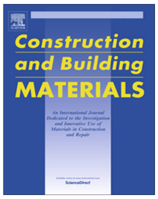
Construction and Building Materials 186 (2018) 773–781

Contents lists available at ScienceDirect

Construction and Building Materials

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



Interactive effects of freeze-thaw cycle and carbonation on tensile property of ecological high ductility cementitious composites for bridge deck link slab

Lijuan Chai [a], Liping Guo [a,b,c,*], Bo Chen [d], Yanhui Xu [a]

[a] School of Materials Science and Engineering, Southeast University, Nanjing 211189, China
[b] Jiangsu Key Laboratory of Construction Materials, Nanjing 211189, China
[c] Collaborative Innovation Center for Advanced Civil Engineering Materials, Nanjing 211189, China
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing 210029, China

HIGHLIGHTS

- Ultimate tensile strain of ECO-HDCC decreases as interaction cycle increases.
- Monotonic and cyclic loading regime have minor differences on tensile property of ECO-HDCC.
- Strain preloading level with a range of 0.6% has little influence on tensile property of ECO-HDCC.

ARTICLE INFO

Article history:
Received 18 June 2018
Received in revised form 27 July 2018
Accepted 31 July 2018

Keywords:
Interaction cycle
Tensile property
Monotonic loading
Cyclic loading
Preloading level
Carbonation front

ABSTRACT

Interactive effects of freeze-thaw cycle and carbonation on ECO-HDCC tensile property were studied. Loading regime, interaction cycle and preloading level of ECO-HDCC were considered. Also, carbonation front was determined using thermal analysis and X-ray diffraction methods. Results indicate that monotonic and cyclic loading regimes create minor differences in tensile performance of ECO-HDCC. Tensile stress of ECO-HDCC increases for 1–5 interaction cycles while decreases for 10–15 interaction cycles. Tensile strain of ECO-HDCC decreases as the interaction cycle increases. In addition, strain preloading level with a range of 0.6% has little influence on tensile property for ECO-HDCC. Results also revealed that carbonation fronts of ECO-HDCC are 3 mm and 7 mm for 1 and 3 interaction cycles, respectively. Finally, after interactions of 15 cycles, tensile property of ECO-HDCC with un-preloading under monotonic loading regime is selected for bridge deck link slab design.

1. Introduction

Many highway bridges are composed of multi-span steel or prestressed concrete girders, which are supported simply by piers or bents, and expansion joints are installed between adjacent simple-span girders. However, water leakage and flow of deicing chemicals through joints may affect the bearing capacity of girders. Thus, an approach to alleviate this problem involves the elimination of expansion joints in multi-span bridges [1].

Bridge deck link slab is an attractive alternative to replace expansion joints, which means the entire bridge structure will be continuous. In addition, bridge deck link slab is subjected to bending moment under traffic loading and is able to bear tensile stress caused by shrinkage, creep and variable temperature. Moreover, crack width should be carefully controlled for water leakage or deicing salt penetration.

Elastic concrete and high ductility cementitious composites (HDCC) are typically used to make bridge deck link slab. Elastic concrete is designed to adapt to traffic direction deformation, which is similar to the purpose of an expansion joint. However, the flexural performance of elastic concrete located in the negative moment zone is not considered in the design of bridge structure. Thus, elastic concrete may crack caused by flexural load, which can affect the service life of bridge structure [2].

HDCC as a fiber-reinforced cement-based composite material, has an average ultimate tensile strain of more than 0.5% and an average crack width of less than 200 μm [3]. Lepech et al. [4] applied HDCC material to cast a bridge deck link slab in Michigan,

---

* Corresponding author at: School of Materials Science and Engineering, Southeast University, Nanjing 211189, China.
E-mail address: guoliping691@163.com (L. Guo).

https://doi.org/10.1016/j.conbuildmat.2018.07.248

and the monitor result showed that the property of link slab remains unchanged after two years. Guo et al. [5] used HDCC material to replace the expansion joint, and the in situ sampling result indicated that HDCC meet the design requirements.

The axial tensile property of HDCC caused by shrinkage, creep or temperature changes should be considered in link slab design. Recently, HDCC behavior under tension brought about by monotonic loading has been intensively studied. However, the bridge structures are usually exposed to severe cyclic loadings such as traffic loads, wind gusts, and sea waves. Thus, a full understanding of HDCC material behaviors under cyclic loading is indispensable to the safe and economical design of bridge deck link slabs. A few investigations of HDCC behavior under cyclic loading have been performed. Dougals et al. [6] conducted a study about strain rate on HDCC stress-strain curve, and the results indicated that the curve from the cyclic test lay below that measured in monotonic loading regime due to high strain rates. Mechtcherine et al. [7] investigated the tensile behavior of HDCC under monotonic and cyclic loading regimes, and the results did not show any pronounced influence of loading conditions on tensile property.

Bridge deck link slab made by HDCC is exposed to a complex environment and subjected to different durability factors. For example, freeze-thaw cycle effect should be considered in a cold climate, and carbonation is one of the main factors in warm climate conditions. Thus, the durability effect on tensile behavior of HDCC needed to be explored.

At present, only a few studies have reported on durability projects. Yun et al. and Kim et al. [8] investigated the freeze-thaw cycle effect on tensile behavior of HDCC under monotonic axial loading as well as cyclic axial loading using cylinder specimens. The results indicated that tensile strength of HDCC increased while ultimate tensile strain decreased after exposure to 200 freeze-thaw cycles. It can also be concluded that loading regime had little influence on tensile behavior of HDCC. Yun et al. [9] conducted a study regarding the freeze-thaw effect on tensile behavior of HDCC with hybrid PVA and PE fiber under monotonic loading, and a dumbbell-shaped specimen was used. The results indicated that freeze-thaw cycle had little influence on tensile strength, while ultimate tensile strain showed a decreasing trend after treatment with 300 freeze-thaw cycles. In addition, research regarding the interaction of freeze-thaw and carbonation in HDCC is rare.

However, studies regarding the interaction of freeze-thaw and carbonation in concrete have been reported, and conclusions can be drawn that the mechanical property for concrete after interaction of multi-factors decreased more severely than that for concrete after single factor. When concrete was subjected to freeze-thaw first and then subjected to carbonation, the mechanical property decreased more severely than that of the concrete with another interaction mode [10].

Notably, bridge deck link slab is subjected to numerous forms of deterioration according to the environment characteristics. For Qinghai Province in northwest China, bridge deck link slab is subjected to freeze-thaw cycle from December to February in winter, and carbonation should be considered for link slab from March to December. The interactive effects of freeze-thaw cycle and carbonation on HDCC must be considered in structural design. In addition, HDCC mixture used in a previous study contained quartz sand and Kuraray-II PVA fiber, resulting in a high cost. To promote cost-efficient HDCC material in engineering applications, river sand and domestic PVA fiber were screened to prepare Ecological HDCC (ECO-HDCC), and the cost of ECO-HDCC was only one third of that of traditional HDCC [11,12].

For compressive property requirements of bridge pavement material [13], an ECO-HDCC mixture with compressive strength of more than 40 MPa was selected. To better understand the durability effect on tensile behavior of ECO-HDCC for bridge deck link slab, interactive effect of freeze-thaw cycle and carbonation was investigated as mechanical property may severely decrease during the interaction mode. In addition, tensile property of ECO-HDCC for monotonic test as well as cyclic test was conducted. Moreover, different preloading levels for ECO-HDCC were also considered in the study. Furthermore, differential scanning calorimetry-thermal gravimetric (DSC-TG) and X-ray diffraction (XRD) methods were adopted to reveal the carbonation front after different interaction cycles. Scanning electron microscope (SEM) was used to observe the fiber surface condition during different interaction cycles.

2. Experimental program

2.1. Materials

The raw materials used in the study were all provided by local manufacturers. The P·II 42.5R Portland cement (C) and Class F fly ash (FA) were used as the binding materials. River sand (S) was selected as the aggregate. Its density, fineness and maximum diameter were 1605 kg/m^3, 1.68 and 1.18 mm, respectively. The domestic short PVA fiber produced in China was used as reinforcement and the main properties were presented in Table 1. Polycarboxylate superplasticizer (PS) was used to adjust the workability of the fresh ECO-HDCC paste. These raw materials were mixed by the tap water (W). The mixture proportion of ECO-HDCC with a designed compressive strength of 40.0–48.0 MPa is shown in Table 2.

2.2. Specimen preparation

Mixer for mixing mortars was used to prepare ECO-HDCC material. The procedures for mixing the ECO-HDCC specimens were as follows: all solid ingredients, including cement, fly ash, river sand and polycarboxylate superplasticizer powder were mixed for 90 s at low speed. Then, water was added and mixed for 240 s at high speed. Stay for 30 s to eliminate bubbles. Finally, fibers were added slowly and mixed for 120 s at high speed.

Three 100 mm cubic specimens were prepared for compressive strength test of ECO-HDCC. Dog-bone specimens with the dimensions of 13 mm × 30 mm × 100 mm at middle zone were obtained for tensile property test [14].

All fresh ECO-HDCC specimens were placed in laboratory with the temperature of 21 °C, and demolded at age of 24 h. Then, specimens were cured in curing room with the temperature of 23 °C and relative humidity of 95% until 28 days of age.

2.3. Test procedures

2.3.1. Interaction test of freeze-thaw cycle and carbonation

Based on the environmental conditions of bridge deck link slab engineering in Qinghai Province of northwest China, an interaction test program of the freeze-thaw cycle and carbonation for ECO-HDCC was determined. Notably, the carbonation speed was quite low during the freeze-thaw process due to low temperature, and the carbonation phenomenon would not occur approximately [15,16]. In addition, the mean freeze-thaw cycle was approximately 118 per year in winter lasting for three months [16,17], and carbonation lasted for nine months. With reference to

Table 2
Mixture proportions of ECO-HDCC (kg/m^3).

C	FA	S	PS	W	PVA
496	744	372	1	372	26

Table 1
Physical and mechanical properties of PVA fiber.

Length (mm)	Mean diameter (μm)	Density (kg/m^3)	Ultimate elongation (%)	Ultimate tensile strength (MPa)	Elastic modulus (GPa)
12	39	1300	5–8	≥1250	30