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Dynamic properties of stone mastic asphalt mixtures containing waste plastic bottles

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ABSTRACT

Fatigue failure is a common problem of asphaltic concrete which can lead to pavement damage. Many studies have been conducted to find ways for increasing fatigue life of asphalt concrete mixtures. This study investigates effects of adding waste polyethylene terephthalate (PET) on stiffness and fatigue properties of SMA mixtures at optimum asphalt contents. Different percentages of waste PET with maximum size of 2.36 mm were added to SMA mixtures. Indirect tensile stiffness modulus test and indirect tensile fatigue test were conducted at temperature of 20 °C and at three different stress levels (250, 350, 450 kPa). The results showed that stiffness modulus of mixture increased at lower amount of PET content; however, adding higher amount of PET made mixture less stiff. In addition, PET reinforced mixtures exhibit significantly higher fatigue lives compared to the mixtures without PET.

1. Introduction

Asphalt Concrete (AC) mixture is subject to many external forces during its service life which could eventually lead to failure. Different types of failures have been observed in asphalt mixtures such as permanent deformation (rutting), fatigue failure, and low temperature cracking. Fatigue failure is a common damage in AC mixtures which appears in the form of cracking (alligator cracking).

Fatigue resistance is the ability of the asphalt mixture to resist repeated bending forces without fracture and cracking. In asphalt concrete pavement fatigue cracking is caused by successive tensile strains due to repeated traffic loading. According to structural analysis fatigue cracks are produced at the bottom of asphalt layer where the maximum tensile strains accrue, thereafter these cracks propagate to the surface of asphalt mixtures. Fatigue life of AC mixtures has a negative correlation with the loads applied by vehicles on road pavements. Besides, fatigue life differs significantly among types of AC mixtures.

Stone Mastic Asphalt (SMA) is a type of asphaltic concrete which consists of more coarse aggregate content and filler, and has better characteristic against permanent deformation compared to the conventional dense graded mixture. SMA was developed in Germany in 1960s, and was used in Europe for years. Because of SMA success in Europe, it has been used in the United States since 1991 [1,2]. Previous studies showed that SMA mixture tends to have lower fatigue life in comparison with dense graded mixture because inherent structure of dense graded mixture provides better interlock between the aggregate particles [3,4].

Using additives is a common way to improve fatigue life of AC mixtures. Different types of fibers and polymers can be used in AC mixtures. In a study, effects of adding polyester, polyacrylonitrile, lignin and asbestos fibers with different percentages were investigated by Xu et al. [5]. It was shown that fatigue life improved by adding fibers, and polyester and polyacrylonitrile which are considered as polymer fibers had the best effect on fatigue properties of AC mixtures. It is also reported that adding polypropylene fiber enhanced the fatigue resistance of asphalt mixtures, while fatigue life increased 27% by adding 1% polypropylene fiber [6].

Although utilization of virgin additives in asphalt mixture can improve fatigue properties of AC, in many cases road construction cost increases considerably. Thus, many investigations were conducted on the mixtures containing waste materials as additives to improve asphalt mixture characteristics and prevent from imposed additional charges due to usage of virgin materials. Furthermore, this would be an alternative solution for environmental pollution by utilizing waste materials as secondary materials in road construction projects. Waste glass, steel slag, tires and plastics (polymers) are examples of waste materials which have been used in AC mixtures in previous studies [7]. Among waste materials waste tire and recycled polymer have a prominent utilization [8–13]. The use of glass fiber has also been found to improve fatigue life of SMA mixes according to studies by Mahrez and Karim [14].

The main objective of this study is to investigate stiffness and fatigue properties of SMA mixtures containing different percentages of waste polyethylene terephthalate (PET).

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2. Experimental procedure

2.1. Materials

SMA is gap-graded AC which is used in this study. Particle size distribution of the gradation is presented in Fig. 1. Granite-rich aggregate particles were obtained from Kajang Rock Quarry in Malaysia. Because of the importance of aggregate quality in SMA mixtures, several tests were done on coarse and fine aggregate particles, and the results are listed in Table 1. Furthermore, in SMA mixture amount of aggregate passing sieve 0.075 mm (filler) is higher than the amount used for conventional Hot Mix Asphalt, and is between 8% and 10% by weight of aggregate particles [1]. In this study 9% filler was used.

In order to prepare AC mixtures, 80–100 penetration-grade virgin asphalt has been utilized. Table 2 illustrates some properties of asphalt cement which is used in this research.

PET is a type of polyester material, and is often used for packing in food and beverage industries. Waste PET was obtained from PET bottles. For utilization of PET bottles as additive in AC mixtures the bottles were cut to small parts, thereafter crushed by crushing machine. The crushed PET particles were sieved, and the particles passing sieve 2.36 mm were used for this investigation (see Fig. 2). Table 3 depicts some properties of PET material.

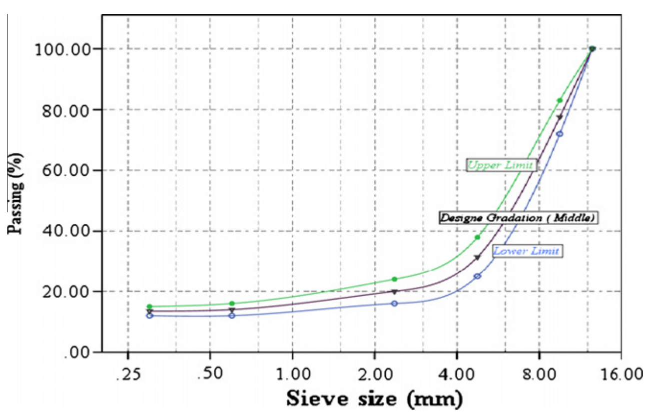

Fig. 1. Particle size distribution for stone mastic asphalt mixture.

Table 1
Properties of coarse and fine aggregate.

Property	Value	Standard test method
Coarse aggregate		
L.A. Abrasion	19.45% < 30%	ASTM C 131
Flakiness index	2% < 20%	BS 812 Part 105.1
Elongation index	11% < 20%	BS 812 Part 105.2
Specific gravity		ASTM C 127
Bulk	2.60	
SSD	2.62	
Apparent	2.65	
Absorption	0.72% < 2%	ASTM C 127
Fine aggregate		
Specific gravity		ASTM C 128
Bulk	2.63	
SSD	2.64	
Apparent	2.66	
Absorption	0.4% < 2%	ASTM C 128
Soundness loss	4.1% < 15%	ASTM C 88

Table 2
Properties of asphalt cement.

Properties	Value	Standard test method
Penetration at 25 °C (0.1 mm)	87	ASTM D 5
Softening point (°C)	46	ASTM D 36
Viscosity at 135 °C (mPa s)	325	ASTM D 4402
Viscosity at 170 °C (mPa s)	62.5	ASTM D 4402
Specific gravity	1.03	ASTM D 70

2.2. Specimen fabrication

The specimens were prepared at optimum asphalt content (OAC) using Marshall Method. All together six different amounts of OACs have been obtained for six different PET contents, 6.77%, 6.45%, 6.43%, 6.29%, 6.36% and 6.51% of OAC each for 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% (all by weight of aggregate particles) of PET content, respectively.

For preparing AC mixtures, 1100 g of mixed aggregate was placed in the oven at 160 °C between 3 and 4 h. Asphalt binder was also heated at 130 °C before mixing with aggregate particles. PET particles, with the maximum size of 2.36 mm, were added directly to the mixture as the method of dry process. Mixing temperature was kept constant at the temperature between 160 and165 °C. The loose mixture was placed in the preheated mold and 50 blows of compaction were applied by Marshall Hammer on each side of specimen at temperature of 140 °C.

2.3. Test method

2.3.1. Indirect tensile stiffness modulus test

Non-destructive indirect tensile stiffness modulus test is used to obtain stiffness of AC mixtures. Indirect tensile stiffness modulus gives the relationship between stress and strain of AC mixtures at specific load and temperature. This test was carried out by Universal Testing Machine (UTM) according to AASHTO TP31. UTM is a computer controlled system and operates automatically. During the test, specimens were subjected to compressive haversine waveform loads across the vertical section across the thickness of specimen, and deformation of specimen was measured by linear variable differential transducers (LVDTs) along diametrical section of specimen. In order to obtain uniform temperature the specimens were placed at controlled temperature environmental chamber for 4 h prior to test. The test was conducted at three different stress levels (250, 350 and 450 kPa) and at temperature of 20 °C.

Horizontal tensile stress and stiffness modulus of AC mixtures can be obtained by the following equations:

$$\sigma_x(\max) = \frac{2 \times P}{\pi \times d \times t} \quad (1)$$

$$S_m = \frac{P \times (\nu + 0.27)}{H \times t} \quad (2)$$

where $\sigma_x(\max)$ is the maximum horizontal tensile stress in middle of specimen; S_m is the stiffness modulus; P, applied vertical peak load, H; amplitude of horizontal deformation, t; average thickness of specimen; d, average diameter of specimen and ν, Poisson's ratio.

Each specimen was tested twice. After the first load repetition was applied (the first 10 cycles) the specimen was rotated around 90° and another cyclic load was applied on the specimen. The final stiffness modulus was calculated as the average value of first and second loading repetition.

2.3.2. Indirect tensile fatigue test

Fatigue generally is expressed as the fracture under repeated stress with a maximum value generally less than tensile strength of material [6]. Fatigue life of asphalt mixture depends on different mixture properties such as type and amount of asphalt binder, air voids, and mix gradation [3]. Fatigue test can be conducted at controlled stress (load) or strain modes. During the controlled stress mode amount of applied stress is kept constant, and amount of strain increases. In controlled strain mode the strain value (deformation) is kept constant while the stress decreases during the test [15].

In this study, Indirect Tensile Fatigue Test (ITFT) was carried out in controlled stress mode according to EN 12697. For running ITFT, UTM was used, and compressive cyclic load was applied along with diametrical section of specimen in the form of haversine waveform with 500 ms repetition time and 100 ms pulse width. ITFT was conducted at the same stress levels and temperature as were used for stiffness modulus test.

Vertical deformation of specimen was monitored during the test. Fatigue life was defined as the number of load repetitions reached when the specimen splits, or deformation reaches to the maximum value of 9 mm [16].

Horizontal tensile strain also can be obtained as the function of stress and stiffness of mixture by using Eq. (3):

$$\varepsilon_x(\max) = \frac{\sigma_x(\max)(1 + 3\nu)}{S_m} \quad (3)$$

$\varepsilon_x(\max)$ is the Maximum tensile strain at the center of specimen, $\sigma_x(\max)$ is the Maximum tensile stress at the center of specimen, S_m is the Stiffness modulus of specimen and ν, Poisson's ratio (0.35 at temperature of 20 °C).