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Development and Test of Super-early-strength Concrete Curing System

Qihan Zhang*

School of Civil Engineering, University of science and technology Liaoning, Anshan,114051 China.

* Corresponding Author

Abstract

In order to realize super-early-strength concrete, a new enclosed wetting-heating curing system suitable for use in the laboratory is designed for this study. According to this system, a concrete specimen is sealed in a covered heating mold, which is then placed in a heat-preservation box with adjustable temperature. The concrete produced by this curing system is subjected to strength testing and 60%–80% of the concrete's design strength is attained within 12 h, thereby showing this system's feasibility for producing super-early-strength concrete.

Keywords

Super-early strength, Enclosed wetting, Curing system, Heating mold, Heat-preservation box.

1. Introduction

With the rapid development of modern industrial production, the urgent repair of ports, wharfs, expressways, railways, bridges, and airport runway projects has increased demand for super-early-strength concrete [1]. To realize such concrete, special raw materials must be adopted with an appropriate mixture ratio.

For example, the material developed by Chang'an University for repairing pavement mainly comprises sulphoaluminate, silicate, aluminate, and an efficient active agent in certain proportions; the pavement repaired in this manner can be opened to traffic after only 6h [2]. Songtao et al. used quick-setting early-strength special cement to prepare and optimize super-early-strength concrete for making roads [3]. This concrete can also be realized by improving curing methods; for example, concrete wrapped in a plastic film or curing agent may be placed in high-temperature steam for curing and super-early strength, or an autoclaved kettle may be used for curing concrete at high temperature and pressure. From the perspective of curing, the super-early strength of concrete mainly depends on moisture and temperature. Since concrete is a hydraulic material, its component surface should be kept wet during its period of strength growth so as to ensure full hydration of the cement, and thus, meet the specifications of strength and durability. This is very important for high-strength concrete with a small water–binder ratio [4]. Temperature increase has two opposing effects on concrete: on one hand, it accelerates the hydration reaction rate and accordingly promotes the early development of strength, while on the other hand, it also accelerates the moisture-evaporation rate, resulting in a decrease in the amount of moisture available for hydration, thereby delaying the process of hydration or even completely stopping it. The effect of temperature on concrete strength depends on the following conditions: if the curing temperature is relatively high, early strength grows faster but late strength is lessened [5].

In case of accelerated curing, it is necessary to directly determine the concrete strength as the final results of accelerated curing depend on the method used [6]. Yuanyang et al. developed a box-like device with automatically adjustable internal air temperature and humidity, which is suitable for standard curing of concrete samples for compression, bending, and impermeability testing; however, it cannot cause early strength development. For this reason, this paper presents an enclosed wetting-heating curing system in the laboratory by increasing the curing temperature and ensuring proper curing moisture. This system can easily realize super-early strength suitable for compression, bending, and impermeability testing.

2. System Components and Preparation Process

2.1. Preparation of the heating mold

According to the Standard for Test Method of Mechanical Properties on Ordinary Concrete, a standard mold should have dimensions of 150 mm×150 mm × 150 mm [8]. To provide the mold heating functionality, five groups of dry heating elements were separately affixed to its bottom and side walls; in order to ensure that these elements were affixed well, their intended positions on the external walls of the mold were milled to be smooth beforehand and a heat-resistant insulation paste was used, as shown in Figure 1.

Figure 1: Standard heating mold

Figure 2 : Mold and cover

The performance indices of the dry heating element are as follows: aluminum-shell thermostatic PTC(Positive Temperature Coefficient) heating plate; working voltage: 220 V; external dimensions: 100 mm × 21 mm × 5 mm (central heating part); leading wire: heat-resistant silicone wire.

The surface temperature of the dry heating element on the mold after heating reached 135°C (with the internal PTC heating core temperature reaching 150°C), with a rated power of 40 W (actual dissipation of 15–80 W) and a dry heating power of 13 W.

To avoid moisture loss from the sample during heating and to meet the wetting needs, a cover was placed over the upper part of the mold, as shown in Figure 2. This cover completely separated the inside of the mold from the outside, maintaining a certain humidity within the mold, so as to ensure full cement hydration and meet the requirements for rapid growth of strength. The cover had dimensions of 240 mm × 240 mm × 20 mm, its surface material was a 0.3-mm-thick stainless-steel sheet, and its interior contained thermal-insulating aluminum foil-glass-wool felt with a thermal conductivity of λ = 0.038–0.045 W/m.h. °C. To ensure a better sealing effect by the cover, a sealing strip was used at the joint between the cover and the mold.

2.2. Preparation of heat-preservation box

The dry heating elements could heat the concrete mold, but the thermal insulation effect was unsatisfactory due to the heat dissipated constantly through its cast iron walls. For this reason, a heat-preservation box was designed and the mold was placed inside it for thermal insulation.

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The curing box size was decided according to the standard mold size and free operation. As shown in Figure 3, the material of the heat-preservation box and the thermal insulation layer were the same as those of the mold cover. The specific dimensions are given as follows:

Internal dimensions of the mold curing box: 320 mm × 320 mm × 260 mm; external dimensions: 400 mm × 400 mm × 300 mm; thermal insulation thickness: 40 mm; dimensions of the curing box cover: 400 mm × 400 mm × 40 mm.


Figure 3: Heat-preservation box


Figure 4: Knob thermostat

2.3. Design and installation of the thermostat system

To control the temperature inside the mold, a power supply was connected to the dry heating element via a knob thermostat, which controlled the box's temperature, as shown in Figure 4.

The specifications of the knob thermostat are as follows: performance of knob thermostat: 220 V/110°C; control range: 30–110°C; contact capacity: resistance 220 V 16 A; weight: 110 g. The circuit diagram is shown in Figure 5.

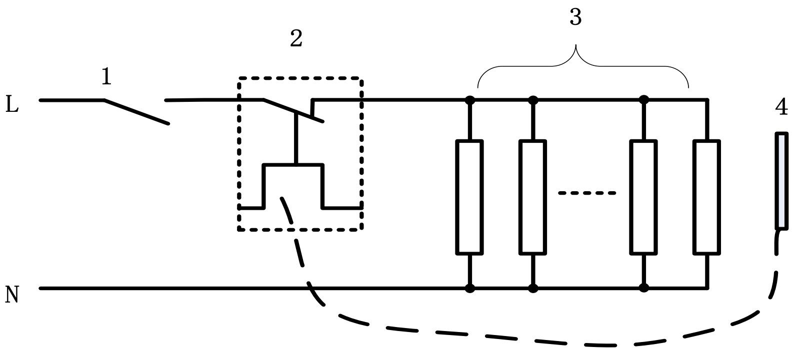

Figure 5: Circuit structure diagram

1. System switch 2. Temperature-controlled switch 3. PTV heating plates 4. Temperature-sensing element

The principle of the knob thermostat's performance states that when the temperature of the controlled object changes, the working medium inside the temperature-sensing element of the thermostat undergoes thermal expansion or contraction—i.e., the working medium changes its volume. In this case, the capacitance transducer connected to the temperature-sensing element also undergoes expansion or contraction, then control the make-and-break action of switch through lever principle and achieve temperature control.

A schematic of the enclosed wetting-heating curing system is shown in Figure 6.

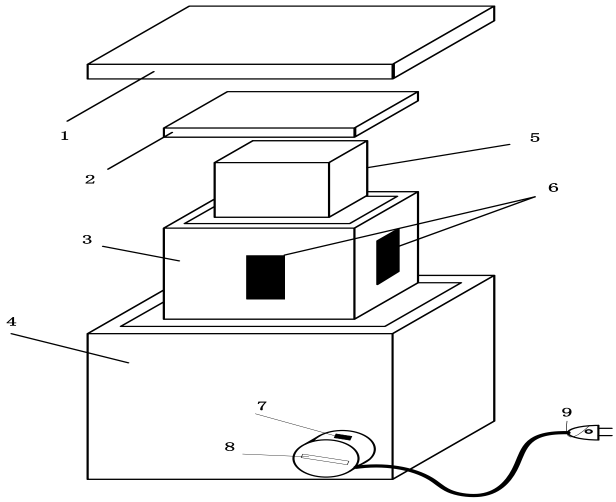

Figure 6 : Schematic curing system as a whole

1. Upper cover of the heat-preservation box; 2. Upper cover of the curing mold; 3. Curing mold; 4. Heat-preservation box; 5. Sample; 6. Dry heating element; 7. Start button; 8. Temperature-setting knob; 9. Power plug

3. Performance Test of the Curing System

The curing system developed above was tested in terms of performance indices such as mold temperature, air temperature inside the curing box, and external surface temperature of the curing box, so as to determine the temperature-control and thermal-insulation effects of the system. The test method is as follows: in a room temperature (20°C) laboratory,the air temperature inside curing box, mold temperature and external surface temperature of curing box were measured once every 5 min. The air temperature inside the curing box was measured by a mercury thermometer within a range up to 100°C, whereas the mold temperature and external surface temperature of the curing box were measured by handheld infrared thermometers. The results are shown in Figure 7.

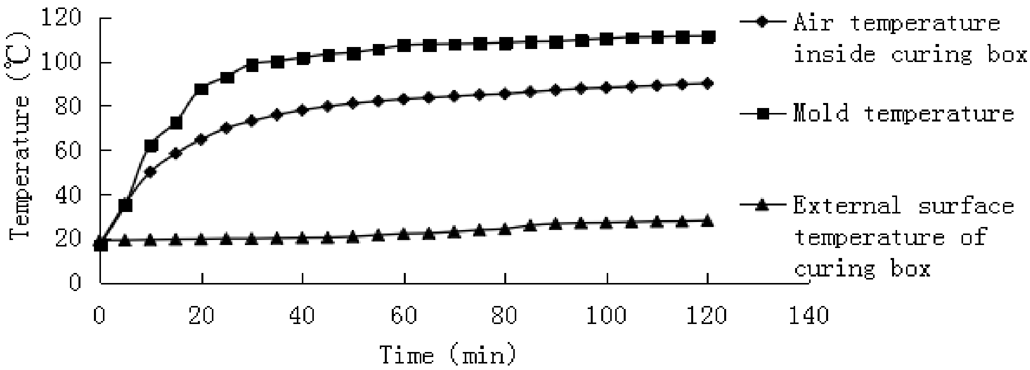

Figure 7 : Changes in temperature and time in the curing system

As seen in Figure 7, the mold temperature of the curing system is similar to the air temperature inside the curing box in terms of its trends, with both undergoing rapid increase in the first 20 min with a small temperature difference, and then undergoing a slow increase after 25 min with a temperature difference of about 20°C, maintaining constant synchronization. This indicates that the device can maintain the internal sample and air at a stable temperature, thereby meeting the curing needs of concrete; the external surface temperature of the curing box barely changed, only rising to about 26°C after the end of the test, showing that the curing box has a good thermal insulation effect with little heat loss.

The temperature test results of the curing system showed that this system can meet the curing requirements of concrete, maintain the mold temperature at its preset value using the knob thermostat, and facilitate temperature control during concrete curing.

4. Concrete-curing Test

This test aims to check whether the sealed wetting-heating curing system allows the sample strength to reach 60%–80% of the design strength (required strength grade) within 12h using suitable raw materials with an appropriate mixture ratio. To this end, C65, C70, C75, and C90 concretes with relatively stable mixture ratios (shown in Table 1) were tested.

Table 1 : Mixture ratios of C65, C70, C75, and C90

Name	Cement	Gravel	Sand	W/C
C65	1	1.966	1.292	0.3
C70	1	1.909	1.225	0.28
C75	1	1.894	1.186	0.27
C90	1	1.826	1.089	0.25

The materials used in the test are as follows: cement 52.5 was produced by Dalian Onoda, with the measured compressive strength of 56 MPa and a density of $\rho_c = 3200 kg/m^3$ after 28 days; Beipiao river sand has an apparent density of $\rho_s = 2650\ kg/m^3$; Beipiao andesite with diameters of 5–20 mm was used as gravel with an apparent density of $\rho_g = 2700 kg/m^3$; Ansteel UNF-5 naphthalene-based superplasticizer was adopted with a water-reducing rate of 20% and a mixing ratio of 1% of the cement amount; tap water was used in the test.

The compressive strength test was conducted after the demolding of the cured sample, using a YE-200A hydraulic compression-testing machine. The results are shown in Table 2.

Table 2 : Results of the compressive strength test on concrete samples cured for 12 h

Strength grade / Performance index	C65	C70	C75	C90
Strength (MPa)	52.2	54	58.5	67.5
Proportion in design strength (%)	80.31	77.1	78	75

As seen in Table 2, the compressive strengths of all samples cured for 12 h reach over 70% of the design strength, with some samples even reaching 80%. This indicates that super-early strength of concrete can be achieved using the curing system developed in this study.

5. Conclusion

Through the above the development of enclosed wetting-heating curing system and its tests, the following conclusions can be drawn.

(1) It is necessary to choose special cementing material, additives and the good formulations , also need to cooperate with the appropriatecuring way to achieve super-early-strength of high strength concrete,.

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(2)The developed enclosed wetting-heating curing system is mainly composed of heating mold, mold cover, heat-preservation box and temperature control system， which is a kind of new curing method to realize super-early-strength of high strength concrete specimen.

(3) The enclosed wetting-heating curing system, can be used as curing way to realize super-early-strength of high strength concrete specimen, also can be used as curing way to realize super-early-strength of other cement base material specimen.

(4) Through the test of enclosed wetting-heating curing system, which can realize the super-early-strength level of 60%–80% of the high strength concrete's design strength within 12 h.

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