Study on the Freeze-Thaw Performance of Concrete Using Granulated Blast-Furnace Slag as Fine Aggregate

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Abstract. In this paper, the freeze-thaw performance of concrete using granulated blast-furnace slag (GBS) as fine aggregate was studied. According to the test method for slow freezing and thawing, degradation of mechanical properties about GBS concrete with 2 kinds W/B ratio and 3 kinds GBS replacement ratio were tested, and micromorphology of GBS concrete were analyzed by scanning electron microscopy (SEM). Furthermore, relations between degradation of mechanical properties and micromorphology about GBS concrete are discussed. Test results show that: after freeze-thaw cycles, the relative compressive strength of GBS concrete is greater than ordinary river sand concrete, and the GBS concrete will produce more mutual interlacing fibrous and flowers from crystal, the growth of these crystals can improve the compressive strength of concrete. Therefore, the frost resistance of GBS concrete is little better than ordinary river sand concrete.

Keywords: granulated blast-furnace slag; concrete; freeze-thaw; SEM

1 Introduction

Concrete is a brittle composite materials with anisotropic, multiple and multilevel characteristics. In general, the internal micro-structure of concrete can reflect the macroscopic properties, such as complex mechanical characteristics and macroscopic durability. Therefore, a large number of research achievements about the freezing and thawing of concrete which is the vital significant influencing factor of internal micro-structure of concrete have been obtained by many of scholars, but there are less researches in terms of combining macroscopic behavior and micro-structure, especially on the microscopic properties of GBS concrete after freeze-thaw cycles, it has a wide research space.

According to Bahador Sabet Dirsholi and Tze Yang Darren Lim, replacing partial amount of Portland cement (PC) with ground granulated blast furnace slag (GGBS) can enhance the compressive strength of the concrete. Since then, they also found that GGBS concrete had higher early strength and stronger flexural strength[1,2]. Escalante et al investigated that GBS would absorb Ca and form C-S-H gel when it hydrate, and the Ca/Si ratio of C-S-H gel GBS produced was lower than cement produced[3]. Q.Wang et al found that the paste morphology of the GBS gelled material looked denser than cement paste at 28 days curing[4].

The physical properties of GBS are similar to natural river sand, and its chemical properties are close to the cement. And, the GBS has the potential activity as fine aggregate used in concrete, it can not only replace natural sand and effectively use industrial waste residue but also effectively utilize its hydration and increase the various performance of concrete[5,6]. In this paper, partial amount of natural sand is replaced with GBS as fine aggregate, to evaluate its frost resistance and hydration mechanism through the compressive strength and paste micromorphology of the GBS concrete before and after freeze-thaw.

2 Experimental

2.1 Materials.

The cement used in this study was P.O42.5 Portland cement supplied by Jidong cement plant in Hohhot. The fine aggregate was GBS supplied by Xuanhua Steel Group, and the chemical compositions of GBS are shown in Table 1. Natural river sand that came from Xiao Heihe of Hohhot was made as a comparison. The coarse aggregate was hard granite that came from Da Qingshan in Hohhot. The chemical admixture was polycarboxylate superplasticizer.

Table 1 Chemical Composition Of Granulated Blast Furnace Slag

Chemical composition	CaO	SiO_2	Al_2O_3	MgO	FeO	S	MnO	P_2O_5
Percentage (%)	41.7	33.8	13.4	7.4	0.4	0.8	0.3	<0.1

The sieve test shows that fineness modulus of natural sand was 2.79, and GBS was 2.70. Both of them were medium sand and belong to II area. Performance of concrete aggregate is shown in Table 2.

Table 2 Performance Of Concrete Aggregate

Performance / Material	Apparent density (kg/m3)	Moisture content (%)	Crushing index (%)	Fineness modulus
Sand	2740	1.1	17	2.79
Slag	2520	2.0	93	2.70
Gravel	2843	1.1	7.0	/

2.2 Mix Ratio of Concrete.

Mix ratio of GBS concrete is shown in Table 3 while W/B of 0.5 and 0.25 are mainly chosen to make analysis in this paper, and the GBS replacement ratio varies from 0% to 100%.

Table3 Mix Ratio Of Slag Concrete

Code	W/B	Mix ratio of concrete (kg•m^{-3})					
		Wat	Ceme	Sand	G	Gr	Superplasticizer
2-1	0.50	180	360	810	0	99	0.40
2-2	0.50	180	360	0	73	10	1.00
2-3	0.50	180	360	380	37	10	0.80
1-1	0.25	200	800	660	0	81	3.20
1-2	0.25	205	820	0	59	82	2.20
1-3	0.25	200	800	310	30	84	2.10

2.3 Testing Method.

According to "Standard for test methods of long-term performance and durability of ordinary concrete" (GB/T50082-2009), slow freezing method was used and the numbers of freeze-thaw cycle were 25 times and 50 times respectively. What's more, the specimens have the same curing time with the freeze-thaw time, and the compressive strength of concrete after freeze-thaw cycling and standard curing were tested respectively. Finally, the micromorphology of GBS concrete and natural river sand concrete that was cured for 28 days and was done with 50 times freeze-thaw cycles were observed respectively with Hitachi S-4800 scanning electron microscope in high vacuum mode.

3 Results and Discussion

3.1 Compressive Strength.

The compressive strength of concrete and the relative compressive strength of concrete are shown in Table 4 and Table 5 respectively. The relative compressive strength of GBS concrete and natural sand concrete decreased with numbers of freeze-thaw cycles. And the compressive strength loss rate of GBS concrete increase with numbers of freeze-thaw cycles, and the greater the water-binder ratio, the greater the compressive strength loss rate. After 25 times freeze-thaw cycles, the relative compressive strength of natural sand concrete are 0.93 ~ 0.96, then the relative compressive strength of 50% GBS replacement ratio concrete and 100% GBS replacement ratio concrete are 0.92 ~ 0.95 and 0.96 ~ 0.99 respectively. After 50 times freeze-thaw cycles, the relative compressive strength of natural sand concrete are 0.81 ~ 0.88, then the relative compressive strength of 50% GBS replacement ratio concrete and 100% GBS replacement ratio concrete are 0.85 ~ 0.91 and 0.90 ~ 0.99 respectively. Furthermore, from the relative compressive strength of contrast specimens, the same changing trend appeared. So it is known that the frost resistance of GBS concrete is better than ordinary river sand concrete.

Table 4. Compressive Strength Of Freeze-Thaw Cycle Effect And The Specimens

W/B	Replacement for sand (%)	Compressive strength（Mpa）				
		28 d	Freezing and thawing test		Contrast specimen	
			25	50	25	50
0.50	0	42.94	39.96	34.96	43.45	44.02
	50	49.35	45.62	42.09	50.00	52.46
	100	39.52	37.91	35.60	40.09	42.88
0.25	0	79.42	76.21	69.89	79.04	80.18
	50	71.82	68.11	65.67	74.82	78.66
	100	66.50	66.12	65.96	71.40	72.39

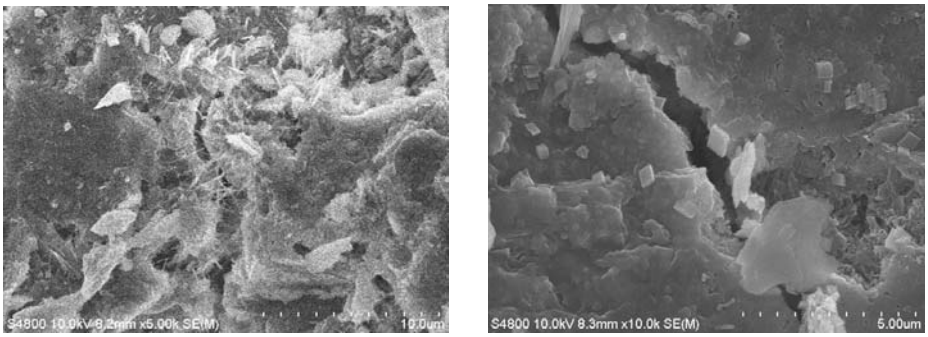
Table 5. Relative Compressive Strength Of Concrete

W/B	Replacement for sand (%)	Freezing and thawing cycles			Contrast specimen	
		0	25	50	25	50
		f c/f c	f a,c/f c	f b,c/f c	f a,c/f d, c	f b,c/f e, c
0.50	0	1	0.93	0.81	0.92	0.79
	50	1	0.92	0.85	0.91	0.80
	100	1	0.96	0.90	0.95	0.83
0.25	0	1	0.96	0.88	0.96	0.87
	50	1	0.95	0.91	0.91	0.83
	100	1	0.99	0.99	0.93	0.91

Note：fc-Compressive strength of concrete for 28 days
fa, c & fb, c -Compressive strength of concrete after different freeze-thaw cycles
fd, c & fe, c -Compressive strength of contrast specimen

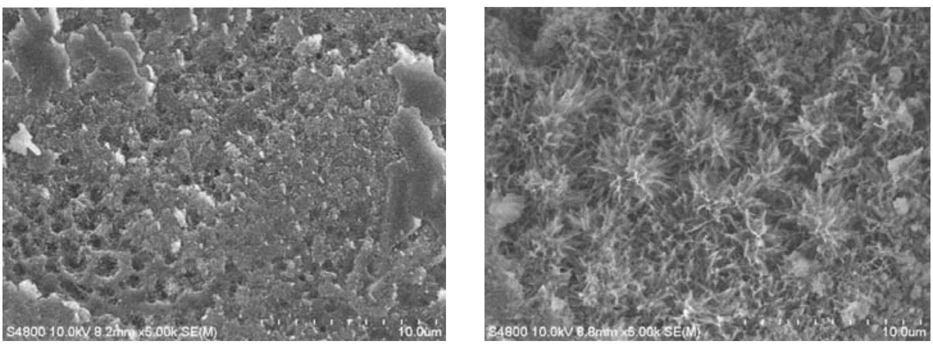
3.2 Analysis by SEM.

To explain the difference of frost resistance performance of concrete with different kinds of fine aggregate, the micromorphology of concrete paste was observed by SEM. GBS has secondary hydration effect when it was put in alkaline environment of concrete. The secondary hydration can improve the compactness of concrete. Especially, the secondary hydration can improve the long-term strength and frost resistance of GBS concrete. The hydration products with two kinds of fine aggregate and mix proportions of W/B=0.50 are observed in this experiment, as shown in the Fig. 1 and Fig. 2.



a. micromorphology of 28d age b. micromorphology in 50cycles

Fig.1 Micromorphology Of Natural River Sand Concrete(W/B=0.50)



a. micromorphology of 28d age b. micromorphology in 50cycles

Fig.2 Micromorphology Of Gbs Concrete (W/B=0.50)

The micromorphology of nature sand concretes that maintain 28 days and suffer 50 times freeze-thaw cycles are shown in Fig.1. In addition, Fig.2 shows the micromorphology of GBS concretes with 100% GBS replacement ratio, which are maintain 28 days and suffering 50 times freeze-thaw cycles.

Making a comparison between Fig.1a and Fig.1b, the hydration products of concrete structure varies from dense to incompact by freezing and thawing cycles, and cracks are found in nature river sand concrete too. The damage of microstructure leads to the decrease of the compressive strength of nature river sand concrete. However, comparing Fig.2a and Fig.2b, the structure of GBS concrete is neat, and there is any cellular porosity before freeze-thaw cycles. Otherwise, 50 times freeze-thaw cycles ago, there are more flowerlike C-S-H gels that produced, and a cluster next to a cluster, the existence of pores in concrete provided certain space for its growth. Although the structure is neat, the compressive strength was not reduced. It is the reason that the characteristics of the GBS is more porous and water absorption, which reduces water-binder ratio of surrounding slurry and makes the slurry more compact, at the same time, the characteristics of GBS inhibits the growth of ettringite, it can reduce expansile probability of concrete.

4 Conclusions

1. After freeze-thaw cycles, the decrease of compressive strength of GBS concrete is less than ordinary river sand concrete.

2. After freeze-thaw cycles, the GBS concrete produce more fibrous and flowerlike crystal, and the growth of these crystals maybe improve the compressive strength of concrete.
3. The frost resistance of GBS concrete is little better than ordinary river sand concrete.

Acknowledgement

The authors are grateful to the financial support by the National Science Foundation of China (No. 51268041) and the Science Foundation of Inner Mongolia (No. 2014MS510). In addition, the authors also acknowledge the help of China Scholarship Council and finance coming from the Cao Yuan Ying Cai Project of Inner Mongolia government of the P. R. China.

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