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Curing process and properties of hydrogenated bisphenol a epoxy resin particles by an interfacial polymerization method for asphalt pavements

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HIGHLIGHTS

- Four hydrogenated bisphenol A epoxy resin (AL-3040) particles were proposed to solve the asphalt pavement temperature problems initiatively.
- The curing process and properties of the AL-3040 particles were investigated in detail. The recovery performance of asphalt with and without the AL-3040 particles were measured.
- The AL-3040 particles are beneficial to improving the recovery performance of the asphalt.

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ABSTRACT

Based on the principle of the interfacial polymerization method and the mechanism of polypropylene glycol diglycidyl ether (JH-230), which can be used to adjust the molecular structure of the polymer, four kinds of hydrogenated bisphenol A epoxy resin (AL-3040) particles were prepared by the hydrogenated bisphenol A epoxy resin (AL-3040), polypropylene glycol diglycidyl ether (JH-230), isophorone diamine (IPDA), gum acacia powder and distilled water with different molar ratios between the AL-3040 and the JH-230. The curing process and molecular structures of the AL-3040 particles were measured by the fourier transform infrared spectroscopy (FT-IR), the thermal property and glass-transition temperature (Tg) of the cured AL-3040 particles were studied by the differential scanning calorimetry (DSC), and the corresponding particle size distribution and the microscopic structure were observed by the laser particle size analyzer and scanning electron microscopy (SEM). The needle penetration, softening point and recovery performance of asphalt with and without the cured AL-3040 particles (Tg = 14.8 °C) were tested by the asphalt penetration test, asphalt softening point test and elasticity recovery test, respectively. Results show that the complete curing time of the AL-3040 particles were extended and the Tg of the cured AL-3040 particles decreased with increased JH-230 content. The AL-3040 particles are smooth regular balls and homogeneous in distribution. It is suggested that the complete curing time and the Tg of cured AL-3040 particles can be controlled by adjusting the JH-230 content. It has proven that the AL-3040 particles are beneficial to improving the recovery performance of the asphalt. The results lead to a solution to the asphalt pavement distress problems caused by the temperature variations.

1. Introduction

The asphalt mixtures are subjected to distresses on account of the environmental temperature and increased traffic loads [1]. The asphalt pavement performance is closely related to its temperature susceptibility [2–4]. The main distresses affected by the temperature include high temperature rutting and low temperature shrinkage cracking [5]. The high temperature rutting is a typical pavement distress formed from non-recoverable accumulative deformation of the asphalt pavement under the compaction deformations caused by the repetitive vehicle loads and temperature loads [6]. After unloading, the partial deformations cannot recover, namely the permanent deformation. A series of applications show that the occurrence probability of rutting increases with increases asphalt pavement temperature. Furthermore, rutting also leads to the surface waterlogging and reduces the thickness of the asphalt

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pavement, which immediately affects the comfort and driving safety of the asphalt pavement [7,8]. In cold climates, the asphalt pavement undergoes extreme thermal conditions which cause premature shrinkage cracking and distress [9,10]. The low temperature shrinkage cracking is formed and accumulated during rapid cooling and continuous low temperatures. In addition, the friction between asphalt and its sub-layer prevents movement between the layers. This causes tensile stresses in the asphalt layer. With temperature decreasing continuously, the stress values increase. When the stress values reach the tensile strength of the asphalt, cracks are initiated at the bottom of asphalt layer. The continuous weather cycles and repeated traffic loading cause the growth and propagation of cracks over the surface of the asphalt pavement. Water infiltration through cracks increase failure and reduce the pavement's load-bearing capacities [11,12], which reduce the skid-resistance, increase highway safety risk, and induce accidents easily. Therefore, it is necessary to find an effective approach to reduce the negative influence of the temperature on the asphalt pavement.

As a thermosetting material, the epoxy asphalt has good durability, high temperature stability, rutting resistance and long service life [13]. Over the last five decades, the epoxy asphalt has been widely applied to civil engineering throughout the world. The service of the pavement of San Mateo Hayward Bridge paved with epoxy asphalt has been proven very good [14]. As early as 1978, the pavement of the Australia Westgate Bridge was epoxy asphalt concrete [15]. In 1994, the Scotland Erskine Bridge was surfaced with epoxy asphalt mastic concrete [16]. The Humber Bridge in U.K. was repaved with epoxy asphalt in 2001–2002. In 1975, the Lions Gate Bridge was repaved with a 38 mm thick layer of epoxy asphalt concrete and then re-decked and repaved with epoxy asphalt concrete in 2002 [17]. Abd El Rahman has synthesized the epoxy resins from the natural rubber and modified asphalt with the epoxy resins. It was found that the asphalt mixed with epoxy resins achieved a high stability [18]. The glass transition of the commercially available epoxy resins used for structural strengthening of concrete members by means of Carbon Fiber Reinforced Polymer (CFRP) strips was studied. The influence of different parameters on the glass transition temperature of the epoxy resins was studied and an appropriate service temperature of the epoxy resins for the structural engineers and end users was recommended [19]. However, research about widely applying the epoxy asphalt to roadways needs to be further conducted. The limitations on the wide application of epoxy asphalt to roadways may be alleviated by modifying the material compositional design of epoxy for a less temperature susceptible product. In general, the "breakout" time and curing time of the epoxy resin asphalt are very short, which is in disagreement with the construction process [20]. In addition, as epoxy is a polar material and asphalt is a nonpolar material, the compatibility between the epoxy resin and asphalt is relatively poor. Under the comprehensive impact of increasing vehicle volumes and harsh environmental conditions, cracks become the primary distress occurring in epoxy asphalt pavement, especially in extremely cold and high-latitude areas [21]. Therefore, it is worthwhile to explore new methods on applying epoxy resin to the asphalt mixture with better compatibility and a broader range of applicable traffic and climate conditions.

Shape-memory polymers (SMPs) are polymeric smart materials that have the ability to return from a temporary shape to their permanent shape induced by an external stimulus, such as temperature, light, electricity and moisture [22]. During the last decades, SMPs have been widely used in the fields of industrial, medical, textile, air craft, intelligent structure and bio-medicine. The thermally activated SMPs exhibit a glass-transition temperature (Tg), above which they can be deformed to a temporary shape from a primary shape by application of temperature change [23]. The deformed shape can be fixed by cooling the SMPs below Tg and then remove the deformation stress. Recovery to the primary shape can subsequently be achieved by heating the SMPs above Tg. Therefore, plenty of temperature sensitive SMPs were developed with a range of transition temperatures [24–26]. As one kind of thermic SMPs, shape-memory epoxy has excellent mechanical and thermal properties, record-breaking composite property, structural design ability, and good chemical stability [27]. The hydrogenated bisphenol A epoxy resin (AL-3040) is shape-memory epoxy without a double bond in the molecular structure, and it has good transparency, excellent durability, low viscosity and malleability [28].

The curing process and properties of the hydrogenated bisphenol A epoxy resin (AL-3040) particles were emphatically studied in this paper. The AL-3040 particles were prepared by introducing the flexible groups in the polypropylene glycol diglycidyl ether (JH-230) into the hydrogenated bisphenol A epoxy resin (AL-3040) by the interfacial polymerization method. The JH-230 has a high boiling point, is non-volatile, non-toxic and nonirritant. The crosslink density, chain segment flexibility of crosslinking points, and the aggregation state of the AL-3040 particles can be changed by adjusting the JH-230 content. The synthesis and characterization of the AL-3040 particles with four different formulations are described in this paper. The molecular structure, thermal property, glass-transition temperature (Tg) and particle size distribution were studied in detail, as well as the microstructure. The recovery performance of the asphalt with and without AL-3040 particles was observed. Due to the AL-3040 particles with different formulations having different Tg, the AL-3040 particles added to the asphalt pavement can be stimulated by the environmental temperature, thus the AL-3040 particles may be used to prevent or reduce the high temperature rutting and low temperature cracking. In addition, the AL-3040 particles surface is smooth, and asphalt mixtures mixed with the AL-3040 particles have the potential to avoid epoxy resin compatible with the asphalt. It may also improve the ductility of the asphalt mixture, because the poor ductility of epoxy asphalt is caused by the cured normal epoxy resin. This study provides a method to apply the AL-3040 particles to the asphalt pavement.

2. Objectives

The objectives of this research are to (i) determine the curing process of the AL-3040 particles with four different formulations; (ii) measure the molecular structure, thermal property, Tg, particle size distribution and microscopic structure of the AL-3040 particles used for asphalt pavements; and (iii) observe the recovery performance of the asphalt with and without AL-3040 particles.

3. Experiment

3.1. Materials

The epoxy resin in this study is hydrogenated bisphenol A epoxy resin (AL-3040) with an epoxy value of 0.43 eq/100 g. The flexibilizer is polypropylene glycol diglycidyl ether (JH-230) with average molecular weight of 2500 g/mol, viscosity at 25 °C of 425mpa.s, and density of 0.925 g/cm^3 is used in this study. The isophorone diamine (IPDA) with 170.3 g/mol average molecular weight was used as a curing agent. The gum acacia powder was also used. All aqueous solutions were prepared using distilled water. The chemical structures of these materials are shown in Fig. 1.