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Laboratory investigation on fatigue performance of modified asphalt concretes considering healing

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HIGHLIGHTS

- N_{fNM} from ASTM D7460 was used to evaluate fatigue performance instead of N_{f50} from AASHTO T321-07.
- Terminal Blend, which presents more storage stability than the traditional asphalt rubber, was used in it.
- Healing was considered to analyze the fatigue performance.
- Fatigue performance grading or analysis was conducted in 3 situations.

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ABSTRACT

Modified asphalt concretes have been used in pavement widely now. Their fatigue life, which can be increased by healing effect, is one of the most important factors in mixture design, however, it is considered less in mixture design. The test in the study involves fatigue tests of 9 modified asphalt mixtures, together with two base asphalt mixtures. Fatigue performances were compared (or graded) through several four-point bending beam fatigue tests, under the same asphalt content (5%), volume design target, and high-temperature performance grading, which are the most common occurrence 3 situations in mixture design process, the results can be a guidance for selection of asphalt in engineering application. Results also demonstrates that crumb rubber and styrene–butadiene–styrene modified asphalt mixtures performed good healing effects. And a partition scatterplot based on the test results was plotted, which provides a modified asphalt mixture design guide.

1. Introduction

The asphalt mixture design in China, Marshall Design method, is a with prejudice high-temperature performance control method [1]. The Specifications for Design of Highway Asphalt Pavement in China [2] demonstrated the considerations in the design process, stability, and flow value, which resulted in a slightly high content of designed mix asphalt and relatively low air void ratio. In the asphalt-binding aspect, the most commonly used parameters include penetration, softening point, ductility, and viscosity or performance grade (PG) for scientific research. These parameters represent high- and low-temperature characteristics [3] mainly because the Marshall design has been used internationally for many years of experience in flexible base designs; the largest risk of which is the rutting damage caused by high temperature [4]. Considering that fatigue damage has been highlighted more seriously in China than in other countries, the aforementioned issue has drawn significant attention. Consequently, increasing number of researchers tend to consider fatigue performance as the basic design evaluation index in the design method of asphalt pavement [5–7]. And in the specification of Superpave design, the Level 2 and 3 requires fatigue cracking tests, however, it only tests the binder rather than the mixture [8]. The findings of fatigue performance involved in these studies are mostly based on common asphalt. Several modified asphalts are used to construct high-grade pavement in China, far and wide. Thus, previous experience based on common asphalt cannot be directly used to guide the current design. The composition of modified asphalt is complicated, involving various modifiers with different characteristics; hence, the factors influencing the fatigue performance of modified asphalt are more complicated [9]. Furthermore, an obvious phenomenon called healing can be observed from the modified asphalt. Previous studies have identified the existence of this phenomenon [10–12], as well as other influencing factors [13–15]. Besides, there also are

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Table 1
Basic properties of 60/80 pen grade bitumen.

Items		Technique index	Detecting result
Penetration(25 °C, 100 g, 5 s) (0.1 mm)		60–80	67
PI		−1.5∼+1.0	−1.04
Ductility 15 °C (cm)	⩾	100	170+
Ductility 10 °C (cm)	⩾	15	19.2
Softening point (°C)	⩾	47	46.7
60 °C dynamic viscosity (Pa s)	⩾	180	183
Specific gravity		N/A	1.013

looming at the healing method research, based on traditional way e.g. Marshall test samples [16] and the popular beam fatigue test on elastic foundation test setup [17]. Nevertheless, these studies are relatively isolated, and considerer less the healing effect into the fatigue life, which is the same as ignoring a part of the fatigue performance. Designs based on these results appear significantly conservative, which will bring waste of materials and even cause adverse effects on the high-temperature performance [18]. Therefore, a further comprehensive study on the fatigue performances of modified asphalt mixtures, considering healing, is necessary. In the current study, the fatigue performances of 11 kinds of asphalt mixtures in three design situations were compared by summarizing several fatigue tests to provide reference for future research and engineering programs.

2. Experimental program

2.1. Asphalt

In order to prepare modified asphalt mixtures, a 60/80 pen grade bitumen was used which was produced by in Caltex refinery. Table 1 presents the basic properties of this bitumen. Caltex 70 # asphalt and anhydride. Asphalt specific parameters are list in Table 1.

2.2. Modifiers

The modified asphalt used in this study are styrene–butadiene–styrene (SBS), polyethylene (PE), terminal blend crumb rubber modified asphalt (TB), terminal blend composite modified asphalt (TBCMA), rock asphalt, and asphalt rubber (AR); 40-mesh powder of crumb rubber modifier (CBM) in asphalt rubber (AR) was obtained from Jinhua, Zhejiang Province; additional 60-mesh powder of AR was collected from the same place; PE was obtained from Wuxi Jiangsu Province, whereas high-density polyethylene (HDPE) and rock asphalt were gathered from Buton island, Indonesia. In addition, base asphalt with PG 64-22 grade was obtained from Esso. Brand new types of crumb rubber modified asphalt were also used in this study, namely, TB and TBCMAs. Fine crumb rubber was used as a modifier in TB, in which desulfurization reaction aroused. The mixture is usually stored in oil tank without stirring, kept evenly dispersed, and stabilized. In previous studies, this process to produce storage stability of crumb rubber-modified asphalt is known as wet process without agitation because of the increase of CRM content. A more accurate name should be Terminal Blend of crumb rubber-modified asphalt or Terminal Blend [19]. In the present research, TB and TBCMAs were made of 20% crumb rubber content. This scheme is summarized in Table 2.

Table 3
Aggregate gravity.

Size (mm)	Mineral powder	0–3	3–5	5–10	10–13	13–19
Gravity	2.788	2.835	2.866	2.875	2.903	2.909

Table 4
Property index of aggregates.

Test index	Basalt aggregate	Standard requirement (JTJ F40-2004) [20]
Crushed stone value (%)	23.2	<28
Weared stone value (Los Angeles) (%)	21.3	<30
Content of flat particle (%) (size between 4.75 and 13.2 mm)	10.3	<20
Sand equivalent value (size < 2.36 mm) (%)	91.0	>60
Angularity (%)		
Size between 2.36 and 4.75 mm	>30	N/A
Size < 2.36 mm	49.2	>30

2.3. Aggregates and grades

All aggregates used in this study are basalt because such aggregates produced by most ore fields exhibit a better shape and strength than other stones; the filler is limestone, and the vast majority of mineral fillers are made of limestone mainly because the limestone powder combines with asphalt strongly, which can produce an effect similar to that of asphalt mastic, thereby reducing the bleeding effectively. The test results of the basic properties of the aggregates are summarized in Tables 3 and 4. Each aggregate was studied separately to fulfill the requirements of the material specifications in China.

Grades Asphalt Concrete-13 and -20 (AC-13 and AC-20), referenced from the Technical Specifications for Construction of Highway Asphalt Pavements [20], were used to grade the common asphalt mixture, in which the binder was not modified. The asphalt rubber mixture is the Asphalt Rubber Asphalt Concrete-13 (ARAC-13) recommended by the Arizona Department of Transportation. Standard specifications for road and bridge construction [21] and the grade of other modified asphalt mixtures, AC-13 and AC-20, are listed in Table 5.

2.4. Test method and index

2.4.1. Test equipment and parameters

Four-point beam (4PB) fatigue testing [22] is the most representative method to determine fatigue performance, and it is adopted in China Standard, the Standard Test Method of Bitumen and Bituminous Mixtures for Highway Engineering [23]. Which provides an acquisition method for the fatigue life and fatigue energy of HMA beams. All specimens are required to be prepared into a beam with a size of 385 mm × 65 mm × 50 mm. A frequency of 10 Hz and strain level of 1000

Table 2
Modified ways of modified asphalt.

Catalog	Modifier and its amount[a]	Binder preparation procedure	Remarks on mixture preparation
SBS modified asphalt	4.5% SBS + 95.5% bitumen	150 °C, 15 min shearing, 45 min stirring	170 °C mixing totally 90 s
AR	20% crumb rubber, 40 mesh	180 °C, 60 min stirring	185 °C mixing totally 90 s
TB	20% crumb rubber, 60 mesh	200 °C stirring for 30 min in high pressure	160 °C mixing totally 90 s
TB + SBS	3%SBS + 20% crumb rubber, 60 mesh	150 °C, 15 min shearing, 30 min stirring based on TB	170 °C mixing totally 90 s
TB + rock asphalt	20% rock asphalt + 20% crumb rubber 60 mesh + 60% bitumen	160 °C, 20 min stirring based on TB	170 °C mixing for totally 90 s
TB + PE	PE accounted for 5‰ of the mixture (dry process) 20% crumb rubber, 60 mesh	200 °C stirring for 30 min in high pressure	170 °C, PE mixed with aggregates, dry process, totally 90 s
PE	PE accounted for 5‰ of the mixture (dry process)	N/A	170 °C, PE mixed with aggregates, dry process, totally 90 s
Rock asphalt	Rock asphalt accounted for 10% of the overall binder	150 °C, 30 min stirring	160 °C mixing totally 90 s
Hard asphalt	20/40 pen grade bitumen for 100% of the overall binder	N/A	170 °C mixing totally 90 s

[a] Modifier volume is selected from the optimal content of the modifiers frequently used in field projects.