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Mechanical properties and reaction characteristics of asphalt emulsion mixture with activated ground granulated blast-furnace slag

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HIGHLIGHTS

- The effects of activated GGBS and OPC on AEM's performance were investigated.
- The proper curing period of AEM with activated GGBS was proposed.
- The hydration reaction of activated GGBS in asphalt emulsion was analyzed.
- The microstructures of mastic-aggregate interface and mastic were observed.

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ABSTRACT

In this study, ground granulated blast-furnace slag (GGBS) activated by hydrated lime (HL) is used to replace the limestone filler and design base course asphalt emulsion mixture (AEM). The mechanical properties, moisture resistance and permanent deformation of AEM with GGBS and HL are investigated and compared with those of AEM contained ordinary Portland cement (OPC). Furthermore, the reaction mechanism of GGBS activated by HL in asphalt emulsion is analyzed by means of Fourier transform infrared (FTIR) spectrometer, X-ray diffraction (XRD) analyzer, and environmental scanning electron microscope (ESEM). The results indicate that the AEM with GGBS and HL can be used for pavement base course as a substitute of AEM with OPC. The materials' proportions and curing periods should be both considered during the mixture design. Compared with the hydration reaction in GGBS-HL paste, the hydration process of GGBS in asphalt-GGBS-HL mastic is delayed by the encapsulation of asphalt binder. The hydration products in the mastic enhance bond strength of mastic-aggregates interface and asphalt stiffness. These positive effects can explain the performance characteristic of AEM with GGBS and HL.

1. Introduction

Asphalt emulsion is viewed as one kind of oil in water systems in which bitumen droplets are dispersed in water phase by an emulsifier [1]. Because of its lower viscosity at ambient temperatures, asphalt emulsion is always applied to produce asphalt emulsion mixture (AEM) without drying aggregates [2]. The energy consumptions reduction and emissions benefits facilitate the application of AEM as a pavement layer material in many countries [3,4]. However, the asphalt film in AEM needs a long curing time to achieve enough bonding capacity [4]. The research results from South Africa and some European countries show that AEM needs 6 months to 3 years prior to reaching a final state [5–7]. The specific curing periods rely on the environmental conditions and mixture proportions [5–8].

A long curing requirement leads to the lower early-stage performance of AEM [6,8]. The performance modification of AEM has been studied since 1970s. Terrell et al. [9] found that the addition of small amounts of cement largely increased curing rate of AEM with anionic emulsion under cold and moisture conditions. The ultimate resilient modulus of AEM was improved to about 200% by the addition of 1% cement. Schmidt et al. [10] revealed that the addition of 1.3% cement raised the stiffness modulus of AEM 5 times after one day of curing. The ratio of the soaked stiffness to the initial stiffness was also increased from 18% to 70%, which indicated that 1.3% cement improved evidently the moisture resistance of AEM. A study from Head [11] designed AEM with cationic emulsion by the Marshall method and obtained similar conclusions as Terrell et al. and Schmidt et al. Furthermore, Li et al. [12] assessed cement-asphalt emulsion mixture (CAEM) in laboratory. They concluded that CAEM possessed combined advantages of concrete materials and asphalt mixtures. It was suggested to use CAEM

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as an alternative base course material in pavement. A case study conducted by Brown and Needham [13] showed that the stiffness modulus, rutting resistance, moisture resistance and fatigue life at low strain of AEM were enhanced obviously by the addition of cement. The improvement of these properties was mainly explained by cement hydration and the increase of the binder viscosity. Oruc et al. [14] investigated the mechanical properties of AEM with cement content up to 6%. The results indicated the performance properties of AEM were improved apparently by cement addition. CAEM was recommended as an alternative pavement layer material in this study. Al-Hdabi et al. [15] found that the cement treated cold rolled asphalt processed approximate mechanical properties of the conventional hot rolled asphalt.

The improvement of cement on AEM performance was attributed to cement hydration. Pouliot et al. [16] showed that the cement hydration in the mortar was affected by the addition of a small amount of emulsion. The compressive strength and elastic modulus of the mortar was reduced notably due to the negative effect of bitumen. Likewise, the flexural strength was slightly decreased. Du [17] demonstrated that cement particles were encapsulated by asphalt film, which led to a delay of hydration process. The cement hydration products can improve the stiffness of asphalt binder [13,17] and the adhesion of mastic-aggregates interface [17,18]. An experiment conducted by Wang et al. [19] showed that the cement hydration rate in cement asphalt emulsion mortar was lowered with the increasing of asphalt to cement ratio. However, the isothermal calorimetry test results from Fang et al. [20] showed that asphalt emulsion might slightly decelerate or accelerate hydration reaction. The hydration degree after 2–3 days was not obviously influenced. The mechanical and microstructure of cement asphalt emulsion mixture were recommended for further study according to this investigation.

Considering environment protection and cost effectiveness, some researchers have introduced waste materials as a substitute of cement to modify AEM. Ellis et al. [21] investigated the recycled mixture stabilized by bitumen emulsion and Ground Granulated Blast-furnace Slag (GGBS). They found that the addition of GGBS might raise stiffness and strength of the recycled mixture under high humidity conditions. Kumar et al. [22] assessed asphalt emulsion recycled mixture combined with cement, lime and fly ash. The results showed that the combined stabilizers led to higher strength, resilient modulus and moisture resistant and lower permanent deformation compared with AEM only stabilized by asphalt emulsion. Nageim et al. [23] evaluated the effect of high calcium fly ash (HCFA) on AEM. The mechanical properties results proved the HCFA enhanced the performance of AEM as a replacement of OPC. Du [24] evaluated the effect of different fillers on performance of AEM. Test results indicate that the physical and chemical properties of fillers significantly affect performance of AEM. The GGBS, low calcium fly ash (LCFA) and a combination of LCFA and HL could not improve the performance of AEM with an accelerated curing. A preliminary study found that the combined filler of GGBS and hydrated lime (HL) resulted in similar effect on performance of AEM with an accelerated curing as cement did. These conclusions were different with the conclusions from Ellis et al. and Nageim et al. Although it is known that the slag can be activated using an activator in water environment, the reaction mechanism of reaction in asphalt emulsion with a normal temperature curing should be further studied. Nassar et al. [25] used the binary and ternary blended fillers (BBF and TBF) to enhance the AEM. The BBF consisted of a combination of Ordinary Portland cement (OPC) and fly ash (FA) or ground granulated blast furnace slag (GGBS). The TBF were composed of BBF and silica fume (SF). The results indicated that the TBF was a better choice to modify the performance of AEM. The microstructure analysis proved the positive effect of SF in TBF. Abbas Al-Hdabi et al. [26] used a waste fly ash and GGBS to improve the performance of AEM. The results revealed that the designed mixture provided an alternative to the conventional hot mixes asphalt (HMA). Dulaimi et al. [27] used HCFA and fluid catalytic cracking catalyst residue (FC3R) activated by a waste alkaline NaOH solution to develop high performance AEM for binder course. They found that the high performance AEM achieved approximate stiffness modulus of the traditional HMA binder course after less than one day curing. Therefore, the waste or byproduct fillers generated by traditional industries provided a more eco-friendliness and cost effectiveness selection for the performance enhancement of AEM than cement.

The aim of this research is to understand the mechanical properties and reaction mechanism of AEM containing GGBS with normal temperature curing. The alkali-activation of HL was introduced to develop AEM with GGBS for based course. The strength parameters, moisture susceptibility and permanent deformation of AEM with GGBS were evaluated and compared with those of AEM with OPC by several laboratory tests. Furthermore, some advanced test methods, including X-ray diffraction (XRD), Fourier-transform infrared (FTIR) spectroscopy, and environmental scanning electron microscopy (ESEM), were used to analyze the reaction mechanism of activated GGBS in AEM.

2. Materials and method

2.1. Materials

The aggregates used in this study were fabricated from a limestone rock. The physical properties of limestone aggregates were: crushing value 20% and sediment percentage 0.9%; needle and sheet percentage13%; moisture content 0.7% and water absorption 2% based on test methods in JTG E42 [28]. The designed gradation is given in Fig. 1, which meets the specified limits of dense graded HMA for base course in China [29]. The limestone filler content (passing 0.075 mm sieve) was chosen to be 3% by the weight of the total aggregates (including filler). A slow setting cationic bitumen emulsion was selected to produce AEM. The basic properties of the emulsion are provided in Table 1. The ground granulated blast-furnace slag (GGBS), hydrated lime (HL) and ordinary cement (OPC) were applied to replace the total or partial weight of limestone filler (LF). The properties of these fillers were presented in Table 2.

2.2. Mixtures and sample preparation

In this study, AEM was designed for base course in pavement structures. The pre-mix water and optimum asphalt emulsion was 2.5% and 4.5% by weight of the total aggregates, respectively. They were estimated from practical engineering experiences. The partial or total LF in AEM was replaced by the same amount of OPC, HL and GGBS. The detail proportions of AEMs with different fillers were given in Table 3.

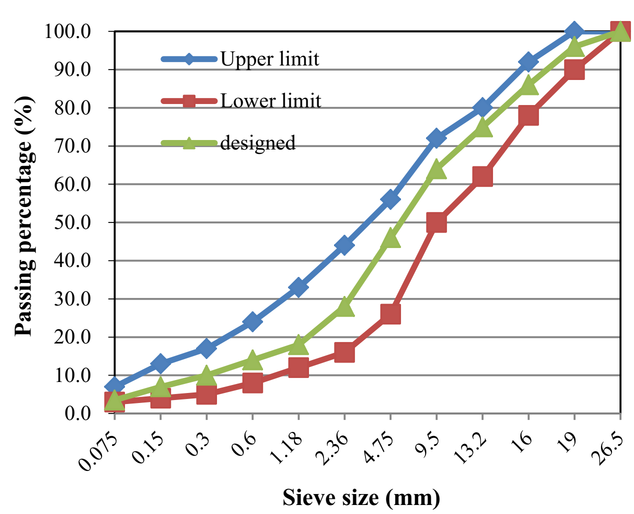

Fig. 1. Aggregates Gradation.