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DURABILITY STUDY OF STEEL SLAG CEMENT

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ABSTRACT

The properties of 525# garde steel slag cements were investigated in the present research, including: long-term strength, sulphate attack, carbonation, sea water attack, and alkali-aggregate reaction. The study shows that steel slag cement is characterized by high later strength, slight expansion, good resistance to harmful materials such as sulphate, carbon dioxide, and sea water, reducing the alkali-aggregate reaction. Its pore structures have also been studied. © *1997 Elsevier Science Ltd*

Introduction

Steel slag cement (SSC) had been developed as a new kind of cement in China two decades ago. It is a product of a ground mixture of steel slag, from Linz-Donawitz converter process (LDS) blast furnace slag (BFS), Portland cement clinker, gypsum and admixture. It can be used in common civil and industrial buildings as well as many special structures, such as road, underground, seaport, mass concrete construction and so on. The total output of SSC is about million tons per year. However, only 325# grade steel slag cements can be produced in most small cement plants, due to its poor production management and the low technology level in those plants, resulting in the restriction of application of SSC. Meanwhile, the disadvantages of slow setting and lower early strength of SSC are inconvenient in construction work. In this study, a higher grade 525# steel slag cement was firstly made by using high quality clinker and steel slag higher fineness of grinding and special admixtures, and then, the properties of such cement were mainly investigated.

Raw Materials and Experimental Methods

Composition of Raw Materials. Converter steel slag from Qingdao Steel Plant, quenched granular blast furance slag, shaft kiln clinker from Laoshan Building Materials Firm (Qingdao), gypsum from Shangdong and admixture A were used in the experiment. The chemical composition of raw materials is listed in Table 1.

TABLE 1

Chemical Composition of Raw Materials

composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3
LDS	42.49	9.08	7.42	5□57	-
BFS	49.71	33.29	10.17	1.23	1.69
Clinker	65.13	20.60	5.50	5.74	1.61

Testing Methods. Mortar strength test was made according to GB117-85, abrasion resistance to the criterion of road Portland cement, corrosion test to National Standard, and pore test by Auto-60, mercury scanning porosimeter from USA.

Results and Discussion

LDS, BFS, clinker, gypsum and admitures A were mixed and ground in certain proportions. The fineness of SSC was below 2.5% (residue on 0.08nm sieve). Table 2 shows that the mortar strength of SSC. K0 is the reference of pure Portland cement, K1-K8 are SSC with different composition. The experiment result indicate that the strength of SSC at 28 days is similar to that of pure protland cement though the quantity of clinker of SSC is only 30%. Not only early strengths but also the late strength of steel slag cements increase to certain extend by adding admixtures. The strength of all specimens, except that of K3, have reached the national standard and still rise after 28 days with higher long term strength according to above test.

Chemical Resistance. Cement mortar specimens were made with 40 × 40 × 160mm in size according to standard method. They were cured in water for 14 days first and then, immersed in different corrosive solutions such as man-made sea water, 3% Na_2SO_4 and 3% $MgSO_4$ for another 28 days and finally subjected to strength test. Taking the strength of

TABLE 2

The Results of Mortar Strength Tests

NO.	Compressive Strength						flexural strength		
	3D	7D	28D	90D	180D	360D	3D	7D	28D
k0	37.0	50.2	69.1	79.3	80.2	86.6	6.6	7.3	8.0
k1	30.8	46.1	65.0	71.2	78.1	79.2	5.1	5.8	8.0
k2	23.7	39.4	55.9	63.5	71.7	73.2	3.7	5.1	6.5
k3	18.2	29.9	49.9	66.6	64.8	67.6	3.4	4.7	6.2
k4	34.8	50.5	65.3				5.6	6.3	7.8
k5	32.5	49.5	65.3				5.4	6.9	8.1
k6	44.5	49.2	61.7				7.4	8.8	9.3
k7	40.8	49.7	60.8				6.9	9.1	9.2
k8	38.7	50.2	66.6				6.6	8.3	9.7

KO is the portland cement, k1-k8 contain 30%wt slag, 30% steel slag, 33% portland clinker, 4% gypsum,and 3% admixture.

TABLE 3

The Result of Chemical Resistance Test

Cement	water	Sea water	3%Na_2SO_4	3%MgSO4
PC	10.2/58.4	9.2/58.4	9.2/53.6	8.5/53.3
SSC1	6.4/55.3	10.2/55.7	9.2/53.8	7.8/52.6
SSC2	6.4/56.3	9.1/59.6	8.1/57.7	8.7/59.9

specimens cured in water at the same age as a control, we can determine the chemical resistance ability of steel slag cements by the strength reduction ratio.

The strength of pure Portland cement decreases to various extents in these three kinds of corrosive solutions; especially the flexural strength decrease by 17% in 3%$MgSO_4$. However, the strength of the two steel slag cements maintain or even increase to different extents; especially the flexural strength increases considerably. Therefore, steel slag cements have good chemical resistance ability (Table 3).

The numerator is flexural strength, and denominator compressive strength (MPa.).

Carbonation Resistance. Mortar specimens were cast with 40 × 40 × 160mm in size, cured in water at room temperature for 14 days, dried at 55°C for 24 hours, and carbonized in a box for 10 days, and then exposed to air for 42 days. Finally, the depth of carbornation and strength were examined. The strength of specimens cured in fresh water at the same age was taken as a control. The results are listed in Table 4.

Carbonation is the result of permeation of carbon dioxide into the open pores of hardened cement and degradation of hydration products, and it can result in the decrease of properties of concrete. If carbonation is slight, calcium hydroxide in cement store is carbonized to $CaCO_3$, which filled in pores may benefit to increase strength and density. The strength of SSC increase considerably after carbonation perhaps because the filling role of $CaCO_3$ in pores surpass its destruction of hydration product and compensate the reduction of strength.

Ability to Reduce Alkali-Aggregate Reaction. The above SSC improve considerably by using admixtures. However, its effect to the deterioration of concrete resulting from alkali-aggregate reaction followed by volume expansion should be given more attention. Two kinds of aggregate, namely, opal and chert were used in this experiment. The expansion of mortar was determined by a rapid method for identification of alkali reactivity of aggregate (4). Cement/aggregate ratio equals to 10:1, w/c = 0.3. The results are shown in Table 5.

Table 5 shows that the expansion caused by the alkali-aggregate reaction in SSC is much lower than that of Portland Cement. The experimental results indicate that steel slag cements have better ability to reduce alkali-aggregate reaction.

TABLE 4

The Results of Carbonation Test

Sample	Depth of carbonation (cm)	Water (MPa)	Carbonated (cm)
PC	0.33	10.20/58.4	7.77/67.6
SSC1	1.01	6.38/55.3	8.22/71.1
SSC2	0.78	6.37/56.3	7.10/77.4

TABLE 5

Expansion Value of Alkali-Aggregate Reaction

	PC	SLC1	SLC2
Opal	1.324	0.704	0.362
Chert	0.170	0.060	0.080

Pore Structure. The volume of hydration products is usually larger than that of clinker mineral during hydration. Previous space filled by water is decreased with the development of hydration and excess pores could exist after the consumption of water in the cement stone. The porosity pore size, shape and pore size distribution affect not only the strength of cement paste but also the resistance and durability of cement as well. In general, if capillary pores decrease, porosity will also decrease, but strength will increase with the development of hydration. The pore structure of SSC and control Portland cement determined is given in Table 6. The relationship between pore structure, strength and durability of cements can be described as follows:

(1) The total porosity of cement stone decrease with increasing hydration time, which corresponds with the increase of the compressive strength.
(2) The porosity of SSC at 7 days and 28 days is a bit higher than that of Portland Cement. But their pore size distribution is similar to each other. If the pore structure of SSC at the age of three years is considered, the porosity decreases considerably; the volume of pores is just only 50 percent of that at 28 days, and the radius of medium pore size is decreased from 31.0nm and 25.0nm to 9.9nm and 14.5nm respectively. It is noted that the harmful pore (>100nm) has almost disappeared after 3 years curing. It shows that the pore structure of SSC is improved due to the late hydration,which means that the hydration products gradually fill up the free space of cement stone and increase the density of the structure. All this could certainly improve the durability of steel slag cements.

TABLE 6

The Results of Pore Structure Tests

Age	7 days			28 days			3 years	
Sample	PC	SSC-1	SSC-2	PC	SSC-1	SSC-2	SSC-1	SSC-2
porosity (%)	14.8	15.9	15.7	13.6	14.8	15.1	7.64	10.8
Volume of pores (mm^3%)	70.1	77.2	74.3	65.3	76.8	76.3	35.8	50.2
(>100nm%)	13.8	12.5	11.8	10.0	18.4	14.3	4.3	0.0
100-50nm	3.8	15.1	12.9	6.2	18.3	7.8	12.8	17.9
50-10nm	60.1	53.3	60.8	69.1	40.5	58.6	56.9	64.8
<10nm	21.9	18.8	14.4	14.5	22.6	9.1	26.6	17.3
Medium size(nm)	21.7	29.2	28.7	26.4	31.0	25.0	9.9	14.5

Conclusion

1) By using various technical means, especially by adding special admixtures, 525 grade steel slag cement could be made, and the problem of low early strength and slow setting of SSC can also be solved. The pore structure and strength of steel slag cements at 28 days are similar to that of Portland cement, but the late properties are superior.
2) Compared with Portland cement, the high grade SSC has good durability, such as good resistance to sulphate and carbonate, and the reduction of alkali-aggregate reaction.

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