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Laboratory evaluation of composed modified asphalt binder and mixture containing nano-silica/rock asphalt/SBS

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HIGHLIGHTS

- Asphalt composed modified by nano-silica, rock asphalt and SBS are proposed.
- Performance improvements are achieved with the addition of nano-silica, rock asphalt and SBS.
- 1% Nano-silica/6% rock asphalt/3% SBS modified asphalt mixture had higher cost performance than 5% SBS modified asphalt mixture.

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ABSTRACT

As SBS modified asphalt has the disadvantages of high initial cost, difficult processing and poor storage stability, many researches have been conducted experiments on composed modified asphalt to get a more satisfactory pavement performance. This study proposed an asphalt mixture modified by nano-silica, rock asphalt and SBS. Basic performance tests of asphalt, rutting tests, low-temperature bending tests, moisture susceptibility tests, fatigue tests and durability tests of asphalt mixtures modified by SBS, rock asphalt, nano-silica/rock asphalt and nano-silica/rock asphalt/SBS were performed to evaluate their pavement performance. Comparing these tests results with the properties of unmodified asphalt mixture, nano-silica and rock asphalt cause an improvement in pavement performance. nano-silica/rock asphalt/SBS modified asphalt mixture had higher temperature stability, low-temperature cracking resistance, moisture susceptibility and durability than 5% SBS modified asphalt except the similar fatigue life. Furthermore, economic analysis indicated that the nano-silica/rock asphalt/SBS modified asphalt mixture had higher cost effectiveness.

1. Introduction

Overloading and channelization have become more and more serious with the development of transportation. There are increasing numbers of damage of road pavement including rutting, pothole, upheaval and cracking. It is essential to choose the materials in improving the performance of the pavement [1]. SBS modified asphalt had the advantages both at high and low temperatures, which is getting to be the mainstream choice in engineering. Meanwhile, it also had the defects of high initial cost, difficult processing and poor storage stability [2].

Given the above defects of SBS modified asphalt, many scholars conducted researches on composed modified asphalt to find out the more cost effective modification, such as rock asphalt (RA) and nano-materials [3–5]. Du et al. [6] evaluated the performance of low content of SBS/RA compound asphalt mixture, which could reach corresponding properties of the SBS modified asphalt mixture and meet the requirements in all temperature regions. The research of Huang et al. [7] proposed the compound modified asphalt using rubber powder/SBS/RA to achieve a better fatigue life than SBS modified asphalt. In addition, Kök [8] and Yang [9] added Gilsonite and Trinidad Lake Asphalt to SBS modified asphalt, whose high-temperature properties were improved continuously. In terms of nano-materials modification, nano-montmorillonite/styrene butadiene rubber (SBR) composed modified asphalt mixture and nano-montmorillonite/ethylene-vinyl acetate copolymer had been prepared by Polacco [10] and Sureshkumar [11], respectively, to improve their rheological performance of the asphalt binders. Study of Sun et al. [12] reported that it is feasible to employ nano-calcium carbonate in SBR modified asphalt mixture. Lu Sun [13] compared the properties of 5% SBS modified asphalt with asphalt composed modified by 0.5% nano-silica (NS) + 5% SBR + 1% polyethylene. The proposed modified asphalt has a significant

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improvement in high/low-temperature performance and ageing resistance. The resistance to moisture damage and ageing of asphalt modified using NS and SBS had been highly improvement based on the results of Yusoff's researches [14].

Previous studies had reported the performance of asphalt modified by polymer with RA or nano-materials, respectively. However, there is limited information in literatures that describe the characteristics of nano-silica/rock asphalt/SBS (NS/RA/SBS) composed modified asphalt. In the former studies, four nano-materials were chosen to identify which is the best choice to match with RA. NS was selected [15]. Then the effects of NS and RA on rheological properties of modified asphalt were compared and the optional content: 1% NS and 6% RA was determined [16]. The above modifier both had slight negative effects on low-temperature properties.

This paper aims to improve NS/RA modified asphalt low-temperature performance, 1%, 2% and 3% SBS was added to 1% NS/6% RA modified asphalt. The reminder of the manuscript is as follow. In Section 2, the basic parameters of materials are listed. The properties of asphalt and mixture are presented. The tests adopted in this research including wheel tracking test, beam bending test, moisture susceptibility test, fatigue performance test, ageing resistance test of modified asphalt mixture are briefly introduced in Section 3. Pavement performances of modified asphalt mixture are discussed in Section 4. Economic analysis is present in Section 5. Last Section 6 draws the conclusions.

2. Materials and sample preparation

2.1. Materials

This paper chose limestone as aggregates and fillers, from Fugu, Shaanxi Province. The properties were given in Table 1.The AC-60/70 asphalt was supplied by Yongshun Commercial and Trading Company from Karamay, which properties were listed in the Table 2. Wanjing New Materials Limited Company offered the NS and RA was provided by Shuitian Mining Technology Research and Development Department. The type of SBS was line SBS: Qimei PB-5302. The parameters of NS, RA and SBS were listed in Tables 3–5.

2.2. Sample preparation and properties of asphalt

Due to the large specific surface area of NS, it is difficult to achieve a homogeneous dispersion in asphalt. Thus KH560 silane couping agent was used to surface treatment. First of all, the unmodified asphalt binder, RA, NS and SBS were mixed in a heating vessel. Then manual mixing maintained for 20 min at 170 °C before high-speed shearing (5000 r/min) lasted for 30 min [16]. Until a homogeneous mass was obtained, stopped the mixing and developed for 2 h.

Experimental results of literature [16] showed that the compound modified asphalt has satisfactory performance at high temperature and slightly easily cracking at low temperature. Furthermore, 1% NS and 6% RA was determined as optional content. The objective of this study was to investigate the pavement performance of proposed asphalt mixture. To improve its cracking resistance, to 1%, 2% and 3% SBS was added to NS/RA composed modified asphalt. Fig. 1 presents the material combinations and the traditional binder tests [18] conducted in this research. The performances of all asphalts were listed in Table 6.

From the table 6, the unmodified asphalt binder has the highest penetration, while its softening point and rotation viscosity are the lowest. When NS and RA (1#, 2# and 3#) are added to the unmodified asphalt binder, there are improvements both in softening point and rotation viscosity, nevertheless, reduction in penetration, which indicates that the two modifiers improve the stiffness and high-temperature stability of the asphalt. The anti-ageing properties are also enhanced from the results of RTFOT. In the meantime, the values of ductility at 5 °C decrease, declaring their negative effects on low-temperature deformability. Compared with NS modified asphalt, RA modified asphalt and NS/RA modified asphalt, NS/RA/SBS modified asphalt (4#, 5# and 6#) has higher values of softening point, ductility, rotary viscosity and lower value of penetration. The addition of SBS caused an increase in deformability at low temperature and terminal stability at high temperature, drowning the conclusion that the modification with SBS improves the linear viscoelastic parameters in bitumen at different temperature conditions. From Table 6, it also can be seen that increasing of the SBS concentration yields higher anti-ageing properties. All of the three modifiers could enhance the ageing resistance performance, due to the stable dispersion of NS [19], the polar molecules of RA [20] and the viscosity characteristics of SBS [21].

2.3. Mix design

Following the procedures described in T0702-2011 [18], the Marshall specimens of eight kinds of mixtures were compacted to mix design. The median value of AC-16 gradation [17] (Table 7) was recommended. Table 8 presents the calculated results of the optimum asphalt contents, theoretical maximum specific gravity, volume of air voids (VA), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) of the final compacted specimens.

3. Experimental design

The pavement performance of the proposed modified asphalt mixture was evaluated by laboratory experiments, including wheel tracking test, low-temperature beam bending test, moisture susceptibility test, fatigue performance test and ageing resistance test.

3.1. Wheel tracking test

According to Standard Test Method of Asphalt and Asphalt Mixture for Highway Engineering [18], wheel tracking test (T0719-2011) was conducted to evaluate high-temperature stability of the asphalt mixture. A solid, hard rubber loading wheel with the

Table 1
Properties of aggregates.

Properties	Specification limitation [17]	Coarse aggregate	Fine aggregate	Filler aggregate
Crushed stone value (%)	≤26	12.4	–	–
Los Angeles abrasion loss (%)	≤28	13.6	–	–
Water absorption (%)	≤2.0	0.49	–	–
Content of flat long and thin particle (%)	≤15	7.2	–	–
Content of particle size less than 0.075 (%)	–	0.53	2.2	–
Polished stone value (%)	≥42	63	–	–
Apparent specific gravity (g/cm^3)	≥2.5	2.84	2.72	2.71
Bulk specific gravity (g/cm^3)	–	2.87	2.67	