



Experimental research on drying control condition with minimal effect on concrete strength

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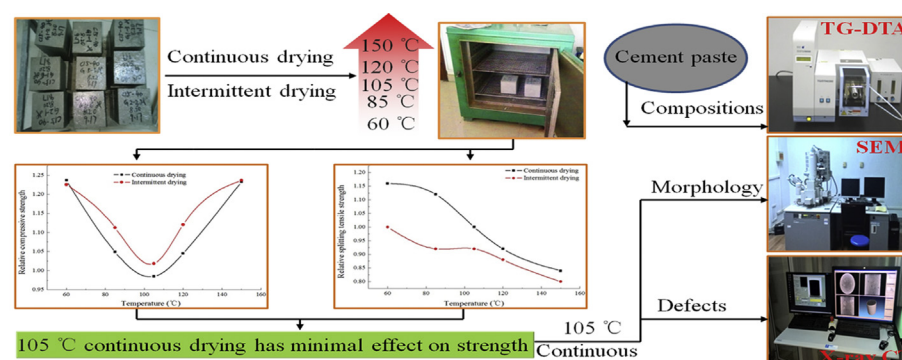
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HIGHLIGHTS

- Compressive strength decreases and then increases with increase in temperature.
- Splitting tensile strength decreases with increase in drying temperature.
- Drying control condition with minimal effect was obtained on concrete strength.
- Components and defects of concrete after nondestructive drying was analyzed.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to obtain the drying control condition with no or minimal effect on concrete strength, various drying temperatures conditions are used as 150 °C, 120 °C, 105 °C, 85 °C and 60 °C, and the drying procedure of continuous and intermittent cyclic are presented independently in this study. The change of specimen mass is recorded in the drying process, and the compressive strength and splitting tensile strength are measured after the natural cooling. The results show that the concrete compressive strength initially decreases and then increases with the increase in drying temperature, while the splitting tensile strength always decreases. The relative compressive and splitting tensile strength of concrete in dry state are 1 and 0.99 respectively after 115.5 h of continuous drying at 105 °C, which denotes the optimal drying control condition has minimal effect on the strength, and efficiency is suitable. Finally, the change in components and defects structure of the concrete after minimal damage drying is analyzed through the thermo-gravimetric analysis, electron microscope scanning and industrial CT scanning.

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1. Introduction

The amount of pore water in concrete has a significant influence on its durability [1–6]. In order to understand the influence laws of moisture content on mechanical properties of the concrete, a

drying treatment for concrete specimens is required to obtain the moisture content of the concrete specimens. The ideal drying treatment on the effect of eliminating physical water in the concrete should be obtained under the condition of inducing no or minimal changes in the concrete strength. However, there are no provisions on control of drying temperature and other conditions in current codes and standards, which cause researchers to use different types of drying conditions. Specimens need to be dried first for

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studying the differences in mechanical properties of dry and saturated concrete. For this, Wang et al. [7] placed the concrete specimens in indoor conditions for presetting and to obtain the dry state. For obtaining the dry state, Wang and Li [8] dried the concrete for 2 days at 30 °C and 50 °C, respectively, and then at 65 °C for 6 days. In another experiment, Wang and Li [9] dried the concrete for 1 day at 50 °C, afterwards the temperature is gradually increased from 65 °C to 75 °C, with drying of concrete at each temperature for 3 days. Finally, it is dried at 85 °C until the change in mass becomes constant. For studying the effect of laws of moisture content on mechanical properties of concrete, researchers generally dry the concrete completely at initial stage and then immersed it for different periods to obtain the concrete with various moisture contents. Liu et al. [10] placed the concrete specimens in the oven for drying at 45 °C until the change in mass becomes constant. In case of Zhou et al. [11,12], the dry state has been reached after drying the concrete specimens at 105 °C, i.e., at this temperature the mass becomes unchanged. Although the drying procedures of concrete are mostly the same, the different drying conditions cause variable loss in water, the required drying time and drying states are all vary. Since the drying process corresponds to the escape of water from the concrete, a rapid escape of water cause serious damages such as initiation, convergence and propagation of micro-cracks in the concrete [13–15]. Coarse and fine aggregates as well as cement binding materials in concrete of heterogeneous nature exhibit different thermal performances, therefore the physical and chemical reactions between these materials are complicated [16,17]. This makes significant differences in appearance, strength and phase compositions of concrete under different drying conditions. Those differences will certainly affect the correct evaluation of the changes that occurred in the mechanical properties of the concrete with different moisture contents.

In this paper, process of water loss and drying results are investigated for the concrete under different drying conditions by using the different drying temperatures and mechanisms. The influence laws of different drying conditions on concrete compressive and splitting tensile strength are analyzed for providing a suitable drying process with having very low or no damage on concrete strength and high drying efficiency. This will provide the basis for experimental designs for the mechanical properties of concrete in the wet states.

2. Experimental

2.1. Test materials and equipment

In this investigation, a complex Portland Cement (P.C32.5) produced in the Jidong cement plant of China was used in all formulations. The water was obtained directly from the city drinking water supply. The aggregate included medium sand (fine aggregate) and pebbles (coarse aggregate) produced in the Weihe plant of Yangling in Shaanxi Province, and the fineness modulus, clay content, apparent density and bulk density of the sand were 2.4, 0.8%, 2590 kg/m³, and 1540 kg/m³ respectively, while the clay content, apparent density, bulk density and maximum aggregate size of the pebbles were 0.6%, 2650 kg/m³, 1563 kg/m³, and 40 mm, respectively. The strength level of concrete in this research was C20, which was cured under the standard conditions

(20 °C ± 2 °C, RH > 95%) for 28 days. Concrete specimens were standard cube specimens whose length of side was 150 mm, and the mix proportions of concrete used are shown in Table 1 according to Chinese national standard DLT5330-2015 (the Code for Mix Design of Hydraulic Concrete). Drying equipment was electro-thermostatic blast oven whose temperature uniformity was within ±2.5%, and the volatility was within 1 °C. The operating temperature range was room temperature from 300 °C. Both compressive strength and splitting tensile strength tests of concrete were carried out using a microcomputer controlled fully automatic pressure tester, which was manufactured by Shanghai Xinsasi Measuring Instrument & Equipment Manufacturing Co., Ltd., China, whose model number was YAW4206 and whose maximum test force was 2000 kN, and the concrete strength test was conducted according to the Chinese national standard SL352-2006 (Hydraulic Concrete Test Procedure) [18].

2.2. Experimental procedure

The controlling factors in the experiment include the drying temperatures and the mechanisms. Drying temperature is realized by setting the operating temperature of the drying oven at 60 °C, 85 °C, 105 °C, 120 °C and 150 °C. Drying mechanisms include the continuous drying and the intermittent drying cycle. Continuous drying means that the specimens will be dried continuously under preset drying conditions until its reach the drying state. Intermittent drying cycle involve the drying of specimens continuously for 4 h under the preset drying conditions, afterwards the heating and air-blowing functions in the drying oven are shut down and specimens are naturally cooled down to the room temperature, followed by another continuous drying for 4 h. The specimens are exposed to such reversed drying cycle until they reach the drying state. Concrete cube specimens after 28 days of standard curing are divided into 11 groups according to the preset controlling factors, in which the 1st group is used as standard one, and the specimen strength of the 1st group is measured directly without implementing any drying temperature after 28 days of standard curing. The rest including the 2nd to 11th groups are shown in Table 2. Among the six specimens in each group, three of them are used to measure compressive strength, while the other three specimens are kept separately to measure the splitting tensile strength.

Specimens are collected from the standard curing room and a wet cloth is used to wipe their surfaces to remove any water. Afterwards, specimens are weighed and the mass of each group of specimens before drying is recorded. For drying the specimens, oven is preheated to predefined temperature and then each group of specimens are placed in using a stainless steel screen plate having dimensions of 800 mm × 800 mm. One group of specimens is dried each time and the specimens are distributed on the screen plate uniformly with intervals of 85 mm to assure the homogenous heating of specimens. At the early drying stage when there is large loss of water in concrete specimens, the specimen mass is measured every 1 h. The drying oven is carefully maintained at the predefined temperature during the measurement process and the specimens are put back in and out as quickly as possible to avoid any experimental error. Every mass measurement process is taking about 5 min. After wards, at the later drying stages, the interval between mass measurements is extended to every 4 h–8 h until

Table 1
Mix proportion and major parameters of concrete specimen.

Mix proportion (kg/m ³)					Water-cement ratio	Sand ratio (%)	Slump (mm)	Compressive strength (MPa)
Water	Cement	Sand	Diminutive stone	Medium-sized stone				
150	273	615	685	685	0.55	30	30–50	27

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