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Impacts of multiple-polymer components on high temperature performance characteristics of airfield modified binders

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HIGHLIGHTS

- PE and ARA were typically added in a dry process in asphalt plant to produce the mixtures.
- Impacts of multiple-polymer components on high temperature performance are effective.
- ARA only increases complex modulus while PE had the influences on rutting factor and phase angle.
- ARA has no significant effects on aging resistance, but PE has better resistance to aging.
- MSCR test results showed that the binders with ARA and PE have more resistant to rutting.

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ABSTRACT

Polymer modified asphalt binders have been commonly used to improve the resistance of the airfield pavements to distresses, especially wheel rutting. The objective of this study was to investigate the rheological and chemical properties of the modified binders containing anti-rutting agent (ARA), polyethylene (PE) and styrene-butadiene-styrene copolymer (SBS) before and after a short-term aging procedure. Rotational viscosity, penetration degree, softening point as well as performance grade, multi-stress creep recovery (MSCR), frequency and amplitude sweep were performed to determine the effects of ARA and PE on rut depths at high temperatures. In addition, Fourier Transform Infrared Spectroscopy (FTIR) was conducted to determine the chemical properties of various polymerized binders. The test results showed that, as expected, the addition of PE and ARA polymer increased the rotational viscosity, softening point and rutting factor values and reduced the penetration degree. However, ARA could only increase complex modulus while PE had the influences on both the complex modulus and phase angle of the modified binders. In addition, the rising tendency of phase angle during frequency sweep test was totally different in terms of the binders with or without PE. Furthermore, the FTIR test results showed that the ARA has no significant effects on aging resistance, while the modified binders with PE have better resistance to aging.

1. Introduction

Airfield pavement is an important part of airport system. Nowadays, due to its numerous advantages such as smoothness, comfort, low-vibration, high-automated construction and easy-maintenance, asphalt mixture pavements have been used as the surface course in various airports all around the world. Compared to the highway pavements, airfield pavement undertakes much more loading, shear force and contact pressure. For example, the maximum takeoff weight and contact pressure of a Boeing 747–400 plane are about 395 tons and 1.38 MPa, respectively. According to some airfield pavement distress reports from American Society of Civil Engineers (ASCE) [1] and Federal Aviation Administration (FAA) [2], permanent deformation is a mainly load-related distress in airfield flexible pavements. It appears as the longitudinal depressions in the wheel paths and may be accompanied by small upheaval to the sides [3]. Permanent deformation in each layer of the pavement structure under repetitive traffic loading is a major contributor to the accumulation of pavement surface rut depth.

Asphalt binder is a visco-elastic material, and its mechanical behavior depends on its ambient service temperature. When temperature rises, asphalt binder becomes softer and more likely to be susceptible to permanent deformation. In recent years, numerous polymer modifiers have been developed and have been proven to

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improve asphalt binder properties including high and low temperature performance, elastic recovery, viscosity, and shear modules. In general, modified Asphalt pavement has greater resistance to wheel rutting and fatigue cracking, and decreases stripping and temperature susceptibility [4], so it has been successfully used at some locations with the high traffic load, such as intersections, airports, vehicle weigh stations, and race tracks [5]. Currently, the most commonly used polymer for asphalt modification is styrene-butadienestyrene copolymer (SBS) followed by other polymers such as styrene-butadiene-rubber (SBR), ethylene vinyl acetate (EVA) and polyethylene (PE) in the form of low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE), polypropylene (PP), crumb rubber, and many others.

Polyethylenes, including LDPE, LLDPE, and high-density polyethylene (HDPE), polypropylenes and their copolymers have frequently been used in asphalt modification [6]. Using recycled Polyethylene (RPE) is an environmental-friendly concept. For instance, recycled LDPE modification increases complex modulus at high temperatures of asphalt binders [7]. The molecular weight and its distribution of recycled LDPE plays crucial role in determining the low-temperature properties and hot storage stability [8]. Yousefi (6) found that, with the addition of different polyethylenes to bitumen, high-temperature performance of bitumen increases as the polymer melt-flow index (MFI) decreases. Though the modified RPE can improve the performance, the problem of stability of the asphalt-PE system remains unsolved [9].

RPE (LDPE or HDPE) modification increases the resilient modulus, fatigue life of asphalt mixtures, and provides better resistance against permanent deformations and it also improves the adhesion between asphalt and aggregate [8,10–12]. The recommended dosage of the grinded HDPE modifier is 12% by the weight of the binder [11]. Some researchers studied other types of PE. For example, María et al. [13] presented that most of blends exhibit an improved performance at a higher temperature with grafted polyethylene because of enhancing rutting resistance, flow activation energy compared to non-grafted polyethylene blends. Zhang et al. [14] found that, compared with samples without LLDPE grafted with maleic anhydride (LLDPE-g-MAH), both penetration and ductility of HDPE/SBS modified asphalts were increased while softening point and the maximum failure temperature were decreased, and LLDPE-g-MAH had no significant effects on high-temperature property.

anti-rutting agent (ARA) is a new composite material which can improve the high temperature performance characteristics of asphalt mixtures. Various types of ARAs, such as polyethylene, Sulfur Extended Asphalt Modifier (SEAM, from Shell, Dutch), Duroflex (from rub BERLIN limited liability company, Germany), PR. PLAST.S (from PR Industry, French), Rad Spunrie (from Haichuan company, China) and many others, were broadly developed recently due to the heavy traffic loading on the asphalt pavements. Also, numerous laboratory evaluations have been conducted to investigate the influence on the high temperature performance of ARA modified asphalt mixtures. The results showed that with the increase of ARA content, the high-temperature performance of the modified asphalt mixture is better than that of base asphalt mixture [15–17].

Meanwhile, ARA, in general, is susceptible to temperature and has a good workability during the mixing process [17]. Hui and Zhang [15] investigated the mixing influences of ARA on the modified asphalt mixture, and found that the workability of dry method is better than that of wet method, followed by premixing method. Xie [18] studied the high temperature performance with PR series additives using repeated shear test (constant height) (RSCH), indicating that asphalt mixture with PR Plast S (PR.S) has the best performance, followed by the PR Flex Module (PR.M) one while the original one had the worst performance. In addition, the rheological properties of ARA modified asphalt binder showed that the softening point and rutting parameter increased significantly, the ductility and penetration decreased due to the introduction of the anti-rutting agent [19].

Plastomeric polymers such as PE and ARA have good high-temperature performance properties but have shown to have limited improvement in elasticity [20], and cannot improve low-temperature performance characteristics of asphalt binders. It is well known that thermoplastic elastomers can improve fatigue resistance and cracking resistance, but it is limited in improving high-temperature performance [14]. Therefore, combining PE, ARA with elastomers such as SBS, SBR to produce multiple-polymer components modified asphalt binders would be an effective method to enhance the properties of asphalt pavements, especially for airfield modified pavements.

The objective of this study was to investigate the rheological and chemical properties of multiple polymer modified asphalt binders containing ARA, PE and SBS at high performance temperatures before and after a short-term aging procedure. A series of tests were carried out to evaluate properties of the modified binders including rotational viscosity, penetration, softening point, phase angle, frequency and amplitude sweep, and Fourier transform spectroscopy.

2. Materials and test methods

2.1. Materials

Two PG 82-22 SBS modified asphalt binders from two sources referred to as A, B were used to blend with ARA and PE. Four proportions are employed in this study, including Control, 4.8% ARA, 4.8% ARA and 7.1% PE, 4.8% ARA and 12% PE (by weight of asphalt binder) named A0, A1, A2, A3 and B0, B1, B2, B3, respectively. The corresponding percentages are control, 0.2% ARA, 0.2% ARA and 0.3% PE, as well as 0.2% ARA and 0.5% PE by weight of asphalt mixture based on a 4.2% optimum asphalt binder content.

ARA and PE were blended with hot asphalt binders A, B in metal containers for an hour at a high-speed shearing speed of 25,000 rpm and a temperature of 180 °C and then were stored at 150 °C for another hour. It was found that the additives were completely melted.

2.2. Tests methods

To achieve the objectives of this study, various rheological and chemical tests were conducted on the blended asphalt binders. The experimental design in this study is shown in Fig. 1. Rolling thin film oven (RTFO) was used for a short-term aging in accordance with AASHTO T 240 [21] and was operated at a rate of 15 rpm for 85 min at 163 °C, the rate of airflow was at 4000 ml/min.

Brookfield rotational viscometer was used to test the viscosity of the virgin binders at three different temperatures (e.g., 135 °C, 150 °C, and 165 °C) in accordance with AASHTO T 316 [22]. A number 27 spindle and a specimen weight of 8–11 g was used for this test. Furthermore, the temperature susceptibility of modified asphalt binders was investigated using viscosity-temperature susceptibility (VTS) method based on the rotational viscosity test results. The basic formulation for two parameters, VTS and A, is conducted as follow [23]:

$$log[log(\eta)]\begin{cases} < 1.0945 \rightarrow \log[\log(\eta)] = A + VTS \times log(T) \\ \geqslant 1.0945 \rightarrow \log[log(\eta)] = 1.0945 \end{cases} \quad (1)$$

where η: viscosity of binder (cp); T: temperature of binder (R: degrees Rankine); A: intercept parameter; and VTS: slope