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Residual compressive strength of cement-based grouting material with early ages after fire

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HIGHLIGHTS

- Residual compressive strength of CGM material reduces considerably after heating.
- Residual compressive strength of CGM decreases with increasing water mixing ratio.
- Residual compressive strength of CGM cannot recover after exposed to 550 °C.
- A set of valuable test data has been generated in this research.

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ABSTRACT

In this paper a comprehensive experimental investigation on the residual compressive strength of cement-based grouting materials after exposed to high temperature is presented. The research focused on the influences of different temperatures, curing ages before and after heating and water mixing ratios on the residual compressive strength of the material. The research indicates that the residual compressive strength of cement-based grouting material reduces significantly after heating. The reduction of the residual compressive strength of the material increases with increasing water mixing ratio. For the specimens exposed to higher temperature, such as 550 °C, the residual compressive strength cannot recover after heating. The research generated a set of reliable and valuable test data for the researches and practical structural engineers in the field of structural fire engineering.

1. Introduction

In recent years, cement-based grouting material (CGM) has been widely used for repairing and strengthening building structures. This is because of CGM has super early strength, fluidity, no shrinkage and convenient for construction [1–3]. Previous researches indicate that the strength of cementitious materials at early ages changes considerable with time. Bentz et al. [4] found that the compressive strengths of concrete (with water cement ratio of 0.425) at early curing ages of 1, 3 and 7 days were 30%, 60%, 74% of the 28 days' strength, respectively. Benaicha et al. [5] found that the compressive strengths of high performance concrete at curing ages of 1, 3 and 7 days were 57%, 62%, 71% of the compressive strength at 28 days, respectively. Kima et al. [6] indicated that the compressive strengths of the concrete (with water cement ratio of 0.4) for curing ages of 1, 3 and 7 days were 41%, 62% and 82% of the compressive strength at 28 days. The experimental results generated by Kocak and Nas [7] indicated that the compressive strengths of the fly ash concrete with curing ages of 2 and 7 days were 43% and 79% of the compressive strength at 28 days, respectively. Madandoust et al. [8] found that the compressive strength of concrete increased with the curing age of the concrete and the strength increase ratio was more significant during the curing ages between 14 and 42 days.

In recent years, there were considerable numbers of fire accidents happened during the construction period of buildings due to some problems related to the organization and management of construction site. For example, a big fire lasted for 4.5 h happened at the 23 floor on the 25 storeys reinforced concrete building which was just finished concreting for 3 days in Wuhan, China [9]. The temperature within the concrete floor reached 400 °C. The concrete strength was significantly affected by the fire. Therefore, for assessing the structural safety of the building after fire it is really important to understand the mechanical properties of such early age of concrete after exposed to fire.

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Hence, the mechanical properties of early age concrete after exposed to high temperatures have attracted many researchers' attention. Chen et al. [10] conducted an experimental study on the mechanical properties of early age normal-strength concrete after exposed to high temperatures. Wang et al. [11] found that the ultimate bearing capacities of the concrete columns in the age of 14 and 28 days were reduced to 41% and 60%, respectively after exposed to the temperature of 550 °C. The test results generated by Ma [12] indicated that the residual compressive strength of fly ash concrete after high temperature increased with the increasing curing age.

At present, some researchers have conducted a number of studies on the mechanical strength of cement-based grouting material after exposed to high temperatures. Yan et al. [13] indicated that the fire resistance of cement-based grouting material is better compared to normal concrete. Yuan et al. [14] found the residual compressive strength of cement-based grouting material after high temperature decreased with increasing water mixing ratio.

Because of the cement-based grouting material has high compressive strength in the early stage of construction, its mechanical properties are considerably different compared to normal concrete. Hence, it is needed to understand the mechanical properties of the early age cement-based grouting material after exposed to fire. This information is very important for structural engineers to assess the structural safety after fire. However, according to the authors' knowledge there are very limited researches on the residual strength of early age cement-based grouting material after exposed to high temperature. Therefore, the main objectives of this research are:

- Conduct a series of tests to investigate the residual compressive strength of cement-based grouting material after exposed to different temperatures.
- Study the influence of temperatures on the degradation of the compressive strength of cement-based grouting material.
- Investigate the influences of different curing ages before and after exposed to high temperatures and water mixing ratios on the residual compressive strengths of cement-based grouting material.
- Generate a set of valuable test data for the fellow researches who develop numerical models and practical structural engineers who conduct repairing and strengthening of reinforced concrete buildings.

2. Test specimens

In this research the cement-based grouting material was provided by Zhengzhou Nuweison Construction Engineering Technology Ltd. The material was high-strength and no shrinkage cement grouting material (CGM-1). Its compositions and properties are given in Tables 1 and 2, respectively. The compositions of additive binding gelled material are shown in Table 3. According to Chinese design code for cementitious grouting material [15], in this research four key design curing ages of 3, 7, 14, and 28 days before heating were adopted. Previous researches [14,16] indicated that when cementitious materials were exposed to the temperature higher than 600 °C, the compressive strength of the materials was significantly degraded. The concrete structural members after such high temperature were unrepairable. Hence, three level temperatures of 150 °C, 350 °C and 550 °C were adopted in this research. The research conducted by Yuan et al. [17] indicated that the water mixing ratio of cement-based grouting material is another important factor needed to be considered. In this research three water mixing ratios of 12%, 14% and 16% were used for the cement-based grouting material. The test specimen size is 100 mm × 100 mm × 100 mm. The specimens were stored in the structural lab under the conditions of 20 °C and R.H. = 95% for curing. Before the heating the specimens were naturally dried for one day.

3. Test procedure

In this research, an electrical heating furnace GWD-02A with power of 18 kW was used to heat the specimens. The furnace has computerized temperature control system. For simulating real fire accident, high heating ratio was adopted. Based on the recommendation from previous researches [16,17], the high heating rate of 10 °C/min was used for all tests. In order to make sure the temperature within the specimens is uniformly distributed, the specimens were heated to the target temperature then the target temperature was maintained for 90 min. After heating the specimens were cooled down to ambient temperature under natural air cooling condition. Then the specimens were stored in normal lab condition (20 °C and R.H. = 95%) until total curing time of 28 days (curing time before heating + curing time after heating) to be reached. After that

Table 1
Mix design of the high-strength cement grouting material (CGM-1).

Composition	High-strength cement	Quartz sand	Water reducing agent	Expanding agent
Content (wt%)	50	48.9	1	0.1

Table 2
Properties of the high-strength cement grouting material (CGM-1).

Density	Fluidity	Vertical expansion rate	Compressive strength (1 day)	Compressive strength (3 days)	Size of quartz sand
2200 kg/m^3	≥300 mm	≥0.02%	≥30 MPa	≥45 MPa	5 μ to 5 mm

Table 3
Chemical composition of additive binding gelled material.

Composition	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	LOI
Content (wt%)	0.38	3.72	7.26	18.99	5.85	0.807	51.49	0.304	2.615	8.59