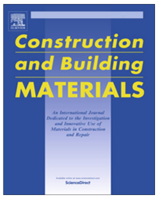
Construction and Building Materials 123 (2016) 317–326

Contents lists available at ScienceDirect

Construction and Building Materials

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



Relationship between tensile Young's modulus and strength of fly ash high strength concrete at early age

Dejian Shen [a,b,*], Xiang Shi [a,b], Shuaishuai Zhu [a,b], Xiaofang Duan [a,b], Jinyang Zhang [c,a]

[a] College of Civil and Transportation Engineering, Hohai Univ., No. 1, Xikang Rd., Nanjing 210098, China
[b] Jiangsu Engineering Research Center of Crack Control in Concrete, No. 1, Xikang Rd., Nanjing 210098, China
[c] Anhui and Huai River Water Resources Research Institute, No. 771, Zhihuai Rd., Bengbu 233000, China

HIGHLIGHTS

- Mechanical properties of fly ash high strength concrete at early age were investigated.
- A model between uniaxial and splitting tensile strength at early age was proposed.
- A model between tensile and compressive Young's modulus at early age was proposed.
- A model between tensile Young's modulus and uniaxial tensile strength was proposed.

ARTICLE INFO

Article history:
Received 3 January 2016
Received in revised form 17 June 2016
Accepted 29 June 2016

Keywords:
High strength concrete
Fly ash
Early age
Prediction model
Uniaxial tensile strength
Tensile Young's modulus
Compressive strength

ABSTRACT

This paper presents an experimental investigation on the tensile properties of hardening fly ash HSC at different ages and quantifies the uniaxial tensile strength and tensile Young's modulus of fly ash HSC. Test results showed that: (1) the axial compressive strength of hardening fly ash HSC at early age was lower than cubic compressive strength at the identical age; (2) the uniaxial tensile strength of hardening fly ash HSC at early age was lower than splitting tensile strength at the identical age; (3) the tensile Young's modulus of the hardening fly ash HSC at early age was approximately 1.06–2.02 times of the compressive Young's modulus at the identical age; (4) the tensile Young's modulus of hardening fly ash HSC at early age increased with the increase of uniaxial tensile strength. The prediction models showed good accuracy with the experimental results.

1. Introduction

High strength concrete (HSC) has been widely used in civil engineering because of its better rheological, mechanical and durability properties than conventional concrete [1–3]. Modern HSC offers high strength and low permeability by using superplasticizers and supplementary cementing materials, such as fly ash, silica fume, granulated blast furnace slag, and natural pozzolan, which are industrial by-products and help in reducing the amount of cement required to make concrete less costly, more environmental friendly, and less energy intensive [4–6]. Moreover, the development of HSC meets the steadily increasing demands on higher, slender, and faster building [7,8]. However, the lower w/c ratio of HSC comes with high hydration heat [9–11] and high temperature rise [12,13], thus tensile stresses may overcome tensile strength and result in cracks in concrete [14]. Limiting crack at early age is crucial for HSC structure as cracks in the surface give access to the interconnected network of pores, micro- and macro cracks, especially in an aggressive environment [7,8]. Fly ash, stockpiled in large quantities in recent decades [15], is used as a supplemental binder of cement in HSC. Fly ash, when used in concrete, has several advantages, such as: improved plasticity, decreased adiabatic temperature rise, reduced permeability, and reduced possibility of alkali silica reaction and sulfate attack [16], which may solve the problem of high hydration heat and high temperature rise effectively. Thus, fly ash HSC is believed to be more crack resistant because of the less mixing water and lower cement content [17,18]. The increased use of fly ash in concrete may contribute to sustainable infrastructures with obvious benefits to the environment

---

* Corresponding author at: College of Civil and Transportation Engineering, Hohai Univ., No. 1, Xikang Rd., Nanjing 210098, China.

E-mail addresses: shendjn@163.com (D. Shen), shixianghhu@163.com (X. Shi), hhuzss@163.com (S. Zhu), duanxiaofang07@163.com (X. Duan), jyjy60085@vip.sina.com (J. Zhang).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.145
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

with possible significant reduction of greenhouse gases emissions. The inherent durability of concrete incorporating fly ash could have significant economic and environmental benefits, in particular for developing countries [16]. Although fly ash has been widely used in HSC, investigations dealing with tensile properties of fly ash HSC are relatively rare. Therefore, studying tensile properties of fly ash HSC at early age (28 days after casting) is necessary to thoroughly understand the cracking resistance of fly ash HSC structures.

Bond behavior [19–21], compressive strength [22–27] and Young's modulus [22,28–30] of concrete at early age have been widely studied. Tensile strength is widely used for evaluating the occurrence of cracks in concrete components and structures [31,32]. An accurate prediction of tensile strength of concrete will help in mitigating cracking problems, improving shear strength prediction and minimizing failure of concrete in tension [33]. Other structures such as pavement slabs and airfield runway, which are designed based on bending strength, are subjected to tensile forces [34]. Thus, in the design of these structures, tensile strength value is more important than the compressive strength. Also, tensile properties are imperative for the study of concrete structures under the state of tensile stresses, such as those due to temperature differentials and drying shrinkage [31]. Therefore, studying tensile strength of concrete at early age is necessary to thoroughly understand the tensile mechanism.

Many investigations dealing with tensile properties of normal strength concrete [28,31,35,36] and self-compacting concrete [37] at early age have been conducted. Tensile Young's moduli of concrete and wet-screened mortar at early age were investigated in [28], and a prediction method using a composite model was proposed. Uniaxial tensile properties of concrete at early age by direct tension test were investigated in [31]. Test program included ground granulated blast furnace slag (GGBFS) and pulverized fuel ash in concrete. Tensile Young's moduli of all concretes were well correlated with tensile strength. Properties of concrete at early age such as strength and deformations were investigated in [35]. Concrete at early age has to be defined in terms of maturity because temperature, as well as time, affects the performance of concrete. Uniaxial tension test using slender concrete beams with embedded reinforcing bars was conducted in [36]. The direct tensile strengths and bond characteristics of concrete at early age was studied, and the tension test was recommended as a testing method for tensile behavior of concrete. Splitting tensile strength and the modulus of elasticity of self-compacting concretes at different ages were investigated in [37]. Test results showed that the splitting tensile strength of self-compacting concrete made with limestone filler was 15% lower than that of normally-vibrated concrete. And the modulus of elasticity of cementitious paste was greater than that of the self-compacting concrete. Although investigations on tensile properties of normal strength concrete and self-compacting concrete at early age have been conducted, experimental study on the tensile properties of fly ash HSC is still lacking. Thus, investigation on tensile properties of fly ash HSC at early age is necessary.

Table 1
Mix proportion (kg/m^3).

Water	OPC	GGBFS	Fly ash	Fine aggregates	Coarse aggregates	Superplasticizer
156	340	73	73	600	1157	6.8

Experimental investigations on the tensile properties of fly ash HSC were conducted in present study. The uniaxial tensile strength, tensile Young's modulus, compressive strength, and compressive Young's modulus were tested and prediction models for uniaxial tensile strength, and tensile Young's modulus were proposed.

2. Experimental investigation

2.1. Material and mixture properties

The mixture proportions of fly ash HSC are shown in Table 1. The cementitious materials used in the present study were ordinary Portland cement (OPC), GGBFS and fly ash. The amount of fly ash used in present study was 15% of the cementitious materials, which was in accordance with the result in [38]. The Blaine fineness of cement used was 375 m^2/kg, which was in accordance with Chinese National Standard GB 175-2009. The fine aggregate was natural river sand with a density of 1.93 g/cm^3, fineness modulus of 2.20 and the maximum size of 1.5 mm. The coarse aggregate was crushed limestone with a density of 2.73 g/cm^3, fineness modulus of 6.66 and the maximum size of 15 mm. UNF-5AST with the water-reducing rate of 30%, supplied by Jiangsu Sobute new materials Co., Ltd., was used as superplasticizer in present study.

2.2. Specimens preparation

A five-piece mould of dimension 100 mm × 100 mm × 550 mm was adopted in present study for uniaxial tensile strength and tensile Young's modulus tests. The two holes accommodating the two embedded bars were carefully drilled to ensure that after the assembly, their centers were exactly at the geometric centers of the two end plates. The main embedded bar was a screw bar of 16 mm diameter and 150 mm in length. The bars were embedded with sufficient embedded length of 125 mm in concrete specimen leaving about 25 mm for the connection between specimen and testing machine, as shown in Figs. 1 and 2.

Concrete were placed into the specially designed tensile moulds for uniaxial tensile strength and tensile Young's modulus tests. The specimens were demoulded about 24 h after casting and cured in an environmentally controlled room with temperature maintained at 20 °C ± 2 °C and relative humidity higher than 95%. Two electrical resistance strain gauges of 100 mm in length and gauge factor of 2.06 ± 1% were glued on two opposite side faces in the middle section of test specimens, as shown in Fig. 1, which was in accordance with the method proposed in [31,39].

To compare the test results with other mechanical properties, cubic compressive strength, axial compressive strength, splitting tensile strength, and compressive Young's modulus tests were conducted at the identical age. Cubic compressive strength and splitting tensile strength tests used three cubic 150 mm specimens while axial compressive strength and compressive Young's modulus tests used six prismatic specimens with the size of 150 mm × 150 mm × 300 mm, as shown in Figs. 2(c)–(f). All the specimens were tested at the age of 1, 3, 5, 7, 14, and 28 days for concrete used in present study. The cylinder compressive strength f'_c could be calculated as $f'_c = 0.79 \times f_{cu}$, and f_{cu} was the cubic compressive strength of fly ash HSC. The equation was proposed in [40] and was also used in [41,42]. Thus, the cylinder compressive strength was 6.76, 24.16, 31.70, 34.03, 41.63, and 49.42 MPa when the concrete age was 1, 3, 5, 7, 14, and 28 days, respectively.

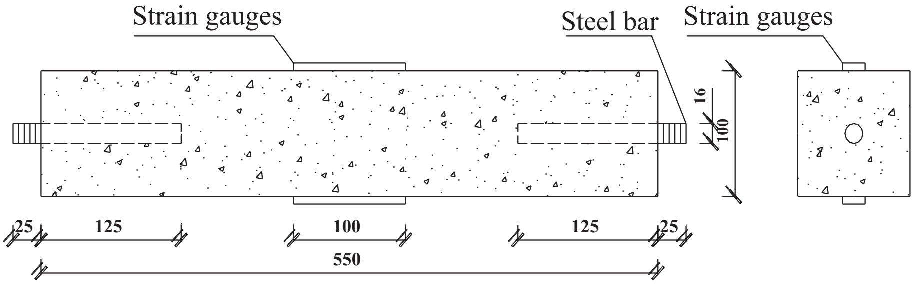


Fig. 1. Schematic drawing of specimen (all units in millimeters).