IJEIT
The International Journal of Engineering and Information Technology
journal homepage:www.ijeit.misuratau.edu.ly
MISURATA UNIVERSITY

The Performance of Concrete Containing Slag as a Partial Replacement for Cement

Farhat Abubaker
Department of Civil Engineering, Omar Al Mukhtar University,
El Beida, Libya
farhat.abubaker@omu.edu.ly

Hadria Ghanim
Department of Civil Engineering, Omar Al Mukhtar University,
El Beida, Libya
hadrea.ghanim@omu.edu.ly

Abstract— **There have been many attempts to examine ground granulated blast furnace slag (GGBS) as partial replacement for cement to improve concrete properties. However, there is a controversy about the proportion of replacement with claiming that a high replacement level might have a negative effect on concrete properties. In this experimental study, the effects of the partial replacement of cement with GGBS varied by 0%, 30%, 50%, and 70% of cement weight on the engineering properties of concrete with a (w/b) of 0.45 were investigated. Workability and setting time were used to evaluate the properties of fresh concrete. Compressive, flexural, and split tensile strength at various curing ages (7, 28, 56 and 90 days) are the mechanical properties of concrete being investigated. A porosity test is also performed at the ages of 7 and 28 days to assess the durability aspect of concrete. The main finding was that increasing the replacement level of GGBS increased the initial setting time, which improved the concrete workability. However, this resulted in a reduction in early strength in comparison to cement type I (CEM I) concrete. Moreover, the partial replacement with 50% GGBS increased the compressive, flexural and tensile strength of concrete at the age of 56 days, whereas partial replacement percentage of 70% GGBS resulted in a lower strength. as a result, the GGBS replacement percentage of 50% might be considered the optimum replacement value. Using a high volume of GGBS in concrete can result in a 40% reduction in concrete voids volume, increasing the resistance of concrete to chemical attack when exposed to severe environmental conditions.**

Index Terms: **GGBS, compressive strength; flexural strength, setting time, Workability, porosity.**

I. INTRODUCTION

Concrete is one of the most commonly utilised construction materials in the world due to its high strength, durability and low cost. In addition, the cement industry is the second most widely used material , in which the world's production of cement reached 4 billion tons. However, the production of cement causes a significant environmental impact, contributes to approximately 8% of total CO_2 gas emissions. This is due to the high energy processes involved in the production of Portland cement, which emits an average of 900 kg of carbon dioxide (CO_2) for every 1000 kg of cement [1-5].

Supplementary cementitious materials (SCM) has been used in the production of high performance concrete over the past four decades, with enhanced fresh and hardened properties. Moreover, the use of SCM has also reduced the consumption of cement in concrete. Therefore, the emissions of CO_2 into the atmosphere during the cement manufacturing are reduced [2,6]. This can be achieved by using pozzolanic materials such as fly ash, silica fumes, rice husk ashes and ground granulated blast furnace slag (GGBS) to partially replacement [6,7]. However, the dosage of these materials should be controlled, as an overdose might have a negative effect on concrete properties [8,9].

Ground granulated blast furnace slag (GGBFS) is available in large quantities and was first found in Germany in 1862. It was initially used in 1880 in combination with Portland cement. Ground granulated blast furnace slag (GGBFS) is a by-product produced during the blast furnace's iron production process, in which granular product are dried and grained to form a powder. The iron and steel industry waste powder is utilised to produce an economical cementitious material that has the potential as a sustainable material for concrete mixes. [2,10]. GGBS reacts with water and the reaction is considered to be slow. Essentially the hydraulicity of the slag is locked and activators should be used in order to release this reactivity. In practice activation is achieved by blending the GGBS with Portland cement as the latter contains both alkalis $Ca(OH)_2$ and NaOH. The rate of the chemical hydration reactions is influenced by the proportion of cement, temperature and chemical composition of both cement and GGBS [11].

Previous studies have used GGBS as a partial replacement for cement in various forms to develop high-strength and high-performance concrete. The authors reported that replacing up to 40% of the cement with slag results in a higher compressive and flexural strength than conventional concrete [12-15], while replacing up to 55% of the total binder results in an optimum compressive strength [9]. Raman and Krishnan [7] indicated that GGBFS can be used as a sustainable cement replacement material, as shown by the concrete compressive strength

Received 3 July, 2022; revised 8 Aug, 2022; accepted 19 Aug, 2022.

Available online 23 Aug , 2022.

increasing until a GGBS replaces 40% - 50% GGBFS of the cement weight. However, the use of GGBS in concrete reduces the strength for the first 28 days. Beyond 28 days, the strength increases with the presence of GGBS up to 60% replacement [16]. With regard to strength development, Portland cement has a higher compressive strength at 7 days and decreases as the amount of GGBS added increases. The average compressive strength obtained for all concrete qualities at 28 days was found to be relatively similar. The results also reveal that the compressive strength increases as the slag content increases [17].

According to Khatib and Hibbert [18], GGBS substitution up to 30% by mass showed higher splitting tensile strength than PC concrete. However, when the replacement level increased, the strength of PC concrete decreased for up to 21 days. Beyond 28 days, the strength increased for substitution up to 70% by mass.

Research conducted by Wang, et al [19] found that concrete made with GGBFS had better workability than concrete made with ordinary Portland cement or OPC, where the paste fluidity is increased.

The durability of GGBS concrete was also investigated by researchers [20-23]. It was revealed that concrete containing 70% GGBS showed good performance in terms of sulfate attack resistance. In addition, the effect of GGBS on controlling corrosion was also investigated by others [24-25]. The higher the GGBS content in concrete, the less chloride diffusion occurs and the longer the corrosion initiation time.

Although ground granulated blast furnace slag (GGBS) has been used as a partial replacement for cement to improve concrete performance, there has been a debate about the quantity of replacement, with some suggesting that a high replacement level might has a negative effect on concrete properties. The aim of this study is to investigate the fresh and mechanical properties of concrete with the various replacement levels of GGBFS the objective of finding an optimum replacement value. The Performance of concrete specimens containing (30%, 50%, 70%) GGBS was compared to specimens made with CEMI using water to binder ratios of (0.45). Workability and setting time tests were used to evaluate fresh properties, whereas compressive, flexural and split tensile strength were tested at various curing ages (7, 28, 56 and 90 days) to assess the hardened properties. A porosity test is carried out to assess the durability aspect of concrete at ages of 7 and 28 days.

II. EXPERIMENTAL WORK

A. Materials properties

In this study, GGBS concrete mixes were made of CEMI cement replaced with (0%, 30%,50%, 70%) GGBS. CEMI cement (42.5N) was used, manufactured by Helwan Company-Egyp and conformed to the requirements of BS EN 197-1:2011. The chemical compositions of the cement are given in Table (1). The ground granulated blastfurnace slag (GGBS) was obtained from Ash Sika Egypt for construction chemicals, and conformed to BS EN 15167-1:2006. The chemical composition of the cement is presented in Table (1).

Natural sand with an apparent specific gravity of 2.63 and an absorption of 0.5% was used. Crushed siliceous aggregate with a maximum size of (10 mm), was used, complying with BS EN 12620:2002+A1:2008.

Table 1. Chemical composition of CEMI and GGBS

Chemical Composition (%)	CEMI	**GGBS**
SiO_2	22.19	35.96
CaO	62.74	40.13
Al_2O_3	4.08	13.00
Fe_2O_3	3.16	0.67
Na_2O	0.2	0.5
K_2O	0.5	0.3
MgO	1.09	7.8
SO_3	3.1	0.05
LOI	**2.52**	**0.22**

B. Mix proportions

Mix design proportioning was performed by using the weight-batching method and was designed in accordance with the Building Research Establishment (British method). The proportioning of concrete mixtures is shown in Table 2. All mixtures were mixed in a laboratory pan mixer with a capacity of 56 liters. The mix ingredients placed in the mixer were in the following order; dry aggregates and cement were mixed in the mixer for 30 seconds, then water was added gradually in 15 seconds and the mixing continued for 2 minutes. Therefore, the total mixing time for each concrete mixture was 3 minutes. After mixing, a series of 100-mm cubes, cylinders(150 x300 mm) and prisms (100 x 100 x 500 mm) were cast in pre-oiled moulds and fully compacted using a vibration table and the top surface was leveled and finished by trowel.

Table 2. Proportions of concrete mixes (kg/m3)

MIX	**Mix Proportions (Kg/m^3)**				
	CEMI	**GGBS**	**w/b**	**Coarse Aggregate**	**Sand**
M-0	380	0	0.45	1215	780
M-30	266	114	0.45	1215	780
M-50	190	190	0.45	1215	780
M-70	114	266	0.45	1215	780

C. Curing of test specimenss

After casting, the specimens were covered with wet hessian and plastic sheets for the first 24 hours at laboratory temperature 20±2°C. After 24 hours, specimens were removed from the mould and kept in water curing at 20°C until the test age

D. Test Methods

The initial and final setting time of cement paste is to be determined according to BS EN 196-3:2005. The workability of freshly mixed concrete was measured by using a slump test according to BS EN 12350-2:2009.

Compressive strength test was performed on standard 100 mm cubes according to BS 1881: Part 116:1983. For the flexural strength test, prisms of 100x100x500 mm were used. Each prism was supported on a steel roller bearing near each end is loaded through similar steel bearings placed at the third points on the top surface according to BS EN 12390-5. The standard cylinder mould (150 x300 mm) used for the splitting tensile test and the test was performed according to BS 1881 part 117:1983. For each test, three specimens were tested at 7, 28, 56 and 90 days of water curing.

The porosity of concrete is measured by the volume of voids in concrete, and there are various techniques to find out the voids in concrete. For this study, the vacuum saturator equipment was used. Appropriate samples of 100 mm diameter by 50 mm long cylindrical specimens were tested per curing conditions at 7, 28 days. After their respective ages of curing, these samples were dried in an oven at the temperature of 70 ± 5°c for approximately 48 hours or until constant weight was reached. Thereafter, they were kept in dedicators for cooling before being subjected to a vacuum saturation test for about 24 hours. Samples were weighed after drying and recorded as (W_{dry}), before being placed in the vacuum device. The samples were weighed completely in water as submerging weight and recorded as (W_{sub}); after that, all of the samples were placed in the vacuum device until a saturation was obtained, then weighed and recorded as (W_{sat}).Then the porosity of concrete was calculated:

$$\text{Porosity}=\frac{(Wsat-Wdry)}{(Wsat-Wsub)} * 100 \qquad (1)$$

III. RESULTS AND DISCUSSION

A. Workability

Figure 1 illustrates the results of concrete workability with various GGBS replacements up to 70%. It was observed that the slump value increased as the replacement percentage of GGBS increases. The slump of CEMI - 0% GGBS was (90 mm), while the slump of mix made with 70% GGBS was 225 mm. According to Bhosale [20], concrete containing GGBS requires less energy for movement. This makes the concrete easier to place and compact, especially when pumping or mechanical vibration are used. It also retains its workability for longer time. Moreover, the differences in rheological behaviour between GGBS and Portland cement may enable a slight reduction in water content to achieve an equivalent consistency class.

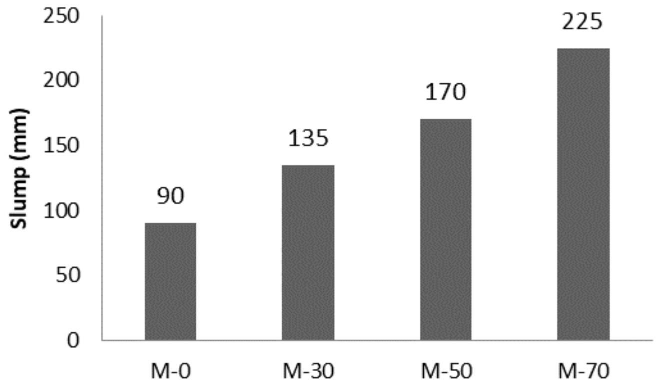

Figure. 1. Slump values of concrete made with different GGBS replacement percentage.

B. Stting time

Figure 2 shows the results of setting time. The general finding was that increasing the GGBS replacement amount increases the setting time. The initial setting time for CEM I concrete was 140 min, and it increased by (35, 55) min in concrete with 30% and 50% GGBS respectively. Additionally, the initial time extended by 100 min, reaching 240mins in concrete with 70% GGBS. Newman et al [11] stated that the initial setting time represents the length of time in which concrete remains workable. Therefore, the use of GGBS in concrete improves the workability of concrete. The final setting time for CEM I concrete was 260 min, while, final setting time for 70% GGBS concrete was 410 min for. This suggests that the concrete containing GGBS started developing strength or achieved early strength longer than the CEM I concrete.

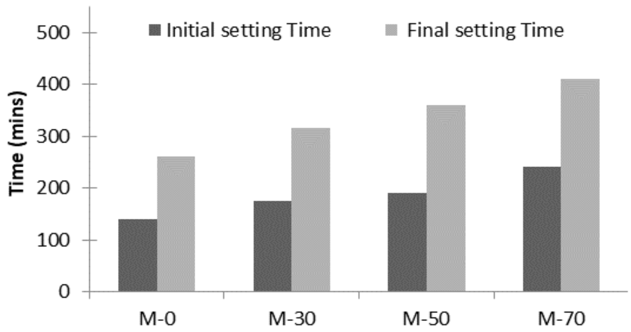

Figure. 2. Setting time of concretes made with different replacement levels of GGBS up to 90 days

C. Compressive strength

Figure 3 depicts the development of compressive concrete up to 90 days. The compressive strength of CEM I concrete was 24 MPa at 7 days, while it declined by 10%, 25% and 33% for M-30, M50 and M70 respectively. Therefore, using GGBS as a partial replacement material for cement causes a reduction in compressive strength at an early age. The compressive strength of concrete mixes with 30 % GGBS slightly lower than that for CEM I concrete at all ages. Furthermore, concrete containing 70% GGBS had the lowest compressive strength over the time, with a value of 37 Mpa after 90 days. However, at the age of 56 days, concrete with 50% GGBFS exceeded the value of compressive strength for CEMI concrete and reached a maximum value of 49 MPa at 90 days. It was also noticed that the optimum percentage of replacement is 50% GGBS. This is in agreement with previous investigations [6,9,7] which found that the optimum percentage of replacement of GGBS without affecting concrete compressive strength is 50%.

D. Flexural Strength

The results of flexure strength are shown in Figures 4. The flexural strength values gradually increase with the passage of time. The flexural strength values of concrete prepared with GGBS were lower at 7 days than those of a controlled specimen (CEM I concrete), which had the highest value of a high flexural strength (3.35 MPa). Additionally, at all ages, specimens with 30 % GGBS showed similar or slightly higher values. An obvious improvement in flexural strength was observed at the replacement level of 50% GGBS at 56 days and a maximum value of (6.4 MPa) was recorded at 90 days in comparison to (M-0, M-30 and M-70) concretes. As a result, the GGBS replacement percentage of 50% might be considered the optimum replacement value. However, increasing the replacement level of GGBS concrete causes a considerable decrease in flexural strength over time, up to 30% compared to M-30 and M50 concrete.

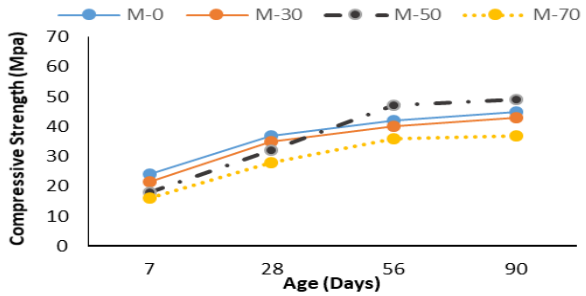

Figure. 3. Compressive Strength Development of concretes made with different replacement levels of silica fume up to 90 days

E. Splliting tensile strength

Figure 5 shows the tensile strength for the various GGBS substitution percentages. There was a decrease in early age strength, but it was less pronounced than compressive strength. In comparison with CEM I concrete, the tensile strength increases as the GGBS replacement level increases, with a maximum value of 4.25 MPa was measured for 50% GGBS at the age of 90 days. However, concrete containing 70% GGBS had the lowest tensile strength during all ages. This confirmed that Slag has higher tensile strength than CEM I [5, 8], and the tensile strength resistance of concrete could be improved by increasing the amount of GGBS content up to 50%.

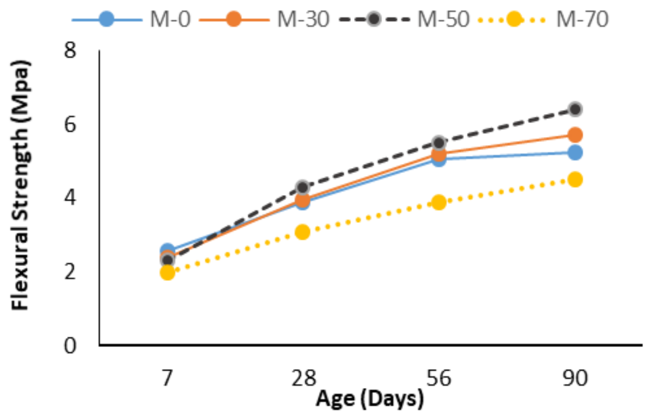

Figure. 4. Flexural Strength of concretes made with different replacement levels of silica fume up to 90 days

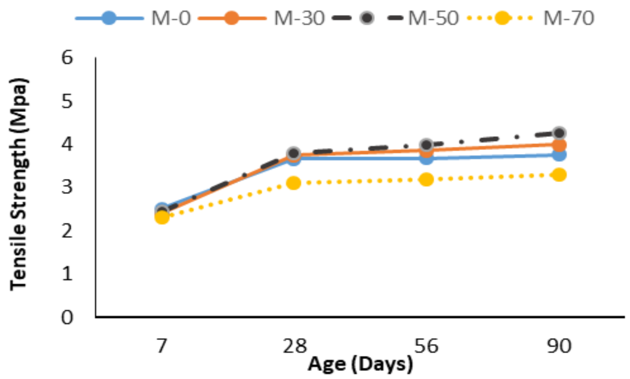

Figure. 5. Tensile Strength Development of concretes made with different replacement levels of silica fume up to 90 days

F. Porosity

The results of the porosity of concrete with varying GGBS content are shown in Figure 6. The porosity of all the concrete mixes reduces with age. The porosity of concrete increases as the GGBS replacement level increases at the age of 7 days. However, at the age of 28 days, it reduced as the GGBS content increased. The lowest porosity value of 6% was obtained for concrete made with 70% GGBS compared to a value of 10% for CEM- I concrete at 28 days, indicating that a high volume of GGBS in concrete may result in a reduction of about 40% in concrete voids volume. The hydration process has reduced the pores in the concrete matrix when the concrete reaches the age of 28 days. The reduction in permeable voids of concrete results in a greater concrete resistance against chemical attack when exposed to extreme environmental conditions [25,26].

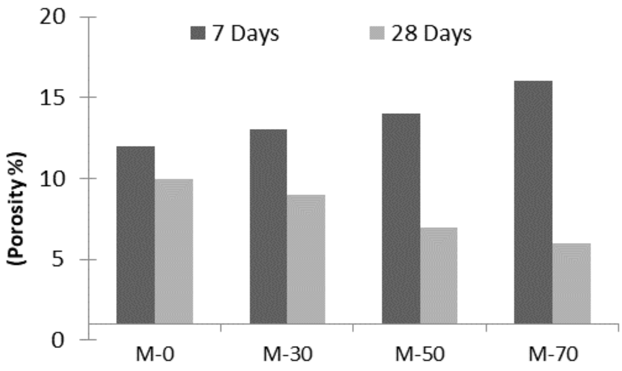

Figure. 6. Porosity values of concrete made with different GGBS replacement percentage.

IV. CONCLUSIONS

This study focuses on the effect of GGBS as a partial replacement on concrete performance. Based on the obtained results, the following are the important findings and conclusions:

- The setting time increases as the replacement level of GGBS increases. This suggests that the concrete containing GGBS achieved early strength longer than the CEM I concrete.
- The use of high content of GGBS improves concrete workability of concrete and a reduce the water demand.
- Early age strength is affected by the addition of GGBS. However, the compressive strength increased with age, with a maximum value recorded at 56 days after a partial replacement with 50% GGBS.
- Flexural strength increased gradually with the passage time, with the highest value at a replacement level of 50% GGBS.
- The tensile strength of GGBS concrete increased as the amount of GGBS content increased up to 50%.
- The pore volume of concrete was reduced as GGBFS content increased, which significantly improves its durability against severe environmental exposure.
- The GGBS replacement percentage of 50% might be considered the optimum replacement amount for improving the mechanical properties of concrete.

ACKNOWLEDMENTS

The authors would like to thank civil engineering laboratory staff at Omar Al-Mukhtar University, Mr. MOHAMAD ABDALWAHAB for their helps throughout the experimental part of this study.

REFRENCES

[1] R A T Cahyaniy and Y Rusdianto, (2020) Concrete Performance with Ground Granulated Blast Furnace Slag as Supplementary Cementitious Materials. 2nd International Conference on Engineering and Applied Sciences: IOP Conf. Series: Materials Science and Engineering 771:1-6.

[2] R. Vinai et al., (2015) Sustainable binders for concrete: A structured approach from waste screening to binder composition development. Heron Journal, 60(1–2):27–57.

[3] Alaa M R, Hosam El-Din H S and Amir F S, (2014). Effect of silica fume and slag on compressive strength and abrasion resistance of HVFA concrete. *Int. J. Concr. Struct. Mater*. 8(1): 69–81.

[4] Barnett S J, Soutsos M N, Millard S G and Bungey J H, (2006). Strength development of mortars containing ground granulated blast-furnace slag: effect of curing temperature and determination of apparent activation energies. *Cement Concrete Research*. 36: 434–440.

[5] Xiang Ming Zhou, Joel R. Slater, Stuart E. Wavell, Olayinka Oladiran, (2012). Effects of PFA and GGBS on Early-Ages Engineering Properties of Portland Cement Systems, *Journal of Advanced Concrete Technology*. 10(2): 74-85.

[6] Ganesh Babu, V Sree Rama Kumar, (2000). Efficiency of GGBS in concrete. *Cement and Concrete Research*. 30(7): 1031-1036.

[7] J. V. M. Raman and V. M. Krishnan, (2017). Partial Replacement of Cement with GGBS in Self Compacting Concrete for Sustainable Construction. *Int. J. Civ. Eng*. 4(3):24–28.

[8] G. Turu'allo and M. Soutsos,(2014). Sustainable Concrete with The Use of GGBS: The Maturity Method for Predicting Strength Development of Concrete, International Conference on Environmentally Friendly Civil Engineering Construction and Materials, pp. 223–232.

[9] R. Rughooputh and J. Rana, (2014). Partial Replacement of Cement by Ground Granulated Blast Furnace Slag in Concrete h, *J. Emerg. Trends Eng. Appl. Sci*. 5(5): 340–343.

[10]. Megat Johari, M.A., Brooks, J.J., Kabir, S.and Rivard, P., (2011). Influence of supplementary cementitious materials on engineering properties of high strength concrete. *Construction Building Materials*, 25(5):.2639–2648.

[11] Newman, J. and Choo, B.S. eds., (2003). Advanced concrete technology 2: Constituent Materials. Butterworth-Heinemann.

[12] Oner and S. Akyuz, (2007). An experimental study on optimum usage of GGBS for the compressive strength of concrete, *Cement & Concrete Composites*, 29(6):505-514.

[13] S.E. Chidiac and D.K. Panesar,(2008). Evolution of mechanical properties of concrete containing ground granulated blast furnace slag and effects on the scaling resistance test at 28 days, *Cement & Concrete Composites*, 30: 63–71.

[14] Susanto Teng, Tze Yang Darren Lim and Bahador Sabet Divsholi,(2013). Durability and mechanical properties of high strength concrete incorporating ultra-fine Ground Granulated Blast-furnace Slag, *Construction and Building Materials*, 40:875–881.

[15] Raghavendra Y B, Ramalinga Reddy Y, Nabil Hossiney & Dinesh H T, Sanjay Kumar Shukla, (2021). Properties of high strength concrete with reduced amount of Portland cement– a case study, *Cogent Engineering, 8(1):1-15.*

[16] Hans Beushausen, Mark Alexander, Yunus Ballim,(2012). Early-age properties, strength development and heat of hydration of concrete containing various South African slags at different replacement ratios. *Construction and Building Materials*, 29: 533-540.

[17] Siddique R and Deepinder K, (2012). Properties of concrete containing ground granulated blast furnace slag (GGBS) at elevated temperatures. *J. Adv. Res*. 3: 45–51.

[18] J.M. Khatib, J.J. Hibbert,(2005). Selected engineering properties of concrete incorporating slag and metakaolin. *Construction and Building Materials*, 19(6): Pages 460-472.

[19] L. Wang, P. Tian, and Y. Yao, (2007). Application of ground granulated blast furnace slag in high performance concrete in China. *Proc. Int. Work. Sustain. Dev. Concr. Technol*: 309–317.

[20] Ashwini T Bhosale, (2017). Ground Granulated Blast Furnace Slag Concrete. *International Journal for Research in Engineering Application & Management*. 2(10): 47-51.

[21] Barnett, S.1., Halliwell, M.A., Crammond, N.1., Adam, C.D. and Jackson, A. R. W, (2002). Study of thaumasite and ettringite phases formed in sulfate blast furnace slag slurries using XRD full pattern fitting. *Cement and Concrete Composites*, 24, (4):339-346.

[22] Higgins, D.D. and Crammond, N.J. (2003). Resistance of concrete containing GGBS to the thaumasite form of sulfate attack. *Cement and Concrete Composites*, 25(8):921-929.

[23] Tsivilis,S., Kakali, A., Skaropolou, A., Sharp, J.H. and Swamy, R.N, (2003) Use of mineral admixtures to prevent thaumasite formation in limestone cement mortar. *Cement and Concrete Composites,* 25(8):969-976.

[24] M. Hulusi Ozkul., Unal Anil Dogan., Ali Raif Saglam., Nazmiye Parlak,(2008) Corrosion Resistance of GGBS Concrete. 11th International Conference on Durability of Building Materials and Components. 11-14 May. Istanbul Turkey.

[25] A. Krishnamoorthy and R. Aswini,(2015). Strength and Corrosion Resistance Properties of Gbgs Concrete Containing Dust as Fine Aggregate. *International Journal of Structural and Civil Engineering Research*.4(2):175-177.

[26] Abubaker F., Lynsdale, C.J. and Cripps, J.C. (2014) Laboratory Study of the Long-Term Durability of Buried Concrete Exposed to Lower Lias Clay. *Construction and Building Materials*, 64:120-130.