Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Durability of concretes containing ground granulated blast furnace GGBS against sulfate attack

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ABSTRACT

Ground granulated blast furnace GGBS (GGBS), a by-product of the steel manufacturing industry, being used as an effective partial cement replacement material, has already been proven to improve several performance characteristics of concrete. The reactivity of GGBS has been found to depend on the properties of GGBS, which varies with the source of GGBS, type of raw material used, method and the rate of cooling. In this paper cement replacement levels of 35%, 42.5% and 50% were selected to study the effects of GGBS on compressive strength and sulfate resistance in concretes. Two tests were used to determine the resistance of GGBS concrete to sulfate attack. These tests involved immersion in 5% sodium sulfate solutions. Furthermore, compressive strength of concrete mixtures that keep in water and sodium sulfate were determined at ages up to 180 and 270 days respectively. Also mass change of concrete mixtures were determined. The experimental results show that at later ages GGBS concrete that keeps in water got closer compressive strength to control concrete. After 270 days of exposure to the sodium sulfate solutions, in mixtures containing 50% GGBS replacement by Portland cement had rather growth compare to 35% GGBS replacement by Ordinary Portland Cement (OPC).

Key word. Ground granulated blast furnace GGBS, mechanical properties, durability, sulfate attack

INTRODUCTION

It is a well-known fact that the causes of damage in concrete are freezing, water penetration, chemical degradation and erosion. Therefore, it is important that durability of concrete be enhanced. This can be accomplished by some additives which improve the properties of both freshly mixed concrete and hardened concrete by pozzolanic reaction. Benefits of using additional binder materials on the durability of concrete are well established. High-performance concrete may contain materials such as fly ash, silica fume, ground granulated GGBS, natural pozzolana , fibers, chemical admixtures and other materials, individually or in various combinations. These materials can enhance the strength and durability of concrete, simultaneously, rendering them recommendable for use in concrete industry. Also It is an efficient procedure for the cement industry in order to decrease CO_2 emissions, which represents about 5% of the total anthropic emissions in the world (Brand 2004). In addition, it can contribute to save natural resources, recycle by-products and preserve the environment. Ground granulate blast furnace GGBS (GGBS) is a by-product from the iron industry; it is one of the most commonly used additions in the cement industry. According to the manufacturing process, GGBS is a quite variable material due to the variability of its chemical composition. Offering latent hydraulic properties when mixed with clinker cement, hydration of GGBS is directly related to its hydraulicity: the dissolution of GGBS glass fraction is ensured by hydroxyl ions (OH^-) resulting from the hydrolysis of Portlandite $Ca(OH)_2$ produced by the hydration of clinker (Glasser 1996, Regourd 1995). The hydration products formed in the cement matrix are mainly additional hydrated calcium silicates and aluminates (CSH, CAH). The resulting hydrated cementitious matrix presents good chemical resistance and a more refined pores structure (Ye 2009, Cheng 2005). Therefore the mechanical performance and durability of concrete are improved.

Many studies show that, in sufficient quantities, GGBS is generally very effective in controlling sulfate attack. GGBS is a latent hydraulic material and is very successful in lowering permeability of concrete. It also improves sulfate resistance by diluting $Ca(OH)_2$. ACI201.2 recommends the use between 40 and 70% GGBS by mass replacement to achieve satisfactory sulfate resistance. Based on a long term study by Building Research Establishment in the UK. on the effects of GGBS on concrete durability, minimum of 70% GGBS (by mass) is recommended in combination with GU cement in severe sulfate exposures (Osborne 1999). results were observed by Brown, Hooton and Clark (2004), who showed that low alumina GGBS was effective in increasing resistance to magnesium and sodium sulfate attack at 45% and 72% replacement level when used with Type I cement.

EXPERIMENTAL PROGRAM

Description of materials

Locally available type I ordinary Portland cement (OPC) complying with Iranian specification 389, with a fineness of 2800 cm^2/g was used for mortar and concrete mixes. The GGBS used in this research project was produced in the iron steel company of Zobahan Esfahan (Iran). The GGBS was ground in a laboratory mill to a Blaine fineness of 4200 cm^2/g. The physical properties and chemical composition of cement and GGBS are given in Table 1 and Table 3, respectively. Also the physical properties of coarse aggregate and fine aggregate are given in Table 2.

Table 1. Physical properties of OPC and GGBS

Property	OPC	GGBS
Specific gravity	3.15	2.85
Specific surface (cm^2/g)	2800	4200
Ignition loss (%)	0.91	-
Color	Gray	whitish (off-white)

Table 2. Physical properties of coarse aggregate and fine aggregate

Aggregates type	Specific gravity	W_b (%)	D_{max}
Coarse aggregate	2.57	1.6	12.5

Fine aggregate	2.56	2.6	

D $_{max}$: maximum aggregate size

Table 3. Chemical compositions of OPC cement and GGBS

Compound (%)	OPC	GGBS
SO_3	2.570	2.49
K_2O	0.63	0.90
Na_2O	0.36	0.38
CaO	65.34	65.34
SiO_2	20.83	37.50
MgO	2.17	8.60
Al_2O_3	4/34	6.40
Fe_2O_3	2.21	0.51

Mix proportion and mix details

For building mortar, in addition to control types, three percentage of 35, 42.5 and 50% were used for substitution of cement with GGBS. The mixture design is submitted in table 4. Also there were eight basic mixes in which OPC and GGBS were incorporated to make concrete mixes. The first mix of concrete was the control type I cement mix. Additionally, the other mixtures were proportioned to have cement replacements in the percentage of 35% to 50% by weight of cement. These mixtures were proportioned for water-to-binder ratio of 35%, 40% and 50%. Slump of 7 - 10 cm was maintained. The mix designs and characteristics of concretes are given in Tables 5, respectively. Since the preliminary compressive resistance of types with GGBS 50% and the w/c of 50% was low, this mixture design was taken out of consideration. The amount of GGBS was varied to reach the highest relative compressive strength.

Table 4. Mortar mixture proportions used in the study

Mix	**Cement**	**GGBS**	**sand**	***w/c* ratio**	**GGBS (%)**
S0	500	0	1375	0.485	0
S35	325	175	1375	0.485	35
S42.5	287.5	212.5	1375	0.485	42.5
S50	250	250	1375	0.485	50

Specimen preparation

Concrete mixtures were used to investigate the effect of GGBS on the properties of concrete exposed to sulfate attack and potable water. Reagent grade Na_2SO_4 were used for sulfate exposure with 5% density. Potable water was used throughout for mixing, initial 28 days curing of all specimens, and curing in the control laboratory water tank.

Table 5. Concrete mixture proportions used in the study

Mix	GGBS (%)	*w/c* ratio	Mixture proportion (kg/m^3)				
			Water (Free water)	Cement	GGBS	Fine aggregate	Coarse aggregate
S0.5-0%	0	0.5	187.5	375	0	784.6	958.9
S0.5-35%	35	0.5	187.5	243.7	131.2	779.5	952.7
S0.4-0%	0	0.4	150	375	0	827.9	1011.9
S0.4-35%	35	0.4	150	243.7	131.2	822.9	1005.7
S0.4-50%	50	0.4	150	187.5	187.5	820.7	1003.1
S0.35-0%	0	35	131.2	375	0	849.6	1038.5
S0.35-35%	35	35	131.2	243.7	131.2	844.6	1032.2
S0.35-50%	50	35	131.2	187.5	187.5	1029.6	842.4

Testing procedures

Compressive strength test was done in the ages of 7, 28, 90 and180 days on the concrete samples that keep on potable water. It is prominent to know that 3 cubic samples of every mix design of every ages mentioned above has been tested. Cubic concrete samples with the dimensions of 10x10x10 are cured in the saturated liquor of water until the age of test. The test was taken according to the national Iranian standard and using the machine to run it. Also for sulfate attack test cubic concrete samples with the dimension of 10 cm, were cured in saturated solution of calcium oxide until the age of 28 days and then located in the solution of sodium sulfate 5% until 270 days. The weight of samples related to weight change, was measured and recorded before putting them in the solution of sulfate. In the test age, samples related to weight change were taken out and after drying their aspects, their weights were recorded. The samples were dislocated once in a while, because the experiment needed the sulfate effect to be even on all of the aspects.

EXPERIMENTAL RESULTS

Development of compressive strength (kept on water)

The figure 1 indicates the amount of growth in compressive resistance of mortar samples from the age 7 days to 28 days. In the light of the numbers in the figure 1, it is possible to judge about the selection of right percentages of GGBS for making concrete.

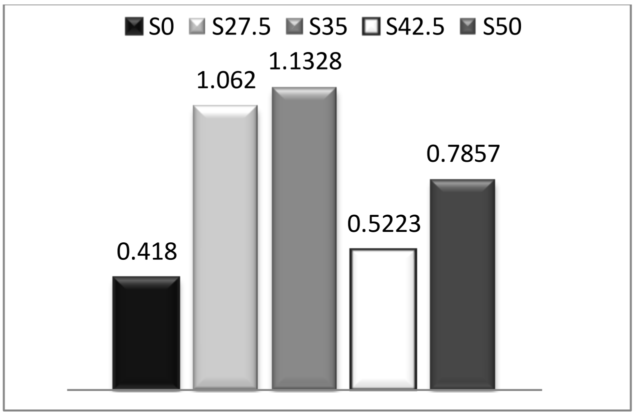

Figure 1.amount of growth in compressive resistance of mortar samples(%)

The pace of cement-Pozzolanic reactions of GGBS has grown in higher ages. The maximum growth of compression resistance has happened in the substitution percentage of 35%. Since the compression resistance of the percentage of 42.5 is close to 50% and the growth rate of compressive resistance is low, this percentage was taken out of consideration for making concrete. With paying attention to table 6 the minimum accepted percentage of GGBS can be inferred, because the GGBS activity index in the age of 28 days for consumed GGBS is less than the minimum in the standards.

Table 6.GGBS activity index

Minimum index(28 days)	Minimum index(7 days)	Grade
70	-	80
69	59	Iranian GGBS

The figure 2 indicates the compressive resistance of concrete samples with various w/c kept in water with the age of 7 days, and the figure 3 is related to ages of 28,90 and 180 days. In the age of 7 days as expected (in consideration with the results of compressive resistance of mortar, the concrete samples indicated the most compressive resistance, and as the substitution percentage increased, the compressive resistance decreased.

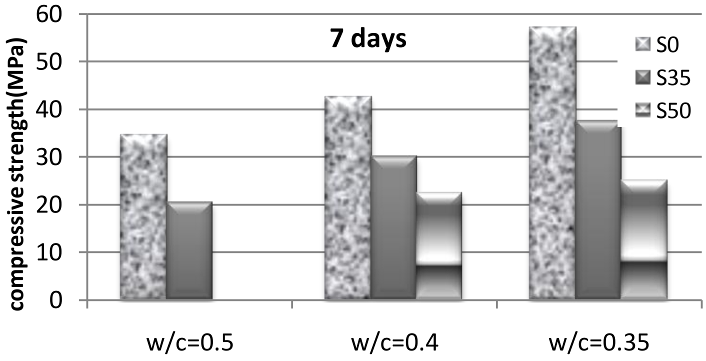

Figure 2.compressive resistance of concrete samples with various w/c kept in water with the age of 7 days

The reason for low compression resistance in samples with GGBS is a decrease in Portland cement and the low reaction ratio in GGBS. This difference between compressive resistance in control types and some samples having GGBS, has decreased in older ages. As it is shown in the figure 3 this difference between the control type and the sample including 27.5 % of GGBS has decreased in the age of 90 days. With consideration to the results for 180 days, in the w/c ratio of 35%, the samples having 50% GGBS have higher compressive resistance in comparison with the samples having 35% GGBS. In the w/c ratio of 40% the compressive resistance of both percentages are quite the same.

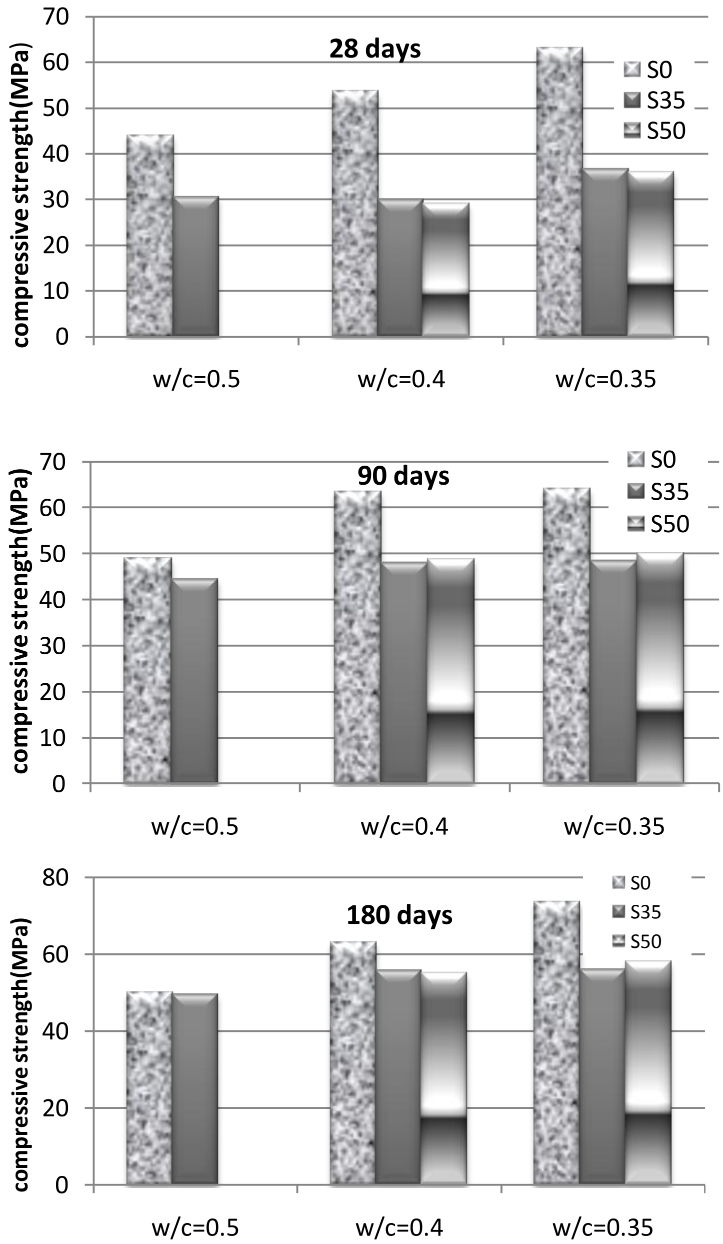

Figure 3.compressive resistance of concrete samples with various w/c kept in water with the age of 28, 90 and 180 days

In all samples with different percentage of substitution and w/c, the ratio of growth in resistance will increase. It can be said that pozzolanic materials will slow down the growth ratio of resistance, but there is a possibility of increase in the ultimate resistance of concrete. The amount of increase of the compressive resistance in the samples including GGBS in the early ages is less than the control types. It is because in the control types, there is more pozolanic material in the cement, though the growth rate of compressive resistance increases in older ages. It can be inferred from the results of compressive resistance tests that, in all cases, as the ages goes up, the compressive resistance soars up. And as it is shown in these figures in all ages studied, the lower w/c ratios indicated higher compressive resistances.

Development of compressive strength (kept on Na_2SO_4)

The figures 4 shows the compressive resistance of concrete samples in the soultion of sodium sulfate 5%. As it is seen, all of the concrete samples have development in compressive resistance until the age of 180 days except the control types which faced a decrease in resistance or consistency in the growth rate of resistance in the age of 180 days and showed some signs of corruption. After 270 days, in addition to all of control types, the samples including 35 percent of GGBS started decreasing in compressive resistance. This procedure has occurred in all of w/c ratios, but the samples having 50 % GGBS, not only didn't face a decrease in resistance, but also gained more compressive resistance in the solution of sodium sulfate.

The first increase in strength may be attributed to two types of reactions: (I) the continuous hydration of unhydrated cement components to form more hydration products in addition to the reaction of SF or GGBS (in case of blended cements) with the liberated lime to form more C-S-H leading to increasing compressive strength and (II) reaction of sulfate ions with hydrated cement components to form gypsum and ettringite. Therefore, at earlier ages, these two reactions lead to a denser structure as a result of precipitation of the products within voids and micropores. Whereas, at later ages, the second type of reactions (sulfate attack) become more dominant leading to formation of microcracks and this decreases strength (Hekal 2002).

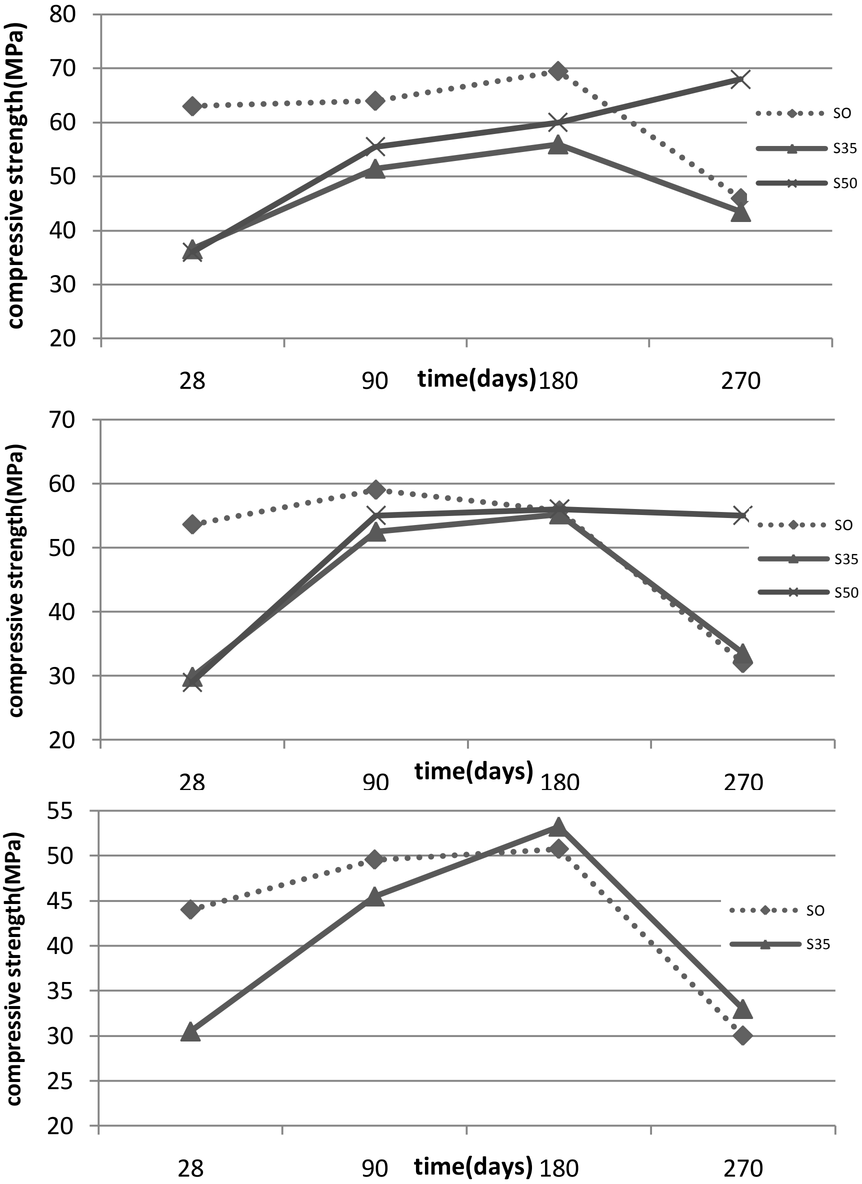

Figure 4.the compressive strength of concrete samples (kept in the solution of sodium sulfate 5%)

Mass change

With paying attention to the figures 5, it is seen that all of the samples in the sodium sulfate had an increase in weight until the age of 270 days, except the samples with the w/c of 35% that had a constant weight increase in the age of 270 days. It is predicted that the weight loss in the older ages are more obvious than the early ages. This result is completely natural, and usually the weight loss in concrete is observed after 1 or 2 years. The weight increase in concrete is because of forming ettringite and plaster as a result of reactions between sodium sulfate and calcium hydroxide and C_3A. It is seen that as the amount of GGBS in concrete mixtures increases, the weight increase of concrete samples decreases**.**

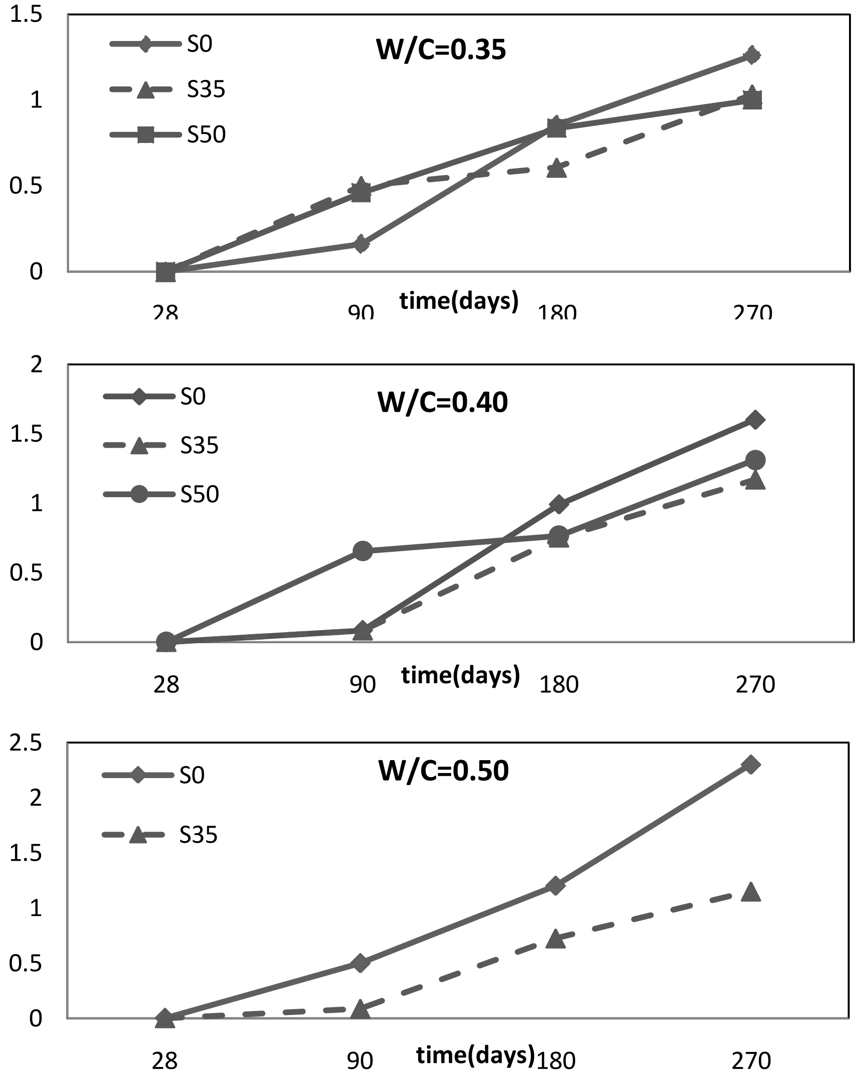

Figure 5.the percentage of weight change of samples in the solution of sodium sulfate 5%

CONCLUSIONS

1. In all concrete samples that kept on water, as the ages goes up, the compressive resistance soars up, and in all ages studied, the lower w/c ratios indicated higher compressive resistances.

2. After 270 days the samples having 50 % GGBS, didn't face a decrease in resistance, yea gained more compressive resistance in the solution of sodium sulfate.

3. It is predicted that the weight loss in the older ages are more obvious than the early ages. Also the amount of GGBS in concrete mixtures increases, the weight increase of concrete samples decreases**.**

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