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Experimental Study on compressive strength recovery effect of fire-damaged high strength concrete after realkalisation treatment

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Abstract

Realkalisation treatment was used to recover carbonated concrete alkalinity nearby the reinforcing region at normal temperature. The feature of the realkalisation treatment which could restore concrete high alkalinity is applied for the neutralization of concrete suffered from high temperature in this paper. This paper develops important data on the application of realkalisation treatment for the mechanical behavior and durability characteristics recovery of fire-damaged high strength concrete. In this paper, the compressive strength of fire-damaged high strength concrete before and after realkalisation was investigated. The test results indicated that the realkalisation treatment results in compressive strength recovery and its effect extent depends upon exposure temperature, current density, treatment time and concentration of electrolyte. When compared with the original unfired values, the residual compressive strengths of tested specimens of cube compressive strength of 71.2 MPa exposed to temperature from 300°C to 700°C for two to three hours ranged from 80.3% to 39.7%, their recovered strengths were 89.6% to 61.4% after 7 days treatment. Compared with obtained experimental results of fire-damaged tested specimens of cube compressive strength of 50.2 MPa, the effect of recovered strengths is better for lower compression strength of compression cube.

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Keywords: Elevated temperature, Realkalisation, Recovery, High strength concrete, Compressiv strength

1. Introduction

In recent years, high strength concrete (HSC) has recently become a widely used concrete construction material for high buildings, bridges and infra-structures. However, when exposed to elevated temperatures, the properties of the HSC will dramatically decrease, and the HSC will lose the capability of load bearing, that will bring great threats to the safety of the fire-damaged structures. More and more researches been carried out on HSC subjected to fire or high temperature. Studies showed that the fire damage of concrete included mechanical strength reduction, spalling and cracking [1-4]. From these researches HSC has been found to be more prone to spalling failure than normal strength concrete (NSC) under high temperature in some cases [3-4]. Under high temperatures, HSC experienced the change of pore structure, known as the "pore-structure coarsening" [5].These changes of pore amount and volume after high temperature exposure would cause an increase in concrete permeability, and worsen the permeability-related durability [6-7].Neutralization slowly deteriorated reinforced concrete structure's durability at high temperatures, because of a reduction in the alkalinity of concrete due to a chemical reaction between CO_2 from the air and Ca $(OH)_2$. The corrosion of the steels in concrete and the deterioration of the protective layer would occur when the concrete alkalinity becomes low [8].

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Electrochemical realkalisation is a technique aimed at stopping rebar corrosion in carbonated concrete at normal temperature, by restoring the alkalinity of the concrete around the rebar [9]. The technique drives a DC current between the external anode placed on the surface of concrete and the cathode (rebar). The anode is usually embedded in cellulose pulp soaked with an alkaline electrolyte. The applied current produces alkalinity at the surface of the rebar, while the alkaline electrolyte in which the anode is immersed penetrates from the external surface. In this way the concrete is realkalised, its protective characteristics towards the steel are restored and rebar can return to passive conditions [10-14].

The feature of the realkalisation treatment which could restore concrete high alkalinity is applied for the neutralization of concrete suffered from high temperature in this paper. The focus of this paper is to investigate how the residual strength is affected by realkalisation treatment of the fire- damaged HSC. A number of experimental study was organized to evaluate the feasibility of using realkalisation treatment for the residual compressive strengths recovery of the fire-damaged HSC, underwent different temperatures, concentration of electrolyte, current density and treatment time.

2. Experimental

2.1. Materials and mix proportions

Forty eight concrete cubes (dimensions 100 mm× 100 mm× 100 mm) were cast using ordinary Portland cement (OPC) provided by Guangzhou Jingyang Cement Plant with a 28-day compressive strength of 42.5MPa. The chemical composition of cement and fly ash are presented in Table 1. The fine aggregate was natural river sand, with the modulus of fineness of 2.5. Coarse aggregate: crushed lime stone, particle size between 5 and 20 mm. The designed compressive strength of concrete is 60MPa at 28 days. The concrete mix proportions are shown in Table 2. The concrete cubes were demolded 24 hours after the casting and placed in a water tank at 20 °C. After a 28 days cure in water, one series specimens (including three cubes) were kept as a sound concrete reference (H60C0) and the other forty five specimens were kept there for 4 weeks until heating. All the specimens were stored in an environmental chamber maintained at 20±2°C, and 60%±10% RH both before and after the realkalisation treatment.

Table 1. Chemical composition of cement and fly ash (%)

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K2O	MnO	TiO_2	P_2O_5	SO_3	LOI
Cement	60.52	21.38	4.47	2.84	1.96	0.79	0.09	0.25	0.14	2.54	4.90
Fly ash	13.47	34.28	3.46	1.91	7.51	0.81	0	0.26	0.09	0.26	37.83

*LOI = loss on ignition.

Table 2. Mixture proportions of concrete

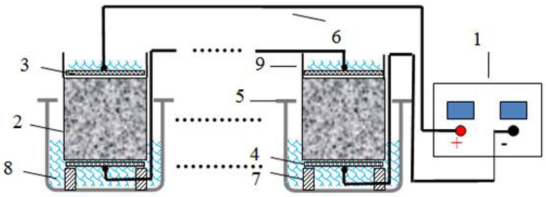
w/cm	Mix proportion (kg/m^3)						28-day cube compressive strength (MPa)
	Cement	Sand	Coarse aggregate	Water	Fly ash	Superplasticizer	
0.35	437	783	1016	170	49	1.9	71.2

2.2. Heating procedure

Before heating, the specimens were put into electric dry oven keeping at 105°C and atmospheric pressure for 24h for drying. Then specimens were taken out and respectively heated in an electric furnace up to 300°C,400°C, 500°C, 600°C and 700°C. The heating rate was set at 8°C/min, with 2h (700°C with 3h) exposure to the temperature in the furnaces. It was ensured that the center of specimen reached the same temperature as outside by fixing a thermocouple. The furnace was turned off and specimens were allowed to cool naturally to room temperature (20°C). After elevated temperature, three cubes of each group were taken out and kept as elevated temperature references (H60C30, H60C40, H60C50, H60C60 and H60C70) and the other specimens would be treated by realkalisation.

2.3. Realkalisation treatment

After natural cooling, the specimens were stored in an environmental chamber maintained at 20±2°C, and 60%±10% RH for one week and then treated by realkalisation treatment. The experimental setup is shown in Figure 1. The auxiliary cathode and anode, a 10×10 mm mesh grid, 1 mm in diameter, made of a piece of stainless steel wire mesh respectively placed on the top and bottom surface of specimen was connected to an external power supply. The electrolyte was sodium carbonate solution, which flooding the bottom surface of specimen. The top surface of specimen was sealed with a plastic sheet to contain the electrolyte. Table 3 gives the parameters of realkalisation treatment.



1—DC power, 2—Specimen, 3—Stainless steel wire mesh (cathode),

4—Stainless steel wire mesh (anode), 5—Containers, 6—Wires,

7—Cushion block, 8— Na_2CO_3 electrolyte, 9—Plastic sheet.

Fig. 1. The experimental setup working scheme

Table 3. Parameters of realkalisation treatment.

Series	Temperature/ Constant temperature time/ Realkalisation Status	Concentration of Na2CO3 electrolyte (mol.L-1)	Current density (A.m-2)	Treatment time(days)
H60C0	20℃/-/-	-	-	-
H60C30	300℃/ 2h/-	-	-	-
H60C31	300℃/ 2h/ Realkalisation	1	1	7
H60C40	400℃/ 2h/-	-	-	-
H60C41	400℃/ 2h/ Realkalisation	1	1	7
H60C50	500℃/ 2h/-	-	-	-
H60C51	500℃/ 2h/ Realkalisation	1	1	7
H60C52	500℃/ 2h/ Realkalisation	1	1	14
H60C53	500℃/ 2h/ Realkalisation	1	2	7
H60C54	500℃/ 2h/ Realkalisation	1	3	7
H60C55	500℃/ 2h/ Realkalisation	0.5	1	7
H60C56	500℃/ 2h/ Realkalisation	1.5	1	7
H60C60	600℃/ 2h/-	-	-	-
H60C61	60℃/ 2h/ Realkalisation	1	1	7
H60C70	700℃/ 3h/-	-	-	-
H60C71	700℃/ 3h/ Realkalisation	1	1	7

2.4. Testing details

Compressive strength test was performed on 100-mm concrete cubes according to GB50152–92. Three specimens were tested at each stage and average values are reported.

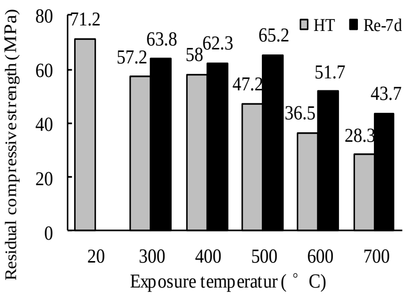
3. Results and Discussion

3.1. Effect of high temperature

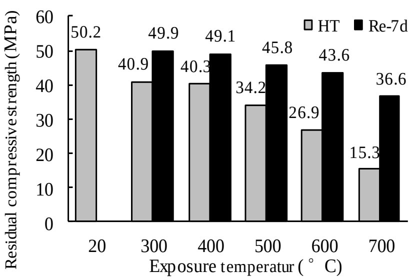
The residual compressive strength results of the tested specimens of cube compressive strength of 50.2 MPa (C50 HSC) [15] and the specimens of cube compressive strength of 71.2 MPa (C70 HSC) after exposure to 300, 400, 500, 6000 and 700°C temperatures are given in Fig. 2. The relationship between compressive strength and exposure temperature was found to be similar to that reported previously [5, 16]. Up to 400°C only a small part of the original strength was lost, almost the same about 20% for C50 HSC and C70 HSC. The severe compressive strength loss occurred mainly within the 400-700°C range. Fig.3 shows for C50 HSC and C70 HSC that the strength loss at 500°C is in the range of 32-34%, at 600°C strength loss is in the range of 47-49%, and at 700°C strength loss is in the range of 60-70%.

3.2. Effect of realkalisation treatment

The residual compressive strength recovery results of the tested specimens of C50 HSC and C70 HSC after 7 days of realkalisation treatment are given in Fig.2. It can be seen that realkalisation treatment of C50 HSC and C70 HSC specimens after exposure to high temperatures has a significantly positive influence on the residual strength recovery. In Fig.3, of C70 HSC, the residual strength ratio of specimens exposed to 300°C can be increased from about 80% for the non-treatment specimens to about 90% for the realkalisation treatment specimens, the residual strength ratio is increased from around 81% to 87% for an exposure temperature of 400°C, the residual strength ratio is increased from around 66% to 91% for an exposure temperature of 500°C, the residual strength ratio is increased from around 51% to 73% for an exposure temperature of 600°C and the residual strength ratio is increased from around 40% to 61% for an exposure temperature of 700°C. Of C50 HSC, the residual strength ratio of specimens exposed to 300°C can be increased from about 81% for the non-treatment specimens to about 99% for the realkalisation treatment specimens, the residual strength ratio is increased from around 80% to 98% for an exposure temperature of 400°C, the residual strength ratio is increased from around 68% to 92% for an exposure temperature of 500°C, the residual strength ratio is increased from around 54% to 87% for an exposure temperature of 600°C and the residual strength ratio is increased from around 30% to 73% for an exposure temperature of 700°C.



(a)



(b)

Fig. 2. Residual compressive strength of (a) the tested specimens of cube compressive strength of 71.2 MPa and (b) the specimens of cube compressive strength of 50.2 MPa [15] before and after 7 days of realkalisation treatment.

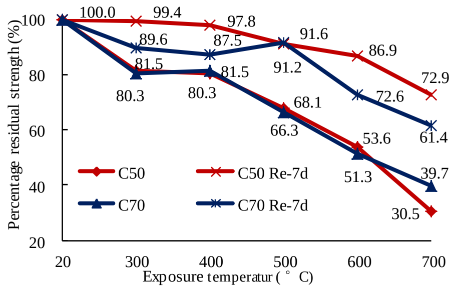


Fig. 3. Percentage of residual compressive strength of the tested specimens of cube compressive strength of 71.2 MPa and the specimens of cube compressive strength of 50.2 MPa before and after 7 days of realkalisation treatment to the original compressive strength at 20°C.

3.3. Comparison of different realkalisation treatment parameters

Figure 4 provides a comparison of different realkalisation treatment parameters on the residual compressive strength recovery. It can be noted that the best recovery in residual compressive strength is current density×treatment time=1×7 A•m^{-2}•d and concentration of Na_2CO_3 electrolyte =1.0 mol•L^{-1} when the tested specimens subjected to 500°C for 2h.

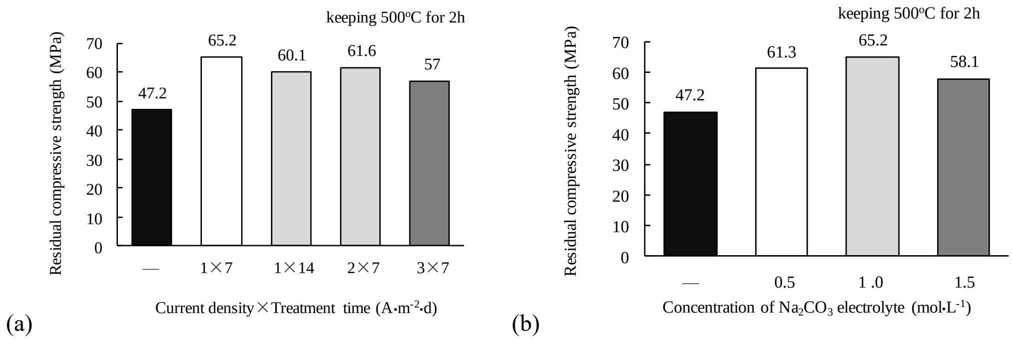


Fig. 4. Effect of different realkalisation treatmen parameters on the residual compressive strength of tested specimens of cube compressive strength of 71.2 MPa subjected to 500°C for 2h.

4. Conclusions

The research aimed to establish the effect of realkalisation treatment on the residual compressive strength recovery of HSC exposed to elevated temperature. Two different high strength concrete grades were selected (C50, C70), five elevated temperatures 300°C,400°C, 500°C, 600°C and 700°C and two different realkalisation treatment parameters current density×treatment time and concentration of Na_2CO_3 electrolyte were selected for the experimentation. It was found that realkalisation treatment has a significantly positive influence on the residual strength recovery of the HSC. The degradation of compressive strength of concrete subjected to high temperature been recovered ranged from 17.5% to 42.4% for C50 HSC and 9.3% to 21.2% for C70 HSC after 7 days realkalisation treatment. The compressive strength recovery of fire-damaged concrete after realkalisation were most attributed to the complex physical-chemical processes including electrolysis, migration, electroosmosis, diffusion and rehydration.

Acknowledgments

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