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Quantification of bituminous mortar ageing and its application in ravelling evaluation of porous asphalt wearing courses

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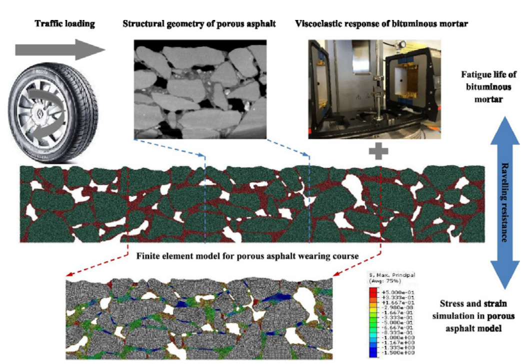
HIGHLIGHTS

- Ageing had more influence on complex shear modulus of mortar with base bitumen than mortar with SBS modified bitumen.
- Ageing had less influence on fatigue resistance of mortar with base bitumen than mortar with SBS modified bitumen.
- Ageing had more significant effect on ravelling resistance of PA wearing course with base mortar than that with SBS mortar.

GRAPHICAL ABSTRACT



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ABSTRACT

Bituminous mortar, consisting of bitumen, filler and fine aggregates (<0.5 mm), plays a dominating role on the viscoelastic properties of Porous Asphalt (PA), and its ageing is one of the key factors causing the ravelling of PA wearing courses. This research is to quantify the ageing effect on the rheological characteristics of bituminous mortars and apply it in evaluation of the ravelling resistance of PA wearing courses. Bituminous mortars for two types of PA (one with base bitumen and the other with Styrene-Butadiene-Styrene (SBS) modified bitumen) were artificially aged in the laboratory. Cylindrical specimens were then prepared with the aged mortars and their complex shear modulus and shear fatigue life were characterized through the Dynamic Shear Rheometer (DSR) tests. Finite element models containing the structural geometries and material responses of the two PA wearing courses were created. Their stresses and strains under traffic loads were simulated and analysed. The experimental results showed that ageing had more influence on the complex shear modulus of the base mortar compared to the SBS mortar. However, its effects on fatigue resistance are opposite. The numerical modelling results indicated that after ageing, the ravelling resistance of the PA wearing course with base mortar decreased more.

1. Introduction

Due to its extremely high population density, Hong Kong has shown increasing interests in low-noise road surfacing (LNRS) materials, such as Porous Asphalt (PA). PA is an open-graded asphalt mixture composed of aggregate skeleton, bituminous mortar and high percentage of air

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voids. Because of the high air void content (>20%), PA wearing courses have excellent performance in rolling noise reduction. Both base bitumen without polymer modification and polymer modified bitumen have been used to build PA wearing courses in Hong Kong. But the PA with polymer modified bitumen was found more cost-effective because of its higher durability, and has been used as the standard surfacing material in highways in force since 2007 [1].

Japan, which decided to use PA for all highways as a standard surface material, has long-term experience with PA wearing courses. The Japan experience has shown that PA with conventional polymer modified bitumen containing 5% Styrene-Butadiene-Styrene (SBS) has poor durability. It was found that a special polymer modified bitumen containing 9% SBS extended the service life of the PA wearing courses, and has been used in force since 1998 [2,3]. Within the United States, Georgia Department of Transportation (DOT) developed the specification for the first generation of PA in the 1990s. After that a number of states in the southern part of the Unities State specified PA and utilized it as the wearing course on all interstates. Most agencies specified polymer modified bitumen. Researches and field applications indicate that polymer modified bitumen, together with stabilizing fibre, can extend the service life and eliminate the ravelling problems [4–7]. The Netherlands, which has PA wearing courses on >90% of its main highway network, also has long-term experience with PA wearing courses. But contradictory to the experience in Hong Kong and many other regions, the Dutch experience has shown that polymer modified bitumen has no effect on the service life extension of PA wearing courses. It was reported that polymer modified bitumen was only useful to obtain a higher binder content in PA which led to a better behaviour in the field, but the same improvement could be obtained with base bitumen and drainage inhibitor [8–13]. These oversea experiences can lead to different polices for the design of PA wearing courses at large scaled application. Thus, it is worth to study and understand the benefits of using base and polymer modified bitumen in PA to improve the design of PA wearing courses in Hong Kong.

Bituminous mortar, also commonly known as fine aggregate matrix in North America, consists of bitumen, filler and fine aggregates smaller than the minimum aggregate size in the aggregate skeleton. It plays a dominating role on the viscoelastic properties of PA. Various studies have shown the potential of testing bituminous mortar as an efficient and repeatable approach to predict the performance of asphalt mixture. For instance, Mohammad et al. [12,13] investigated the viscoelastic behaviour of the bituminous mortar and hot mix asphalt. Certain linkages between them were found and used to explain the effect of hydrated lime under moisture damage conditions. Huurman et al. [14–17] designed a mechanistic lifetime optimization tool for PA, based on the experimental tests of the behaviour of bituminous mortar and the adhesive bond between stone and bituminous mortar. It was found that the lifetime optimization tool calculations had a strong correlation with the full-scale PA performance. Underwood and Kim [18] found that bituminous mortar can be useful for both practical and model tasks with proper material design and testing. Sousa et al. [19] developed a new procedure for preparing bituminous mortar specimens and conducted fracture mechanics-based analysis of damage in bituminous mortar. He et al. [20] reported that the bituminous mortar testing can be considered as an effective alternative approach to chemical binder extraction for characterizing the properties of blended binders in asphalt mixtures containing high quantities of reclaimed asphalt pavement.

The high air void content makes PA more sensitive to damage due to traffic and environmental effects than dense-graded mixtures. Ravelling, defined as the loss of stone particles from the pavement surface, is the most common type of damage of PA. Due to ravelling, the average service life of PA wearing courses is usually shorter than that of dense-graded wearing courses [8–10]. Ageing of bituminous binder is believed to be one of the main reasons for ravelling damage of PA wearing courses [21,22]. Therefore, the benefits of using base and polymer modified bitumen in PA can be investigated through quantification of bituminous mortar ageing and evaluation of ravelling resistance of PA wearing courses with aged mortars.

The main objectives of this study are to quantify the ageing effect on the rheological characteristics of bituminous mortars and apply it in evaluation of the ravelling resistance of PA wearing courses. To achieve these objectives, bituminous mortars for two typical types of PA wearing courses, one with base bitumen and the other with SBS modified bitumen, were artificially aged in the laboratory. Cylindrical specimens were then prepared with these aged mortars and tested using the Dynamic Shear Rheometer (DSR). Their rheological properties were characterized by constructing the master curves of complex shear modulus and phase angle, and determining the shear fatigue lives at various shear strain levels, respectively. Finite element models containing the structural geometries and material responses of the two PA wearing courses were created in the program ABAQUS. The stresses and strains in these two PA wearing courses under traffic loads were simulated and analysed.

2. Experimental programs and numerical models

2.1. Materials

Bituminous mortars for two types of PA were studied in this research. One is the PA 0/16, which has been widely used as highway surfacing material in the Netherlands. It consists of crushed stones with a nominal maximum aggregate size of 16 mm, crushed sand, mineral filler and base bitumen with a penetration grade of 70/100. Its bitumen content is 5.5% by mass of total mineral aggregates [9]. The other is the PA 0/10, which is the typical type of PA used in Hong Kong. This mixture consists of crushed stones with a nominal maximum aggregate size of 10 mm, crushed sand, mineral filler and SBS modified bitumen with a Superpave performance grade of PG76. It has a bitumen content of 5.8% by mass of total mineral aggregates [1]. The gradations of these two asphalt mixtures are presented in Table 1. The gradations of PA 0/16 and PA 0/10 were used to calculate the material compositions of their bituminous mortars.

According to Muraya's research on aggregate skeletons of asphalt mixtures [23], the aggregate skeleton in PA is composed of aggregates with sizes larger than 0.5 mm. Therefore, the bituminous mortar used in this research contained fine aggregates with sizes smaller than 0.5 mm. In order to determine binder content of the bituminous mortar, it was assumed that all mineral aggregates in PA mixture are coated with a thin bitumen film of 10 μm [14,15]. The binder content of bituminous mortars was calculated by deducting the amount of bitumen that coats the aggregates with sizes larger than 0.5 mm from the total amount of bitumen used in the asphalt mixture. The surfaces of aggregates were estimated by simplifying the aggregates as spheres with representative sizes. Table 2 presents the material compositions of the two bituminous mortars used in this research.

To prepare bituminous mortar, fine aggregates, mineral filler and bitumen were completely mixed at a temperature of 165 °C. Afterwards, the bituminous mortar was aged in an oven at 165 °C for 2 h and then

Table 1
Gradations of the asphalt mixtures PA 0/16 and PA 0/10.

Mixture	Sieve size (mm)	22.4	16.0	11.2	8.0	5.6	2.0	0.5	0.18	0.063
PA 0/16	Passing percentage	100	97.0	73.0	47.0	22.0	15.0	9.3	6.0	4.5
PA 0/10	Passing percentage	100	100	97.0	65.0	21.0	14.0	8.0	5.8	4.2