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Permeability of asphalt mixtures exposed to freeze–thaw cycles

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ABSTRACT

The objective of this research is to assess the permeability of asphalt mixtures exposed to freeze–thaw cycles in the cold region. Three types of asphalt mixtures were produced in a lab environment. A special constant head permeameter following the UNI EN 12697/19 protocol was adopted to evaluate the permeability of asphalt mixtures exposed to freeze–thaw cycles. The permeability of asphalt mixtures mainly focuses on two aspects: regime of flow in asphalt mixtures and hydraulic conductivity of asphalt mixtures. Results showed that the discharge velocity and hydraulic conductivity of asphalt mixtures are aggravated when samples are subjected to freeze–thaw cycles. Accordingly, the critical Reynolds number and corresponding critical hydraulic gradient for each sample decrease when freeze–thaw cycles increase. Results indicated that water can move through the asphalt mixture more easily because of the freeze–thaw cycles, and the scouring effect of water flow on the internal structure of asphalt mixtures becomes more significant. Linear regression equations were utilized on the collected data to determine the susceptibility of permeability growth rate of asphalt mixtures under freeze–thaw cycles to gradation type. Open graded asphalt mixtures exhibited steeper slopes compared with the other mixtures, which indicated their higher susceptibility to freeze–thaw cycles.

1. Introduction

Freeze–thaw damage is considered one of the major causes of premature degradation of asphalt pavements in frozen regions. The infiltration of water in asphalt mixtures combined with alternating positive and negative ambient temperature degrades the internal structure and weakens the adhesive bond between the aggregates and the binder (Ozgan and Serin, 2013; Tang et al., 2013). Thus, freeze–thaw damage starts from the infiltration of moisture in asphalt mixtures. Knowledge of moisture transport in asphalt mixtures exposed to freeze–thaw cycles will help researchers understand the progression of freeze–thaw damage in asphalt pavements.

Permeability is defined as the ability of a porous medium to allow water to pass through it. Asphalt pavement is a porous medium that consists of voids, aggregates, and asphalt binder. The complex void structure in asphalt mixture facilitates the abundant flow path for water (Kutay et al., 2007a). Researchers have conducted extensive studies to understand the permeability of asphalt mixtures in both macro-scale and micro-scale.

Air voids are generally regarded as the most useful macro-scale parameter to describe the void structure of asphalt mixtures. A high level of air voids always results in a significantly high probability of flow paths to exist within asphalt mixtures (Zube, 1962; Waters, 1998; Kanitpong et al., 2001; Cooley et al., 2002; Arambula et al., 2007; Feng et al, 2010; Vardanega and Waters, 2011). Zube (1962) and Cooley et al. (2001) suggested that 6%–8% of critical air voids are necessary for asphalt mixtures to form a connected void network. The results of Mallick et al. (2003), Hainin et al. (2003), Choubane et al. (2008) and Liu and Cao (2009) verified those of Zube's and also reported the air voids size increasing with increased nominal maximum aggregate size (NMAS). Thus, they modified critical air void limits by categorizing on the basis of NMAS from field data. Brown et al. (2004) demonstrated that a high number of air voids is connected in a thin lift thickness and a high risk of permeability problems. Hamzah et al. (2012) determined that binder creep in asphalt mixtures caused by gravitational forces always disrupts air void continuity over a long-term period, and subsequently reduces the permeability of asphalt mixtures.

Advanced test technologies, X-ray computed tomography (CT) characterize porous media based on their micro-level structure distribution. Many research used pore-scale images to examine the permeability of asphalt mixtures from the micro-scale. Shakiba et al. (2015) and Al-Omari and Masad (2004) developed a numerical scheme to simulate water flow by using X-ray CT images and discussed the moisture distribution characteristic in the pore structure of asphalt mixtures. Kutay and Aydilek (2007b) combined the Lattice-Boltzmann moisture model with X-ray images to analyze the permeability with void distribution in the micro-scale and depict the flow path in asphalt mixtures. Bhargava et al. (2012) used a simple numerical scheme and cross-sectional images to discuss the length of flow channels in asphalt mixtures and correlate this parameter with permeability. Benedetto and Umiliaco (2014) simulated the unsteady flow of moisture through

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Table 1
Properties of binders.

Index	Virgin asphalt	Modified asphalt
Penetration at 25 °C, 5 s, 100 g 0.1 mm	83.7	68.7
Softening point °C	51.4	85.2
Ductility at 15 °C cm	133	–
Ductility at 5 °C cm	–	33.4
Viscosity at 60 °C Pa s	–	82,367
Retained penetration after RTFOT %	85	75
Retained ductility at 15 °C after RTFOT cm	45	–
Retained ductility at 5 °C after RTFOT cm	–	25.6

Table 2
Properties of aggregate.

Aggregate size/mm	Properties				
	Bulk specific gravity	Apparent specific gravity	Water absorption/%	Angularity value/s	Flat and elongated particles/%
13.2	2.717	2.784	0.54	–	6.5
9.5	2.736	2.781	0.56	–	9.7
4.75	2.738	2.793	0.77	–	11.3
2.36	2.721	2.780	0.78	–	9.2
1.18	–	2.796	–	41	–
0.6	–	2.810	–		–
0.3	–	2.751	–		–
0.15	–	2.718	–		–
0.075	–	2.919	–		–

Table 3
Gradation of mixtures.

Gradation	Percent passing/%									
	16 mm	13.2 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm	0.075 mm
AC-13	100	95	76.5	53	37	26.5	19	13.5	10	6
SMA-13	100	95	62.5	27	20.5	19	16	13	12	10
OGFC-13	100	95	70	21	16	12	9.5	7.5	5.5	4

open-graded asphalt mixtures and analyzed moisture velocity vectors at different pore structures.

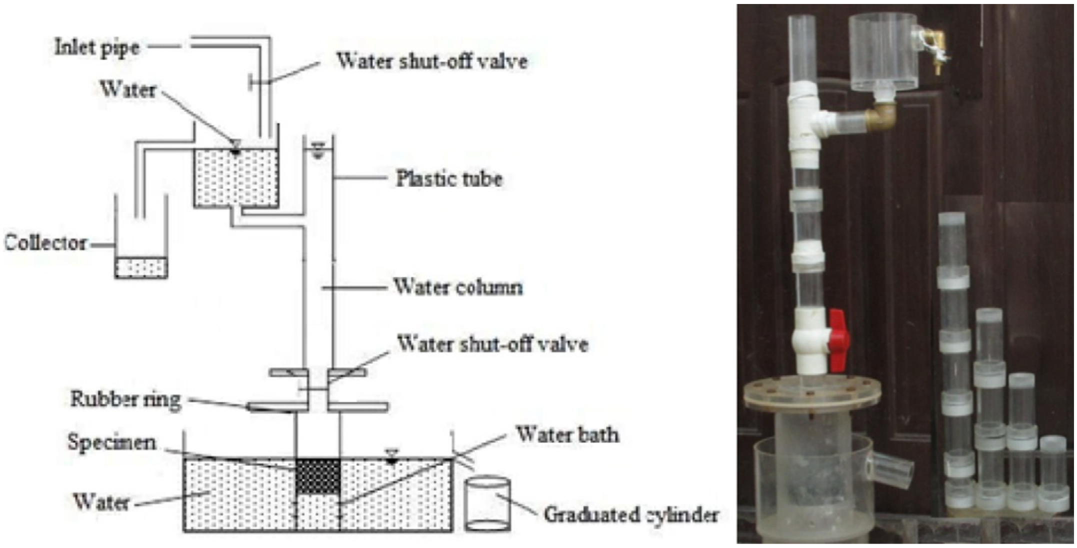
In conclusion, in open literature, void structure is considered to be the major factor affecting the permeability of asphalt mixtures. Efforts done by previous studies were prepared with details on void structure impact on permeability of undamaged asphalt mixtures from both macro-scale and micro-scale. Although a number of researches claimed the important role of irreversible expansion of ice volume on the air void distribution in asphalt mixture (Attia and Abdelrahman, 2010; Feng et al., 2010), few emphasized on the permeability evolution of asphalt mixture during freeze–thaw cycles, which could provide evidence for the progression of freeze–thaw damage. Therefore, three kinds of asphalt mixtures were taken in this study. Asphalt mixture samples were tested before freeze–thaw cycles to discuss the flow regime and characterize the initial void structure. Thereafter, samples were subjected to the freeze–thaw cycles. After 5, 10, 15, 20, 25, and 30 freeze–thaw cycles, damaged samples were collected for permeability test and X-ray CT to identify the changes in permeability and internal structure. Changes in permeability and void structure were used to evaluate the effect of freeze–thaw cycles on the permeability of asphalt mixtures. The effect of gradation type on the permeability of asphalt mixture exposed to freeze–thaw cycles was also discussed on the basis of test results.

2. Materials and methods

2.1. Materials

Three types of asphalt mixtures were used for the test: a stone mastic asphalt mixture (SMA), a conventional dense graded asphalt mixture (AC), and an open graded asphalt mixture (OGFC). The nominal maximum aggregate sizes for all asphalt mixtures were 13.2 mm. The air void content for the AC-13 and SMA-13 mixtures was set to 6 ± 1% to simulate the density of asphalt pavement in the field, which is typically between 93% and 95% of the theoretical maximum density. The design air voids of the OGFC-13 mixtures were maintained at 20 ± 1%.

An asphalt binder with a penetration grade of 80/100 was adopted to prepare the AC-13 and SMA-13 mixtures. Rubberized asphalt binder of 80 grades was selected to prepare of OGFC-13 mixtures. The properties of the two types of asphalt binders are presented in Table 1.



(a) Schematic diagram of apparatus (b) Physical map of apparatus

Fig. 1. Constant head permeameter used in this study.