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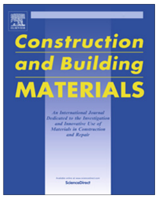

Disruption of air voids continuity based on permeability loss due to mortar creep

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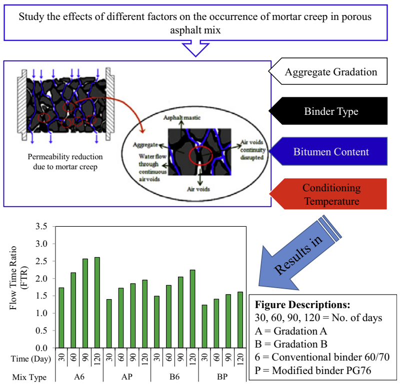
HIGHLIGHTS

- Mortar creep takes place due to the downward migration of asphalt mortar.
- Effects of gradations, binder types, binder contents, and temperatures were studied.
- Assessment was continuously monitored using a simple falling head permeameter.
- Mortar creep has significantly disrupted the continuity of air voids in the samples.
- Samples prepared using conventional bitumen at high binder content undergoes greater permeability loss.

GRAPHICAL ABSTRACT

All factors significantly affect the occurrence of mortar creep in porous asphalt prepared in the laboratory, especially for the specimens conditioned at the highest temperature. Permeability loss was more significant on the specimens prepared using conventional binder at a higher bitumen content.



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ABSTRACT

Mortar creep takes place when the asphalt mortar continuously migrates downwards due to gravitational forces and can significantly disrupt air voids continuity in porous asphalt samples. This study was an extension to a previous work that ascertained the existence of the binder creep phenomenon as reflected from the continual permeability loss especially on samples conditioned at elevated temperatures. Nonetheless, in this paper, the terminology "mortar creep" was adopted instead of "binder creep". This is because, in an asphalt mixture, the aggregates are glued together not by the binder in isolation, but by the mortar; which is comprised of asphalt binder, fine aggregates and filler. The variables investigated included aggregate gradation, binder type, bitumen content and conditioning temperature. The mixes were prepared using conventional bitumen (60/70 pen. grade) and modified asphalt binder (PG76) at three levels of binder content at 0.5% increment. Permeability loss was continuously monitored over an extended period up to 120 days using a simple falling head water permeameter. Over the test period, the samples were separately conditioned at 15 °C, 20 °C, 30 °C and 35 °C. The results showed that all factors significantly affect the occurrence of mortar creep in porous asphalt prepared in the laboratory, especially for the specimens conditioned at the highest temperature. Permeability loss was more significant on specimens' prepared using conventional binder at a higher bitumen content.

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1. Introduction

The physical characteristics of porous asphalt (PA) differ from conventional dense mixes due to its high air voids and macro-texture. The air voids in PA function to mitigate noise due to the friction between rolling vehicle tires and the pavement surface. The porous pavement surfacing layer eliminates ponding water on the pavement during rain, especially during the heavy monsoon downpours. However, the drainage capacity of porous pavement is only governed by the presence of continuous air voids in PA [1], which also contributes to higher pavement skid resistance, provides better visibility and enhances the riding quality especially at night and in wet weather [2].

After a few years in service, the reduction in effective (interconnected) air voids occurs due to the clogging of air voids and densification under heavy traffic, which can decrease its functionality as a permeable mix [3–5]. Typical clogging agents include fine particles such as dust, tire rubber, debris, and deicing materials, as well as dead vegetation and accumulated oily materials [6–8]. In addition, clogging can also occur due to deterioration of aged asphalt mastic from the PA and this is described as micro-raveling [9,10]. Isolated air voids do not contribute to the drainage capacity of PA. Previous studies indicated that the efficiency of drainage is obviously enhanced when the air voids exceed 15% [11,12]. Air voids is not a good indicator of mix permeability. Rather, the drainage capacity of PA can be better quantified in terms of mix permeability or hydraulic conductivity. Tan et al. [13] acknowledged that evaluations on the effective air voids of a porous medium can be rather complicated, while direct measurement of the permeability seemed more practical and accurate since it is directly linked to the drainage performance.

Two known sources of permeability loss in porous asphalt include clogging and traffic overcompaction causing mixture densification. Hamzah et al. [14] discovered a new source of permeability loss termed as binder creep and this takes place due to the action of gravity. The occurrence of binder creep was manifested in terms of gradual permeability loss. In order to ascertain this phenomenon, permeability measurements were carried out at regular intervals up to 60 days on samples conditioned at four temperatures ranging from 15 to 35 °C to respectively mitigate and accelerate the binder creep phenomenon. It was found that binder creep was magnified when samples were conditioned at elevated temperatures, namely; 30 °C and 35 °C. When the asphalt binder creep takes place, it flow and filled up the air voids in the PA mixtures, disrupting air voids continuity, making it more torturous for water to permeate through the specimen. This increased the time taken for water to flow through the sample. Simple linear regression equations were also developed to determine the susceptibility of PA mix to binder creep.

This paper investigates the effects of aggregate gradation, conditioning temperature, binder type and binder content on mortar creep of laboratory-prepared PA specimens. However, the terminology "mortar creep" was adopted instead of "binder creep" that was coined in the previously published paper [14]. This is because, in an asphalt mixture, the aggregates are glued together by the mortar, not the binder in isolation. By convention, the mortar comprises of the asphalt binder, fine aggregates and filler material. A falling head permeameter was used to measure samples permeability for up to 120 days at designated intervals. Samples were prepared based on the specified Malaysian PA gradation and modified PA gradation designated as Grading A and B, respectively. Fig. 1 shows the detailed plan of the study.

2. Materials and methods

2.1. Materials

The crushed granite aggregates used were obtained from a local quarry, KUAD Sdn. Bhd. that is located in the northern part of Peninsula Malaysia. Meanwhile, both conventional bitumen (60/70 Pen Grade) and modified bitumen (PG76) used were supplied by Shell Ltd., Singapore. The two aggregate gradations A and Grading B differ in terms of their breakpoint locations, corresponding to sieve sizes 2.36 mm and 5 mm respectively, as shown in Fig. 2. Grading B was designed by making reference to the Dutch PA mixture design and properties due to its durability and good performance with a service life ranging from 10 to 12 years for the heavy lane [15] and in many instances up to 16 years for the fast lane [16]. The properties of aggregate and asphalt binder were evaluated and tabulated in Tables 1 and 2.

PA samples were prepared by impact mode of compaction at 50 blows per face. The samples were then left to cool at the laboratory ambient temperature for four hours before being immediately tested for permeability. After the initial permeability was measured, the specimens were conditioned at the designated conditioning temperatures. All specimens were left in the mold (un-extruded) to take advantage of the strong bond between the sample and the walls of the mold.

2.2. Evaluation on mortar creep

To evaluate the extent of mortar creep the permeability of each mix was recorded at a selected time for up to 120 days for the specimen conditioned at 15 °C and 35 °C, and 60 days for the samples conditioned at 20 °C and at the ambient temperature (30 °C). The permeability reading was taken quickly to avoid changes in specimen temperature, and the permeant's temperature was also taken into consideration. The detailed explanation of the testing procedure was mentioned in a previously published paper [14]. Prior to the test, the specimens were prepared with design binder contents as shown in Table 3. The design binder contents of each mixture were selected based on the following four specified requirements:

i. compacted PA mixture's air voids should not be less than 18% [17]
ii. coefficient of permeability should be higher than 0.116 cm/s [6]
iii. binder drainage should not exceed 0.3% [6]
iv. permitted abrasion loss at 30 °C should be less than 16% [18]

Based on the collected data, the results were then presented in terms of flow or discharge time and coefficient of permeability in units of seconds and cm/s, respectively. Flow time is the time taken for water in the standpipe to fall from one level (h_1) to another level (h_2) in the permeameter [14]. The coefficient of permeability (k) was computed using Eq. (1).

$$k = 2.3\frac{aL}{At}\log_{10}\left(\frac{h1}{h2}\right) \tag{1}$$

where;
k = Coefficient of permeability (cm/s)
A = Cross section area of specimen (cm^2)
a = Cross section area of standpipe (cm^2)
L = Height of specimen (cm)
t = Time taken for water in the standpipe to fall from h_1 to h_2(s)
$h1$ = Head at the beginning of time measurement (cm)
$h2$ = Head at the end of time measurement (cm)

The Flow Time Ratio (FTR) was used to estimate the extent of the voids continuity disruption due to mortar creep. Changes in permeability or flow time, rather than changes in mix air voids, can better reflect changes in continuity of accessible voids in a porous mix. An ideal mix would have FTR equal to 1.0, and this implicates that the air voids remain continuous without any interference by mortar creep [14]. The ratio is expressed by Eq. (2).

$$\mathrm{FTR} = \mathrm{F_n}/\mathrm{F_0} \tag{2}$$

where;
FTR = Flow Time Ratio
F_n = Flow time at selected duration n (s)
F_0 = Initial flow time at day 0 (s)

3. Results and discussion

3.1. Effects of temperature and time

Fig. 3 shows the relationship between temperatures and the flow time (FT) of PA specimens. From the results, it can be seen that the temperature significantly affects the FT of the porous mixes. The specimens conditioned at a higher temperature resulted in higher rate of FT. This implies that mortar creep had taken place and steadily disrupted the air voids continuity of the PA mixtures which can be seen clearly in specimens conditioned at 35 °C. For example, the A6 mixes conditioned at 15 °C only experienced a slight increase of 10.5% in FT at day 120 while those at 35 °C exhibit more than 138% increase in FT. Overall, the mixes showed sim-