

Mechanical Properties of Manufactured-Sand Concrete after High Temperatures

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Abstract: In this paper, to study mechanical properties of manufactured-sand concrete after high temperatures, experiments on the residual strength of manufactured-sand concrete were carried out under high temperatures in which raw materials performances and concrete mixture proportion were considered. The mechanism of elevated temperatures on residual strength was theoretically discussed, and the calculation formula of residual strength was given. The results indicated that with the increasing of temperature, the mass loss was small while the reducing of strength and the elastic modulus of manufactured-sand concrete were significantly.

Keywords: Concrete, durability, high temperature, manufactured-sand, strength.

1. INTRODUCTION

The consumption of sand has been increasing fast along with the boom of engineering construction in the past few years. There is a severe lack of natural sand (NS) in many areas. In addition, the excessive and indiscriminate exploitation of natural sand causes serious ecological problems. Manufactured sand (MS) is not only with easily-controllable gradation and low cost, but also beneficial to environment. Therefore, MS begins to be widely used to substitute NS in engineering projects.

Actually, concrete structures are used not only in usual circumstances but in conditions of high temperatures. Fire disaster has become one of the main disasters for constructions. When fire breaks out, the temperature in constructions can achieve 800 K in ten minutes. The bearing capacity of concrete structures will be greatly weakened. Therefore, it is necessary to do a comprehensive study on high-temperature performance of manufactured-sand concrete (MSC), to evaluate the extent of damage and the residual strength after high temperature in order to take reasonable reinforcement measures.

Many experiments about the strength and durability of natural-sand concrete (NSC) after high temperature have been conducted in the past [1-8]. However, only a small proportion of those tests are about the strength and durability of MSC after high temperature. Zhang [9] analyzed the effects of high temperature on the compressive strength and splitting tensile strength of C40 MSC and compared the high temperature performance of MSC with that of NSC. Chen [10] investigated mechanical properties and constitutive relation of C60 MSC at temperatures of 293.15, 373.15, 473.15, and 573.15 K. However, these studies only focus on a single strength grade.

MSCs considered in this study include strength grades of C30, C40, C50 and C60, and the strength and durability of them after high temperature are investigated. It demonstrates the experimental basis for high-temperature performance of MSC, thereby promoting its widely utilization in civil engineering.

2. METHODOLOGY

The procedure followed for this study is shown in Fig. (1) Firstly, the physical and mechanical properties of raw materials were checked. Secondly, specimens were prepared based on the mix proportion design, slump test and strength at age of seven days. Lastly, high temperature experiment was carried out and mechanical properties of specimens were tested after high temperature.

2.1. Properties Test of Raw Material

MS came from ZiBo WANTAI Building Aggregate Ltd and was produced by limestone. The crushed stones were taken from an engineering site. Their properties were tested and met the requirements according to national standard of the People's Republic of China GB/T14684-2011 and GB/T14685-2011. Table 1 and Table 2 list the main properties of MS and crushed sand, respectively. Cement was ordinary Portland cement produced by Zibo ShanLv Cement Company.

2.2. Design of Concrete Mixture Proportion

Mix proportion of MSC was designed according to industry standard of the People's Republic of China JGJ55-2011. The slump of concrete was set to 80~90 mm. The final mixture proportion of MSC was obtained based on the slump test and strength at age of seven days, as shown in Table 3.

Fresh concrete were prepared in forced mixer by mixing for four minutes. Then specimens were cast using plastics moulds with dimensions of 150 mm×150 mm×150 mm. All specimens were demoulded at concrete age of two days and

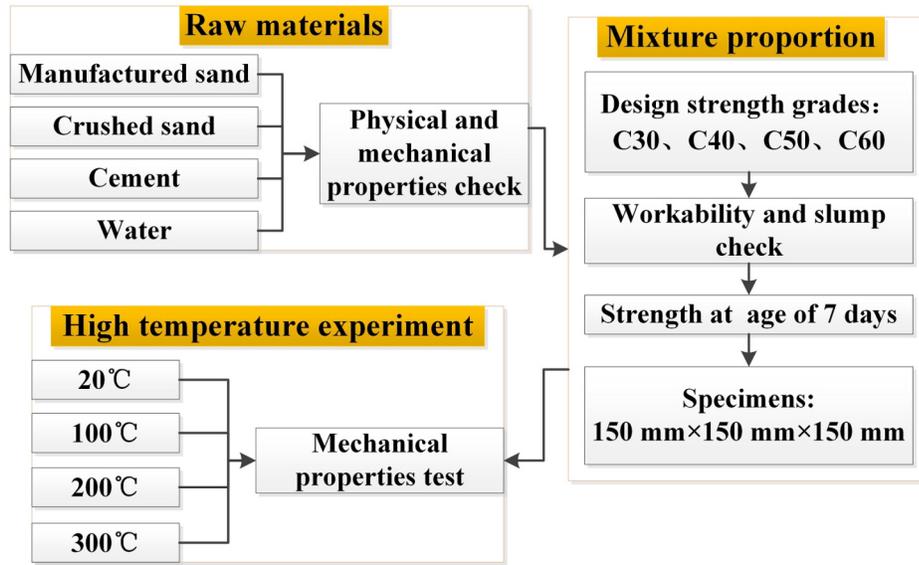


Fig. (1). The procedure of study.

Table 1. Properties of MS.

Physical properties		Main chemical composition	
Methylene blue value	0.9 (<1.4)	CaO	50.04
Apparent density/Kg·m ⁻³	2690	SiO ₂	5.10
Packing density/Kg·m ⁻³	1760	Al ₂ O ₃	1.16
Clay content	2.1%	MgO	1.07
Fineness module	2.8	Fe ₂ O ₃	0.64
Fine content	8.1%	K ₂ O	0.46
Crush index	34.1%	Loss on ignition	41.35

Table 2. Properties of the crushed stones.

Apparent density /Kg·m ⁻³	Packing density /Kg·m ⁻³	Crush index	Clay content	Acicular and flaky granule content
2685	1750	9.0%	2.8%	8.1%

Table 3. Mix proportion of concrete.

Design strength	Cement	Water-cement ratio	Mix proportion m(cement):m(sand):m(stone):m(water)
C30	P·O 32.5	0.47	1:1.06:2.16:0.47
C40	P·O 42.5	0.5	1:1.09:1.86:0.5
C50	P·O 42.5	0.45	1:0.94:1.61:0.45
C60	P·O 52.5	0.4	1:0.75:1.28:0.4

Table 4. The residual compressive strength of cube specimens after high temperature.

T/K	Compressive strength/MPa			
	C30	C40	C50	C60
293.15	33.31	40.53	51.42	60.47
373.15	32.71	37.51	48.51	58.6
473.15	31.72	37.56	45.42	54.23
573.15	27.2	34.96	43.39	50.23

continued to be cured in standard curing room in the temperature of 293.15 ± 2 K and relative humidity of more than 95% for 26 days.

2.3. High Temperature Experiment

Cubic specimens was used for high temperature experiment and compressive strength test. The testing specimens were divided into four sets at temperatures of 293.15, 373.15, 473.15, and 573.15 K. Each set contained nine cubic specimens.

At the concrete age of 28 days, all specimens were first placed in box-type high-temperature furnace and heated to the predetermined temperature. Then the specimens were kept in the target temperature for 3 hours in the furnace. After that, the furnace was turned off and the specimens were cooled to normal temperature in air. Three days later, the mass and compressive strength were tested according to national standard of the People’s Republic of China GB/T50081-2002.

3, RESULTS AND ANALYSIS

3.1. High-Temperature Test

The residual compressive strength was tested and the results are presented in Table 4. The mass loss results are shown in Fig. (2) while Fig. (3) displays the relative compressive strength of MSC with different strength grades after high temperature.

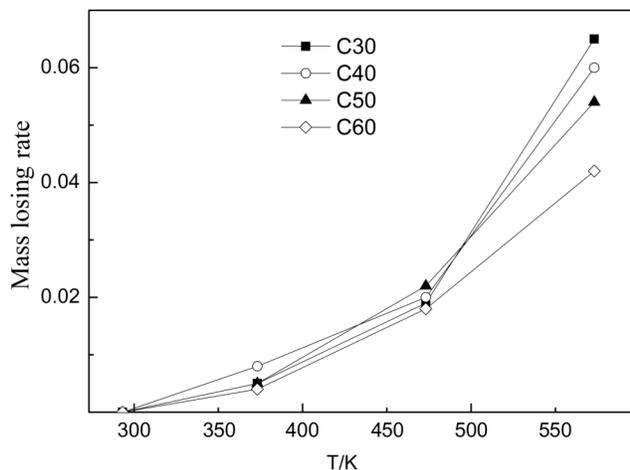


Fig. (2). Mass losing rate of concrete after high temperatures.

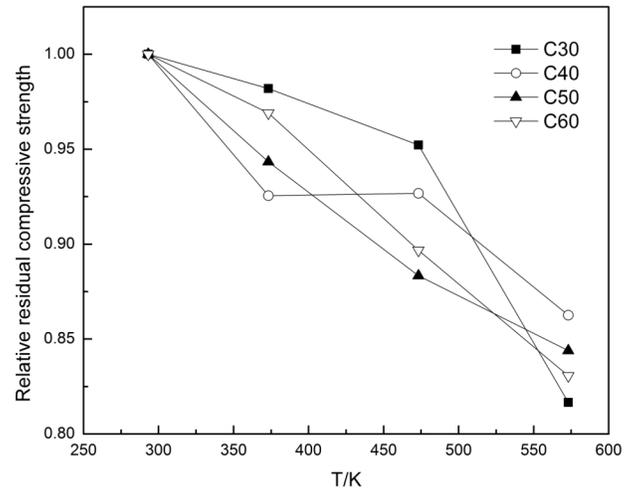


Fig. (3). Relative residual compressive strength of cube specimens.

As can be seen from Table 4, the higher the strength grade of MSC, the more the loss of strength under high temperature. The destruction of internal structure caused the first decline of strength at high temperatures. During the cooling process, the temperature inside the specimens was higher than outside, which aggravated the deterioration of properties and caused further strength loss.

As can be seen in Fig. (2), the mass of specimens reduces little before 373.15 K and trend to increase after 373.15 K. However, the specimens didn’t flake or burst. It indicated that the cement colloid began to dehydrate severely.

Table 4 and Fig. (3) show the basic law of the cube compressive strength of MSC varying with temperature which is to natural sand concrete at high temperatures [11].

When the temperature was 293.15 - 373.15 K (T = 293.15 - 373.15 K), free water inside MSC was evaporated, pores and cracks were formed inside the specimen, and the compressive strength decreased. At this stage, the water-cement ratio and water consumption were the main factors influencing the residual strength after the high temperature test. The larger water-cement ratio and water consumption could cause more internal pores and lower residual strength after the high temperature.

When T = 373.15 - 573.15 K, all free water inside the specimen was evaporated, but the overall trend was still downward and differed for different strength levels. At this stage, the descent rate of strength of C30 MSC increased significantly after 473.15 K as shown in Fig. (3). It indicated

that the free water of C30 concrete had completely evaporated at 473.15 K. And with increasing temperature, the deformation difference increased gradually between cement colloid and coarse aggregate and the interface cracks continued to expand. As a result, the strength declined sharply. The strength of C40 MSC turned to rebound a bit at 473.15 K because the cement colloid was contracted gradually by dehydration and it strengthened the bond between cement colloid and aggregate. After 473.15 K, the deformation difference increased gradually between cement colloid and coarse aggregate and the interface cracks expanded resulting in the second decline of strength. The strength of C50 MSC declined less per 100 K as the temperature rising. It indicated that the contraction occlusion phenomenon occurred after 373.15 K which eased the decrease of strength of manufactured sand concrete. The strength of C60 MSC dropped linear. It evinced that there was little free water in C60 MSC and that the occlusion was not obvious brought by cement colloid contraction.

Besides, the void sizes and porosity could be enlarged by the evaporation of water and contraction of cement colloid. This was another factor that caused the reducing of strength of MSC.

In summary, the main reasons for strength loss of MSC under high temperature are: (1) a variety of water were evaporated and pores and cracks was formed inside the manufactured sand concrete; (2) the severe dehydration made cement colloid contract. The deformation difference and thermal stresses, caused by uncoordinated thermal performance between cement colloid and coarse aggregate, resulted in the extending of crack. (3) the void sizes and porosity could be enlarged.

3.2. The Formula of Residual Strength after High Temperature

Fig. (3) shows the experimental results of MSC and the fitted curve after high temperature test. The fitting formula (1) was

$$\begin{aligned} f_{cu}^t / f_{cu}^{20} = & -0.00537 \left[(T - 273.15) / 100 \right]^2 \\ & - 0.0397 \left[(T - 273.15) / 100 \right] + 1 \end{aligned} \quad (1)$$

(R=0.90)

According to experimental data of 737.15 K and 937.15 K in the literature [10], the fitting curve 1 deviated far from the data points. Therefore, the fitting Formula (1) was corrected to obtain the improved curve 2 in Fig. (4) as

$$\begin{aligned} f_{cu}^t / f_{cu}^{20} = & -0.00877 \left[(T - 273.15) / 100 \right]^2 \\ & - 0.0336 \left[(T - 273.15) / 100 \right] + 1 \end{aligned} \quad (2)$$

(R=0.97)

In Fig. (4), the two curves labeled CEN are the recommended curves of residual strength of ordinary concrete after high temperature in the United States (SA presents siliceous aggregate, and CA for calcium aggregate) [12]. Contrast between the fitting curve and recommended curves indicates the residual strength of MSC after high temperature was slightly lower than the recommended curves before 673.15

K. This was because the water consumption of concrete compounded in laboratory was larger and the water inside specimens was more so that more voids and cracks were formed by evaporation in high temperature. After 673.15 K, residual strength of MSC was close to or even higher than the recommended curves.

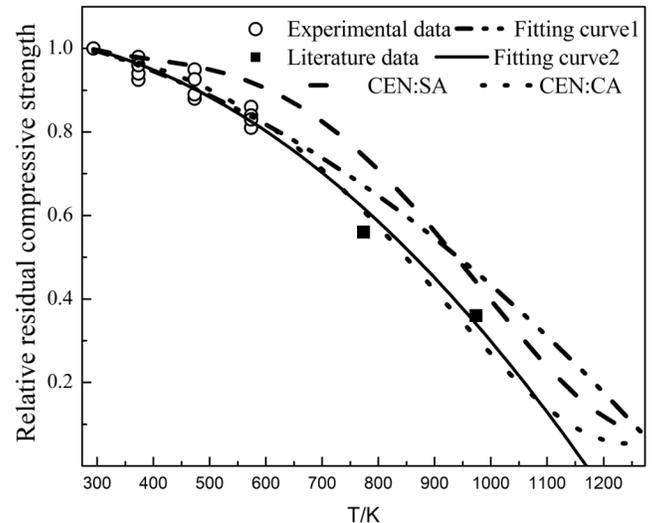


Fig. (4). Comparison with suggested curves from USA.

CONCLUSION

- (1) When Temperature was below 373.15 K, the mass loss of MSC was small and compressive strength reduction can be ignored. When the temperature was 373.15 - 573.15 K, the mass loss of MSC increased. And the higher the temperature, the more the loss.
- (2) The high temperature resistance of MSC had a great relationship with water-cement ratio and water consumption. The larger moisture content of concrete would result in the higher internal vapor in heating process.
- (3) The fitting formula (2) could describe well the strength of MSC changing with temperature and indicated that MSC had a good applicability in the high temperature environment.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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