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The exploitation of Blast furnace Slag as Sand Replacement in Concrete

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***Abstract*-This research exploits ground granulated blast furnace slag(GGBFS) as a replacement of sand on the physico-mechanical properties of concrete. Using these natural materials helps in the natural exchequer such as aggregate and cement. In addition to, it also helps in reducing the cost of manufacturing concrete. The benefits derived from the use of waste materials are the reduction in the cost of waste conductance, helps to save manpower and protect the environment from the effects of more pollution. A study was conducted on the use of recyclable ground granulated blast furnace slag materials, as sand replacement material in concrete mix with replacement percentage (10%, 20%,30%, 40%, and 50%). Lab tests, including slump tests, compressive and flexure strengths were conducted in this study. The results of compressive and flexural strength showed improvement by the use of ground granulated blast furnace slag as a replacement of sand in concrete mixtures. The optimum percentage is between 30 % and 40 %, after those percentages there is no observed increase.**

Keywords: Concrete; Compressive strength; Flexural properties; Ground granulated blast furnace slag, replacement as a sand

I. INTRODUCTION

Over time waste control has become one of the most complicated and challenging problems affecting the environment. The use of waste materials saves the cost and the environmental. The industrialization gave birth to numerous kinds of waste materials which are environmentally risky and differentiate problems of storage. At the forefront in consuming these waste materials becomes the construction industry. The use of slag in concrete as cement or aggregates helps in reducing gases, makes green houses environmentally friendly and has a great effect on the concrete construction cost. GGBFS as a partial replacement of cement is more effective to increase the physical and mechanical properties and durability resistance of concrete [1,2,3].The coke is burned to produce carbon monoxide, which reduces the iron ore into the molten iron product. Through the manufacture of iron and steel, flow (limestone and/or dolomite) charge into a blast furnace along with coke for fuel. During the separation of molten steel there is flowing agents separate wrinkles and slag is produced. About 20 percentage of iron mass production consists of the molten slag which absorbs much of the sulfur from the charge comprises.

II. BACKGROUND

Many researches used The GGBFS as a partial replacement of cement in concrete, but a few of them used it as a replacement of aggregates specially as a sand.Chen et al [4] investigated on mortar made up of ground granulated blast furnace, gypsum, clinker and steel slag sand. The

Application of steel slag sand results reduced the cement clinker dosage and increasing the content of industrial waste products. Use of non ground granulated blast furnace slag as fine aggregate in concrete was experimented by Isa Yuksel and Omer Ozkan [5]. The study obtained that the ratio of GGBs/s and is governing criteria for the effects on the strength and durability characteristics.

Juan M. Et al [6] worked in laboratory producing concrete with good properties using oxidizing slag as fine and coarse aggregate. Durability characteristics like soundness, leaching test, accelerated ageing test it of concrete was tested. The slag concrete durability was acceptable, especially in the geographical region for which its use was proposed, where the winter temperature hardly ever falls below 32°F (0°C). KeunHayek et al [7] studied the effect of using lightweight aggregates on alkali activated mortars and concrete. The compressive strength of alkali activated mortar decreased linearly with the increase of replacement level of lightweight fine aggregate regardless of the water binder ratio.

Effects of steel slag powder on the workability and mechanical properties of concrete were investigated by Li Yun-Feng et al [8]. Mechanical properties can be improved further due to the synergistic effect and mutual activation when compound mineral admixtures with steel slag powder and blast furnace slag powder mixed with concrete, as a result of this study.

Lung Yunxia et al [9] studied enhancing the volume stability of mortar using steel slag as fine aggregate. Results indicated that there are different factors affecting the improvement in volume stability, such as powder ratio, content of free lime and rate of linear expansion. The most effective treatment process was autoclave treated, steam for enhancing the volume of stability of steel slag.L. Zeghichi [10] worked on substitution of sand by GBF crystallized slag. Cubes of concrete were tested to show the effect of the substituting part of sand by granulated slag (30%, 50%) and the total substitution on compressive strength. Test results were carried out at 3, 7, 28, 60 days and 5 months of hard. Tests obtained that the total substitution of natural coarse aggregate with crystallized slag improves tensile, flexural and compressive strength of concrete. Entire substitution of natural aggregates decreases the strength (a loss in strength of 38%) but the partial substitution of natural aggregate with slag aggregate increases strength at long term.

Saud Al-Otaibi [11] studied the effect of use recycled steel mill as fine aggregate in cement mortars. Compressive strength increased by 40% in case of replacement of 40% steel mill scale with that of fine aggregate, drying shrinkage was lower when using a steel mill scale. Sean Monkman et al [12] investigated using a carbonated LF slag as a fine aggregate in concrete. To reduce the free lime content while binding gaseous CO2 into solid carbonates, the slag was carbonated using CO2. Samples were tested using the carbonated LF slag as a fine aggregate in zero-slump press-formed compact mortar and compared to similar samples containing control river sand. The samples of 28day strengths of the mortars made with the carbonated slag sand were compared to the strengths of the normal river sand mortars.

TarunR, et al [13] investigated the application of foundry, materials in the manufacture of concrete and masonry products. The compressive strength of concrete results showed that decreased slightly due to the replacement of regular coarse aggregate with foundry slag although strengths were suitable for structural concrete. Gurpreet Singh et al,[14] used iron slag as a fine aggregate with percentages (0, 10,25 and 40%) with self-compacting concrete (SCC) to study the durability feature. The test result shows that SCC blending iron slag gives better strength and durability than control mixture of SCC.

The coarse and fine aggregates were partially replacement of by GGBFS influence, on the various strength and durability properties of concrete using the mix design of M20 grade. It was found that the workability of concrete gradually decreases, as the percentage of replacement increases, which is found using slump test. The optimum percentage of replacement for fine aggregate (FA) is 40% and for coarse aggregate (CA) is 30%, beyond which the compressive strength decreases on further replacement. It was observed that the partial replacement of fine aggregate by steel slag improves the compressive, tensile and flexural strength of concrete. Compressive strength increased in large number when both CA and FA were replaced by steel slag.,Subathra and Gnanavel, [15].

Qasrawi et al, [16] used steel slag in concrete mixes. Various mixes with compressive strength ranging from 25 to 45 MPa were studied. The slag is used as fine aggregate replacing the sand in the mixes, partly or totally. Depending on the grade of concrete, the compressive strength is improved when the steel slag is used for low sand replacement ratios (up to 30%). When optimum values are used, the 28-day tensile strength of concrete is improved by 1.4–2.4 times and the compressive strength is improved by 1.1–1.3 times depending on the replacement ratio and the grade of concrete. The best results are obtained for replacement ratios of 30–50% for tensile strength and 15–30% for compressive strength.

A study was conducted using Ground-Granulated Blast-Furnace Slag (GGBFS) as a partial replacement material for fine aggregates. Test results showed that the compressive strength of the concrete increases and the optimum value was found at a slag replacement proportion of 30% of fine aggregate and after that any further replacement of slag decreases the compressive strength. Kothai and Malathy, [17].

III. MATERIALS

A. Cement

The cement used in this study is the ASTM type (I) Ordinary Portland cement (OPC) (El Momtaz) produced by Lavarg Company in Egypt. The physical properties of the cement sample as a result of these tests are given in Table (I).

Table (I): Physical properties of cement

Property	Result
Specific gravity	3.17
Fineness	2000 cm2/g
Initial setting time	75 minutes
Final setting time	195 minutes
Compressive strength	N/mm^2
3 days	20.50
7 days	30.00
28 days	43.50
Soundness	1mm

B. Fine aggregates

Fine sand was purchased from a nearby crusher in the 6th October city, which are typically the same materials used in normal concrete mixtures. The graduation test conducted on aggregates showed that they met the specified requirements. The specific gravity of sand is 2.65Its sieve analysis is given in Table (II)

Table (II): Sieve analysis of standard sand

Sieve size	4.75	2.8	1.4	0.71	0.355	0.18
Residual %	0	0	19.3	52.5	74.1	90.1
Passing %	100	100	80.7	47.5	25.9	9.9

C. Coarse aggregates

The aggregate used in this study was beset. Bazalt aggregate was obtained from Elmenia quarry. There are different sizes of basalt, but in this research have been using smallest size. Tests have been made of basalt for specific gravity, analytical sieves, crushing value and the percentage of absorption. The sieve analysis of basalt is given in table (III). The physical properties of basalt samples are given in Table (IV).

Table (III): Sieve analysis of coarse aggregate

Sieve size	37.5	31.5	22.4	19	16	9.5	4.75
Residual	0	0	0	0	5.73	42.98	95
Passing %	100	100	100	100	95.1	55.92	5

Table (IV): Physical properties of coarse aggregate

Property	Result
Specific gravity	2.75
Crushing value	19.5%
Percentage of absorption	0.5%

D.Ground granulated steel slag (GGBFS)

The coke is burned to produce carbon monoxide, which reduces the iron ore into the molten iron product. Through the manufacture of iron and steel, flow (limestone and/or dolomite) charge into a blast furnace along with coke for fuel. During the separation of molten steel there is flowing agents separate wrinkles and slag is produced. Then mechanically grind the slag. The Chemical Composition percentages of GGBFS shown in Table (v). The table explains the high percentage of CaO, and SiO_2, which helping to improve the concrete properties. Different sieves used for GGBFSare shown in Figure. (1). The sieve analysis of GGBFSis given in table (VI) and shown in Figure. (2). The physical properties of the GGBFSsampleas results of these tests areSpecific Gravity, bulk density and soundness 2.00,1.15 gm/cm^{3}and 0.9% respectively.

Table (V): Chemical Composition of GGBFS

Chemical Composition (as oxides)	%
SiO_2	40
Al_2O_3	13.5
CaO	39.2
MgO	3.6
Fe_2O_3	1.8
SO_3	0.2
L.O.I	0.0


Figure1: GGBFS compared to sand sample

Table (VI): Sieve analysis of GGBFS

Sieve size	4.75	2.8	1.4	0.71	0.355	0.18	Pan
Residual %	---	21.47	47.16	58.62	73.19	90.90	100
Passing %	100	78.53	52.84	41.38	26.81	9.1	------

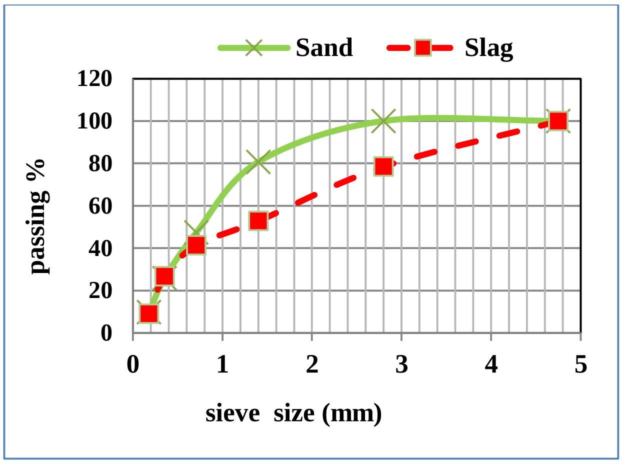


Figure 2: Sieve analysis of GGBFSand sand sample

E. Superplasticizer

In order to improve the workability of concrete, Superplasticizer in the form of polycarboxylate ether based Superplasticizer is incorporated into all mixes.Superplasticizer have density 1.07± 0.02 kg/l, total soluble chloride ion content max 0.1% chloride free, pH value 6-10 and brown liquid color.

IV. MIX PROPORTIONS

Six mixture proportions were made according to the Egyptian Code of Practice for Design and Execution of Concrete Structures [15]. First was control mix (without GGBFS), and the other five mixes contained slag. Fine aggregate (sand) was replaced with slag by weight. The proportions of fine aggregate replaced ranged from 10% to 50%. Mix proportions are given in Table VI. The control mix without slag was proportioned according to ACI-116 [17]. A fresh concrete property such as slump was determined according to ASTM C 138 [18] presented in Table VII.

Table (VI I): Mixture proportions

Mix. No.	C-1	C-2	C-3	C-4	C-5	C-6
Cement (kg)	390	390	390	390	390	390
GGBFS (%)	0	10	20	30	40	50
GGBFS (kg/m^3)	0	50	110	170	220	280
Water(liter)	164	164	164	164	164	164
W/C	0.42	0.42	0.42	0.42	0.42	0.42
Sand	560	510	450	390	340	280
Bazalt	1020	1020	1020	1020	1020	1020
Slump (mm)	100	90	65	40	30	20

V. PREPARING AND CASTING OF TEST SPECIMENS

The 150-mm concrete cubes were cast for compressive strength and100x100x50 mm beams for flexural strength. After casting, all the test specimens were finished with a steel trowel. Immediately after finishing, the specimens were covered with plastic sheets to minimize the moisture loss from them. All the test specimens were stored at temperature of about 20 °C in the casting room as shown in Figure. (3). They were remolded after 24 h, and were put into a water-curing tank. Tests were performed at 7, 14, 28, 60, 90, and 365 days in accordance with the provisions of the ASTM C 39 [15].Compressive strength results are shown in Figures. 4 and 5and flexural strength results in Figures.6 and 7.

Figure. 3: Compressive and flexural tests

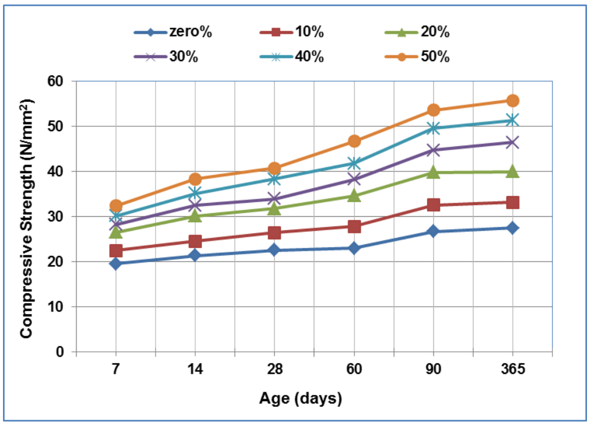
VI. RESULTS AND DISCUSSION

A. Compressive strength

Compressive strength of concrete specimens made with and without GGBFSwas determined at 7, 14, 28, 60, 90, and 365 days of curing. The test results are given in Table 6 and shown in Figures. 4 and 5.Figure.4shows the variation of compressive strength with age for various GGBFS percentages, and Figure. 5shows the variation of compressive strength with ground slag percentages at different ages. From the test results, it can be seen that the compressive strength of GGBFS concrete mixes with 10%, 20%, 30%, 40%, and 50% fine aggregate replacement with GGBFS, were higher than the control mix (C-1) at all ages. It is evident from Table VIII and Figure. 4 that the compressive strength of all mixes continued to increase with the increase in age. From Figure.4, it can be seen that there is an increase in strength with the increase in GGBFS percentages; however, the rate of increase of strength decreases with the increase in GGBFS content. This trend is more obvious between 40% and 50% replacement level. However, maximum strength at all ages occurs with 50% fine aggregate replacement. This increase in strength due to the replacement of fine aggregate with GGBFS is attributed to the pozzolanic action of GGBFS. In the beginning (early age), GGBFS reacts slowly with calcium hydroxide liberated during hydration of cement and does not contribute significantly to the densification of the concrete matrix at early ages. Concrete with GGBFS shows higher strength at early ages because inclusion of GGBFS as partial replacement of sand starts pozzolanic action and densification of the concrete matrix and due to this strength of GGBFS concrete is higher than the strength of control mix even at early ages.

Table (VIII) Compressive Strength test result

Mix	C-1	C-2	C-3	C-4	C-5	C-6
GGBFS (%)	0	10	20	30	40	50
Test age (days)	Compressive strength (N/mm^2)					
7	19.62	21.41	22.62	23.00	26.73	27.54
14	22.50	24.63	26.51	27.83	32.64	33.21
28	26.60	30.24	31.84	34.72	39.82	40.00
60	28.33	32.51	34.01	38.33	44.80	46.53
90	30.20	35.24	38.35	41.84	49.61	51.42
365	32.42	38.35	42.8	46.72	53.66	55.83



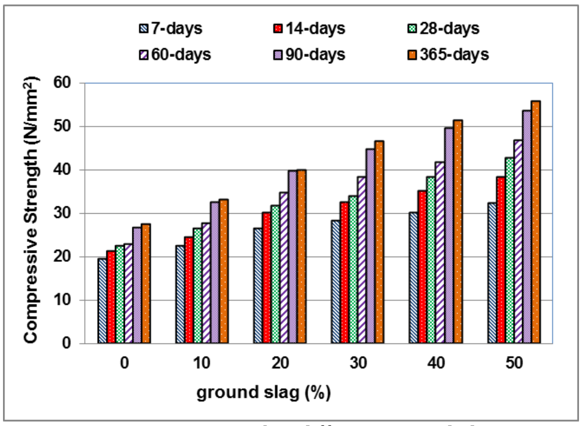


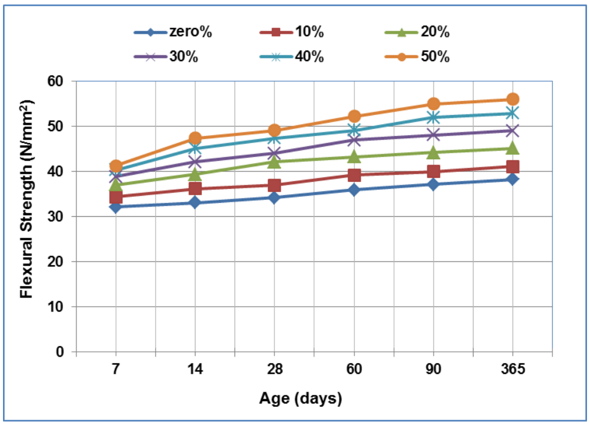
Figure4:Compressive strength at different ages and Slag percentag

B. Flexural strength

The flexural strength test results of GGBFS concrete are given in Table IX and shown in Figures 5. Figure.5shows the flexural strength development with age, and the variation of flexural strength with various percentages of GGBFS. It is evident from Table 8 and Figure. 5 that the flexural strength of GGBFScontinued to increase with the age.it can be seen that flexural strength continued to increase with the increase in GGBFSpercentages at all ages, and there is a significant increase in strength with that of strength of control mix. This is believed to be due to the large pozzolanic reaction and improved interfacial bond between paste and aggregates. As GGBFS is available free of cost and it may only involve transportation cost of bringing it to either laboratory or site, it does not incur any additional cost in making concrete as money will be saved on use of lesser sand.

Table (IX) Flexural Strength test result

Mix	C-1	C-2	C-3	C-4	C-5	C-6
GGBFS (%)	0	10	20	30	40	50
Test (days)	Flexural strength (N/mm^2)					
7	32.20	33.11	34.22	36.00	37.20	38.30
14	34.40	36.24	37.00	39.22	40.00	41.11
28	37.10	39.42	42.20	43.30	44.22	45.21
60	38.90	42.22	44.10	47.00	48.13	49.05
90	40.36	45.22	47.40	49.20	52.00	53.00
365	41.33	47.45	49.20	52.24	55.04	56.03



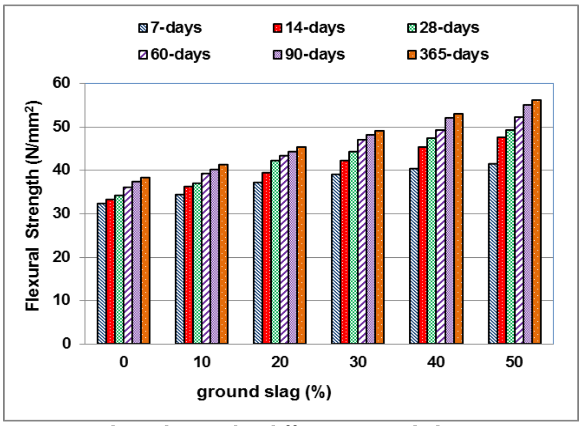


Figure 5.Flexural strengthat different ages and Slag percentage

The change of compressive and flexural strength of GGBFS modified concrete with GGBFS% compared to the control mix (C1) at the same curing time (7, 17,28,60,90and365days) is given in Table (X-XI), and graphically represented in Figure 6, respectively. On the other hand, the effect of curing time is the rate of compressive and flexural strength enhancement of C5 (60% OPC + 40% GGBFS) in a comparison with C1is shown in Figure 6. The specimens containing 10, 20, 30, 40 and 50% GGBFS the rate of increase ranges from 40.36% to 72.20 % in their compressive strength in comparison with that of control specimens at different curing times. The results also indicate that, the rate of increase of flexural strength ranges from 18.63 to35.56 % in comparison with that of control specimens at 365 days.

Table (X) Change rate of compressive strength%

Mix	C-2	C-3	C-4	C-5	C-6
GGBFS (%)	10	20	30	40	50
Test age(days)	Change rate of compressive strength%				
7	9.12	15.29	17.22	36.23	40.36
14	9.46	17.82	23.68	45.1	47.76
28	13.68	19.69	30.52	49.69	50.40
60	14.75	20.04	35.29	58.13	64.24
90	16.53	26.98	38.54	64.3	70.26
365	18.29	35.10	44.10	65.51	72.20

Table (XI) Change rate of flexural strength%

Mix	C-2	C-3	C-4	C-5	C-6
GGBFS (%)	10	20	30	40	50
Test age(days)	Change rate of flexural strength%				
7	2.82	6.27	11.80	15.52	18.63
14	5.34	7.56	14.01	16.3	19.50
28	6.25	13.74	16.71	19.19	21.85
60	8.53	13.36	20.82	23.73	20.95
90	12.04	17.44	22.00	28.84	31.31
365	14.80	19.04	26.39	33.17	35.56

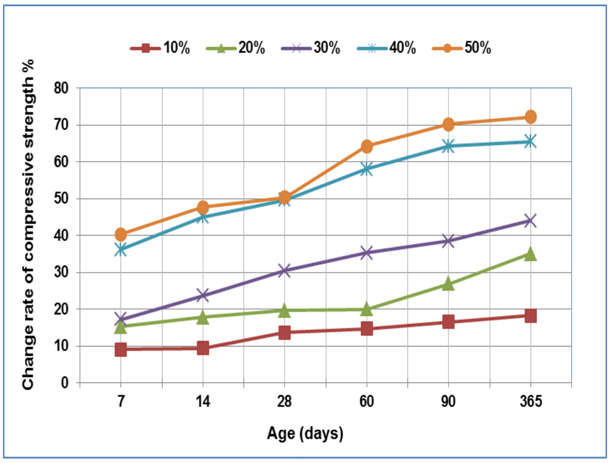


Figure6.Change rate of compressive strength %

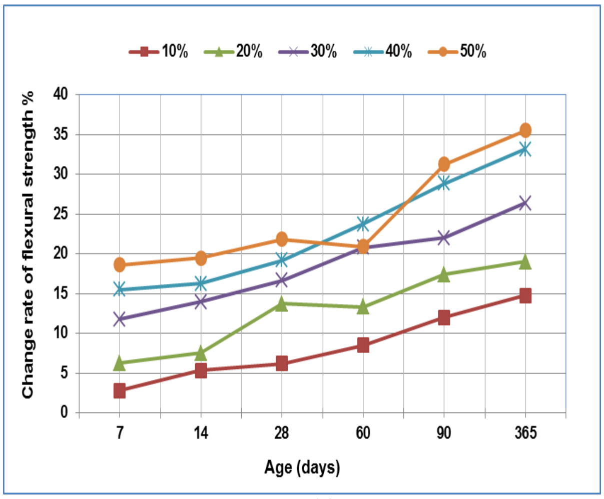


Figure7 .Change rate of flexural strength %

VI. CONCLUSIONS

In trying to find a possibility to reduce cost and saving the environment of construction materials in conjunction with improving the performance of Portland cement concrete, waste materials ground-granulated blast-furnace slag (GGBFS)was used by means of partial replacement of fine aggregates in concrete.

Six of different mix proportions were designed to estimate the effect of GGBFS as a replacement of sand on the fresh and hardening properties of concrete.

Results showed that up to 30 to 40 % of GGBFS, as a replacement of sand, gives good results in increasing a compressive and flexure strength of concrete. The following conclusions can be drawn:

1. Compressive and flexural strengths of sand replaced GGBFS concrete specimens were higher than the plain concrete specimens at all the ages. The strength differential between the specimens with GGBFSand plain concrete specimens became more distinct after 28 days.The effect on different properties continued to increase with age for all GGBFS percentages.
2. The maximum compressive strength occurs with 50% GGBFS content at all ages. It is 40 N/mm^{2}at 28 days, 52.42 N/mm^{2}at 90 days, and 54.83 N/mm^{2}at 365 days.The maximum flexural strength has been found to occur with 50% GGBFS content at all ages. It is 43.21 N/mm^{2}at 28 days, 52.00 N/mm^{2}at 90 days, and 54.03N/mm^2 at 365 days.
3. Optimum improve the percentage of GGBFS was 40% in compressive and flexural strength tests, with a little increase in percentage 50%. In the same way the curing age 60 days had the big enhancement of different strengthen.
4. The results of this investigation suggest that GGBFS could be very convenient used in structural concrete.
5. The chemical composition of the GGBFS is characterized by high calcium oxide (CaO) and silicon oxide (SiO2), so it is a hydrolytic substance (reacts with water, such as cement) and a potassium substance (reacts with the calcium hydroxide produced by the reaction of water with water).

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