour is strongly affected by the relative dosage and unique properties of each of the two components. Asphalt mastic greatly contributes to the overall performance of asphalt concrete in road pavements, conveying most of its viscoelastic, chemical and physical properties to the asphalt mixture [1]. In this study, magnetite was added to the asphalt binder as possible replacement for filler material (particle size smaller than 75 μm), commonly sourced from nearby quarries.

Magnetite (Fe_3O_4) is a mineral that can be easily found in Australia, Europe and USA; large deposits are also found in India and China, where tailing ponds of magnetite occupy vast spaces and represent serious risk of pollution, health hazard and environmental danger [2]. Magnetite is a quite inexpensive iron ore commonly

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used in coal processing and, together with other iron oxides, in the production of steel and iron products.

Nowadays, since non-renewable resources used in road pavements (i.e. natural aggregates and bitumen) are limited [3], researchers are trying to include alternative materials such as recycled and waste materials into asphalt pavement mixes [4]. At the same time, research effort is being carried out to reuse and recycle products that also provide additional properties to the asphalt mixes by means of improved strength, durability, lower environmental impacts, or various engineered properties; e.g. waste oil to promote rejuvenation of asphalt or ferrous material to generate induction healing capabilities [5,6].

Among the most used recycled materials in road engineering it can be found plastic [7,8], shredded tire rubber [9,10], foundry sand [11], glass [12], reclaimed asphalt pavements (RAP) [13,46], and metal-related tailings from mining industry. The latter counts many studies for the use of asbestos [14], coal [15], copper mine [16], iron and magnetic ore waste [17] as potential aggregates to enhance asphalt's mechanical behaviour and several other properties (e.g. healing, snow-melting, self-sensing). Wang et al. [18] used magnetite as aggregates in asphalt mixes to enhance the healing property of bitumen by microwave heating due to the ferromagnetic properties of magnetite. Several research studies also focused on the effects of different types of filler in asphalt mastics [19]. Glass waste was used as filler in asphalt material [12]; the study proved that stiffer and denser asphalt could be achieved and more stone-to-stone contact points were found in the aggregate matrix, which suggested improved strength. Li et al. [20] used steel slags as filler; their results showed improved high temperature rheological properties in comparison to limestone natural fillers. Asphalt mixes involving ferromagnetic materials such as magnetite or residuals from steel wool fibres processing [21] can be very useful to enhance healing properties of bitumen by induction heating, electric conductivity or microwave heating [17].

In this study, rheology of standard bitumen and asphalt composite mastics was evaluated to analyse and compare the viscoelastic behaviour at different temperature and loading condition; specifically, three magnetite-based filler/bitumen ratios (0.5, 1.0 and 1.5) were studied in accordance with Superpave specifications [22] and common road construction practice and mix-design.

As shown by several studies [23–25], the addition of filler to bitumen makes the mastic stiffer; the stiffening effect commonly improves the resistance to high temperature deformation (e.g. rutting) although resistance to cracking and low-temperature behaviour could be jeopardized. The magnitude of these effects depends on the type of mineral filler, its size and shape [26], alkalinity and surface characteristics [27], and physical and chemical interactions that happen between the filler and the bitumen [28].

2. Materials and experimental plan

The present research study aimed to evaluate the viscoelastic properties of twelve different magnetite-bitumen composite mixes obtained by combining two types of bitumen, magnetite from two mining sites and three filler/bitumen ratios. Comparisons were also made with six mixes containing standard bitumen and natural limestone filler supplied from a nearby quarry.

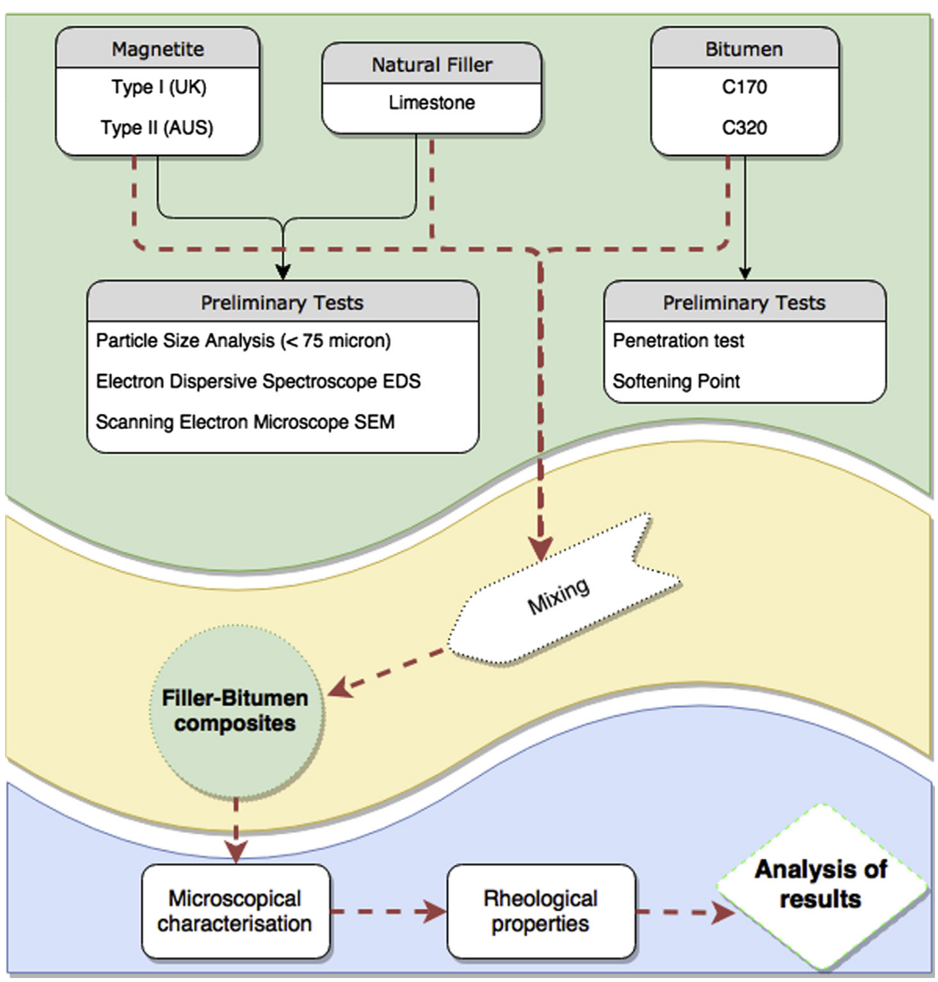

Fig. 1. Experimental plan.