Construction and Building Materials xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of pore water saturation on the mechanical properties of fly ash concrete

Wei Wang [a], Caifeng Lu [a,b,*], Guanglin Yuan [a], Yanlong Zhang [c]

[a] State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221116, China
[b] JiangSu Collaborative Innovation Center for Building Energy Saving and Construct Technology, Xuzhou 221008, China
[c] XuZhou YuanTu Architectural Design Co, LTD, Xuzhou 221008, China

HIGHLIGHTS

- Pore water saturation was achieved by controlling the micro-environment of concrete.
- The mechanical properties all reached maximum value at the 15% fly ash replacement.
- Different degrees of pore water saturation were investigated.
- The trend of elastic modulus variation is opposite to compressive strength.

ARTICLE INFO

Article history:
Received 9 July 2016
Received in revised form 14 October 2016
Accepted 9 November 2016
Available online xxxx

Keywords:
Pore water saturation
Rebound method
Ultrasonic method
Compressive strength
Elastic modulus
Fly ash concrete

ABSTRACT

This paper investigates the effects of pore water saturation on the ultrasonic pulse velocity, rebound value, compressive strength, and elastic modulus of fly ash concrete. Fly ash concrete was placed in an artificial climate chamber to achieve different degrees of pore water saturation. Effects of the level of fly ash replacement and the degree of pore water saturation were examined on the concrete rebound value, ultrasonic pulse velocity, compressive strength and elastic modulus. The results showed that the influence of fly ash replacement on rebound values, ultrasonic velocity and elastic modulus was basically the same as on compressive strength. For the range of 0–45% for the level of fly ash replacement, the rebound value, the ultrasonic velocity, the elastic modulus and the compressive strength all reached their maximum value corresponding to the fly ash replacement level of 15%. As the degree of pore water saturation increased, the rebound value of fly ash concrete was increased first and then decreased, the compressive strength was decreased, but the ultrasonic velocity and the elastic modulus were increased.

1. Introduction

Concrete is a porous composite material made of cement, coarse and fine aggregate, and water mixed in a certain proportion. In addition to the porous structure, a large number of micro-cracks are generated in the surface and interior of concrete due to, (i) the drying shrinkage [1–6]; (ii) the differential thermal deformation [7–11] of the various components of concrete; (iii) the influence of the load [12–16], and so on. The existence of pores and cracks provides a channel for water to enter the interior of concrete. For hydraulic concrete structures, such as dams and bridge piers, water can penetrate into the concrete pores at different degrees depending on the extent of water pressure, and can make the concrete in such structures in a wet and even saturated condition. For concrete structures in the natural environment, the moisture in the air may also diffuse into the interior of concrete, and moreover, concrete has a certain degree of moisture content from the beginning [17–19].

Water is one of the essential ingredients for concrete, and it plays an important role in the mechanical properties of concrete [20–22]. For example, water affects the pouring of concrete mixture (workability) during construction. During the maintenance phase, the hydration of cement requires water; shortage of water can cause the cement hydration to end prematurely which can seriously affect the development of the later-age strength of concrete. However, excessive moisture in concrete negatively influences the strength and durability of concrete [23–25].

Pore water will lead to a significant change in the mechanical properties of concrete [26–29]. Changes in the mechanical

* Corresponding author at: State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221116, China.

E-mail address: 02110470@cumt.edu.cn (C. Lu).

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.031
0950-0618/

Table 1
Chemical composition of cement and fly ash.

Oxide	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	MnO	TiO_2	P_2O_5	SO_3
Fly ash	0.51	0.75	32.8	54.5	1.4	2.7	4.1	0.02	1.3	0.15	0.4
Cement	0.17	**2.5**	7.0	22.5	0.78	59	3.3	0.03	0.31	0.1	1.8

Table 2
Physical properties of cement and fly ash.

Properties	Cement	Fly ash
Specific gravity(g/cm^3)	3.15	2.4
Fineness(% retain in 45 μm)	–	7%
Specific surface area(cm^2/ g)	3280	3075
Water demand ratio (%)	–	84
Loss on ignition (%)	4.14	6.2

properties of concrete caused by water generally include two aspects: the chemical corrosive action of water and the mechanical action of water [30–33]. Even though the change in mechanical properties of concrete caused by the chemical action of water is relatively well understood, the effect of the mechanical action of water on the mechanical properties of concrete is more complicated; in particular, the mechanisms at the macro and micro levels are poorly understood.

Traditionally, pore water in concrete has not been adequately considered in the study of the mechanical properties of concrete. Even for a study [34] that investigated the influence of pore water, pore water was reported not to affect the compressive strength and elastic modulus of concrete. However, recent studies [20,35–45] have indicated that the mechanical properties of concrete are greatly influenced by the pore water content. Mehta and Monteiro [20] proposed that the compressive strength of wet concrete is lower than that of dry concrete. While some other investigations also showed that the compressive strength of dry concrete is greater compared to wet concrete, the elastic modulus is lower for the dry concrete [36–40]. Some studies have further shown that the influence of moisture content on the compressive strength of concrete is largely influenced by the loading rate [36,40–45]. Owing to the relatively fewer studies and often contradictory findings, it is essential to experimentally investigate the effects of pore water on the mechanical properties of concrete through macro mechanics approach.

Since the moisture content of concrete is difficult to control, existing studies mainly concentrate either in the dry concrete or the fully saturated concrete [36–37,39,46]. However, most concrete structures are generally exposed to the atmospheric environment, and the outside conditions may undoubtedly affect the material properties of concrete. The influence of relative humidity on concrete properties in normal humidity condition (Null To 100 %) is mainly governed by the change in air humidity [19,47–50]. Therefore, the effect of relative humidity should be investigated for a range of humidity rather than just the dry or fully saturated conditions.

Ultrasonic-rebound combined method is one of the most commonly used methods for the non-destructive testing of concrete strength. Ultrasonic-rebound strength curves, which are developed as a basis to correlate the rebound values to the strength of concrete, are generally established for dry concrete. However, pore water saturation of the surface or interior of concrete specimens will change if concrete specimens are exposed to a humid environment or immersed in water. Consequently, the accuracy of the ultrasonic-rebound test may be substantially impaired [39,48,51–52]. Thus, it is necessary to study the effect of concrete pore water saturation on the ultrasonic-rebound combined method.

In this study, fly ash concrete specimens are put into an artificial climate chamber whose temperature and humidity are preset to achieve different states of pore water saturation. The rebound values, ultrasonic velocities, compressive strength and elastic modulus were, respectively, tested by the Schmidt hammer, ultrasonic testing and standard test methods [53]. The effects of pore water saturation on the ultrasonic velocity, rebound value, compressive strength and elastic modulus of fly ash concrete were discussed.

2. Experimental details

2.1. Materials

2.1.1. Cement

Cement used was Dragon brand P.O 42.5 Ordinary Portland Cement (OPC) produced by the Huaihai Cement Factory, China. According to the current specifications described in the Chinese National Standard [54], the chemical composition and physical properties of the cement used in this study are given in Tables 1 and 2, respectively.

2.1.2. Fly ash

The class F fly ash from Xuzhou Liu Xin Pengcheng Power Plant in China was used. The fly ash met the requirements of Chinese National Standards [55–56] to be used in concrete. Its chemical composition and physical properties are given in Table 1 and Table 2, respectively.

2.1.3. Aggregate

Crushed stone with 20 mm nominal maximum size was used as coarse aggregate. Its water absorption value was 0.21% and specific gravity was 2.70 g/cm^3. Fine aggregate was natural river sand with specific gravity of 2.65 g/cm^3, water absorption value of 1.22%, and fineness modulus of 2.42 (medium sand). The stone and sand both met the requirements of the relevant Chinese National Standards [57–58].

2.2. Fly ash concrete mix proportion

This study considered C20 and C30 as the two base grades of concrete. Four levels of fly ash replacement were considered for each grade of concrete strength. The replacement levels included 0% (standard concrete), 15%, 30%, and 45% with corresponding designations as FA0, FA15, FA30, FA45, respectively. The 0%, 15%, 30%, 45% are the amounts of the replaced cement by mass; the mass of fly ash were 1.2 times of those of the replaced cement. Table 3 shows the mix proportions of concrete types used in this study. Water reducing admixture was used to control the slump of all concrete types in the range of 90 ± 5 mm. The water reducing admixture was the SBTJM-VIII naphthalene superplasticizer with a specified water reduction ratio of 28%. Water used in the concrete mixtures was ordinary tap water.

2.3. Preparation and casting of specimens

Cube specimens (150 × 150 × 150 mm) were prepared for performing ultrasonic-rebound testing and compressive strength testing. Prismatic specimens (100 × 100 × 300 mm) were prepared for testing elastic modulus. All concrete specimens were cast in steel moulds and were compacted by a vibrating table. After stripping