STUDY ON PROPERTIES OF ULTRA-HIGH-STRENGTH FIBER-REINFORCED CONCRETE CONTAINING ORDINARY PORTLAND CEMENT AND BLAST FURNACE SLAG WITH VARIOUS FINENESS

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Abstract

This paper is presenting a research on properties of ultra-high-strength fiber-reinforced concrete (UFC), containing ordinary Portland cement (OPC) and blast furnace slag (BFS) having various fineness. The compressive strength of ordinary UFC is more than 150 N/mm^2, and it has high toughness and durability. However, UFC has a problem with its workability due to the high viscosity. And in order to achieve its performance, it is necessary to use special cement and cure at high temperature for long time. The purpose of this study is to improve the workability of UFC and to achieve its performance by using OPC normal temperature. The main materials used are OPC, BFS powders with several levels of fineness, silica fume and other inorganic powders such as Wollastonite and Gypsum. The effect of these materials and their mix proportions on the properties were examined. Based on the results, the fresh properties of UFC were much improved and hardened performances were also improved by using OPC at normal temperature.

Keywords: Ultra-hight-strenght fiber-reinforced concrete, Blast furnace slag, Fineness and Workability.

1. INTRODUCTION

Ultra-high-strength fiber-reinforced concrete (UFC) has excellent strength, achieving compressive strength more than 150 N/mm^2, high toughness due to the addition of fibers, and excellent durability with respect to chloride ion penetration and freeze-thaw cycles. These properties have attracted attention in recent years, and it is expected that the usage of UFC can significantly reduce construction costs by achieving smaller member cross sections, reducing the quantity of materials, and improving durability.

Most UFC is typically steam-cured at high temperature and for long hours to exhibit high strength and durability, therefore UFC members are generally precasted in a factory. This factory production ensures its quality, but a series of this process including steam curing, transport, and installation increases its construction cost. In order to expand the usage of UFC, it is required to be able to cast and cure UFC on-site[1], 2]].

In Japan, a new type of UFC, whose performance is achieved without steam curing, has been developed[1]]. However, this method requires a special cement which contains high percentage of C3S. Therefore, this type of UFC has not been widely used yet.

Based on this background, this study evaluated the effect of powder composition of UFC on its fundamental characteristics.

2. FUNDAMENTAL PROPERTIES OF ULTRA HIGH STRENGTH MORTAR CONTAINING FIBER, ORDINARY PORTLAND CEMENT AND BLAST FURNACE SLAG POWER WITH VARIOUS FINENESS

2.1 Outline of tests

The characteristics of UFC mixed fibers were investigated in this section. The fresh and hardened properties of UFC containing steel fiber, ordinary Portland cement and blast-furnace slag powder, which have different Blane specific surface area, were evaluated.

2.2 Materials

Table 1 shows the materials used in this study. The binders were ordinary Portland cement, silica fume, anhydrous gypsum, wollastonite and blast furnace slag whose Blane specific surface area are 8000, 12000 and 20000 cm^2/g. The purpose of using wollastonite and anhydrous gypsum is respectively to improve pumpability and to improve strength at early age.

Table 2 shows the properties of the fiber.

2.3 Test conditions

Table 3 presents the powder compositions. In these tests, the water-to-powder ratio (W/P) was 17%, and the sand binder ratio (S/P) was 30%. In order to improve strength of mortar, anhydrous gypsum and silica fume were mixed at 5% and 10% respectively. Wollastonite was mixed to ordinary Portland cement at an inner volume ratio of 10% in order to improve pumpability[3].

The blast furnace slag fine powder was mixed at 7%. The mixing combination of these blast furnace slag with different Blane specific surface area is shown in table 4. Fiber containing ratio was 2.0vol%[4]. A 10 litter capacity Omni type mixer was used for mixing.

2.4 Blending and mixing method

A 10 litter capacity Omni type mixer was used for maxing. First, only the powder and fine aggregate were added and mixed for 30 s, then water and supper plasticizer were added and mixed for 10 min. An antifoaming agent was then added and mixed for 1 min. The addition of the antifoaming agent is to increase the bending and compressive strength.

Table 1: Materials

Materials	Type	Blane (cm^2/g)	Symbol	Density (g/cm^3)
Binder	Ordinary Portland cement	3340	OPC	3.16
	Blast furnace slag	8000	BS8	2.91
		12000	BS12	2.91
		20000	BS20	2.91
	Wollastonite	-	WA	2.91
	Anhydrous gypsum	3320	AG	2.90
	silica fume	150000	SF	2.25
Fine aggregate	silica sand	-	S	2.61
Water	Tap water	-	W	1.00
Chemistry admixture	Super plasticizer	-	SP	1.10
	Defoamer	-	DF	1.00

Table 2: Properties of the fibers used

	length (mm)	Diameter (mm)	Tensile strength (MPa)	shape
Steel fiber	13.0	0.16	2000over	straight

Table 3: Powder compositions

No.	Symbol	Mass ratio(%)				No.	Symbol	Mass ratio(%)			
		U	BS	AG	SF			U*	BS	AG	SF
1	SF5AG5	83	7	5	5	3	SF10AG5	78	7	5	10
2	SF5AG10	78		10	5	4	SF10AG10	73		10	10

U*: OPC=90vol%, WA=10vol%

Table 4: Breakdown of blast-furnace slag in powder composition

No.	Symbol	Mass ratio (%)			No.	Symbol	Mass ratio (%)		
		BS8	BS12	BS20			BS8	BS12	BS20
i	BS8	7	-	-	v	BS8BS20	3.5	-	3.5
ii	BS12	-	7	-	vi	BS12BS20	-	3.5	3.5
iii	BS20	-	-	7	vii	BS8BS12BS20	2.33	2.33	2.33
iv	BS8BS12	3.5	3.5	-					

2.5 Test items and methods

2.5.1 Fresh property tests

(1) Mortar flow test

A mortar flow test was carried out in accordance with "JIS R 5201 Physical Testing Methods for Cement." The spread of the test specimen when not dropped is taken as the mortar flow value.

(2) JP funnel test under high pressure

The discharging time from JP-funnel under high pressure was measured. This test was previously proposed by Fujiwara H., et al as a test for evaluating thixotropy [5]. The test device is shown in Fig.1. The test procedure is as follows.

1. The clock was closed and the test sample is poured into JP funnel, then the container is closed. The pressure valve is adjusted so that the pressure within the container is 0.1 MPa.
2. The clock was opened to allow the test sample to flow out, and the time from the start of the flow to its finish is measured in steps of 0.1 second.
3. The inside of the container is depressurized and the container is opened to visually confirm that all the test sample within the funnel is discharged.

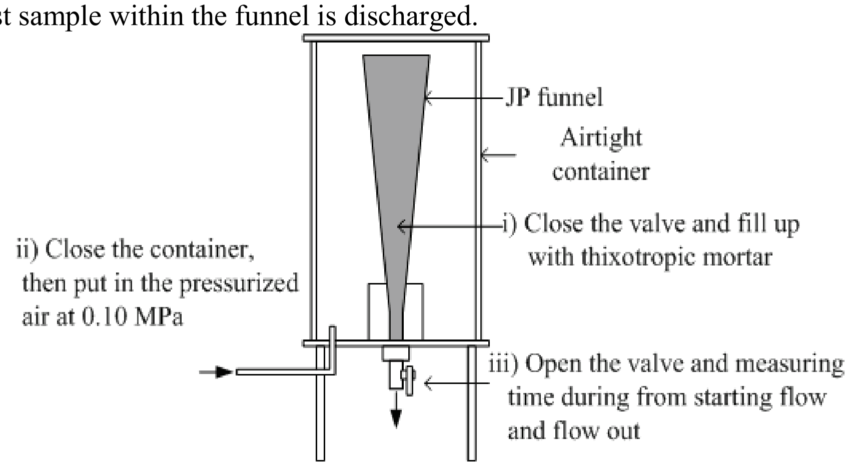

Figure 1: Test device of discharge time from JP-funnel under high pressure

(3) Air content test

The air content test was carried out in accordance with "JIS A 1116 Test Method for Unit Mass and Air Content of Fresh Concrete by Mass Method."

(4) Temperature measurement

A thermometer was used to measure the temperature of the mortar when mixing was completed.

(5) J_{14} Funnel Test

The discharging time of mortar was measured by using J_{14} funnel (height: 392mm, upper end radius: 35mm and, lower end radius: 7mm).

2.5.2 Hardened properties test

(1) Compressive strength tests

Compressive strength tests were carried out in accordance with "JSCE-G 505-1999 Test Method for Compressive Strength of Mortar and Cement Paste Using Cylindrical Specimens (φ5×10cm)." Measurement was carried out 1 day after casting, and at 7 and 28 days after curing in water (20℃) and hot water (60℃).

(2) Bending strength test

Bending strength tests were carried out in accordance with "JIS A 1106:2006 Test Method for bending strength test." Measurement was carried out 1 day after casting, and at 7 and 28 days after curing in water (20℃) and hot water (60℃) by using cuboid specimen (4×4×16cm).

2.6 Test results

Fresh property test result

Figures 1 and 2 show the test results of fresh properties. In all the mixes, segregation of materials, uneven distribution of fiber and occurrence of fiber balls were not observed.

As shown in figure 1, by comparing test results of specimen containing 10% of AG to those containing 5% of AG, flowability of specimen containing 10% of AG is higher. This means that flowability is improved by adding anhydrous gypsum.

And by comparing test results of specimen containing 10% of SF to those containing 5% of SF, flowability of specimen containing 5% of SF is higher. Therefore, mixture containing 10% of AG and 5% SF showed the highest flowability.

It was found the clear tendency on flowability by blending composition of BS with different fineness. Comparing the results of BS8, BS12 and BS20, it is found the tendency that flowability is higher when fineness is higher. However, the specimen containing multiple types BS (BS8, BS12 and/or BS20) did not show clear tendency of flowability.

From Furnace's close packing theory[6], if the difference between average particle size of two kinds of powder (D_1 and D_2) is more than 100 times (D_1/D_2), third powder should be used with medium average particle size(D_3) in order to achieve more closed packing. And recommended particle size is calculated by following formula.

$$D_3 = \sqrt{D_1 * D_2} \ (\mu m) \quad (1)$$

The average particle size of OPC used in this test is 15.4μm and that of SF is 0.1μm. The difference of their particle size is 154 times, so the third powder with medium particle size should be used and the recommended size D_3 is calculated as 1.24μm. The average particle size of BS is BS8: 4.5μm, BS12: 3.7μm and BS20: 1.8μm, respectively. Therefore, the average particle size of BS20 is closer to the recommended size, 1.24μm, and this could be the reason why flowability of the specimen using BS20 was higher.

And the specimen containing all of BS (BS8, BS12 and BS20) showed relatively high flowability. This is because wide particle size distribution created closer packing situation, which makes it more flowable.

By comparing J14 funnel test results of specimen containing 10% of AG to those containing 5% of AG, the discharging time of specimen containing 10% of AG is shorter. Specimen containing 5% of AG almost caused clogging, so discharging time could not be measured.

In this experiment, the discharging time from a JP-funnel under high pressure could not be measured. This is due to the interlocking of fibers while the mixture is discharging.

From these test results, it is confirmed that the workability of UFC could be improved by adding blast furnace slag powder which has fine average particle size and wide particle size distribution. This suggests the possibility of casting UFC at a construction site.

Test results of compressive strength

Figure 3 and Figure 4 show the test results of compressive strength. All mixture showed high strength more than 150 N/mm^2 at 20℃ and at 60℃, mixture of BS8BS12BS20 in SF5AG10 series showed highest compressive strength of 227.2 N/mm^2. This is considered to be enough compressive strength for UFC. Therefore, it is possible to achieve enough compressive strength by using ordinary Portland cement and curing at normal temperature.

Test results of bending strength

Figure 5 and Figure 6 show the test results of bending strength. All mixture showed high bending strength more than 30 N/mm^2 at 20℃ and at 60℃, mixture of BS8BS12BS20 in SF5AG10 series and BS8BS20 in SF10AG5 series showed high bending strength more than 45 N/mm^2. This is also considered to be enough bending strength for UFC. Therefore, it is also possible to achieve enough bending strength by using ordinary Portland cement and curing at normal temperature.

3.CONCLUSIONS

In this study, the effect of powder composition of UFC containing ordinary Portland cement and blast furnace slag powder with different fineness was evaluated and possibility of casting and curing UFC at the construction site was investigated.

Based on the several tests, the following findings were obtained.

・The flowability of UFC containing more anhydrous gypsum is higher. And it is considered that much anhydrous gypsum causes some problem for its durability[7]. Therefore, it is necessary to investigate the durability, especially its expansion and shrinkage for a long time.

・The flowability of UFC containing more silica fume is higher. When wollastonite is used in mixes, the flowability is improved.

・When the fineness of blast furnace slag used in UFC is higher, flowability tends to be higher.

・When the particle size distribution of blast furnace slag is wider, flowability tends to be higher.

・By using steel fibers for UFC containing ordinary Portland cement and blast furnace slag, high compressive strength could be achieved more than 150N/mm^2 and high bending strength more than 30N/mm^{2}at 20℃.

・By curing at 60℃, it can be achieved high compressive strength more than 200N/mm^2 and higher bending strength more than 45N/mm^2.

This suggests the possibility of casting UFC at constructing site with achieving the required properties for UFC.

REFERENCES

[1] H. Kiyama, E. Marutani, T. Hirata: Properties of Ambient Temperature Curing Ultra High Strength Fiber Reinforced Concrete, 66th JSCE Annual Technical Meeting, V-199, 2011, pp. 397-398.

[2] H. Takayoshi: Development of UFC from which high strength is obtained ad an early age in normal temperature environment, Japan Cement Association, No.782, Apr.2012, pp24-28.

[3] Mai Iguchi: Fundamental Properties of Ambient Temperature Cured, Master’s thesis, graduate school of Utsunomiya University of Japan, 2015.

[4] M.Kurita, T. Shitani, H. Hayashi, K. Yoshitake.,: Properties of High Strength Steel Fiber-Reinforced Mortar Containing a High Content of Steel Fiber, V-22, No.2, 2011, pp. 307-312.

[5] Fujiwara H., et al.: Development of High Thyxotropic Grout. Construction Materials, ConMat '05 and Mindess Symposium. 26. Vancouver. 2005, CD-ROM.

[6] C. C. Furnas. Grading aggregate –Mathematical relations for beds of broken solids of maximum density. Industrial and Engineering Chemistry. 1931,23(9), p.1052-1058.
[7] F.Shikuya, H. hunsuke, M. Hisayuki.,: Relationship between mortar and concrete in DEF expansion, Proceedings of Japan Concrete Institute, V-30, No.1, 2008, p.723-728.

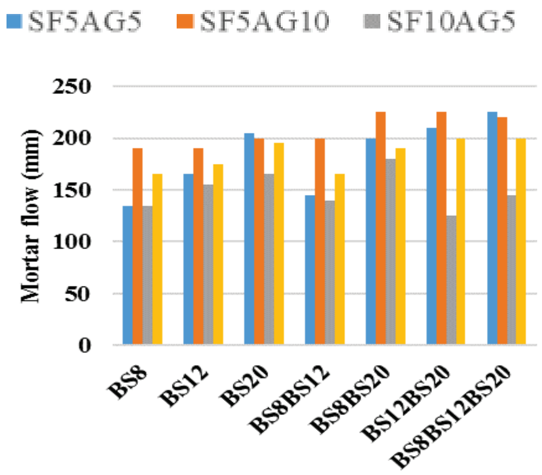

Figure 1: Test results of Mortar flow

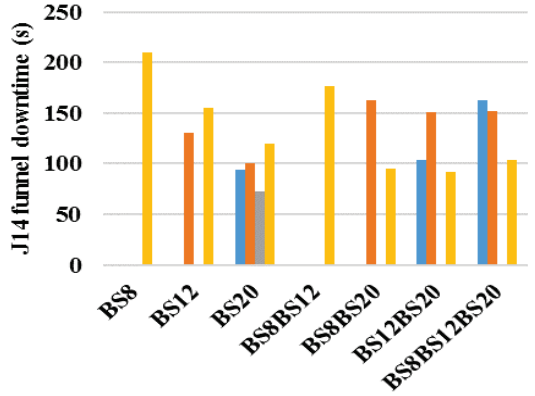

Figure 2: Test results of J_{14} Funnel Flow Test

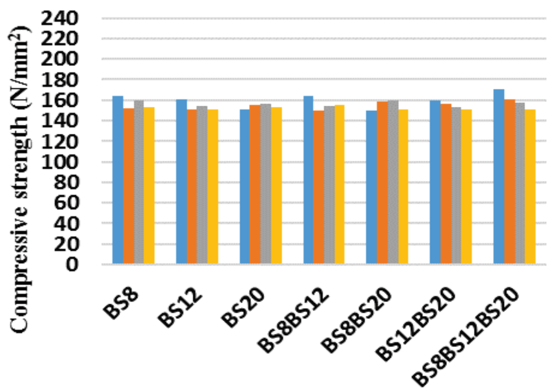

Figure 3: Test results of compressive Strength- 28 days (20℃)

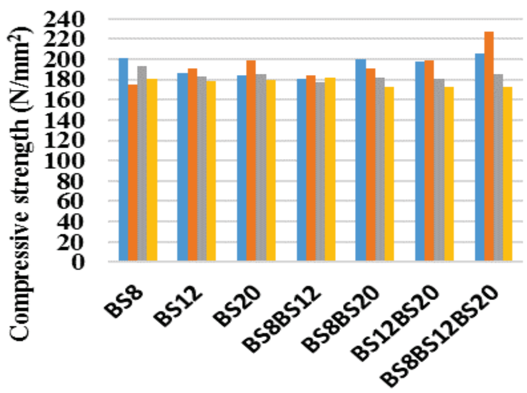

Figure 4: Test results of compressive strength- 28 days (60℃)

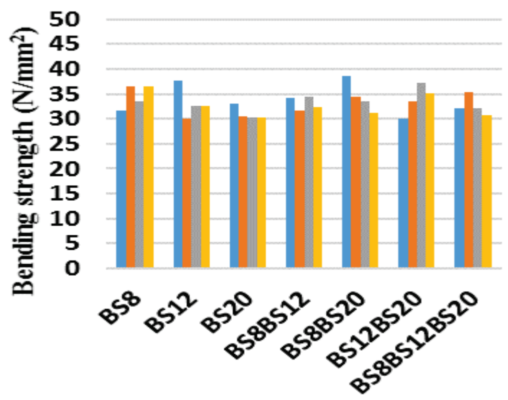

Figure 5: Test results of bending Strength- 28 days (20℃)

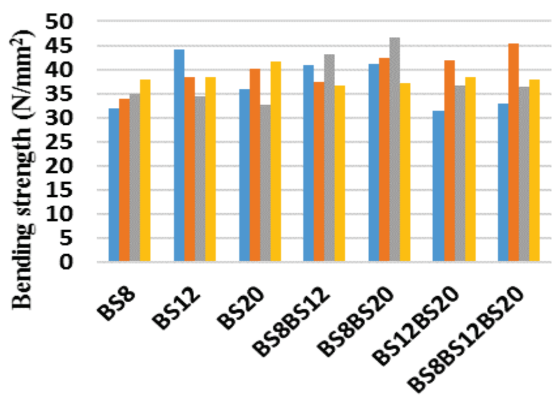

Figure 6: Test results of bending strength- 28 days (60℃)