APPLICATION OF GROUND GRANULATED BLAST FURNACE SLAG IN HIGH-PERFORMANCE CONCRETE IN CHINA

Wang Ling, Tian Pei, and Yao Yan
China Building Materials Academy, PRC

Abstract

This paper introduces studies and the application of ground granulated blast furnace slag (GGBS) in China. The performance of GGBS is measured and the effect of GGBS on fresh concrete and harden concrete is analyzed. GGBS concrete is characterized by high strength, lower heat of hydration, and resistance to chemical corrosion.

1. Introduction

Annual granulated blast furnace slag (GBFS) production capacity in China is around 15 million tons. GBFS powder has been successfully applied as the raw material of cement block, pavement block, and slag cement.

GBFS is usually used as additives in Portland cement production in China. Traditional production technology is to grind cement clinker, GBFS and gypsum together. Because GBFS is more difficult to grind than clinker, specific surface area of GBFS in cement is under 300 m^2/g. The grain size of GBFS is mostly over 60 um; thus its activity in early age is limited and cannot been brought into full play. Concrete mixed with this kind of slag cement has some shortage, such as low early strength, poor durability, and ease of bleeding.

At present, with the quick development of high efficient grinding apparatus, GBFS is produced to ground granulated blast furnace slag. GGBFS is different to the GBFS used as additive in slag cement. Its specific surface is more than 350 m^2/kg, some even more than 800 m^2/kg. Nation standard GB18736-2001, *Mineral Admixture for High-Performance Concrete (HPC),* regulates the properties of GGBFS, which can be used in HPC. When used in concrete, it make concrete has good workability, high strength, and good durability. GBFS is a kind of industry waste. Through advanced processing technology, the material turns into GGBFS, which can act as an economical and ecological resource for modern concrete. Research, production and application of GGBFS in HPC promote the comprehensive utilization of slag into a new stage in China.

2. Influence of GGBFS on the Effect of Superplasticizer

2.1. Materials

- GGBFS: S1 (350 m^2/kg), S2 (450 m^2/kg), S3 (550 m^2/kg), produced by Wuhan Iron & Steel Group Co.
- Cement Q: 42.5 portland cement, Jidong Cement Company
- Cement W1: 70%Q + 30%S1
- Cement W2: 70%Q + 30%S2
- Cement W3: 70%Q + 30%S3
- Superplasticizer:
  - BW (naphthalenesulfonic acid based admixture)
  - SM (sulfonated melamine formaldehyde based admixture)

2.2. Influence of GGBFS on absorption to admixture

Absorption of cement Q, W3, slag S1 and S3 were tested. W/S = 5, and admixture concentration is 2 g/L. The initial absorption volume and the admixture concentration after 1 hour are list in Table 1.

Apparently, the absorption of slag S1 and S3 to BW and SM are both smaller than cement Q. If the content of admixture is fixed, there would be much more superplasticizer to disperse the cement particle when use GGBFS to replace part of cement. That is to say, absorption of cement particle to superplasticizer will be larger.

Table 1: Absorption of cement and slag to admixture

	Initial absorption (mg/g)		Concentration of admixture after 1 hr (g/l)	
	BW	SM	BW	SM
Cement Q	3.25	5.3	0.58	0.29
CementW3	3.12	4.4	0.62	0.42
Slag S1 (350)	2.61	2.14		
Slag S3 (550)	2.80	2.38		

2.3. Influence of GGBFS on ζ- potential between cement particles

The repulsion between cement particles can be expressed in ζ-potential of cement particles. We tested ζ-potential of a series of cement paste that included slag. The results are in Table 2.

Table 2: Influence of GGBFS to ζ-potential (mv)

	Admixture	
	BW	SM
Q	-37.25	-35.63
Q + 10%S1	-40.46	-38.67
W1 (Q + 30%S1)	-42.49	-42.11
Q + 50%S1	-46.52	-47.19
W2	-42.93	-42.91
W3	-43.38	-43.54

With the increase of specific surface and content of the GGBFS, the ζ-potential increases apparently. That means that the repulsion between cement particles increases too at that case. This is one of the reasons that GGBFS can improve workability of concrete.

Influence of specific surface of GGBFS on paste workability is expressed in Figs. 1 and 2. Influence of GGBFS content on paste workability is expressed in Figs. 3 and 4.

From the four mentioned figures, we can find that: when add GGBFS (10%-30%) into cement, the saturation dosage of superplasticizer changes a little, the flow of cement paste improves and the loss of flow decrease at the recommended dosage of the two superplasticizers. When the specific surface of GGBFS changes from 350 to 550 m^2/kg, the saturation dosage of superplasticizer is almost the same, the flow of cement paste improves and the loss of flow decrease.

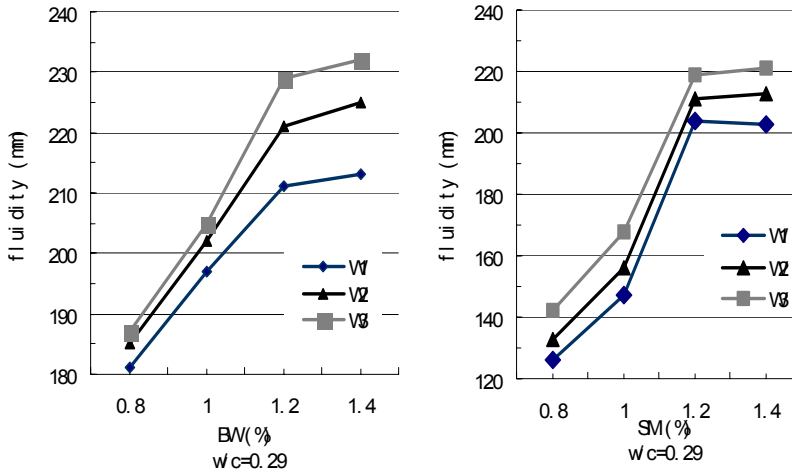

Fig. 1: Influence of slag fineness to solution dosage of admixture

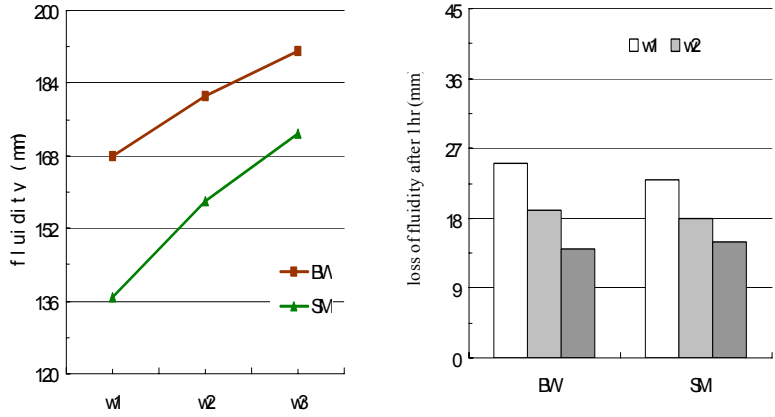

Fig. 2: Influence of slag fineness to flow and flow loss of cement past

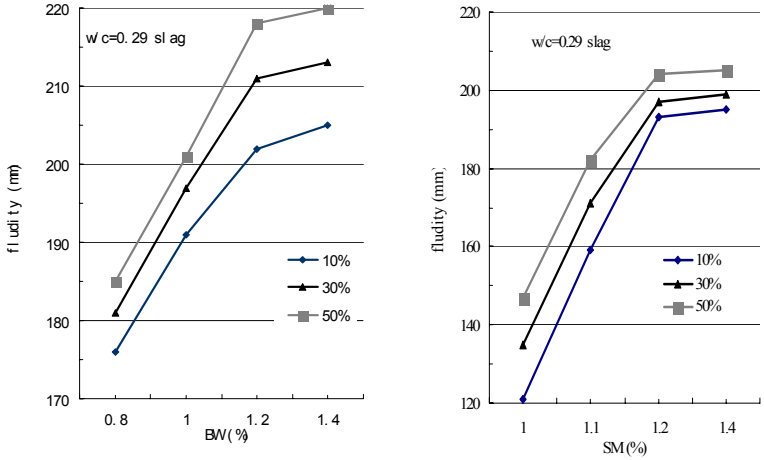

Fig. 3: Influence of slag content to solution dosage of admixture

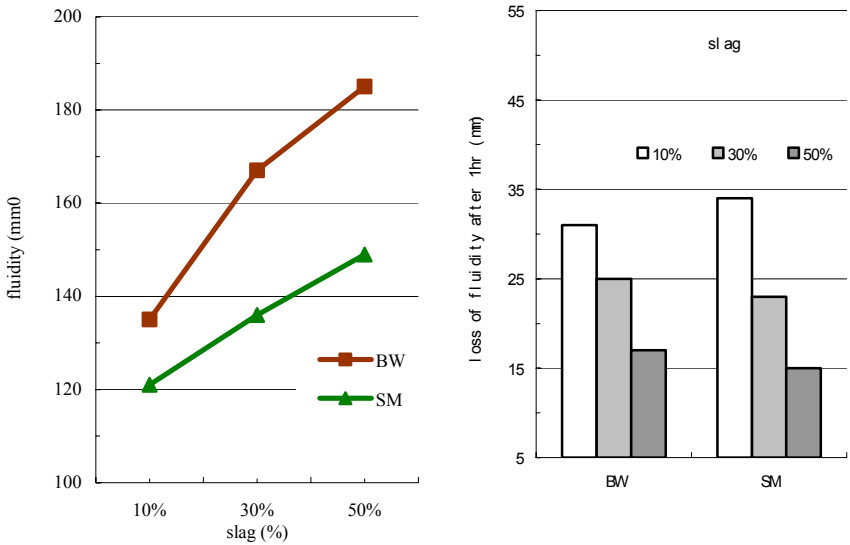

Fig. 4: Influence of slag content to flow and flow loss of cement past

3. Application of GGBFS in High-Strength HPC

If the specific surface of GGBFS is grinded to 500-800m^2/kg, it shows very different properties with lower fineness slag (<400 m^2/kg). High specific surface slag can replace 20%-50% cement to mix high strength concrete (>C60). When it adds into concrete, workability and strength of concrete will change a lot.

3.1. Materials

- GGBFS: specific surface 400, 500, 700, and 800m^2/kg, produced by Wuhan Iron & Steel Group Co.
- Cement: 42.5 portland cement, Jidong Cement Company
- Superplasticizer: JB-1 (naphthalenesulfonic acid based admixture)
- Sand: Mx = 2.9
- Stone: 5-20-mm gravel

3.2. Test results

Typical mix proportion of high strength HPC and the properties are in Table 3.

Table 3: Mix proportion (kg/m^3) and properties of high strength HPC

No.	Cement	Slag (m^2/kg)				Water	Stone	Sand	Admixture (%)	Slump (cm)	Compressive strength (MPa)			
		300	500	700	800						3d	7d	28d	60d
1	500	–	–	–	–	150	1085	665	1.3	23.0	56.4	60.0	70.7	74.1
2	350	150	–	–	–	150	1085	665	1.3	22.0	61.5	70.0	79.5	84.3
3	350	–	150	–	–	150	1085	665	1.3	23.0	64.7	74.2	81.3	84.1
4	350	–	–	–	150	150	1085	665	1.3	23.0	76.7	88.3	93.6	99.0
5	600	–	–	–	–	150	1134	610	1.5	22.5	63.0	71.2	81.1	–
6	480	–	–	120	–	150	1134	610	1.5	24.0	65.6	79.9	93.0	–
7	420	–	–	–	180	150	1134	610	1.5	24.5	69.3	83.2	100.4	–

From Table 3, we can see that strength of concrete at each age increase with the increase of GGBFS fineness when the substitute contents are the same. Control the cementitious materials to 500 kg/m^3, compressive strength of 3 and 28 days are increase 9% and 12%, respectively, when using GGBFS of 400 m^2/kg; and in the meantime the compressive strength of 3 and 28 days are increase 35% and 32%, respectively, when using GGBFS of 800 m^2/kg. At very early age, the very fine GGBFS acts as assistant cementitious in concrete, it has *pozzuolana role*. On the other hands, GGBFS grain has a *filling role,* which can improve the hydration structure, the strength, and the durability of HPC.

4. Application of GGBFS in Middle-Strength HPC

Research on HPC in China is different to most of the European countries. It is believed that the range of HPC cannot be restricted only in high strength concrete. To make the C30-C50 concrete, high performance is also a focus of HPC research in China. Proportion of concrete of C10-C25, C30-C50, and C55-C75 are 31.6%, 67.1%, and 1.3%, respectively, in Beijing in the second quarter in 2003. Situation in the other province in China is almost the same. C30-C50 concrete is almost 70% of all concrete output.

Slag in C30-C50 concrete should not have very high specific surface due to cost and economy reason. GGBFS with 350-500 m^2/kg is very appropriate.

4.1. Materials

- GGBFS: specific surface 450 m^2/kg, produced by Shougang Group Corporation
- Cement: 42.5 portland cement, Beijing Cement Company
- Superplasticizer: TK-1 (naphthalenesulfonic acid based admixture)
- Sand: $M_x = 2.9$
- Stone: 5-25-mm gravel

4.2. Test results

The fresh and hardened concrete properties of GGBFS concrete (C30-C50) were tested and illustrated in Figs. 4-6. Strength of concrete with different slag content is according to substitute content and water cementitious ratio. When the substitute content is higher, the early strength is lower, but the 28- and 60-day strength is almost the same.

Table 4: Influence of GGBFS to compressive strength of middle strength HPC (cementitious materials 390 kg/m^3, W/B = 0.46)

	Compressive strength (MPa)			
Substitute content of GGBFS (%)	3d	7d	28d	60d
45	19.8	30.6	53.8	60.5
50	18.3	29.8	53.3	56.5
55	18.0	29.4	51.9	60.7
60	17.0	29.4	50.6	56.2
65	14.7	28.1	49.2	53.8

Table 5: Influence of GGBFS to compressive strength of middle strength HPC (cementitious materials 438 kg/m3, W/B = 0.40)

	Compressive strength (MPa)			
Substitute content of GGBFS (%)	3d	7d	28d	60d
45	27.2	36.1	57.3	67.4
50	26.6	35.5	58.9	63.5
55	25.8	35.0	58.0	66.4
60	24.1	34.0	56.5	64.4
65	23.8	32.6	57.8	68.0

Table 6: Influence of GGBFS to compressive strength of middle strength HPC (cementitious materials 500 kg/m^3, W/B = 0.35)

	Compressive strength (MPa)			
Substitute content of GGBFS (%)	3d	7d	28d	60d
45	34.4	45.6	65.6	73.6
50	31.	43.8	67.6	72.3
55	30.9	44.7	68.0	71.8
60	28.7	40.9	64.4	76.3
65	28.6	41.6	61.8	75.4

Curing temperature is a key factor of strength of slag concrete, especially to the early strength. If the temperature is raised, strength at 1 day may be bigger than reference concrete. So curing of GGBFS concrete should be controlled under fit temperature and wet condition. GGBFS concrete is more sensitive to curing condition than Portland cement concrete. Due to lower hydration rate of slag, curing time should be prolonged than portland cement concrete.

GGBFS HPC is an important breakthrough to traditional concrete in China. It is characterized by energy savings, cement savings, low cost, environmental protection, and environmental and social benefits as well as economic profit. This kind of new building material can be called green concrete. It has good properties and its application should be more widespread.