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Effect of aggregate saturation degree on the freeze–thaw resistance of high performance polypropylene fiber lightweight aggregate concrete

Cong Zhu [a,1], Jiangang Niu [b,*], Jingjun Li [a,*,1], Chaojun Wan [a], Jiahui Peng [a]

[a] College of Materials Science and Engineering, Chongqing University, Chongqing 400045, China
[b] School of Architecture and Civil Engineering, Inner Mongolia University of Science and Technology, Baotou 014010, China

HIGHLIGHTS

- Two pre-wetting aggregate methods were adopted: pre-wetted under normal and 1.5 MPa pressure.
- Effect of aggregate saturation degree on the workability, compressive strength was studied.
- High aggregate saturation degree had a negative effect on the freeze–thaw resistance.
- High aggregate saturation degree served to the growth of AFt and CH crystal.

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ABSTRACT

The aim of this study was to investigate the influence of lightweight aggregate (LWA) saturation degree on such properties of high performance polypropylene fiber lightweight aggregate concrete (HPPLWC) as workability, compressive strength and freeze–thaw resistance. LWAs pre-wetted into four different degrees were used in this experiment. The results showed that: (1) increasing saturation degree of LWA could significantly decrease the slump loss with time of the fresh mixtures; (2) the 28 and 56-day compressive strength of samples with different saturation degree of LWA had no significant variation; (3) the relative dynamic elastic modulus was seriously reduced when the pre-soaked degree of LWA was close to saturation. In addition to SEM investigations of interfacial transition zone (ITZ), it was observed that increasing the amount of LWA water absorption served to the growth of ettringite (AFt) and calcium hydroxide (CH) crystal at 3 d; when cured for 28 d, the variation in saturation degree of LWA had no obvious effect on the ITZ morphology.

1. Introduction

Lightweight aggregate concrete (LWC) has been used in construction industry as masonry blocks, lightweight floor fills, wall panels, precast concrete units and so on for many years due to its various unique advantages including reduced self-weight, higher strength/weight ratio, construction costs effective and superior durability properties [1–4]. The key advantages of LWC should be attributed to porous lightweight aggregates (LWAs) which play an important role in providing the necessary strength and low density of concrete [5]. However, along with the porous property of ceramsites, some drawbacks of LWC, such as brittleness texture and inferior workability, would also be found [6–9], which seriously restrict the widespread use of LWC in civil engineering.

Extensive researches about the brittleness texture of LWA have been carried out up to now. Studies indicated that fracture resistance, crack resistance and toughness properties were improved in some degree by applying appropriate amount of HPP to LWC. Previous researches have shown that the brittleness of LWC is higher than ordinary concrete in the same mix proportion and the brittleness increases with the improvement of LWC strength [10]. In order to mitigate the brittleness and enhance the strength of LWC, many kinds of suitable fibers, such as steel fiber, polypropylene fiber and polyvinyl alcohol fiber, were usually added into LWC in a single or hybrid way. Until now, a lot of studies on the mechanical properties of fiber reinforced LWC have been done [11–14]. Most of them considered that the addition of fibers in LWC could significantly enhance the splitting tensile strength, flexural strength, flexural toughness and impact resistance.

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* Corresponding authors.
E-mail addresses: niujiangang@imust.edu.cn (J. Niu), 20150901014@cqu.edu.cn (J. Li).

[1] These authors contributed equally to this work.

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However, most investigations showed that the fibers had no obvious negative effect on the compressive strength of LWC.

LWAs usually have a very high water absorption compared with normal aggregates, which is ascribed to its numerous inner voids. Due to the porous structure, LWAs could easily absorb the free water, which significantly deteriorated the workability of fresh LWC unless the LWAs were adequately pre-wetted [8,9]. Now in engineering, such properties of fresh LWC as workability and pumpability are tremendously improved by means of pre-wetting LWAs. The pre-wetted LWAs which could play the role of water reservoir in the concrete were also utilized to prevent autogenous shrinkage cracking [15]. Simultaneously, the water saturated state of LWA would also affect such properties of hardened LWC as density, thermal insulation and freeze–thaw resistance [16].

Until now, some investigations of the influence of LWA saturation degree on the physical and mechanical properties of LWC have been carried out. R. Wasserme indicated that the early strength of LWC made of LWAs with strong water absorption capacity was very high [17,18]. Studies on the mechanical properties of LWC containing LWAs with different water saturation degree showed that LWC achieved higher strength when LWAs were pre-wetted for 30 min than that without pre-wetting or pre-wetted for 24 h [19]. Fujili held the view that when the water absorption of LWA was more than 90%, the freeze–thaw resistance of LWC would be significantly reduced [20].

Excessive water content of LWA would cause an increase in the amount of total water and thus might cause lack of cohesiveness between the aggregate and mortar, which affected the strength and durability of LWC. On the other hand, low LWA water content would lead the aggregates to absorb part of the mix water, which influenced the workability of LWC [21]. However, there has little report about the appropriate water saturation degree of LWA so far, which seriously restrict the widespread use of LWC in civil engineering. Therefore, it is obvious that extra attention should be paid to determining the moderate water saturation degree of LWA, which is based on the comprehensive consideration into macroscopic properties of LWC.

In order to avoid dry lightweight aggregates absorbing free water from surrounding cement paste resulting in the rapid reduction of concrete mixture workability, in most cases, one of the effective approaches was pre-wetting treatment of LWAs. However, excessive water content of LWA would cause an increase in the amount of total water, which had a negative impact on the durability of LWC. Even though numerous studies on the mechanical properties and durability of LWC have be carried out up to now, there is little information on the moderate water saturation degree of LWA. Hence, the main purpose of this study was to investigate the influence of LWA saturation degree on the freeze–thaw resistance of high performance polypropylene fiber lightweight aggregate concrete (HPPLWC). In order to enlarge the range of LWA saturation degree, the lightweight aggregates were pre-soaked under normal pressure and 1.5 MPa pressure by self-made device, respectively.

2. Experimental program

2.1. Raw materials

The cement used in this study was P·O 42.5R Portland cement, complying with the requirement of Chinese Standard GB175-2007 [22]. The fundamental properties of the Portland cement are showed in Table 1. Two types of lightweight aggregates (shown in Table 2) were used as coarse aggregates: lytag and shale ceramsite. The high performance polypropylene fiber (HPP) with corrugated surface was selected as reinforcement materials (L = 30 mm, D = 0.91 mm), produced by Ningbo Dacheng Advanced Material Co., Ltd. The fundamental properties of LWAs and HPP fibers are presented in Table 2. The fine aggregate was natural river sand (maximum size = 5.0 mm, bulk density = 1547 kg/m^3, fineness modulus = 2.9).

2.2. Test method

The details of the experimental set and the procedure are as follows

The test method of lightweight aggregate water absorption referenced to “Lightweight aggregates and its test methods-Part 2: Test methods for lightweight aggregates” (Chinese National Standard GB/T 17431.2-2010) [23]. Firstly, divided 4 L of dry LWAs into three equal parts and the mass of each part was denoted as m_1. Then, pre-wetted the LWAs for a certain period of time, the mass of each part after water absorption was denoted as m_0. The equation of the LWA water absorption for a specified period of time was $\omega_a=(m_0-m_1)/m_1\times 100$. The arithmetic mean of the three measured values was taken as the experimental result.

The compressive strength was measured on 100 × 100 × 100 mm cubes and the strength was the mean values of three identical specimens for each mixture according to “Standard for test method of mechanical properties on ordinary concrete” (Chinese National Standard GB/T 50081-2002) [24].

The test method of freeze–thaw resistance was on the basis of “Standard for test methods of long-term performance and durability of ordinary concrete” (Chinese National Standard GB/T 50082-2009) [25]. The freeze–thaw resistance was performed on 100 × 100 × 400-mm prismatic specimens which were cured for 28 d. The non-destructive test (NDT) method was employed to determine the freeze–thaw resistance of specimens. DT-W18 dynamic elastic modulus tester (Fig. 1) with frequency measurement ranging from 100 Hz to 20 kHz was used to measure the initial fundamental frequency of concrete specimens before and after freeze–thaw cycles. The NDT test was executed regularly every 25 freeze–thaw cycles. When any of the following conditions occurred, the set of tests was ended: ① reached 300 freeze–thaw cycles; ② The relative dynamic elastic modulus of the specimens decreased to 60%; ③ The mass loss rate of the specimens was up to 5%. The arithmetic mean of the three measured values was taken as the experimental result.

Concrete is a non-homogeneous material and can be classified as three phases: aggregates, cement paste and interfacial transition zone (ITZ). Even though the IZT occupies only a small volume in concrete, it has great effect on the strength and durability of concrete. In this study, we mainly focused on the microstructure characteristics of ITZ between lightweight aggregates and cement paste by using Hitachi S-3400 N SEM.

2.3. Mixture proportions

The strength class of LC30 was designed in the experiment due to the wide application of concrete with this strength class in construction engineering. The mixture proportions used in this study are shown in Table 3. Before mixing, the coarse aggregates were immersed in enough water for specified time under normal pressure and 1.5 MPa pressure, respectively. Then, the pre-wetted coarse aggregates were processed into saturated surface dry state with wet towels. The self-made pressurized pre-wetting device is shown in Fig. 2.

The mixing procedure was performed according to Ref. [26]. During the mixing procedure, the HPP fibers were gradually fed into the mixer by hand in order to attain the excellent distribution