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Influence of Ground Granulated Blast Furnace Slag as Cement Replacement on Some Properties of Paste and Concrete Mixes

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Abstract

Portland cement, already being a very expensive material constitutes a substantial part of the total construction cost of any project and the situation has further aggravated by the energy crisis, which has further increased the cost of production of Portland cement. Therefore, it is of current importance for the country to explore and develop cementing materials cheaper than Portland cement. This research, focus on investigating Physical and Chemical properties of Portland cement with partial replacement with Ground Granulated Blast furnace Slag (GGBS), such properties are compressive strength, normal consistency, setting times of neat cement mixes (control) and partial replacement of cement with GGBS levels of 20, 40, 60 and 80%, and the main focus to find the optimum percentage of GGBS that gives the greater compressive strengths improvements of concrete. Ground Granulated Blast furnace Slag was collected from Steel Mills Misurata (Libya) and pulverized to a very fine degree.

Concrete of target mean strength 50MPa were produced to determine the compressive strength development under standard curing conditions (20^{0} C). The tests results of normal consistency, setting times showed that the higher the percentage of the GGBS reduce the needed percentage of the water and as the percentage of GGBS increase the initial and final setting time decrease. The strength development appears to be similar to Portland cement concrete strength at all ages for 20% GGBS concrete only, For the concretes with 40, 60 and 80% GGBS the compressive strength was lower than the control concrete during all ages.

GGBS collected from Steel Mills Misurata (Libya), better of it is used as aggregate and not as a binder component in cement manufacture.

Keywords: *Ground Granulated Blast furnace Slag (GGBS), the compressive strength , Portland cement , Blast furnace Slag.*

1. Introduction

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure such as buildings, industrial structures, bridges and highways…etc. leading to utilization of large quantity of concrete. High Performance Concrete (HPC) is a concrete meeting special combinations of performance and uniformity requirements that cannot always achieved routinely by using conventional constituents and normal mixing. This leads to examine an admixtures to improve the performance of the concrete. On the other side, cost of concrete is attributed to the cost of its ingredients which is scarce and expensive, this leading to usage of economically alternative materials in its production. This requirement is drawn the attention of investigators to explore new replacements of ingredients of concrete.

The production of GGBS requires little additional energy as compared with the energy needed for the production of Portland cement, the replacement of Portland cement with GGBS will lead to significant reduction of carbon dioxide gas emission.

The Blast Furnace Slag can be used in cement and concrete either as an aggregate (coarse or fine), or as a binder component in concrete manufacture.

The Blast Furnace Slag produced in three forms:-

1. Blast Furnace Rock Slag (BFRS)
2. Granulated Blast Furnace Slag (GBFS)
3. Ground Granulated Blast Furnace Slag (GGBS)

The Advantages of Using Blast Furnace Slag Cement:-

- High resistance against Sulfate and Acid attacks, prevention of chloride ion leakage into concrete, it also decreases the permeability of chloride ions.
- Effective against possible expansion due to alkali-silica reaction.
- Longer strength development compared to CEM I type cement.
- Increasing economic life of buildings.

- Increase of low temperature at early ages.
- Low heat of hydration that prevents thermal cracks.
- Resistance to high temperature as in case of fire, deformation is less compare to CEM I type cement when subject to fire and high temperatures.

GGBS is therefore an environmentally friendly construction material. It can used to replace as much as 80% of the Portland cement used in concrete.

GGBS concrete has better water impermeability characteristics as well as improved resistance to corrosion and sulfate attack. As a result, the service life of a structure is enhanced and the maintenance cost reduced [1,2,3,4,5,6,7,8,9,10].

The main objectives of this paper is to investigate the effect of partial replacement of cement by 20, 40, 60, 80% of ground granulated blast furnace slag (GGBS) on cement properties and on compressive strength of concrete.

To investigate the effect of GGBS on normal consistency and setting time of cement, first the normal consistency and setting time of cement has been obtained and then the cement were replaced with GGBS levels of 20, 40, 60 and 80% to obtain the effect of each level of replacement of GGBS on normal consistency and setting time of cement.

To obtain concrete of target mean strength 50MPa, concrete mix were produced to determine the compressive strength development under standard curing conditions 20 ^{o}C of concrete, with neat Portland cement mix as control mix, and partial replacement of cement with GGBS levels of 20, 40, 60 and 80%. The proportions of the concretes were obtained according to the BRE method (mix design of normal concrete)[12] for concrete with water/cement ratio (w/c) of 0.44.

2. Materials, Experimental Procedures and Mix Design of GGBS Concrete.

- **Materials Used:-**

The same materials were use throughout this study. All the materials were in accordance with relevant BS and ASTM standards and considered suitable for the scope of this study.

Aggregate:-

Fine and coarse aggregate was used in this study, it was obtained from Alkhalij 4*350MW Power Plant which are about 15 kilometers west of Sirte.

Sieve analysis of fine and coarse aggregate according to BS 882:1992[13]:-

- **Fine Aggregate:-**

The sieve analysis results of the fine aggregate are shown in figure (1):-

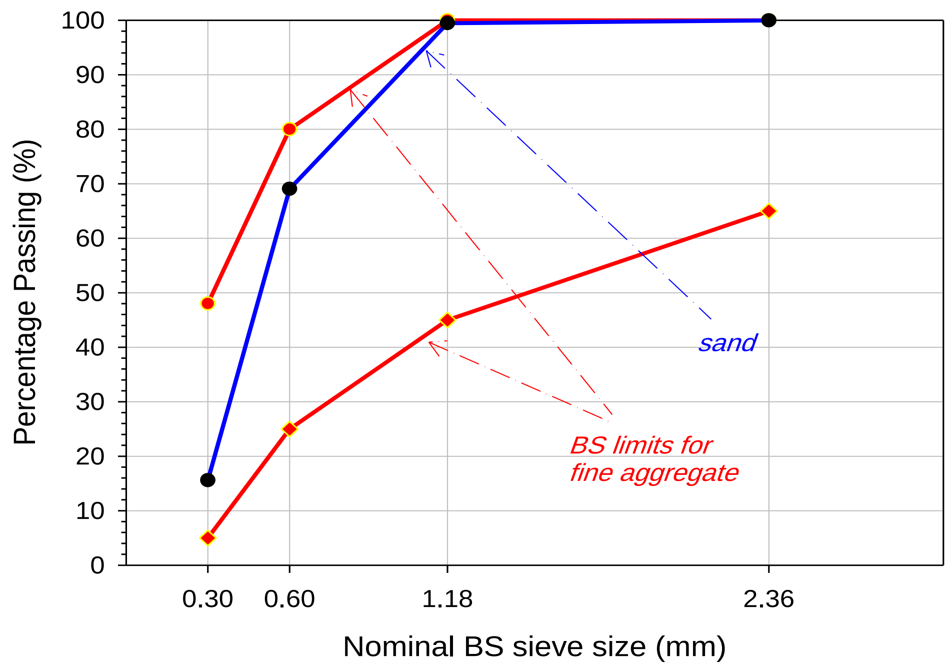

Figure 1. Grading of sand

According to the standard the fine aggregate complies with the specification as medium sand, adding fine aggregate (the ruins of a small size 5mm aggregate) to improve the gradation in the concrete mix proportions.

The sieve analysis results of the fine aggregate (the ruins of a small size) are shown in figure (2):-

According to BS 882:1992**[13]** the above fine aggregate complies with the specification as single sized aggregate (5mm). Mixing of sand with fine aggregate graduation rates give appropriate and in conformity with the specifications 30% size 5mm aggregate & 70% fine aggregate as shown in figure (3):-

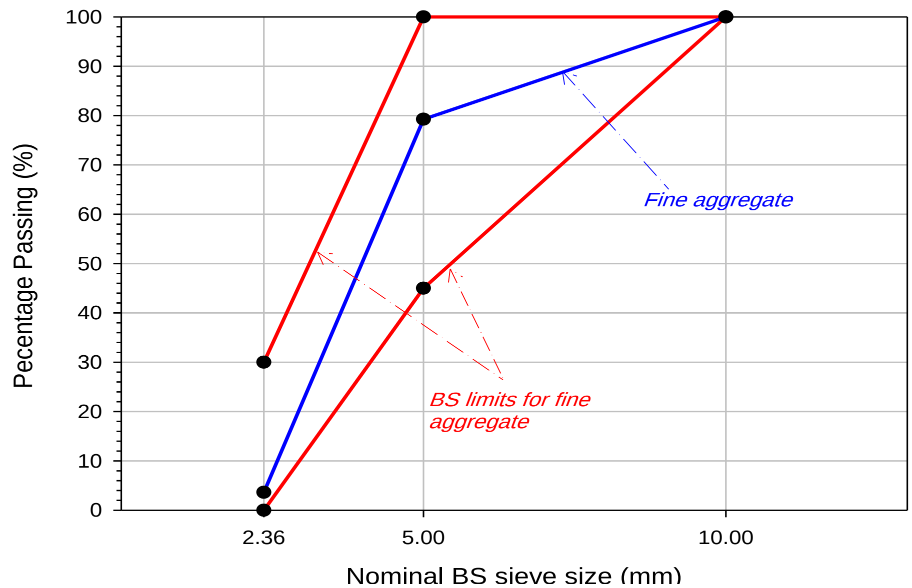

Figure 2. Grading of size 5mm aggregate

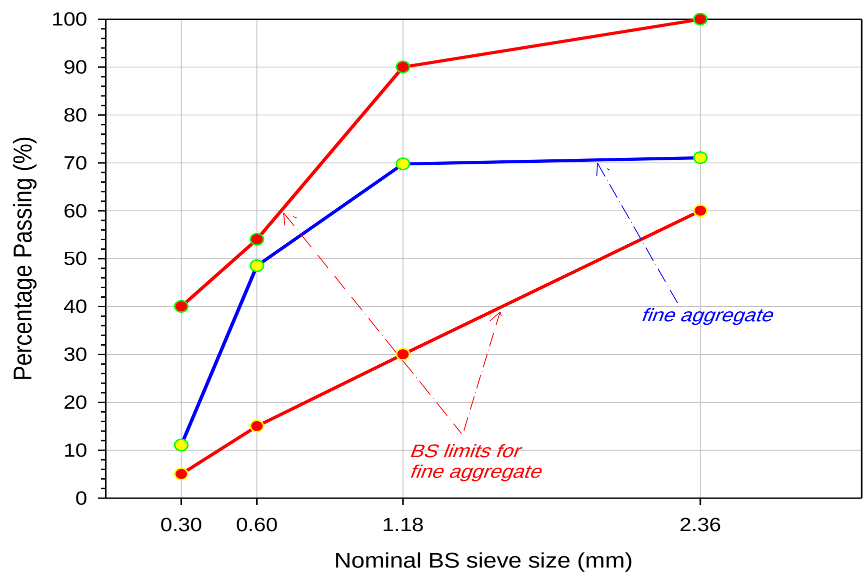

Figure 3. Grading of combined sand with size (5mm) aggregate

According to BS 882:1992**[13]** the above fine aggregate complies with the specification as medium sand.

- **Coarse Aggregate:-**

The natural coarse aggregate sizes (10mm and 20mm) was used, which is identical to the standard specifications.

- **Coarse Aggregate (size 10 mm):-**

The results of sieve analysis for coarse aggregate size (10mm) can be seen in figure (4), according to BS 882: 1992 [13] the above coarse aggregate complies with the specification as single sized aggregate (10mm).

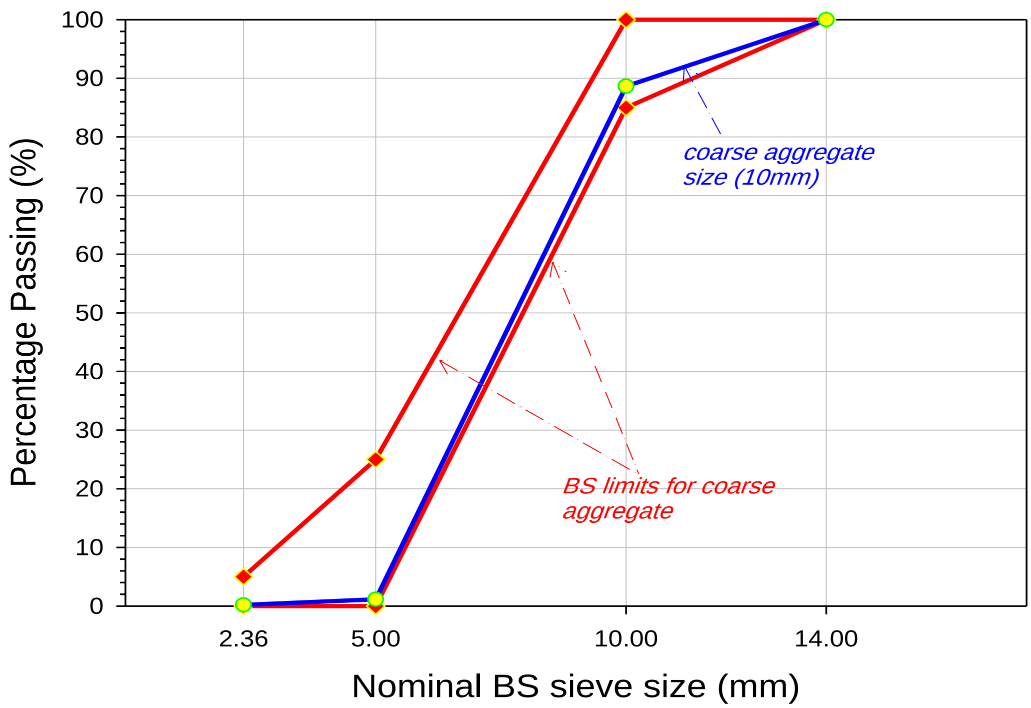

Figure 4. Grading of aggregate size (10mm)

- **Coarse aggregate size (20 mm):-**

The sieve analysis results of the coarse aggregate size (20mm) is shown in figure (5), according to BS 882:1992[13] the above coarse aggregate complies with the specification as single sized aggregate (20mm).

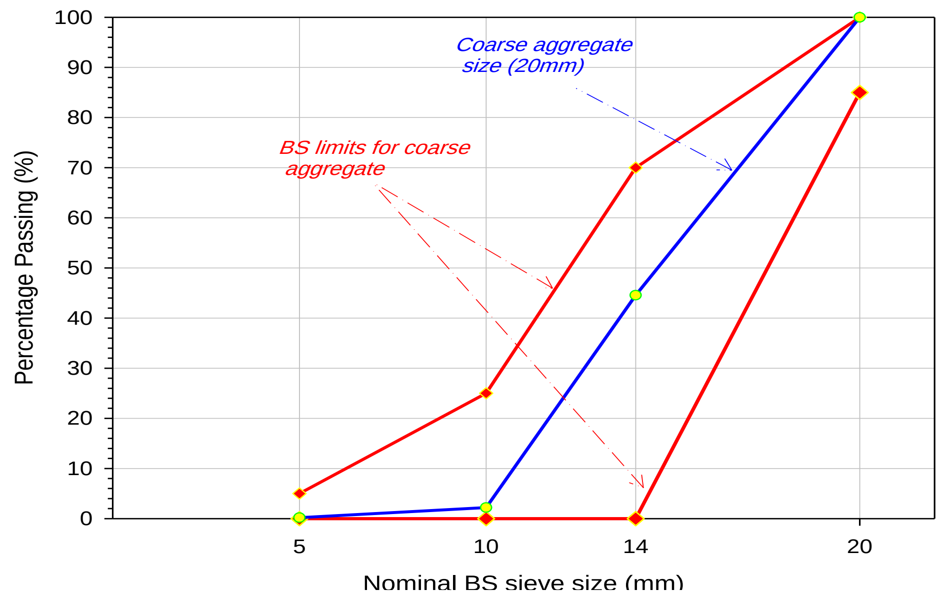

Figure 5. Grading of aggregate size (20mm)

Mixing 50% for each size to achieves the specifications as shown in figure (6).

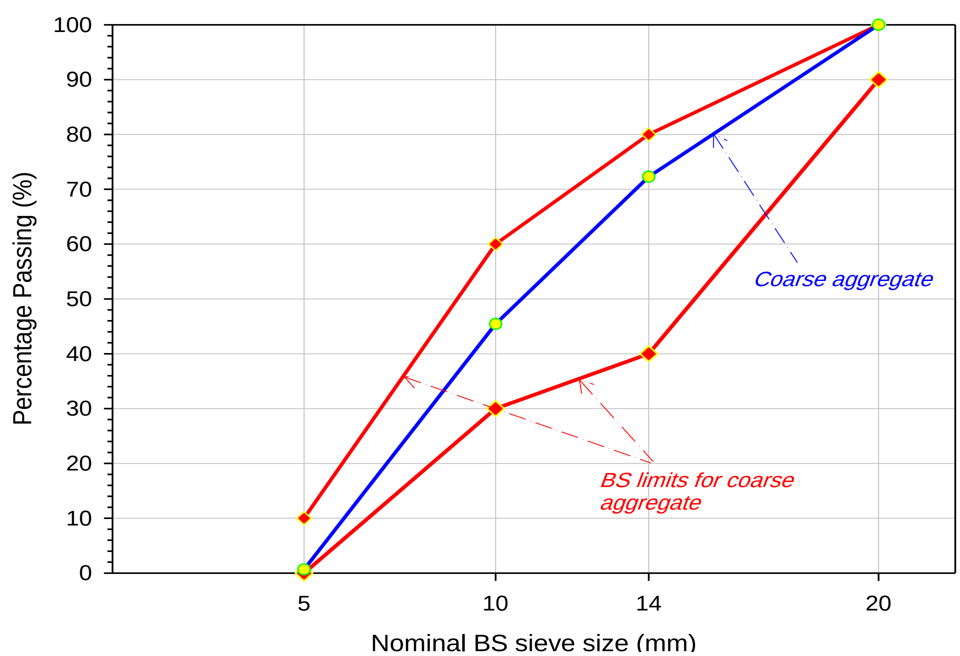

Figure 6 Grading of combined 20-10mm of aggregate

- **Moisture content of fine and coarse aggregate according to (ASTM C-566-84)[14] are:-**

  Moisture content percentage (fine aggregate) = 0.68%.

  Moisture content percentage (coarse aggregate) = 2.06%.

- **Specific gravity and absorption of coarse and fine aggregate determined according to (ASTM C 127-88)[15], (ASTM C 128-88)[16] respectively are shown in table (1):**

Table 1. Specific gravity and absorption of coarse and fine aggregate

Aggregate size	Bulk specific gravity (gm/cm^3)	Bulk specific gravity (saturated surface dry) (gm/cm^3)	Apparent specific gravity (gm/cm^3)	Absorption %
(20mm)	2.35	2.456	2.633	4.603
(10mm)	2.34	2.453	2.638	4.838
5mm	2.34	2.46	2.621	5.12
Sand	2.61	2.62	2.71	0.664

- **Cement:-**

  Zliten cement was used in this study which can be classified as normal Portland cement type 42.5N and the results of the tests of fineness, specific gravity, normal consistency and setting time were confirm to the specifications.

- **Ground granulated blast furnace slag (GGBS):-**

  The GGBS was obtained in the solid state and it was in the form of aggregate in large volumes, and it's size was approx. (40-80) mm as shown in figure (7).

Figure 7. Solid GGBS

In this case, it is not suitable for use as a substitute for cement, and thus it was necessary to find a way to convert this aggregate to a state close to, although it is difficult to achieve that and the following steps to grind the GGBS:-

1. Solid GGBS was placed in the machine dedicated to crushing the aggregate and breaks up into small diameter of 5 mm approx as shown in figure (8).

Figure 8. GGBS after crushing

2. Gathering the GGBS that has been crushed into 5mm rocks then the rocks were placed with iron balls into Los Angeles machine for further grinding as shown in figure (9).

Figure 9. GGBS after grinding inside Los Angeles machine

- **Fineness of hydraulic cement by No.100 sieve (ASTM C 184-83)[18] :-**

  This test method covers determination of the fineness of hydraulic cement by means of the (No.100) sieve.

  Percentage of retaining on (NO.100) sieve=0.2% <10% on specifications.

- **Density and specific gravity of cement (ASTM C 188-87)[19]:-**

  This test covers determination of the density of cement and its specific gravity.

  Specific gravity=3.12 gm/cm^3.

- **Normal consistency of cement (ASTM C 187-86)[20]:-**

  This test method covers, the determination of the normal consistency of hydraulic cement. That is by determining the amount of water required to prepare cement pastes for initial and final time of setting test.

  In this test the effect of the GGBS on the normal consistency of the cement was studied and the same steps to determine the normal consistency of the cement was followed and the results as shown in figure (10).

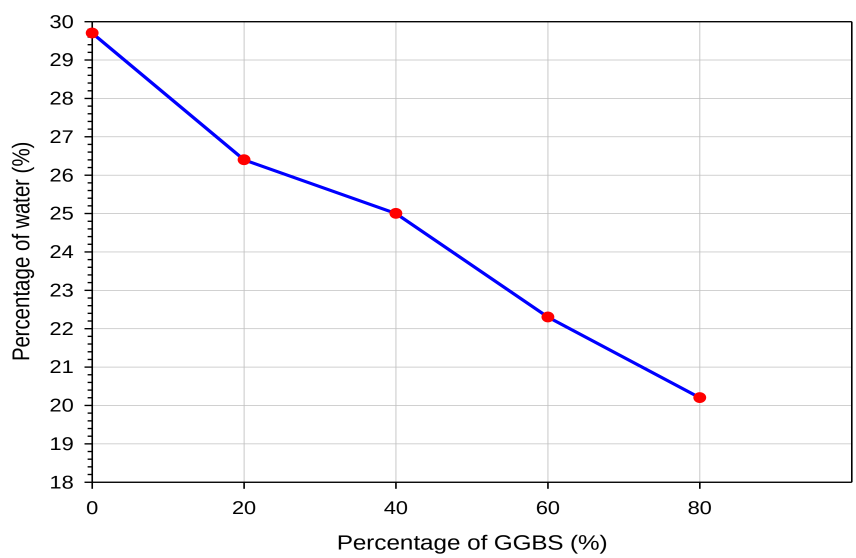

Figure 10. Effect of GGBS on normal consistency of cement

curve shown that, the percentage of water is inversely proportional with the GGBS, increase the percentage of the GGBS is reducing the needed percentage of the water.

- **Water:-**

The quality of concrete mixing water should not contain undesirable organic substances or inorganic constituents in excessive proportion. Therefore, tap water used throughout the mixing and curing procedures of concrete in this study.

Experimental procedures:-

Mix design of Portland cement and GGBS concrete:-

In this study, the BRE method (mix design of normal concrete)**[12]** was used to design the concrete mixes. The method suggested that when GGBS is used as a replacement with levels of 20 and 40% for some of Portland cement in the concrete mix it is generally done on the basis of a direct mass for mass replacement of Portland cement by GGBS .

When GGBS is used as a replacement with levels of 60 and 80% it is generally necessary to increase the content of cement plus GGBS above that of Portland cement concrete to achieve comparable compressive strength at 28 days. Typically, an additional cement plus GGBS content of about 10Kg/m^3 is required.

In this study, the following values were used to design the concrete mixes:-

Target mean strength = 50 MPa.

Free-water/cement ratio = 0.44.

The obtained values of mixes proportions presented in table (2).

Table 2. Weights of concrete constituents for cubic meter

Materials	Weight (Kg/ m^3)				
	0% GGBS	20% GGBS	40% GGBS	60% GGBS	80% GGBS
Cement	431.82	345.456	259.092	176.728	88.364
GGBS	0	86.364	172.728	265.092	353.456
Water	190	190	190	190	190
Fine aggregate	398.63	398.63	398.63	398.63	398.63
Coarse aggregate	567.28	567.28	567.28	567.28	567.28

(10mm)					
Coarse aggregate (20mm)	567.28	567.28	567.28	567.28	567.28

3. Mixing, casting and curing procedures of concrete cubes:-

Mixing:-

The concrete mixing was done in two phases. All aggregates were premixed with half of the mixing water for about two minutes. Cementitious materials and the remaining mixing water were added and mixing was carried out for about three minutes to ensure concrete was homogeneous.

Casting and compaction:-

The concrete was casted into 100 mm^3 cube moulds to measure the compressive strength and then compacted on three layers using steel bar to ensure a satisfactory level of compaction

Curing:-

In this study, for the first 24hours the surface of concrete was covered by a piece of wet burlap. From this age onward, the cubes were immersed in water at the room temperature (about 20^{o}C).

Initial and final time of setting of cement and GGBS (ASTM C191-82)[21]:-

This test covers determination of time of setting of cement by means of the Vicat needle. In this test, the effect of the GGBS on the initial and final time of setting of the cement was studied and the same steps to determine the initial and final time of setting of the cement was followed and the results are shown in table (3):-

Table 3. Initial and final setting time of cement and GGBS

Ratio of GGBS	Initial setting time (Minute)	Final setting time (Minute)
0%	189	315
20 %	148	269
40 %	78	250
60 %	46	132
80 %	22	95

Figure (11) shows the relationship between initial time and penetration rate of each percentage of GGBS, the rate of sclerosis increased with the increasing of the percentage of the GGBS; simple differences in the degree of softness could be the reason.

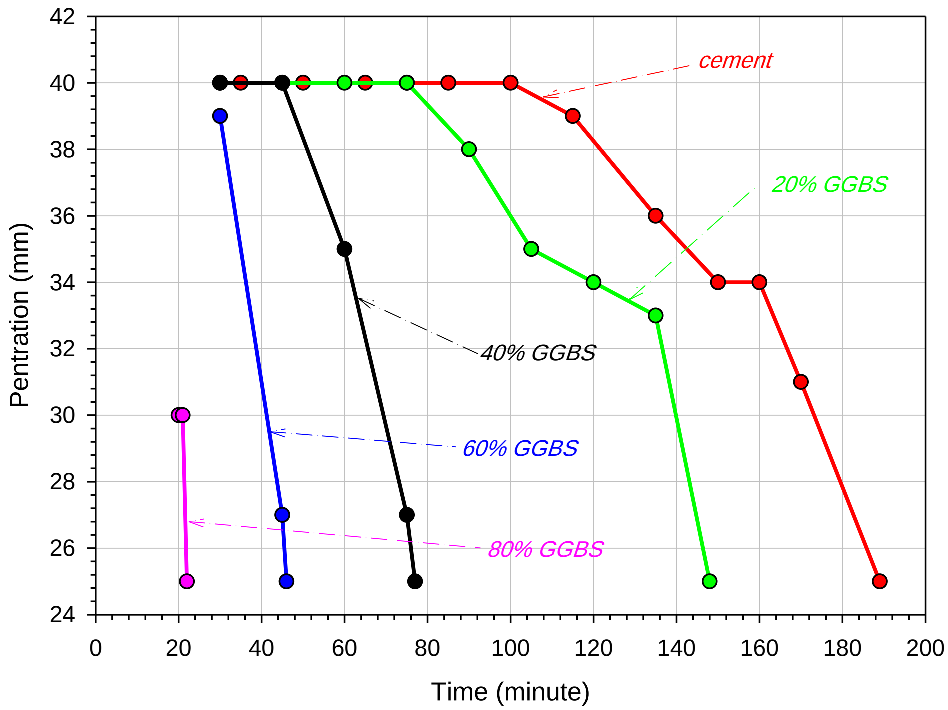

Figure 11. Relationship between initial time and penetration rate of each percentage of GGBS

4. Compressive Strength of Portland Cement and Ground Granulated Blast Furnace Slag Concrete

Standard cubes size (100*100*100) mm^3 was used to determine the compressive strength of ordinary concrete and other concrete that contain different ratios of GGBS. It was investigated at different ages of (0.25, 1, 2, 3, 7, 14, 28 and 56) days to determine the effect of GGBS on early age strength and long-term strength of ordinary concrete, note that both concretes subjected to the same conditions of mixing, molding, compaction, curing and testing.

Effect of GGBS concrete mixes on compressive strength:-

The strength development for Portland cement and Portland cement with 20, 40, 60 and 80% replacement level of GGBS are shown in table (4) and figure (12) :-

Table 4. Compressive strength of the concretes

Age (days)	Compressive strength (MPa)				
	Cement	20% GGBS	40% GGBS	60% GGBS	80% GGBS
0.25	0.8	0.9	0.4	0.5	0.6
1	15.8	13.7	9.3	3	0.8
2	25.4	23.6	18.6	7.4	1.12
3	29.7	24.5	20.4	12.4	1.6
7	48.1	47.1	35	19.5	6.3
14	55.8	55.6	42.2	24.8	9.9
28	65.8	62.5	47	29.7	13.4
56	68	69	54.8	36.9	20.6

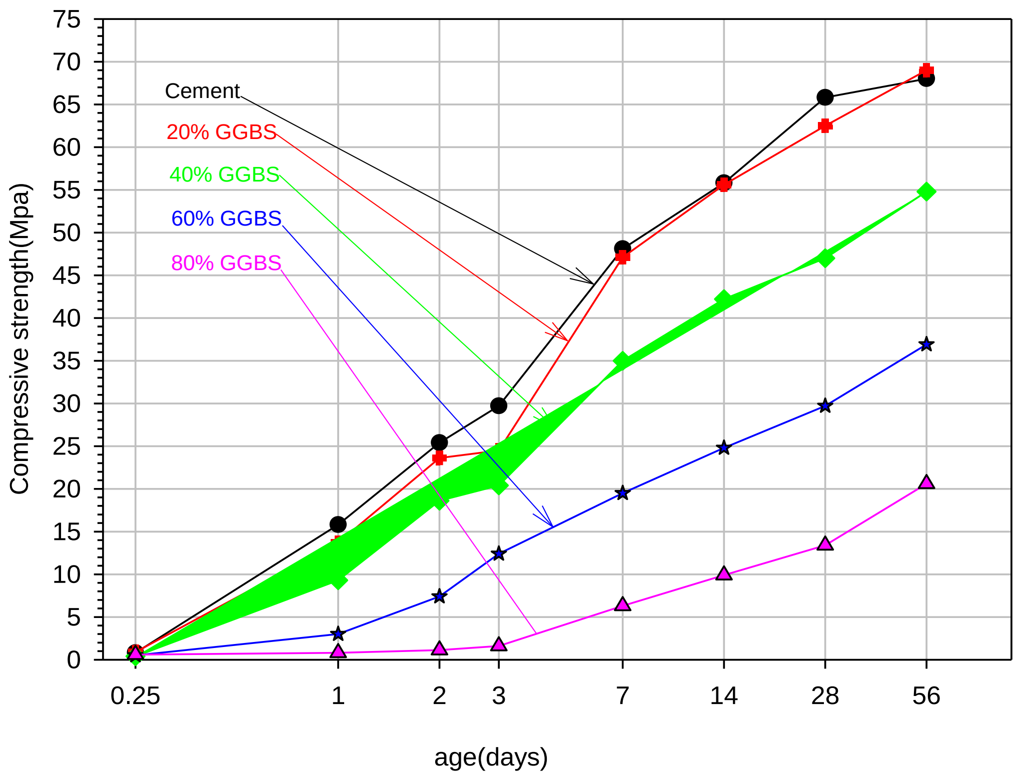

Figure 12. Compressive strength of the concretes

At all ages, the strength development of Portland cement concrete is greater than that of GGBS concretes and as percentage of GGBS increases the strength development decreases. This attributed to the fact that the GGBS could be reacting as sand, and the hydration of Portland cement only is largely responsible for the strength development. For 20% GGBS concrete, the strength development appears to be similar to Portland cement concrete strength at the majority of the ages.

Figure (13) shows the ratio of the strength development of Portland cement and GGBS concretes. The strength development ratio of 40, 60 and 80% was lower than that of Portland cement for early age to later age. For concrete that contain 20% GGBS, the ratio of strength development in the first 6 hours after casting was around 113.6 % of Portland cement concrete strength development, after that the strength is ranging between (85 – 97)% of Portland cement concrete strength development.

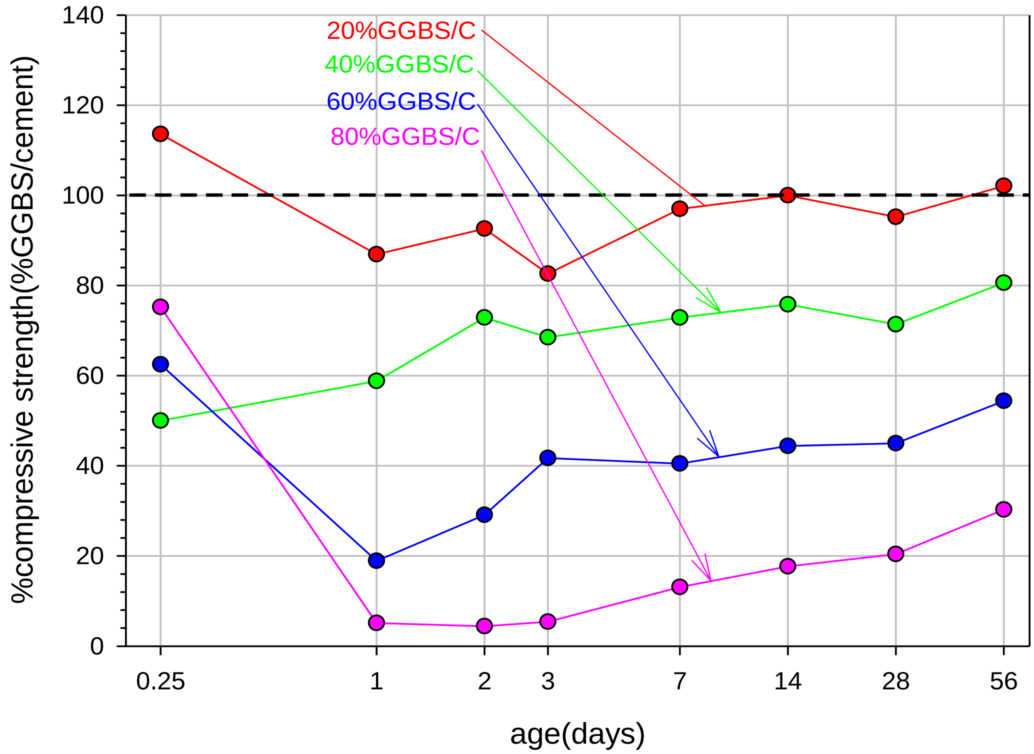

Figure 13. Percentage of compressive strength (% GGBS/cement)

GGBS contribution to concrete strength development:-

To evaluate the relative contribution of GGBS to strength development, the four concretes with different levels of GGBS and normal concrete were investigated. These concretes had the same mix design. The concrete specimens were kept in water curing condition and subjected to 20 ^{o}C temperature and the strength development measured at ages of 0.25, 1, 2, 3, 7, 14, 28 and 56 days. Based on the fact that when the ratio of (GGBS) increases the water cement ratio (W/C) increases that leads to decrease the compressive strength.

To calculate the water cement ratio, the weight of water and net cement is used only (without the weight of GGBS), for ratio of 60 and 80% GGBS according to specifications requirements add 10 Kg of cement to the total weight of cement and GGBS then subtract the weight of GGBS ratios are illustrated in table (5):-

Table 5. Calculation of water/cement ratio (W/C)

Ratio of GGBS	Wt of (cement + GGBS) (Kg)	Wt of GGBS (Kg)	Net Wt of cement (Kg)	Wt of water (Kg)	W/C ratio
0%	431.82	0	431.82	190	0.44
20%	431.82	86.4	345.42	190	0.55
40%	431.82	172.7	259.12	190	0.73
60%	441.82	265.1	176.72	190	1.08
80%	441.82	353.5	88.32	190	2.15

Table 6. Relationship between (W/C) and compressive strength

Ratio of (GGBS)	Water / cement ratio	Compressive strength (MPa)
0%	0.44	65.8
20%	0.55	62.5
40%	0.73	47
60%	1.08	29.7
80%	2.15	13.4

Table (6) and Figure (14) shown the relationship between water/cement ratio (W/C) and compressive strength at the age of 28 days:-

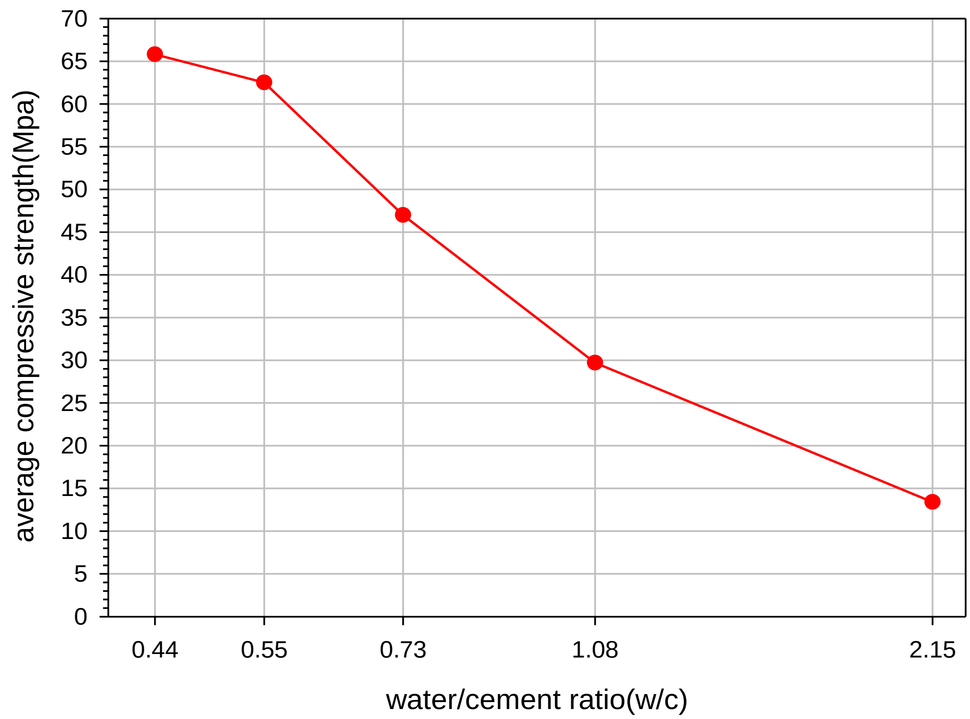

Figure 14 Relationship between water/cement ratio and compressive strength

5. Conclusion

The experimental results shows that, the increasing of the percentage of GGBS as cement replacement decreases the setting time. The compressive strength devolvement of 40, 60 and 80% GGBS concretes was lower than Portland cement concrete at early and later ages and as the percentage of GGBS increases the strength development decreases. For 20% GGBS concrete the compressive strength was almost the same as Portland cement concrete at early and later ages. GGBS brought from steel mills Misurata (Libya) could be used as one of the alternative material for the cement but not more than 20%.

Based on the experimental investigation Ground Granulated Blast furnace Slag collected from Steel Mills Misurata (Libya), is recommended to use as aggregate not as a binder component in cement manufacture.

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[20] ASTM C-187-86 American Standard Test Method for Normal consistency of cement
[21]- ASTM C-191-82 American Standard Test Method for Initial and final time of setting of cement

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