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Study on the process of isothermal continuous drying and its effect on the strength of concrete of different strength grades

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HIGHLIGHTS

- A drying model considering temperature and strength grade was obtained.
- The changes of water mass loss and ultrasonic were analysed before and after drying.
- Compressive strength decreases and then increases with increase in temperature.
- Splitting tensile strength decreases and then increases with increase in temperature.
- Optimal drying temperature with minimal effect on concrete strength is 100–125 °C.

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ABSTRACT

Dry-based concrete specimens must be obtained to investigate a moisture effect, but the drying law and strength change vary for concrete of different strength grades under different drying temperatures. In this work, concrete specimens with different strength grades are dried in a thermostatic electric drier at constant temperatures of 60, 80, 105, 120 and 150 °C, and the changes in mass, ultrasonic data and strength of the specimens before and after drying are analysed. The test results demonstrate that the drying stages of concrete with different strength grades at different drying temperatures are generally the same even with variations in drying rate, time and the total water mass loss. Considering the drying temperature and strength grade, a model for concrete drying is obtained based on the modified Page model II. After drying, changes in the concrete compressive and splitting tensile strengths of different strength grade materials are highly similar and are slightly higher than those before drying. The relative strength initially decreases and subsequently increases with increasing drying temperature. The drying temperature 100–125 °C is recommended as the optimal drying temperature for different strength grades of concrete according to the minimal strength change. Further analysis shows that the change in concrete strength is the result of mutual competition between the damage caused by water evaporation and the density increase caused by drying.

1. Introduction

The level of concrete moisture has a significant impact on its mechanical properties [1,2]. To study the moisture effect on concrete mechanics properties, the relatively dry concrete specimens must first be obtained. However, no standards currently exist for controlling the drying temperature and drying time; therefore, researchers have set different types of drying conditions on their own. To obtain dry concrete specimens, Beyea et al. [3] placed concrete specimens in a drier at 70 °C until the daily mass change was less than 0.01 g. In another study on the influence of moisture content on water absorption, Rucker-Gramm et al. [4] placed concrete specimens in an oven for drying at 50 °C for three months. Liu et al. [5] placed the concrete specimens in the drying oven at 45 °C until the change in mass became constant. To investigate the concrete initial moisture content, Aldred et al. [6] dried concrete specimens in an oven at 40 °C for 14 days and subsequently placed them on a ventilation rack in the same environment for 14 days. Weerdt et al. [7] dried concrete specimens at 105 °C until no mass changes occurred. When Wu et al. [8] studied the performance of concrete after a wet-dry cycle, the concrete samples were placed at 105 °C as a reference. To study the water absorption characteristics, Barbare et al. [9] dried concrete samples at 50 °C until the mass

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no longer changed. Yurtdas et al. [10] studied the effect of drying on concrete mechanical properties by continuously drying concrete samples at 60 °C until their masses were constant. Cadoni et al. [11] dried concrete specimens at 50 °C until the sample mass was constant. Under the given drying conditions, certain parameters, such as the drying time and rate of water mass loss are influenced by different drying temperatures. These differences result in evaluation discrepancies in the mechanical properties of concrete.

During the drying process, water escape can cause certain types of damage, such as the initiation, convergence and propagation of micro-cracks in the samples. Different drying conditions have been employed by different researchers, which leads to different water evaporation rates and results in different degrees of damage to the concrete as well as various degrees of concrete strength changes. In analysing the causes of concrete strength changes, Lin et al. [12] concluded that the changes in concrete strength were primarily affected by both the changes in mortar strength and the restraint of the coarse aggregate. Yurtdas et al. [10] found that concrete strength changes after drying were the result of the competitive effect that occurs between the increase in material due to capillary suction and hygral phenomena and drying-induced micro-cracking due to material heterogeneities and differential shrinkage rates. Maruyama et al. [13] suggested that the change in compressive strength under various drying conditions could be explained by cement-based component changes and damage accumulation caused by different values of thermal expansion between aggregates. Zhang et al. [14] considered the drying process to be a process of the further hydration of concrete that corresponded to water escape. Water escape can cause serious additional damage, and different drying temperatures could lead to different degrees of hydration and damage and thus different intensity changes. The concrete specimens should be dried continuously at 105 °C until the mass change becomes constant. At this temperature, the drying has minimal effect on the compressive strength and splitting tensile strength of concrete [14], and the volume fraction of defects after drying is increased by 20%, while the number of defects increases by 42% as compared to standard specimens according to XCT test [14]. However, the concrete strength grade in the study is only C20, and the concrete changes are of different strength grades at different drying temperatures. Therefore, in this paper, in-depth test studies on concrete of different strength grades were conducted, the effects of different drying temperatures on the compressive and splitting tensile strengths were analysed. The optimal drying condition was determined for different strength grades concrete. The results supply a theoretical basis for the concrete heating and drying process.

2. Test investigation

2.1. Test materials

In this test, the materials required for the preparation of concrete are ordinary Portland cement (P.O.42.5) produced by the Jidong Cement Plant of China, medium sand (fine aggregate) and pebbles (coarse aggregate) produced by the Weihe Plant of Shaanxi Province, the water reducing agent produced in Qingdao, Shandong Province consisted of polycarboxylic acid superplasticizer, fly ash produced in Henan Province and the ordinary water, respectively. The main materials properties are shown in the Tables 1–4.

2.2. Text equipment and specimen preparation

The drying equipment was an electro-thermostatic blast oven, whose temperature uniformity was within ±2.5%, the volatility was within 1 °C, and the operating temperature ranged from room temperature to 300 °C. The compressive and splitting tensile strength tests of concrete were both performed using a microcomputer-controlled electro-hydraulic servo universal testing machine, which was manufactured by Shanghai Xinsansi Measuring Instrument & Equipment Manufacturing Co., Ltd., (China, model number: YAW4206), with a maximum test force of 1000 kN. The concrete strength test was conducted according to Chinese national standard SL352-2006 (Hydraulic Concrete Test Procedure). The internal change in the concrete was analysed using a non-metallic ultrasonic analyser with a receiver sensitivity, amplifier bandwidth, amplitude range, ultrasonic sounding measurement range, ultrasonic sampling period and sampling length of ≤10 μV, 5 Hz–500 kHz, 0–177 dB, 0–19,999.9 μs, 0.02 μs and 1024 kB, respectively. Concrete specimens were cube shaped with side length of 100 mm. The mix proportions of concrete according to Chinese national standard DLT5330-2015 (Code for Mix Design of Hydraulic Concrete) are provided in Table 5.

Table 1
The ordinary Portland cement properties.

Water consumption for a normal consistency (%)	Initial setting times (h)	Final setting times (h)	Compressive strength at28d (MPa)	Splitting tensile strength at 28 d (MPa)
28.78	3.7	5.7	49.3	8.43

Table 2
The medium sand (fine aggregate) properties.

Fineness modulus	Dense packing density (kg/m^3)	Apparent density (kg/m^3)
2.75	1772	2560

Table 3
The pebbles (coarse aggregate) properties.

Particle size (mm)	Bulk density (kg/m^3)	Apparent density (kg/m^3)	Clay content (%)
5–20	1649	2620	0.33

2.3. Test procedure

After 28 days of standard curing (the temperature is about 20 ± 5 °C and the relative humidity is above 95%), the specimens were divided into test groups and standard control groups. The test groups were divided into 5 temperature groups to dry for 4 strength grades concrete respectively. The standard control group was measured strength directly. Within each group, 3 specimens were used to measure compressive strength and another 3 specimens for splitting tensile strength. In order to test whether the sample reached the dry state, the broken specimens, which were obtained from the control group after measuring compressive strength, were dried at the same temperatures as normal drying specimens. The broken specimens were broken into fragments until their diameters were less than twice the size of the maximum aggregate. The broken specimens were placed on a tray to avoid losses during the drying process. The specimens were dried until each specimen's daily mass change was less than 1.0 g (0.0007 kg/(h·m^2)), at which point the concrete was considered to have reached the drying state. We used the water mass loss rate of the broken specimens to determine whether the specimens in the test groups were dry. In the test groups, the specimens were weighed, and their ultrasonic velocities were measured twice, before and after drying, at 5 double locations using the arrangement shown in Fig. 1.