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Investigation of rheological properties of light colored synthetic asphalt binders containing different polymer modifiers

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HIGHLIGHTS

- Colored asphalt is prepared by means of synthetic resin.
- Combination of SBS, EVA and PE Polymer is used for modification.
- Rheological properties confirm the modification effect of various polymers.
- Colored asphalt is susceptible to low temperatures and PAV aging.

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ABSTRACT

Light colored synthetic asphalt (LCSA) binders were prepared by using aromatic oil, petroleum resin and various polymer modifiers. The polymers used included styrene-butadiene-styrene block copolymers (SBS), ethylene-vinyl acetate copolymer (EVA) and polyethylene (PE). The modification effects of single and combined polymers were investigated. Fluorescence microscopy analysis confirmed the well dispersion of polymer phase and the compatibility of the binder. Fundamental research into rheological behaviors was conducted by using viscosity test, dynamic shear rheological test and bending beam test. Test results showed that LCSA had a high viscosity at construction temperatures and strong frequency/temperature dependence on rheological properties. Polymer modification was identified by the master curves of phase angle and rheological black diagrams. BBR results demonstrated that LCSA binders were susceptible to low temperature and aging. Data analysis indicated that LCSA binders prepared by using SBS, EVA and the combination of SBS plus EVA showed considerable performance for practical application.

1. Introduction

Roads and pavements are usually paved with asphalt concrete or cement concrete. The application of asphalt concrete results in a black pavement surface, or a grey-white surface for cement concrete. The combination of black and grey-white pavement surfaces is colorless [1]. The increasing demand for colorful life requires that some roads and pavements are covered with colored surfaces. Therefore, colored pavements have become popular for the purpose of beautifying parks, residential areas and scenic routes. In some cities, specific colored lanes are designed for buses, bicycles and pedestrians in order to improve transport safety and smoothness [2–6]. Compared with black asphalt pavements, cool colored pavements are beneficial in reducing urban heat effect [7,8].

Colored pavements mainly consist of colored coating, colored cement concrete and colored asphalt concrete. Among them, the colored coating offers a wide variety of material and color. Adhesive binders including epoxy, acrylic and polyurethane resin are widely used to paste a thin colored coating on an existing pavement surface [9]. Colored cement concrete pavements make use of white cement and various pigments to create colored surfaces [10]. Colored asphalt is an artificial light colored binder which could be mixed with various pigments, additives and aggregates to produce colored asphalt mixtures [3,11]. Colored asphalt mixture were designed and constructed in a manner similar to conventional asphalt mixture [12]. This indicated that light colored asphalt should have a viscosity-temperature characteristic that similar to traditional black asphalts at mixing and compaction temperatures. In general, colored asphalt binder can be prepared

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in two ways; one is black color removal from asphalt and the other is light-colored synthetic resin binder prepared by using oil refining residue, petroleum resin and polymer modifiers. Colored asphalt is widely prepared by the light-colored synthetic method because of the convenience and easiness of this production method [11,13]. Aromatic oil and petroleum resin were used as the main raw materials for the preparation of light colored asphalt. Sticky aromatic oil could acted as fluxing medium to reduce viscosity at production and construction temperature, while petroleum resin contributed to hardness. The addition of petroleum resin was reported to be a high amount of 35–50%, which could resulted in increased softening point and viscosity, but reduced ductility as well flexibility at low temperatures [13]. Polymer modifiers commonly used for asphalt modification were also available for light colored synthetic asphalt (LCSA) binders. Polymer modifiers formed network structure in LCSA binder and thus significantly influenced the performance at both high and low temperatures [13,14]. Munera reported that the optimum polymer content could be determined by the flexibility and compatibility of modified asphalt binder [15]. LCSA binder was shown to be sensitive to aging, which destroyed the colloidal structure and thus deteriorated its performance. Ultraviolet light could result in color fading in colored asphalt containing various pigments. Compared with green colored asphalt mixture, red colored asphalt mixture had better fading resistance [16,17]. Previous results obtained from Marshall test, wheel tracking test and raveling test showed that the performance of colored asphalt mixtures was comparable with traditional asphalt mixture and has been successfully paved on roads [18–20]. However, field inspection found that color fading and loose of aggregate was the main distress for colored asphalt pavements in Hubei province, China.

Colored asphalt pavements are increasingly applied to beautify the environment and improve driving safety. Previous studies mainly focused on the mixture design and construction technology of colored asphalt mixture. Limited studies were done on the rheological properties of LCSA binders containing various polymer modifiers. This paper aimed to get a fundamental understanding on the rheological properties of LCSA binders prepared by synthetic method. Aromatic oil, petroleum resin and polymer modifiers (SBS, EVA and PE) were used as raw materials. Modification effects of single and combined polymers were considered. For the purpose of comparison, base asphalt and SBS modified asphalt were employed. Fluorescence microscopy analysis was carried out to examine the state of polymer dispersion. Detailed rheological investigation was performed by means of dynamic shear rheometer (DSR) and bending beam rheometer. The obtained results would be used as a guideline for the development and optimization of LCSA binders.

2. Experimental part

2.1. Raw materials and binder preparation

In this paper, light colored synthetic asphalt (LCSA) binders were prepared by using aromatic oil and petroleum resin blended with various polymer modifiers including SBS, EVA and PE. The content of aromatic hydrocarbon of the aromatic oil employed was 78% according to ASTM D2140. Its kinematic viscosity at 100 °C was 20 mm^2/s tested in accordance with ASTM D445. The used petroleum resin had a relative molecular weight ranging from 1000 to 2500 measured by Gel Permeation Chromatography (GPC) and its softening point was between 80 °C and 90 °C determined by ASTM E 28 Ring & Ball Method. SBS polymer that used in this study is a linear type containing 30% styrene content with a molecular weight of 105000. The value of melt flow index (MFI, ASTM D1238) and vinyl acetic content (VA, ASTM-D5594) of EVA used in this study were 50.1 g/10 min and 17.5%, respectively. Linear low-density polyethylene (LDPE) was used and it had a Vicat softening point (ASTM D1525) of 89 °C.

Among the raw materials mentioned above, aromatic oil is a sticky liquid with a very low softening point. It plays as a fluxing medium for other raw materials. It also helps to reduce the viscosity at production and construction temperature as well as to improve the compatibility of mixed binder. Petroleum resin is a brittle solid but can be softened and melted at high temperatures. As cooled down it contributes to hardness. The addition of polymer could improve the thermal stability at high temperatures and the flexibility at low temperatures. Previous study done by Xi indicated that polymer content of 7% together with resin content of 45% was economical to prepared colored asphalt binders. Jin reported two colored asphalt binders with polymer content 5% and 7% plus polyester fibre 3%. High polymer content was used to improve the rutting resistance of colored asphalt mixtures [14]. Table 1 gives the detailed information on the materials compositions of various LCSA binders. In total, Eight LCSA binders were prepared in laboratory. These asphalt binders were labeled A0 to A7. The test program was designed to investigate the effects of single polymer as well as the combined effects of two and three types of polymer modifiers on the rheological properties. For this reason, the amounts of aromatic oil and petroleum resin were constant as 52% and 40%, respectively for each binder, while polymer content varied with the polymer type and the content of combined polymers. High content of single polymer modifier and combined two/three polymers was considered to form a continuous polymer phase in LCSA binder. Among these eight LCSA binder, A0 was the control sample that only consisted of aromatic oil and petroleum resin without polymer modification. A1, A2 and A3 were prepared by the addition of 8% SBS, 8% EVA and 8% PE, respectively. For A4, A5 and A6, the combinations of 4.5% SBS plus 3.5% EVA, 4.5% SBS plus 3.5% PE and 4.5% EVA plus 3.5% PE were considered, respectively. Finally, A7 was prepared by considering the combination of 3% SBS, 2% EVA plus 2% PE.

In this study, all of these LCSA binders were prepared by a similar method of melting at high temperature and shear blending at high speed. Aromatic oil was first heated to 180 °C in an oil-bath heating container. Various polymers were added into aromatic oil slowly and blended until completely melt and well dispersed using a mix equipment (ESR-500, made by Shanghai ELE Co., Ltd., China) with a shear blending speed of 4000 rpm for 45 min. Petroleum resin was finally added and shear blended at a speed of 3000 rpm for 15 min.

For the purpose of comparison with these prepared LCSA binders, two commercial road paving asphalt binders, one base asphalt binder and one SBS modified asphalt binders with 4.5% SBS content were used as a reference. The base asphalt and SBS modified asphalt were commonly used for hot-mix asphalt pavements in Hubei province, China. The base asphalt had a penetration of 67 dmm at 25 °C, a softening point of 47 °C and ductility at 15 °C larger than100 cm. The properties of the SBS modified asphalt were following: penetration of 54 dmm at 25 °C, softening point of 76 °C and ductility of 52.1 cm at 5 °C.

2.2. Test methods

Differential scanning calorimetry (DSC) analysis (TG-DSC, model STA449C, made by NETZSCH GmbH, Germany) was performed to get insight into the thermal stability and melting point of SBS, EVA, PE and petroleum resin. The sample of about 10 mg was heated from room temperature to 600 °C at a heating rate of 10 °C/min under nitrogen condition supporting with a flowing nitrogen of 20 ml/min.