Construction and Building Materials 182 (2018) 167–177

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Expansion and contraction of clogged open graded friction course exposed to freeze-thaw cycles and degradation of mechanical performance

Jun Chen [a,*], Cheng Yao [a], Hao Wang [b], Yangmin Ding [b], Tao Xu [c]

[a] College of Civil and Transportation Engineering, Hohai University, Nanjing 210098, Jiangsu, China
[b] Department of Civil and Environmental Engineering, Rutgers, The State University of New Jersey, Piscataway, NJ 08854, USA
[c] School of Civil Engineering, Nanjing Forestry University, Nanjing 210037, Jiangsu, China

HIGHLIGHTS

- Compared connected and total void content in OGFC mixture.
- Measured expansion and contraction of OGFC mixture exposed to FT cycles.
- Evaluated degradation of mechanical performance of OGFC mixture subjected to FT cycles.
- Proved negative effect of clogging on OGFC with frequent FT cycles.

ARTICLE INFO

Article history:
Received 22 March 2018
Received in revised form 16 May 2018
Accepted 11 June 2018

Keywords:
Open graded friction course (OGFC)
Freeze thaw (FT)
Clogging
Cantabro loss
Compressive strength

ABSTRACT

OGFC specimens with five air void contents and two clogging levels were scanned using X-ray computed tomography (CT). The contents of total and connected voids before and after clogging were calculated based on the reconstructed three-dimensional (3D) microstructure. The expansion and contraction of unclogged and clogged OGFC during eight freeze-thaw (FT) cycles were measured using a self-developed drainage instrument. Cantabro test and uniaxial compressive strength test were conducted on OGFC specimens before and after FT cycles. Results show that the expansion of OGFC during freezing is larger than the following contraction due to ice melting, which cause the residual expansion deformation in each FT cycle. OGFC has significant mass loss in the Cantabro test and reduction in compressive strength after FT cycles. The accumulated residual deformation and mechanical degradation after FT cycles increase with the increase of void content and clogging level.

1. Introduction

Open graded friction course (OGFC) has been widely used in asphalt pavements to improve traffic safety at rainy conditions (e.g., high skid resistance, visibility improvement and reduction of splash and spray) and provide environmental benefits (e.g., reduction of tire/road noise and enhancement of water runoff quality) [1,2]. Rungruangvirojn and Kanitpong [3] reported that the visibility of OGFC pavements increase by 1.4 times when compared to pavement surface with dense-graded asphalt mixtures (DGAM). Field study has showed that the noise of OGFC pavement decreases by 3–6 dB and 5.5–10.5 dB as compared to DGAM and Portland cement concrete respectively [4-7]. Mitchell [8], and Eck and Klenzendorf [9] found that the total suspended solids and lead present in the water runoff from OGFC decreases around 90% in comparison to those from the traditional DGAM.

Despite of the functionality benefits of OGFC, engineering practices have found that the application of OGFC faces three challenges during its service life, including clogging of air voids [10,11], raveling [12-14], and freeze thaw (FT) induced damage in winter [15,16]. Mallick et al. [17] reported obvious loss in permeability of OGFC pavement after 2–3 years in service due to clogging. According to Nielsen et al. [18], the clogging of OGFC pavement in urban roads generally occurred in Japan after 3–4 years of construction. Hu et al. [19] found that the permeability of one OGFC pavement section decreased from 1,700 ml/15 s to 450 ml/15 s after only eight months of construction. In addition, OGFC freezes sooner and for longer periods in winter in comparison to conventional asphalt mixture due to its high content of

* Corresponding author.
E-mail address: jun.chen@hhu.edu.cn (J. Chen).

https://doi.org/10.1016/j.conbuildmat.2018.06.095
0950-0618/

open and connected voids [6,20]. However, it limits the use of salt or sand during cold weather events, since sand tends to clog the open void structure of OGFC and salt will degrade the mixture microstructure and reduce adhesive strength [21,22]. This causes FT induced distress of OGFC, which limits its wider application in cold regions. Hernandez-Saenz et al. [23] reported that 19 northern states in the United States have discontinued the use of OGFC due to FT induced distress. Unlike the OGFC used in the United States, porous friction course (PFC) in Europe has coarser gradation, higher in-place air voids, with thickness of 40–50 mm, which caused low thermal conductivity (40–70% less than DGAM) and low internal temperature in winter (2 °C lower than DGAM) [24]. In Netherlands, it was found that the temperatures fluctuation in winter caused excessive raveling developed at different sections of the Dutch primary road network [25].

Considering the negative effect of clogging, researchers have investigated particle-related and deformation-related clogging of OGFC mixtures. One of the first published studies on particle-related clogging of OGFC was conducted by Fwa et al. [26]. The results of the study indicated that the permeability decreased relatively rapidly first and was followed by gradual reduction. Subsequently, the effect of aggregate gradations on particle-related clogging behavior was evaluated by Tan et al. [27]. The permeability loss of OGFC slab due to deformation-related clogging was evaluated in laboratory by Chen et al. [11]. It was found that clogging of OGFC could be reduced effectively by using larger nominal maximum aggregate size (NMAS) and greater air voids. In the clogged OGFC specimen, the critical sizes of trapped particles were 0.15–0.3 mm and 1.18–2.36 mm.

In addition to particle-related clogging, deformation-related clogging was investigated recently. Hamzah et al. [28] found that the permeability loss was significant on OGFC samples conditioned at high temperatures. To eliminate inaccuracy in permeability measurements due to binder creep, it is recommended that the permeability test is conducted not exceeding one day after preparation of OGFC specimens. Chen et al. [11] conducted wheel rutting tests on OGFC slabs with different loading times. Permeability loss after wheel loading was evaluated to explore the effects of initial air void content, NMAS, temperature, and loading pressure on deformation-related clogging. In addition to the permeability loss, clogging was also evaluated based on the internal structure of OGFC obtained by X-ray computed tomography (CT). Coleri et al. [29] compared X-ray CT images taken before and after full-scale accelerated pavement rutting tests (APT) to investigate deformation-related clogging of OGFC layers. It was found that the air-void content of core samples decreased significantly after APT rutting tests. Nielsen [30] compared CT images of cores drilled from different lanes in OGFC pavements and found that clogging was concentrated between wheel tracks and in emergency lane. Ahmed [31] utilized CT scanning and three-dimensional (3D) visualization to detect clogging of voids in OGFC cores and concluded that X-ray CT together with image analysis were precise and versatile tools in analyzing clogging degree of OGFC. Su et al. [32] reported that the clogging occurred mainly 20 mm below pavement surface after assessment of voids distribution of OGFC cores using X-ray CT.

In terms of OGFC damage due to FT cycles, Feng et al. [33] demonstrated that air voids in unclogged OGFC were more easily affected by FT cycles than those in DGAM. Xu et al. [34] found significant degradation in internal structure of unclogged OGFC after FT tests. The FT induced change in internal structure mainly occurs in three ways: (1) expansion of existing individual voids; (2) coalescing of two separated air voids; and (3) formation of new voids. Ozgan and Serin [35] concluded that air voids in asphalt mixtures increased by 40% after being exposed to FT for 24 days. After monitoring OGFC test cells at MnRoad for over two years, Weiss et al. [36] pointed out that severe raveling occurred in the clogged pavement exposed to FT cycles as compared to unclogged pavement and vacuuming could reduce raveling in cold climates.

By summarizing the literature cited above, clogging and FT related distress are two main challenges of OGFC, which limit its wider application. However, FT resistance was mainly investigated for unclogged OGFC, although the raveling of OGFC in winter mainly occurs at clogged sections as observed in MnRoad field sections. The expansion and contraction of clogged OGFC during FT cycles have not been studied. The effect of OGFC clogging degree on the degradation of strength and raveling resistance subjected to FT cycles are not well understood. Therefore, it is needed to investigate the raveling resistance of clogged OGFC and its volume change during the FT cycles.

2. Objective and scope

This study aims to investigate volume change and mechanical degradation of clogged OGFC subjected to FT cycles. Marshall specimens of OGFC with five void contents were clogged by fine soils with two clogging levels. X-ray CT technology was used to identify the total and interconnected air voids in unclogged and clogged OGFC specimens. The expansion and contraction of clogged OGFC during water-saturated FT cycles were measured using a self-developed drainage instrument. The residual expansion rate (RER) and accumulated residual expansion rate (ARER) of clogged OGFC after FT cycles were calculated. The Cantabro loss and uniaxial compressive strength of clogged OGFC before and after FT cycles were also tested. The volume change in clogged OGFC and mechanical degradation due to FT cycles were compared to that of unclogged OGFC.

3. Testing materials

Cores drilled from OGFC pavement usually have been damaged by traffic and environment (rain, temperature, and ultraviolet) [2,15], which may affects the evaluation of FT damage. In this study, OGFC with the NMAS of 13.2 mm (OGFC-13) specimens were prepared by laboratory compaction using crushed basalt aggregate, limestone filler, and high-viscosity modified asphalt. Five aggregate gradations were developed based on the theory of aggregate packing [37], as listed in Table 1. The basic rheological properties of high-viscosity modified asphalt prepared by 90# base asphalt and styrene-butadienestyrene (SBS) with the content of 5.4% were measured and listed in Table 2. The optimum asphalt content (AC) for each gradation was determined based on the binder drainage and Cantabro tests, which was previously developed in Spain by Pérez Jiménez and Calzada Pérez [38]. The content of air voids was determined after the bulk specific gravity of compacted specimen and the theoretical maximum specific gravity was measured following AASHTO T 275 (Eq. (1)) and AASHTO T 209, respectively [39,40]. Twelve standard Marshall specimens (101.6 mm in diameter and 63.5 ± 1.5 mm in height) for each gradation were prepared after the compaction of 50 blows on each side of the specimen.

$$G = \frac{m_0}{m_1 - m_2 - \left(\frac{m_1 - m_0}{\rho}\right)} \quad (1)$$

where G is the bulk specific gravity (g/cm^3), m_0 is the mass of dry specimen in air (g), m_1 is the mass of specimen with wax coating in air (g), m_2 is the weight of specimen with wax coating in water (g), and ρ is the specific gravity of wax at 25 °C (g/cm^3), which is 0.905 g/cm^3 in this study.

Twelve Marshall specimens at each air void content were divided into three groups (four in each group). One group of