Pergamon

Cement and Concrete Research 31 (2001) 1203–1206

CEMENT AND CONCRETE RESEARCH

A study on creep and drying shrinkage of high performance concrete

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Received 3 January 2001; accepted 10 May 2001

Abstract

Creep and drying shrinkage are two important time-dependent properties of high-performance concrete (HPC). In this study, three groups of HPC with same mix proportioning except the type of binding materials were prepared. Their creep behaviour and drying shrinkage characteristics were measured in accordance with the Chinese Standard GBJ82-85. The effects of ultrafine ground granulated blast-furnace slag (GGBS) and silica fume (SF) on creep and drying shrinkage of HPC were compared and the mechanism was analysed.

Keywords: High-performance concrete; Creep; Shrinkage; Granulated blast-furnace slag; Silica fume; Compressive strength; Workability

1. Introduction

The creep of concrete refers to deformation of hardened concrete caused by a long-lasting constant load applied on it. Drying shrinkage of concrete is the shrinkage caused by evaporation of internal water in hardened concrete. Creep and drying shrinkage are very important time-dependent properties of high-performance concrete (HPC), they are in direct relation to the performance of HPC in concrete structures. With the rapid development of HPC in the world, more and more attention has been paid to the creep and drying shrinkage behaviour of HPC. In China, there are many research projects at present concentrating on raw materials, mixture design, properties and construction technology of HPC. Ground granulated blast-furnace slag (GGBS) and silica fume (SF) have been used to produce HPC as supplementary binding materials for a long time. As well known to all, the ultrafine GGBS that has a very large specific surface of often to be more than 600 m^2/kg will play a substantially different role in concrete from that of normal GGBS with a specific surface range of 300–400 m^2/kg. The authors have conducted extensive research on ultrafine GGBS HPC in the past several years. In this study, portland cement, ultrafine GGBS and SF were used to prepare three groups of HPC. The aim of this study is to investigate the creep and drying shrinkage behaviour of these HPCs and compare the effects of different binding materials in concrete.

2. Experimental

2.1. Materials

Three binding materials used in the study including portland cement, ultrafine GGBS and SF were all manufactured in China. Their chemical compositions and properties are presented in Table 1. The strength grade of cement was R525 according to Chinese Standard GB175-85. The coarse aggregate used was crushed limestone with a density of 2.65×10^3 kg/m^3, its maximum particle size is 20 mm. The fine aggregate was quartz sand with a density of 2.7×10^3 kg/m^3 and a fineness modulus of 3.0. A naphthalene superplasticizer (SP) was used to keep the water–binder ratio of concrete at a very low level. The properties of the SP are shown in Table 2.

2.2. Mix proportioning of HPC

Three groups of HPC mixtures were designed, that is, Concrete A, B and C, their mix proportioning is listed in Table 3. These three concrete mixtures were of same mix proportioning except the type of binding materials. Only portland cement was used as binder in Concrete A. In

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0008-8846/01/$ – see front matter
PII: S0008-8846(01)00539-7

Table 1
Chemical compositions (%) and properties of binding materials

	Chemical compositions							
Binder	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SS[a] (m^2/kg)	SG[b]	APS[c] (μm)
Cement	19.95	4.71	60.58	1.41	2.90	314	3.1	≈ 40
GGBS	34.35	15.26	36.80	9.10	1.40	≈ 800	2.9	2.5
SF	91.25	0.47	0.43	0.93	0.91	≈ 20,000	2.2	0.2

[a] Specific surface.
[b] Specific gravity.
[c] Average particle size.

Table 3
Mix proportioning (kg/m^3) and workability (cm) of HPC

	Mix proportioning							Workability	
Concrete	C[a]	GGBS	SF	SP (%)	CA[b]	FA[c]	Water	Slump	Slump flow
A	600	–	–	1.6	1134	610	156	22.5	49.0
B	420	180	–	1.6	1134	610	156	24.5	67.0
C	360	180	60	1.6	1134	610	156	24.0	56.0

[a] Cement.
[b] Coarse aggregate.
[c] Fine aggregate.

Concrete B, ultrafine GGBS replaced cement by 30% of cement weight, while in Concrete C 40% of cement was substituted by ultrafine GGBS (30% of cement weight) and SF (10% of cement weight). The dosage of SP in all concrete mixtures was kept constant at 1.6% of total weight of binder.

2.3. Test of concrete

The raw materials of concrete were put in a forced mixer at the same time and were mixed for 3 min. When mixing was ended, the workability of fresh concrete including slump and slump flow was measured at once. The slump flow is the spread diameter of slumped concrete cone. The result is listed in Table 3.

The mixture was cast into test specimens in mold by vibration at temperature of 20 ± 2°C. The specimens were demolded at 1 day and then cured in water of temperature of 20 ± 3°C.

The properties of hardened concrete such as compressive strength, splitting tensile strength, creep and drying shrinkage were investigated. The cubic specimens for compressive strength and splitting tensile strength test were of dimensions of 10 × 10 × 10 cm. The specimens for creep and drying shrinkage test were prisms, with dimensions of 10 × 10 × 30 and 10 × 10 × 50 cm, respectively. For all properties, the average of experimental results of three identical specimens was adopted.

The compressive and splitting tensile strengths were tested according to Chinese Standard GBJ82-85. At ages of 3, 7 and 28 days, the specimens were taken out of water and tested for strength at a temperature range of 20 ± 2°C.

Creep and drying shrinkage were tested according to Chinese Standard GBJ82-85 at the age of 28 days. The creep test was carried out at temperature of 20 ± 3°C and lasted for 180 days. The specimens were initially loaded to 40% of the 28-day axial compressive strength of concrete. The drying shrinkage test was conducted simultaneously with creep test at the same temperature. A comparator was used to measure the drying shrinkage of concrete specimens.

Table 2
Properties of SP

SG[a]	pH	Dosage (cement wt.%)	Colour	Main component
1.18	7–8	0.75–2	yellow	Sulphonate naphthalene

[a] Specific gravity.

3. Results and analyses

3.1. Compressive strength and splitting tensile strength

The experimental results of concrete strengths are listed in Table 4.

As shown in Table 4, Concrete B and C acquired much higher compressive strength and splitting tensile strength than Concrete A at each testing age. At the age of 3 days, the compressive strengths of concrete A, B and C were 63.8, 69.3 and 69.3 MPa, respectively. At 28 days of age, the compressive strengths of Concrete B and C increased greatly to 100.4 and 104.0 MPa, respectively, compared with 81.1 MPa of Concrete A. The development of splitting tensile strength showed the same tendency as that of compressive strength. Such a tendency reflects the strengthening effect of ultrafine GGBS and SF on mechanical properties of concrete.

3.2. Creep

The experimental results of creep test for three groups of concrete are shown in Fig. 1.

It is seen from Fig. 1 that during the whole period of test (from 1 day until 180 days), the two groups of HPC containing supplementary binders (Concrete B and C) always obtained much smaller creep value than portland

Table 4
Strengths (MPa) of HPC

	Compressive strength			Splitting tensile strength		
Concrete	3 days	7 days	28 days	3 days	7 days	28 days
A	63.8	71.2	81.1	3.80	4.54	5.54
B	69.3	83.2	100.4	4.06	5.03	5.91
C	69.3	87.0	104.0	5.20	5.44	6.14

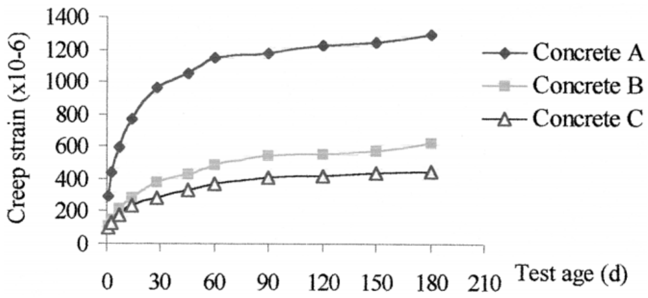

Fig. 1. Development of creep of concrete.

cement concrete A. When ultrafine GGBS and SF were used at the same time (Concrete C), the creep value was the lowest, which is in accordance with the development trend of mechanical strengths. At test age of 180 days, the creep value for Concrete A, B and C was 1293×10^{-6}, 623×10^{-6} and 450×10^{-6}, respectively, the biggest is almost three times the smallest.

According to creep rate, three groups of concrete tested were all subject to a faster development of creep at early ages than at late ages, and the age of 60 days was the turning point. For the individual concrete, the value of creep rate was different. Before 60 days, Concrete A was much greater than B and C, and C was the lowest. After 60 days, the creep rates of A, B and C became similar while Concrete B and C can be thought to have equal creep rate.

3.3. Drying shrinkage

The results of drying shrinkage test of three groups of concrete are shown in Fig. 2.

As shown in Fig. 2, at early test ages the difference between amounts of drying shrinkage of Concrete A, B and C was small. After 28 days, Concrete A obtained substantially greater amount of drying shrinkage than Concrete B and C, while the latter two always had similar shrinkage amount. At age of 180 days, the amount of shrinkage for Concrete A, B and C was 220×10^{-6}, 96×10^{-6} and 127×10^{-6}, respectively. During the whole test period, Concrete B always acquired the lowest shrinkage strain, which is different from the creep development where Concrete C was the smallest. As for the shrinkage rate, before test age of 28 days, Concrete A got the highest one. After this age, the shrinkage rate for the three groups of concrete became close gradually. However, Concrete A still had the highest rate.

4. Discussions on roles of ultrafine GGBS and SF in HPC

GGBS and SF are effective supplementary binding materials to be used for preparation of HPC [1–4]. GGBS has similar chemical compositions to those of portland cement and is almost wholly composed of glass phase, which offer the ability of hydration to GGBS. The content of glass phase in the ultrafine GGBS used in this study is more than 98%. SF used here contains more than 90% of amorphous SiO_2, the average particle size of SF is only about 0.2 μm. Especially, the GGBS used here has been ground to an ultrafine state with specific surface greater than 800 m^2/kg, and its average particle size is 2.5 μm. These chemical and physical characteristics make ultrafine GGBS and SF very active in reacting with hydrates of cement.

Extensive researches have proved that the both materials can apparently promote hydration of cement and react with CH crystal hydrates so as to increase the amount of C-S-H gel hydrates and the density of hardened cement paste [5–7]. Some researchers even discovered that ultrafine GGBS and SF would exert a synergistic effect on facilitating cement hydration when they are used simultaneously in cement. Such an effect can be seen at early age of 3 days or even 1 day of hydration of cement. According to XRD, TG-DSC and SEM analyses on hydrates of cement, both amount of AFt crystal hydrates and that of C-S-H gel hydrates in cement paste blended with ultrafine GGBS and SF were greater than their counterparts in cement paste blended with only ultrafine GGBS or SF. At the same time, the amount of CH crystal hydrates in the former paste was less than that in the latter paste [5,6].

As a result of tiny particles, ultrafine GGBS and SF can fill the small pores and voids which are harmful to structure and macroperformance of concrete. This effect is physical and can be called the effect of microsized particles.

In summary, the addition of ultrafine GGBS and SF in concrete will greatly strengthen the structure and reduce the creep and drying shrinkage of concrete.

As well known to all, creep and drying shrinkage of concrete are determined by many factors, such as properties and amount of hardened cement paste, type and amount of aggregate, curing system and testing method. In this study, only one factor, type of binder, varies for three groups of concrete. The variation of binders leads to different properties of hardened cement paste for three groups of concrete. As mentioned above, ultrafine GGBS

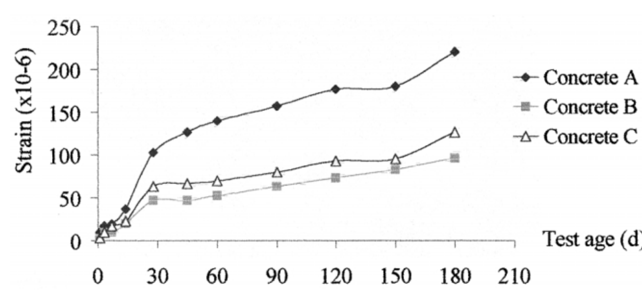

Fig. 2. Results of drying shrinkage test of concrete.

and SF will greatly increase the amount of AFt hydrates and C-S-H gel hydrates and the density of hardened cement paste, which make concrete stronger and more resistant to deformation caused by force applied on it. On the same conditions of test (e.g., same load applied on specimens), the amount of creep and drying shrinkage of concrete will decrease greatly.

5. Conclusions

From the above experimental results, the following conclusions were drawn:

• HPC of high mechanical strength and good workability can be made by using portland cement blended with ultrafine GGBS and SF. The two supplementary binders are important to ensure the high performance of concrete.

• Creep and drying shrinkage will be greatly reduced by use of ultrafine GGBS and SF. On the same conditions, the amount of creep and drying shrinkage of HPC containing ultrafine GGBS and/or SF is much smaller than that of high-strength concrete without the supplementary binders. On the other hand, in this study, after 60 days of test age, three groups of concrete obtained similar creep rate.

• Ultrafine GGBS and SF can substantially promote hydration of cement and increase the amount of AFt crystal hydrates and C-S-H gel hydrates in cement paste, which offers hardened concrete a stronger structure and higher resistance to deformation caused by applied force. As well, these two binders may fill small pores and voids harmful to the structure of concrete. That may be the mechanism of reducing effect of ultrafine GGBS and SF on creep and drying shrinkage of concrete.

Acknowledgments

This research is sponsored by the former State Planning Commission of China. The authors also want to express thanks to State Supervision and Inspection Centre for Quality of Civil Engineering of China for its cooperation.

References

[1] P.C. Aictin, High Performance Concrete, E&FN SPON, London, 1998.
[2] W. Zhongwei, L. Huizhen, High Performance Concrete, China Railways Publishing House, Beijing, 1999.
[3] F. Naiqian, Technology of High Strength Concrete, China Building Materials Industry Publishing House, Beijing, 1992.
[4] L. Jianyong, Y. Yan, T. Pei, S. Lizhong, Preparation of high performance concrete using ultra-fine ground granulated blast-furnace slag and silica fume, Proceedings of 1st National Conference on High Strength Concrete and High Performance Concrete, Lushan, China, (1997) pp. 48–59.
[5] L. Jianyong, T. Pei, Effects of slag and silica fume on the mechanical properties of high strength concrete, Cem. Concr. Res. 6, (1997) pp. 833–837.
[6] S. Sarkar, P.C. Aictin, H. Djellouli, Synergistic roles of slag and silica fume in high-strength concrete, Cem., Concr., Aggregates 12 (1) (1990) 32–37.
[7] M.W. Grutezk, D.M. Roy, D. Wolfe-Confer, Mechanism of hydration of portland cement composites containing ferro-silicon dust, Proceedings of 4th International Conference on cement Microscopy, International Cement Microscopy Association, Las Vegas, TX, (1982) 193–202.