Pergamon

Cement and Concrete Research, Vol. 27, No. 6, pp. 833-837, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00076-8

EFFECT OF SLAG AND SILICA FUME ON MECHANICAL PROPERTIES OF HIGH STRENGTH CONCRETE

Li Jianyong and Tian Pei
Building Materials and Concrete Research Institute
China Building Materials Academy
Beijing, P.R.China, 100024

(Communicated by D.M. Roy)
(Received December 3, 1996; in final form April 10, 1997)

ABSTRACT

This paper presents the study on changes of the mechanical properties, including compressive strength, split tensile strength and rupture strength of four high strength concretes, caused by the addition of ground blast-furnace slag and silica fume. The study indicates that the mechanical properties of high strength concrete were improved to a great extent at later ages when cement used in concrete was replaced by slag and silica fume by 25% by weight. © *1997 Elsevier Science Ltd*

Introduction

A lot of scientific research and construction practices have proved that the most efficient and economical method of preparing high strength concrete and high performance concrete at the present time is to simultaneously use water reducer or superplasticizer and strengthening blenders in concrete mixture. Such strengthening blenders usually include silica fume and the pozzolanic materials such as ground blast-furnace slag and fly ash that can react with the hydrates of cement in concrete (1-3). Most previous research centered on the changes of the slump and compressive strength of blended concrete and there is not much research on the effect of blenders on the other mechanical properties of high strength concrete. It is well known that silica fume is mostly made up of free silica and has a large specific surface so it is very active in reacting with the hydrates of cement, but its price is very high and the concrete mixture blended with it may be very viscous or even dry, for silica fume has a big demand for water. On the other hand, ground slag can be used to replace some cement in order to improve the workability and strength of concrete, but its reactivity is much lower than silica fume. In the present study, these two blenders were simultaneously used in concrete for a synergistic effect and some mechanical properties of concrete, including compressive strength,split tensile strength and rupture strength, were studied.

Experimental

Four concrete mixtures were proportioned using the following materials. The cement was Chinese 525# portland cement, the two blenders were ground blast-furnace slag with a

TABLE 1

Chemical Composition of Materials (%)

	CaO	SiO_2	MgO	Na_2O	K_2O	Al_2O_3	SO_3	L-O-I*
Cement	64.50	21.56	3.34	0.20	0.70	5.40	1.48	1.25
Slag	42.28	33.08	6.90	0.22	0.31	13.93	2.61	0.54
SF**	2.69	90.89	0.39	0.08	0.50	0.21	0.18	3.67

(* Loss on ignition , ** Silica Fume)

specific surface of 3500 cm^2/g and density of 2.5×10^3 kg/m^3 and silica fume with a specific surface of 2.2×10^5 cm^2/g. The chemical composition of these three materials are presented in Table 1. The coarse aggregate was gravel with the maximum particle size of 30 mm, the fine aggregate was graded silica sand with fineness modulus of 2.8. The superplasticizer was a dry naphthalene powder product, the water reducing rate is about 20% at the dosage of 1.0% of cement weight.

The blank concrete that did not contain slag and silica fume was marked as Concrete A. The combined blenders of silica fume and slag were used in concrete at the total dosage of 25% while replacing the same amount of cement to keep the weight of bonding materials in concrete unchanged. There were three types of substitution: 15% silica fume plus 10% slag, 10% silica fume plus 15% slag, 5% silica fume plus 20% slag; three kinds of concretes thus proportioned were marked as Concrete B, C and D, respectively. The proportions and slumps of the four concretes are reported in Table 2.

According to the stipulations in the Chinese national standard GB 81-85, the dimensions of concrete specimens are: cubic specimen of $10 \times 10 \times 10$ *cm* for testing compressive strength and split tensile strength, prism specimen of $10 \times 10 \times 40$ *cm* for testing rupture strength. The concrete mixtures were mixed in a drum mixer and specimens were moulded by vibration. After being placed at the room temperature for 24 hours, the specimens were demoulded and then cured in water at the temperature of 20 ± 2°C. At 3, 7 and 28 days, the specimens were taken out from water for testing mechanical properties.

Results and Discussion

*Compressive Strength. Table 3 gives the compressive strength values of all four concretes. It is indicated in Table 3 that at the early age (3 days),Concrete B, C and D, which were

TABLE 2

Proportions (kg/m^3) and Slumps (cm) of Concretes

Materials	Concrete A	Concrete B	Concrete C	Concrete D
Cement	474	356	356	356
Water	180	180	180	180
Coarse Aggregate	1191	1191	1191	1191
Fine Aggregate	561	561	561	561
Slag	---	47.4	71.1	94.8
Silica Fume	---	71.1	47.4	23.7
Superplasticizer	1.0%	1.2%	1.1%	1.0%
Slump	19.0	18.0	17.5	18.5

TABLE 3

Compressive Strength (MPa) of Concretes

Age	Concrete A	Concrete B	Concrete C	Concrete D
3 days	43.1	36.1	34.8	34.5
7 days	51.5	52.6	50.5	48.2
28 days	64.5	77.7	75.1	68.7
50 days	73.2	84.1	82.4	77.5

blended with slag and silica fume, all displayed lower compressive strength than the blank concrete (Concrete A), so it is clear that curing for more than 3 days is necessary for the strength development of blended concrete. After 7 days of curing, these four concretes reached a nearly equal level of compressive strength; Concrete B had the highest strength, followed by Concrete A, C and D in turn. Up to the ages of 28 days and 50 days, the reactivity of slag and silica fume was displayed greatly, so all three blended concretes possessed greater compressive strength than Concrete A. Concrete B and C, especially, showed much higher strength values. It is worthwhile to note that at all ages, as far as compressive strength is concerned, it was always true of such a tendency: Concrete B in the first place, Concrete C the next and then Concrete D, with the former two concretes had almost equal compressive strength values.

It is concluded from above results that when blended with an appropriate amount of slag and silica fume, concrete can achieve improved compressive strength while its slump is kept unchanged, and the dosage of slag and silica fume both vary from 10% to 15% of the total weight of bonding materials.

*Split Tensile Strength (STS). The split tensile strength test was performed on cubic specimens according to the Chinese national standard GB81-85, the results were tabulated in Table 4.

At the age of 3 days, the STS of blank Concrete A was much greater than that of three blended concretes B, C and D. As the curing age went on (after 7 days), the STS of three blended concretes caught up with and exceeded that of Concrete A. As far as the value of STS was concerned, the tendency was still: B > C > D > A and Concretes B and C displayed equal STS values, which was identical to the development trend of compressive strength.

TABLE 4

Split Tensile Strength (MPa) of Concretes

Concrete		A	B	C	D
3 days	STS	4.11	3.34	3.42	3.25
	TCSR*	0.095	0.093	0.098	0.094
7 days	STS	4.29	4.14	4.16	4.10
	TCSR	0.083	0.080	0.092	0.085
28 days	STS	4.84	6.18	6.09	5.32
	TCSR	0.075	0.080	0.081	0.077
50 days	STS	5.13	6.49	6.28	5.81
	TCSR	0.070	0.077	0.076	0.075

(* the ratio of tensile strength to compressive strength)

The results in Table 4 also show the values of TCSR of four concretes at all ages. At the ages of 3 days and 7 days, these four concretes achieved almost equal TCSR values, which were approximately 0.095 (3 days) and 0.080 (7 days). As the curing age extended up to 50 days, the TCSR value of Concrete A descended to 0.075 (28 days) and 0.070 (50 days) from 0.083 (7 days); the reduction rate was 9.6% and 15.7%, respectively. However, the three blended concretes B, C and D kept almost unchanged TCSR values at about 0.080.

These aforesaid results demonstrate that the blended concretes had improved split tensile strength compared with blank concrete which contained no slag and silica fume.

*Rupture Strength (RS). The rupture strength test was conducted according to the stipulations of the Chinese national standard GB 81-85, Table 5 gives the results of this test.

The results in Table 5 also show that RS and RCSR of concrete were both greatly improved by adding an appropriate amount of slag and silica fume in concrete.

After 7 days of curing, the RS of three blended concretes B, C and D had already surpassed that of blank Concrete A. At the age of 50 days, the RS values of Concretes B, C and D were 27%, 21% and 13% higher than that of Concrete A, respectively.

As regard to RCSR, at each age, there existed the same situation. That is, Concrete B in the first place, Concrete C next, then Concrete D and Concrete A the last, with the RCSR of Concretes B, C and D being much higher than that of Concrete A. At 3 days, the RCSR of Concretes B, C and D was 29%, 22% and 11% higher than Concret A. It is also shown that as the curing age extended, the RCSR of all four concretes decreased and the reduction degree of RCSR of the three blended concretes was greater than blank Concrete A. For example, compared with the RCSR at 3 days, there was a reduction of 29.8% and 27.8% for Concretes B and C respectively, but only 17.6% for blank Concrete A, at the age of 50 days.

The RCSR of concrete respresents the rupture-resistance of concrete, so with compressive strength as a reference, the high strength concrete has a more apparent brittleness at later ages than at earlier ages, because the development of rupture strength of HSC is slower than that of compressive strength. Adding slag and silica fume in concrete can improve the rupture-resistance and reduce brittleness of concrete, especially at earlier ages, but the basic relationship between the development speed of rupture strength and compressive strength is not changed.

To sum up all these above analyses on three kinds of strengths, it can be seen that applying an appropriate amount of slag and silica fume to concrete shall synergise the advantages

TABLE 5

Rupture Strength (MPa) of Concretes

Concrete		A	B	C	D
3 days	RS	6.61	7.14	6.52	5.87
	RCSR*	0.153	0.198	0.187	0.170
7 days	RS	7.38	9.32	8.40	7.64
	RCSR	0.143	0.181	0.166	0.159
28 days	RS	8.40	11.44	10.56	9.28
	RCSR	0.130	0.147	0.141	0.135
50 days	RS	9.20	11.68	11.16	10.40
	RCSR	0.126	0.139	0.135	0.134

(* the ratio of rupture strength to compressive strength) of each of the two blenders, so that the mechanical properties of concrete shall be improved while the fresh concrete mixture keeps a good workability.

It is interesting to pay more attention to the TCSR and RCSR values. The TCSR value varies between 0.050 and 0.079 and the RCSR value fluctuates in the scope of 0.075 to 0.125 for some high strength concretes in Reference 3, while in the present study, the TCSR value is 0.070-0.098 and the RCSR value is 0.126-0.198, which are higher than each own counterpart in Reference 3. So it can be said that the high strength concretes in this study have better rupture-resistance.

Conclusions

The following conclusions were drawn from the present experiments:

- Blending ground blast-furnace slag and silica fume in combination with superplasticizer in concrete (total amount is 25% of binders' weight) shall evidently improve the compressive strength, split tensile strength and rupture strength and enhance the rupture-resistance of concrete. The appropriate dosage of slag and silica fume are both 10-15% of the total weight of bonding materials in concrete.
- The development of compressive strength, split tensile strength and rupture strength of concrete does not synchronize, the compressive strength develops faster than the latter two ones. The addition of ground slag and silica fume may relatively accelerate the growth of split tensile strength and rupture strength compared with compressive strength, but the fundamental relationship between the development of three strengths is unchanged.
- The high strength concretes in this paper obtained higher TCSR and RCSR values, which varied in the range of 0.070-0.098 and 0.126-0.198, respectively.

References

1. W.M. Hague, Silica fume in the high strength concrete, ACI Materials Journal, April 4 (1987), pp. 55-61.
2. Tarun R. Naik, Shiw S. Singh and M.M. Hossain, Enhancement in mechanical properties of concrete due to blended ash, Cement and Concrete Research, 26(1) pp. 49-54 (1996).
3. Feng Naiqian, The technology of high strength concrete, p.118, China Building Materials Industry Publishing House, Beijing, 1992.