The Development of a New Cementitious Material Produced from Cement and GGBS

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Abstract

The aim of this research is to study the effect of using Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement to Ordinary Portland Cement (OPC) and produce a more environmentally friendly cementitious material with comparable compressive strength to OPC. Six mixes were prepared with different percentages of GGBS replacement 0%, 10%, 20%, 30%, 40% and 50% of the weight of OPC. The compressive strength with ages of 7 and 28 days was used for evaluating the performance of the tested specimens in comparison to the control mix with (0% GGBS). The results demonstrated that the compressive strength at the age of 7 days for the mixes with 10% and 20% GGBS were higher than the control mix by 2% and 4%, respectively. However, the addition of 30%, 40% and 50% caused a reduction in the compressive strength relative to control mix by 3.6%, 12.7% and 15.6%, respectively. Interestingly, all the mixes containing GGBS provided higher compressive strength in comparison to the control mix at the age of 28 days. This means that increasing the period of curing for mixes containing GGBS can improve the compressive strength. At 50%, GGBS substitution the strength of mortar was better than the strength of control mix at 28 days. In this study, the optimum replacement of OPC by GGBS was considered to be 50%. Such replacement will contribute to reduce the CO_2 emissions (carbon footprint) and at the same time provide better compressive strength at suitable curing times.

Keywords: Cementitious material, compressive strength, GGBS and OPC.

Introduction

Cement based concrete is the most used construction material worldwide with production of about 10 billion tonnes per year in modern industrial society (Aprianti, 2017). It is estimated that the use of concrete as a construction material is about double the total of all other construction materials such as steel, wood, etc. (Mcleod, 2005). This is because concrete is versatile and has many desirable characteristics such as strength, high fire resistance, affordability and it can be moulded in to any shape (Aprianti, et al., 2015). The annual consumption of cement worldwide is about 2.9 billion tonnes and due to the rapid development in the construction industry worldwide, therefore inevitably there will be an increase in the production of cement that is expected to be about 5% annually (Karim, et al., 2013) and (Jafer, et al., 2015).

The production of cement is responsible for almost 6-8% of all the CO_2 emissions worldwide (Hawileh, et al., 2017). This is because the production of one tonne of cement is associated with nearly one-tonne CO_2 emissions into the atmosphere (Aprianti, 2017). This fact put the cement industry as the third largest producer of Greenhouse gases after the sectors of transportation and energy generation (Mcleod, 2005). Therefore, in order to comply with the Kyoto Protocol to reduce the CO_2 emissions, many studies have been carried out for investigating the effectiveness of other viable alternative cementitious materials such as by-products or waste materials from different resources to be used as cement replacement and produce new environmentally friendly cementitious materials (Aprianti, et al., 2015).

One of the known viable alternative materials to OPC in different applications, such as concrete production and soil stabilization is Ground Granulated Blast Furnace Slag (GGBS). GGBS is a by-product material of iron or steel that is extracted from blast furnaces in water or steam, in order to produce granular particles that are then dried and ground in a rotating ball-mill into a very fine powder of GGBS (Grist, et al., 2015).

An investigation has been carried out by Hawileh, et al., (2017) to evaluate the effect of using GGBS as a partial replacement to OPC in reinforced concrete (RC) beams. The results indicated that the RC beams with up to 70% GGBS replacement to OPC have similar performance in comparison to the control beam with (0% GGBS) in terms of both compressive and tensile strengths. In addition, an experimental study on the replacement of OPC with GGBS in concrete has been conducted by Mangamma, et al., (2016) by using two types of concrete (M20 and M30). The results demonstrated that the replacement of OPC by up to 50% GGBS were generally close to the results of the normal mix and the maximum compressive strength was achieved by the 30% replacement. Furthermore, Oner & Akyuz (2007) have carried out an experimental study to determine the optimum dosage of GGBS as partial replacement to OPC in concrete production that provided the best compressive strength when comparing to the control mix. The results showed that the concretes with different percentages of replacement to OPC have lower early strength relative to the control concretes having the same binder content. However, with increasing curing period, the compressive strength for the GGBS concretes were improved with increasing the GGBS content up 59%. Furthermore, the optimum level of GGBS concrete that provided the highest compressive strength in comparison to the control concrete was 55%.

This paper presents the results of experimental work to investigate the utilization of GGBS as partial replacement to OPC on compressive strength. The replacements of GGBS were (0%, 10%, 20%, 30%, 40% and 50%) by the weight of OPC, and the compressive strength for ages of 7 and 28 days were used for assessing the performance of the Binary Blended Cementitious Material (BBCM) mortar cubes in comparison to the control mix (0% GGBS).

Materials

Sand

The sand used is this experimental study was building sand passing through 3.35 mm IS sieve. Table 1 below shows the physical properties of the sand.

Table 1. The physical properties of the sand

Property	Value
Maximum size of the smallest 10% of the	0.12 mm
Maximum size of the smallest 10% of the	0.19 mm
Maximum size of the smallest 10% of the	0.28 mm
Uniformly coefficient (C_u)	2.33
Coefficient of curvature (C_c)	1.07
Saturated Surface Dry	2.62 kg/m3
Classification of sand	Uniformly graded sand
Max Water Absorption	2.8% WA

From the coefficient of uniformity (Cu), coefficient of curvature (Cc) and the particle size distribution chart showing in Figure 1, the sand that has been used in the mix of the mortars can be classified as uniformly graded sand. Uniformly graded sand means that it consists of particles that are all about the same size and it has more void spaces between the particles (Ahmed, 2014).

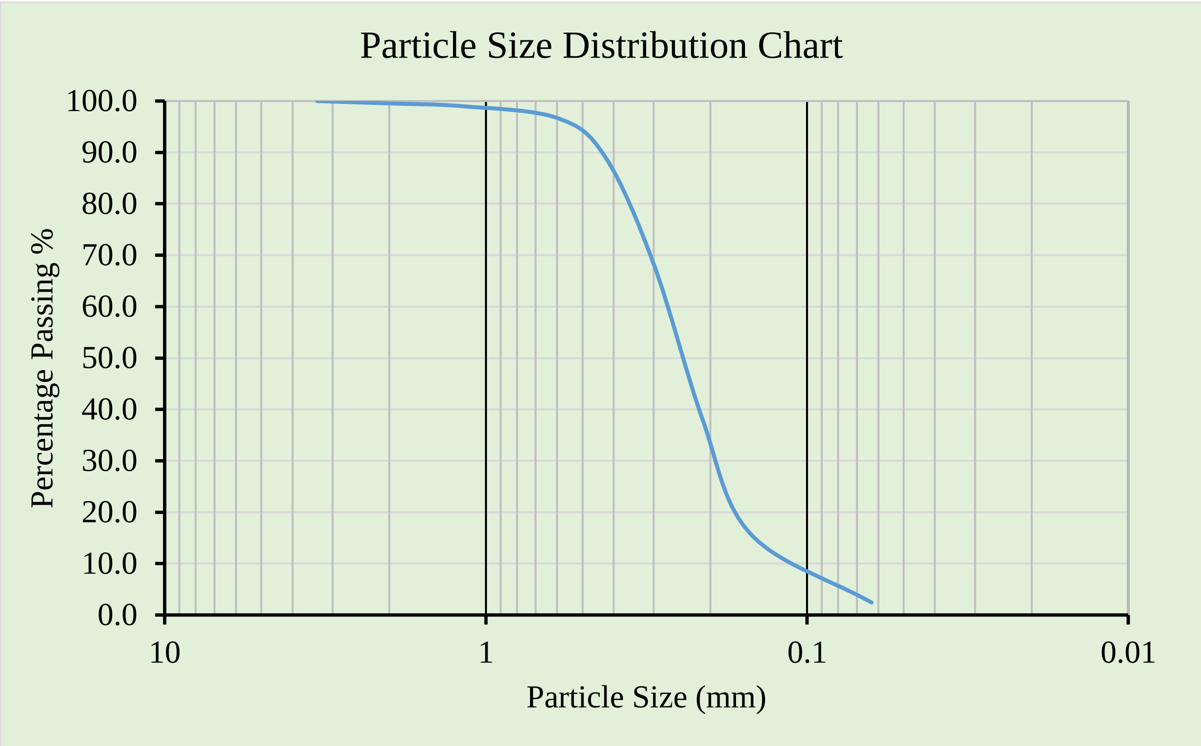


Figure 1. Particle size distribution chart of sand

Cement

The cement used in this study was Ordinary Portland Cement type CEM-II/A/LL 32.5-N. This cement was supplied by CEMEX, Warwichshire, UK. The specific gravity of OPC is 2.936 kg/m^3.

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product material of iron or steel that extracted from blast furnaces. Hanson Heidelberg Cement Group supplied the GGBS for this research. The specific gravity of GGBS is 2.9 kg/m^3, and it complies with BS EN 15167-1 standards as provided by the supplier.

Mixing, casting and curing of specimens

1. Prepare all the material needed for the mortar mix, this starts with weighing the sand, the cement, the GGBS and the water.
2. Initially, all the materials of the mortar except the water were mixed together for about 2 minutes, and then the water was added to the mix and the paste mixed until uniform prior to placing in the mould.
3. Then the mortars were cast inside the steel prism moulds with dimensions of (160mm x 40mm x 40mm) and compacted by tamping rod according to (BS EN 1015-11: 2007), which requires the casting to be in two layers with compaction of 25 tamps for each layer.
4. The mortar prisms were demoulded after 24 hours from the start of the casting process and the samples were placed in small containers for curing until the time of testing.

Method of testing

At the time of testing, the mortars with dimensions of (160mm x 40mm x 40mm) were cut into three equal smaller prisms. Two steel plates with dimensions of (40mm x 40mm) were placed on the top and bottom of the mortar cubes, in order to make the surface exposed to load with the dimensions of (40mm x 40mm) to correspond the dimensions of mortar cubes and the testing machine set according to BS EN 1015-11: 2007. The rate of loading for the compressive testing machine was (0.4 MPa/s). Three mortar cubes for each percentage of replacement (0%, 10%, 20%, 30%, 40% and 50%) were tested on each day of curing and an average obtained giving an idea of the potential quality of the new cementitious material to be used instead of cement.

Mix proportions

Ten mixtures were prepared that contained GGBS as a replacement to cement. The replacement of GGBS were (0%, 10%, 20%, 30%, 40% and 50%) of the weight of OPC. The compressive strength at ages of 7 and 28 days have been used for evaluating the performance of the BBCM mortar cubs in comparison to the control mix with (0% GGBS). The water to binder ratio (W/B) and the binder to sand ratio (B/S) that have been used for this study were (0.4) and (1:2.5) respectively. Table 2 shows the mix proportions for all the specimens.

Table 2. Mix proportions

MIX	OPC	GGBS
G0	100%	0%
G10	90%	10%
G20	80%	20%
G30	70%	30%
G40	60%	40%
G50	50%	50%

Results and Discussion

Physical Properties

Two tests were carried out to investigate the physical properties of the OPC and GGBS, which they are:

1) **Particle Size Distribution (PSD)**

PSD test is an important physical test that provided information about the fineness of the materials. Figure 2 shows the PSD of the OPC and GGBS as obtained from the laser particle size analyser.

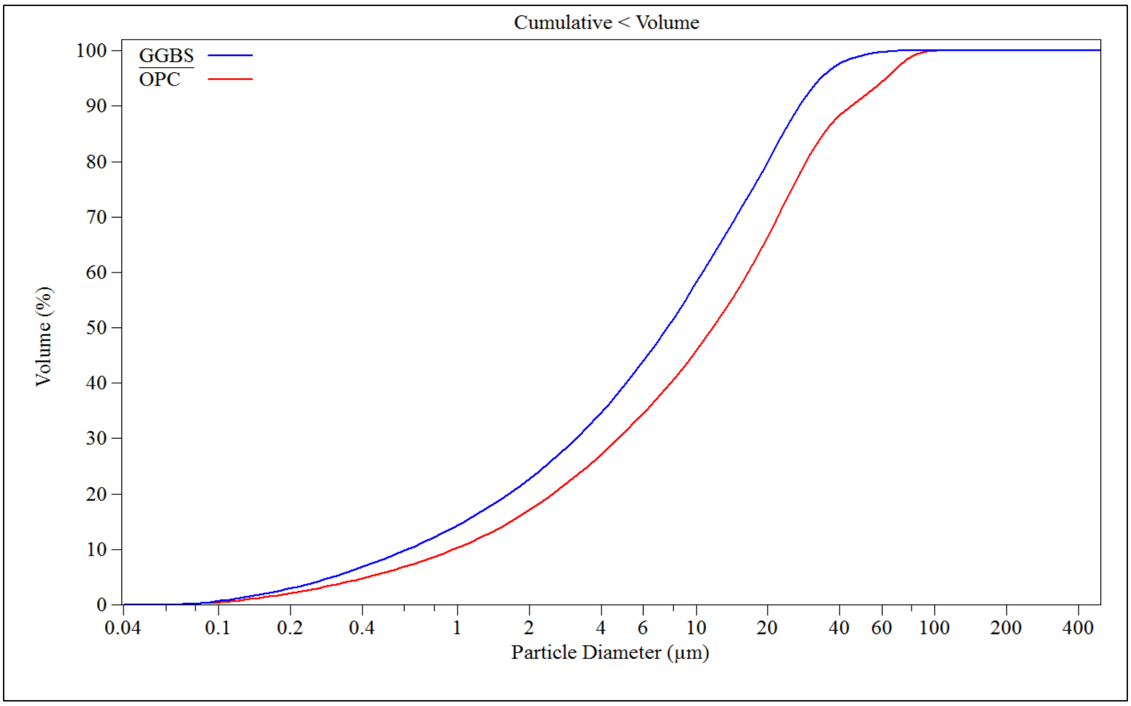


Figure 2. Cumulative particle size distribution of OPC and GGBS

In addition, Table 3 shows the differences in d_{10}, d_{50}, and d_{90} for the GGBS in comparison to OPC.

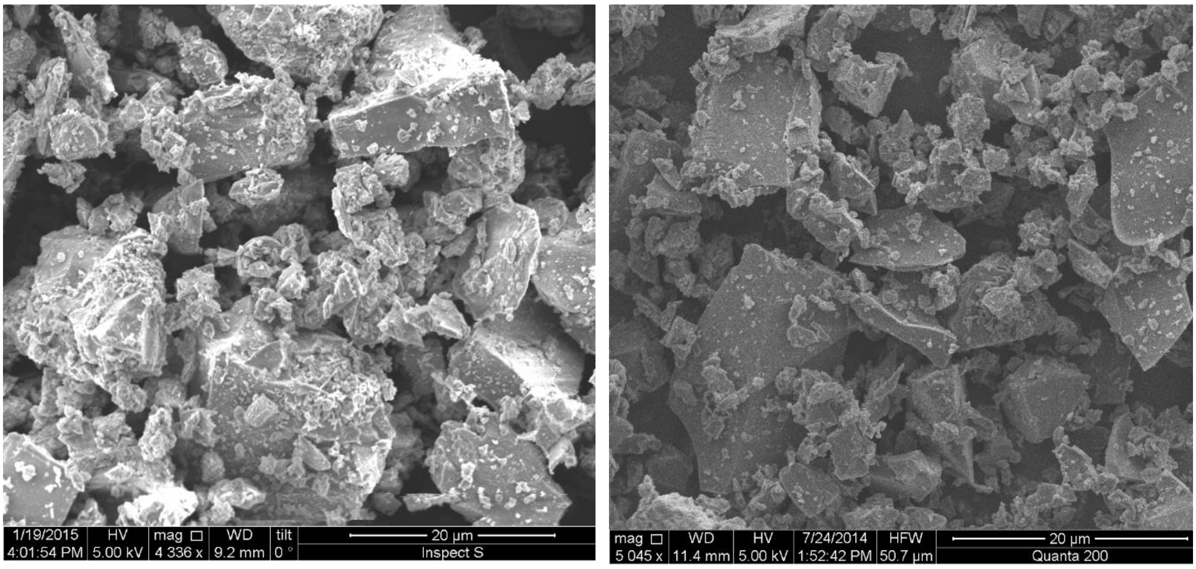
Table 3. Volume statistics for OPC and GGBS

Item	OPC	GGBS
d_{10} (µm)	0.936	0.62
D_{50} (µm)	13.08	7.542
D_{90} (µm)	54.29	27.96
Mean (µm)	21.10	11.55
Median (µm)	13.08	7.542

The particle size distribution and the specific surface area (SSA) of OPC and GGBS have a significant effect on the compressive strength of the mortars. Celik, et al., (2008) found that the finer the particles of waste materials used as partial replacement to cement in concrete production, the higher compressive strength obtained. It can be seen from the particle size distribution chart in Figure 2 that GGBS has finer particle size relative to OPC. This means that the GGBS has a higher pozzolanic reactivity than the OPC as it has a higher SSA (ZHAO, et al., 2016).

2) Scanning electronic microscopy test (SEM)

The SEM test was carried out on the GGBS and OPC to realise the general shape of material particles that would help in anticipating the behaviour of these two materials when they were mixed to produce a binary blended cementitious material. Figures 3 a and b illustrate SEM testing images of the binder materials. From the SEM test results, it can be seen that both the OPC and GGBS have angular and flaky shape and the GGBS material particles are finer than the OPC, which agreed with the PSD tests.



(a) OPC (b) GGBS

Figure 3. SEM test images of the binder materials

Chemical Properties

Three tests were conducted to indicate the chemical properties of the OPC and GGBS, which they are:

1) pH value

Solutions of dried and pulverised OPC with water and GGBS with water were made to find the pH value of both OPC and GGBS. This method of measuring the pH is according to BS ISO 10390:2005. The results of the pH value for OPC and GGBS were 13.04 and 11.65 respectively.

2) Loss of Ignition (LOI)

The loss of ignition is a method to find the content of the organic matter in materials; the adopted procedure is described in BS 7755-3.8:1995. The obtained values for the LOI were 0.28 % for OPC and 0.373 for GGBS.

3) X-Ray Florescence Spectrometry (XRF)

The elemental composition of OPC and GGBS were analysed by the energy dispersive X-ray florescence spectrometer apparatus (EDXRF). This test evaluates the major oxide and trace elements for both OPC and GGBS by providing the chemical composition, which is considered as the most important indicator for material quality in different applications. Table 4 below shows the chemical properties for OPC and GGBS.

Table 4. Chemical properties for OPC and GGBS

Item	OPC	GGBS
CaO %	65.108	42.506
SiO_2 %	24.783	41.060
Al_2O_3 %	1.716	5.105
Fe_2O_3 %	1.628	…….
MgO %	1.322	4.248
Na_2O %	1.337	3.093
K_2O %	0.811	0.685
SO_3 %	2.542	1.271
TiO_2 %	0.342	0.976
SrO %	0.116	0.086
CuO %	0.014	……
MnO %	0.039	0.655
P_2O_5 %	0.242	0.270
Cl^-	0.040	0.044

Compressive Strength

The compressive strengths of the mortars for different percentage combinations of OPC and GGBS with different curing ages are shown in Table 5.

Table 5. Compressive strength for 7 and 28 days

MIX	OPC	GGBS	7 days (MPa)	28 days (MPa)
G0	100%	0%	27.5	29.1
G10	90%	10%	28.0	29.3
G20	80%	20%	28.6	31.6
G30	70%	30%	26.5	32.1
G40	60%	40%	24.0	31.0
G50	50%	50%	23.2	30.0

The compressive strength at 7 days for different percentages of the combination of GGBS and OPC is also expressed graphically in Figure 4.

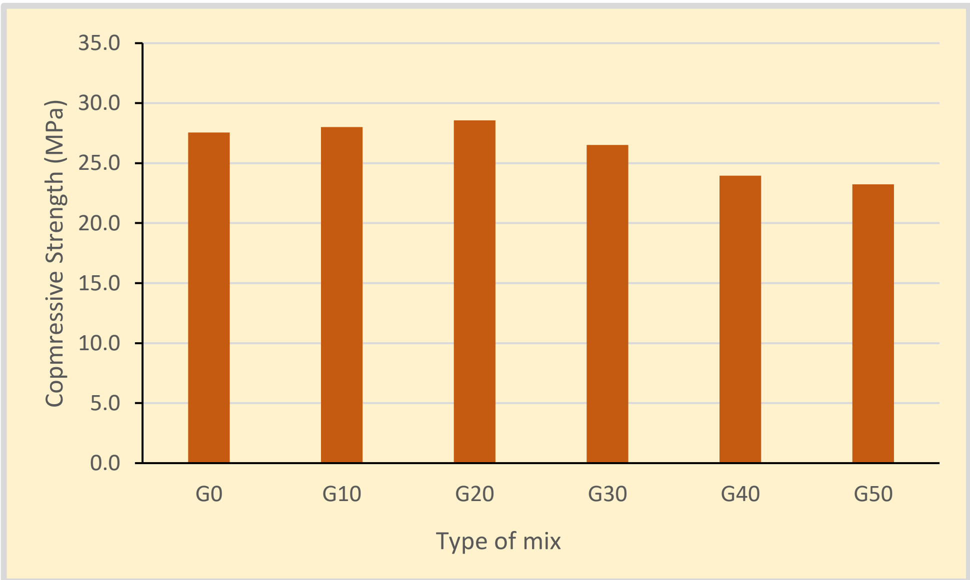


Figure 4. The effect of GGBS on compressive strength at 7 days

It can be seen from the bar chart above (Fig, 4) that at the age of 7 days, only G10 and G20 showed an increment in the compressive strength by about 2% for G10 and 4% for G20 in comparison with the control mortar with 0% GGBS. However, the addition of 30% GGBS caused a reduction in the compressive strength by about 3.6%. Furthermore, the replacement of OPC by 40% and 50% GGBS, resulted in a significant decrease in compressive strength, with reduction of between 12.7% and 15.6% for G40 and G50, respectively. This is not in agreement with what has been obtained by (Kumar, 2013), which found that at the age of 7 days increasing the amount of GGBS as replacement to OPC can enhance the compressive strength. This however may be caused due to the slow acquisition of strength at initial curing ages for the mixes contain more than 30% GGBS.

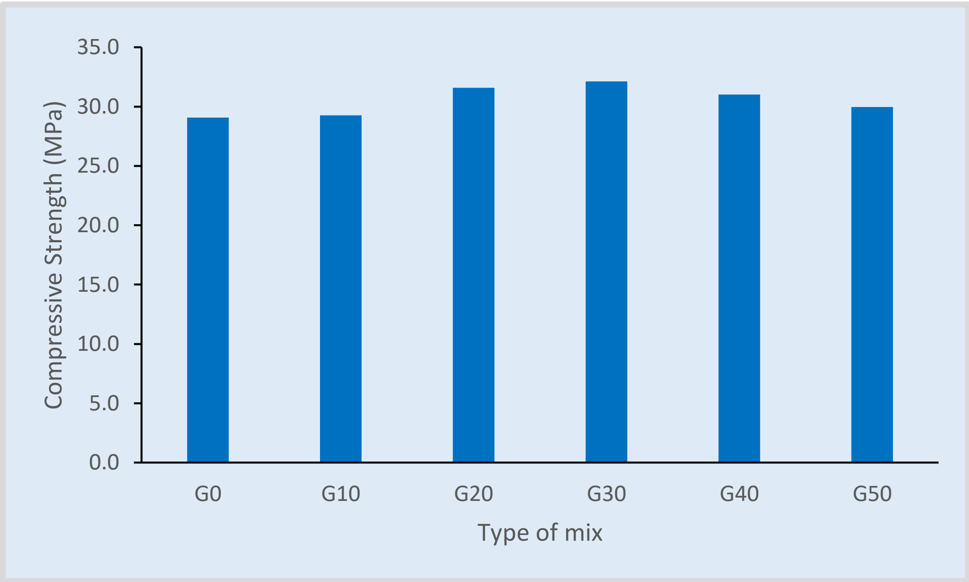


Figure 5. Effect of GGBS on compressive strength at 28 days

A glance at the bar chart above (Fig. 5) reveals that at the age of 28 days, the compressive strength increased 0.7, 8.6, 10.3, 6.5 and 3.1% for mixes G10, G20, G30, G40 and G50, respectively when compared to the control mix. This means that at the age of 28 days, the presence of GGBS in the mixes have improved the compressive strength for all the mixes in comparison to the control mix. This agreed with the findings concluded by (Mangamma, et al., 2016) and (Cheng, et al., 2005).

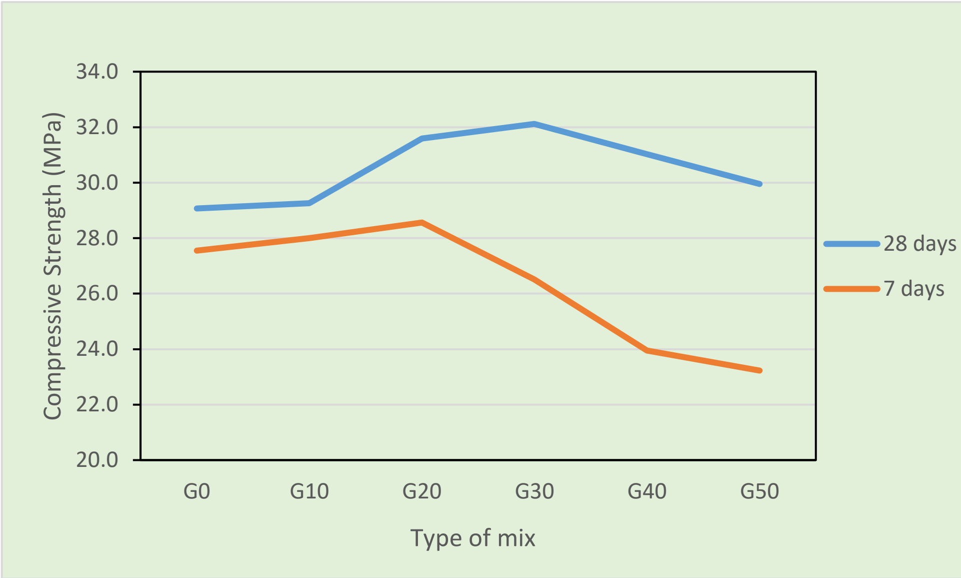


Figure 6. Compressive Strength Development Curves

From the results shown in Figure 6, it can be seen that the compressive strength of all the mixes increased with age. With increase in age from 7 to 28 days, increase in compressive strength of mixes G10, G20, G30, G40 and G50 was observed to be 4.6, 10.5, 21.1, 29.2 and 29.3% respectively. A comparative study of compressive strength between 7 and 28 days indicated that percentage of increase is less in control mix in comparison to all other mixes containing GGBS except G10. In addition, test results indicated that the inclusion of GGBS enhanced the compressive strength with increasing the age of curing. This performance can be attributed to the glassy phase of GGBS that reacts slowly with water and takes time to gain the hydroxyl ions from the hydration product of OPC to breakdown the glassy phase at early age. At 50%, GGBS substitution, the strength of mortar was superior to the strength of control mix at 28 days. So the maximum replacement of OPC by GGBS was considered to be 50% in this study.

Conclusion

The aim of this study was to investigate the effect of using GGBS as a partial replacement to OPC and to produce a more environmentally friendly cementitious material with comparable compressive strength to OPC. According to the results of the experimental investigations, it can conclude that:

- Mortar containing GGBS is significantly affected by the age of curing. Curing for more than 7 days is crucial for the strength development of the mortars containing GGBS.
- At the age of 7 days, only the mortars with 10% and 20% GGBS have shown improvement in the compressive strength relative to the control mix. However, the mortars with 30%, 40% and 50% GGBS have caused a reduction in the compressive strength in comparison to the control mix. This can be due to the slow pozzolonic reaction for mortars with high percentage of GGBS and largely dependent on the formation of calcium hydroxide that requires time.
- At the age of 28 days, all the mixes that containing GGBS showed higher compressive strength in comparison to the control mix.
- At 50%, GGBS substitution, the strength of mortar was higher than the strength of control mix at 28 days. So the maximum replacement of OPC by GGBS was considered to be 50% in this study.

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References

Ahmed, S. S., 2014. *Soil Mechanics & Foundation.* [Online]
Available at: http://faculty.mu.edu.sa/public/uploads/1392381352.9635Sheet2-ce210.pdf
[Accessed 1 April 2016].

Aprianti, E., 2017. A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production e a review part II. *Construction and Building Materials,* Volume 142, pp. 4178-4194.

Aprianti, E., Shafigh, P., Bahri, S. & Farahani, J. N., 2015. Supplementary cementitious materials origin from agricultural wastes – A review. *Construction and Building Materials,* Volume 74, p. 176–187.

Celik, O., Damci, E. & Paskin, S., 2008. Characterisation of fly ash and its effect on the compressive strength properties of portland cement. *Indian Journal of Engineering & Materials Science ,* 15(5), pp. 433-440.

Cheng, A., Huang, R., Wu, J.-K. & Chen, C.-H., 2005. Influence of GGBS on durability and corrosion behavior of reinforced concrete. *Materials Chemistry and Physics,* Volume 93, pp. 404-411.

Grist, E. R. et al., 2015. The environmental credentials of hydraulic lime-pozzolan concretes. *Journal of Cleaner Production,* Volume 93, pp. 26-37.

Hawileh, R. A. et al., 2017. Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement. *Archives Civil and Mechanical Engineering ,* Volume 17, pp. 511-519.

Jafer, H. M., Atherton, W., Ruddock, F. & Loffil, E., 2015. Assessing the Potential of a Waste Material for Cement Replacement and the Effect of Its Fineness in Soft Soil Stabilisation. *World Academy of Science, Engineering and Technology,* 9(8), pp. 894-900.

Karim, M., Zain, M., Jamil, M. & Lai, F., 2013. Fabrication of a non-cement binder using slag, palm oil fuel ash and rice husk ash with sodium hydroxide. *Construction and Building Materials,* Volume 49, p. 894–902.

Kumar, Y. H., 2013. Studies on Strength Characteristics of GGBS Based Concrete. *International Journal of Applied Sciences, Engineering and Management,* 2(1), pp. 29-31.

Mangamma, babu, D. N. & G.Hymavathi, 2016. An Experimental Study on Behavior of Partial Replacement of Cement with Ground Granulated Blast Furnace Slag. *Int. Journal of Engineering Research and Application,* 6(12), pp. 01-04.

Mcleod, R. S., 2005. *Newbuilder.* [Online]
Available at: http://www.uaecement.com/articles/ordinary_portland_cement.pdf
[Accessed 22 3 2017].

Oner, A. & Akyuz, S., 2007 . An experimental study on optimum usage of GGBS for the compressive strength of concrete. *Cement & Concrete Composites,* Volume 29, pp. 505-514.

ZHAO, J. et al., 2016. Particle characteristics and hydration activity of ground granulated blast furnace slag powder containing industrial crude glycerol-based grinding aids. *Construction and Building Materials,* Volume 104, pp. 134-141.