International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:11, No:7, 2017

The Development of a Low Carbon Cementitious Material Produced from Cement, Ground Granulated Blast Furnace Slag and High Calcium Fly Ash

Ali Shubbar, Hassnen M. Jafer, Anmar Dulaimi, William Atherton, Ali Al-Rifaie

***Abstract*—**This research represents experimental work for investigation of the influence of utilising Ground Granulated Blast Furnace Slag (GGBS) and High Calcium Fly Ash (HCFA) as a partial replacement for Ordinary Portland Cement (OPC) and produce a low carbon cementitious material with comparable compressive strength to OPC. Firstly, GGBS was used as a partial replacement to OPC to produce a binary blended cementitious material (BBCM); the replacements were 0, 10, 15, 20, 25, 30, 35, 40, 45 and 50% by the dry mass of OPC. The optimum BBCM was mixed with HCFA to produce a ternary blended cementitious material (TBCM). The replacements were 0, 10, 15, 20, 25, 30, 35, 40, 45 and 50% by the dry mass of BBCM. The compressive strength at ages of 7 and 28 days was utilised for assessing the performance of the test specimens in comparison to the reference mixture using 100% OPC as a binder. The results showed that the optimum BBCM was the mix produced from 25% GGBS and 75% OPC with compressive strength of 32.2 MPa at the age of 28 days. In addition, the results of the TBCM have shown that the addition of 10, 15, 20 and 25% of HCFA to the optimum BBCM improved the compressive strength by 22.7, 11.3, 5.2 and 2.1% respectively at 28 days. However, the replacement of optimum BBCM with more than 25% HCFA have showed a gradual drop in the compressive strength in comparison to the control mix**.** TBCM with 25% HCFA was considered to be the optimum as it showed better compressive strength than the control mix and at the same time reduced the amount of cement to 56%. Reducing the cement content to 56% will contribute to decrease the cost of construction materials, provide better compressive strength and also reduce the CO_2 emissions into the atmosphere.

***Keywords*—**Cementitious material, compressive strength, GGBS, HCFA, OPC.

I. INTRODUCTION

NOWADAYS, the global environmental warming and the emission of greenhouse gases have become one of the most important issues worldwide. Cement manufacturing alone is responsible for about 7% of the CO_2 emissions universally. Production of one tonne of cement results in about one tonne CO_2 emissions into the atmosphere [1]. This fact ranked cement manufacturing as the third major producer of greenhouse gases after the transportation and energy generation sectors [2]. In addition, it is estimated that there will be an increase in the production of cement of about 5% annually, as a result of the rapid development in the construction industry worldwide [3].

Numerous studies have been conducted for studying the effectiveness of utilising by-products or waste materials as full or partial replacement for OPC and produce new low carbon cementitious materials [4]. GGBS, a by-product material of the steel industry that is extracted from blast furnaces, is one of the identified viable alternatives to OPC in different applications [5]. An experimental study has been carried out to investigate the effectiveness of using GGBS as partial replacement to OPC by utilising two categories of concrete (M20 and M30) [6]. The results showed that substitution of OPC by GGBS up to 50% was not affecting the compressive strength relative to the control mix and the maximum compressive strength was achieved by the 30% replacement.

The HCFA is classified as fly ash (FA) class C, which has, in addition to its pozzolanic properties, some self-cementing properties that can be attributed to the adequate calcium content [7]. The development of new binary blended cement filler (BBCF) material produced from HCFA and a fluid catalytic cracking catalyst (FC3R), in the field of cold bituminous emulsion mixtures (CBEMs), was conducted by Dulaimi et al. [8]. The new BBCF containing 4.5% HCFA and 1.5% FC3R enhanced the stiffness modulus by around 9% in comparison to mixture treated with OPC.

This paper presents the results of experimental investigation to study the effect of the partial replacement of OPC by GGBS and HCFA to produce a ternary cementitious material with comparable compressive strength to OPC. GGBS was initially used as partial replacement to OPC to produce a BBCM. The compressive strength at ages of 7 and 28 days were used for evaluating the performance of the BBCM relative to the control mix. The optimum BBCM was then utilised with different percentage of substitution by HCFA to produce a TBCM. The compressive strength at the ages of 7 and 28 days was used to assess the performance of the TBCM in comparison to the control mix.

II. MATERIALS

A. Sand

The sand used in this investigation was a normal building

Ali Shubbar, MSc Student, is with the Liverpool John Moores University, Department of Civil Engineering, Liverpool, L3 3AF, UK (e-mail: alishubbar993@gmail.com).

Hassnen M. Jafer, PhD Researcher, and Dr Anmar Dulaimi are with the Liverpool John Moores University, Department of Civil Engineering, Henry Cotton Building, 15-21 Webster Street, Liverpool, L3 2ET, UK.

Dr. William Atherton, Programme Manager, is with the Liverpool John Moores University, Department of Civil Engineering, Peter Jost Enterprise Centre, Byrom Street, Liverpool, L3 3AF, UK.

Ali Al-Rifaie is with the School of Engineering, University of Liverpool, Liverpool, L69 3GQ, UK.

sand that identified in BS EN 196-1 with a specific gravity of 2.62 Mg/m^3 [9]. Fig. 1 shows the particle size distribution chart for the sand.

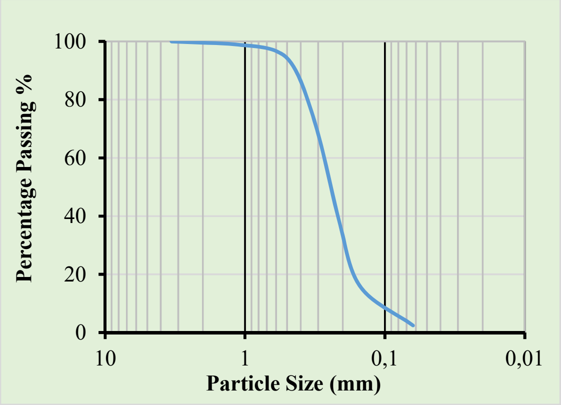

Fig. 1 Particle size distribution chart of sand

TABLE I
MIXING PROPORTION FOR BINARY BLENDING

Mix	OPC	GGBS	B/S	W/B
R	100%	0%	1:2.5	0.4
OG10	90%	10%	1:2.5	0.4
OG15	85%	15%	1:2.5	0.4
OG20	80%	20%	1:2.5	0.4
OG25	75%	25%	1:2.5	0.4
OG30	70%	30%	1:2.5	0.4
OG35	65%	35%	1:2.5	0.4
OG40	60%	40%	1:2.5	0.4
OG45	55%	45%	1:2.5	0.4
OG50	50%	50%	1:2.5	0.4

B. Cement

OPC type CEM-II/A/LL 32.5-N was used in this study with specific gravity of 2.936 Mg/m^3.

C. GGBS

GGBS is a by-product material of iron that is extracted from blast furnaces in water or steam. The specific gravity of GGBS is 2.9 Mg/m^3 as provided by the Hanson Heidelberg Cement Group who supplied the GGBS for this research.

D. HCFA

HCFA is a waste powder material that is produced from the burning processes in a domestic power generation station. This FA has a sufficient amount of silica and high content of CaO to which the pozolanic reactivity and self-cementing properties are attributed respectively.

III. EXPERIMENTAL WORKS

A. Methodology

The OPC was initially replaced by GGBS using different percentages (0, 10, 15, 20, 25, 30, 35, 40, 45 and 50%) by the dry mass of OPC to identify the optimum percentage of GGBS in the BBCM, which was found to be 25%. Then, HCFA was used to replace the BBCM using different percentages (10, 15, 20, 25, 30, 35, 40, 45 and 50%) by the dry mass of the BBCM. Tables I and II show the mixing proportions for the binary and ternary blending respectively. The specimens of each mixture were exposed to two different curing periods (7 and 28 days) prior to being subjected to the compression test. Three cubic specimens of 40×40×40 mm dimensions were prepared for each curing period and mixing proportion. Then, the averages were considered as the final values for the compressive strengths.

TABLE II
MIXING PROPORTION FOR TERNARY BLENDING

Mix	OG25	HCFA	B/S	W/B
T10	90%	10%	1:2.5	0.4
T15	85%	15%	1:2.5	0.4
T20	80%	20%	1:2.5	0.4
T25	75%	25%	1:2.5	0.45
T30	70%	30%	1:2.5	0.5
T35	65%	35%	1:2.5	0.55
T40	60%	40%	1:2.5	0.55
T45	55%	45%	1:2.5	0.55
T50	50%	50%	1:2.5	0.55

IV. RESULTS AND DISCUSSION

A. Particle Size Distribution (PSD)

The PSD test is an essential test that provides information about the fineness of the materials. Fig. 2 shows the PSD of the OPC, GBS and HCFA as obtained from the laser particle size analyser.

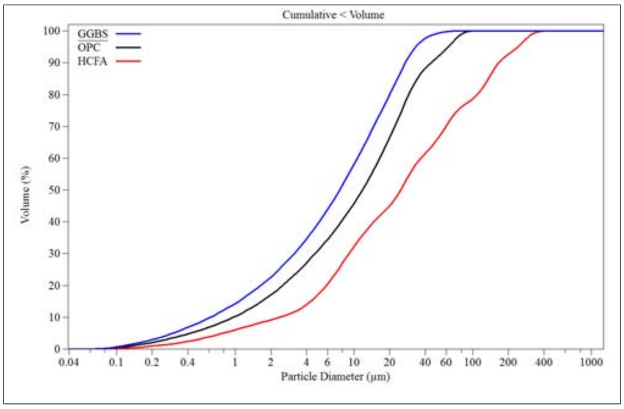

Fig. 2 Cumulative particle size distribution of OPC, GGBS and HCFA

The particle size distribution chart in Fig. 2 shows that GGBS has finer particle size in comparison to OPC. This means that the GGBS has a higher pozzolanic reactivity than the OPC as it has a higher specific surface area (SSA) [9]. Fig. 2 also shows that the HCFA has larger particles relative to OPC, which could retard the performance of the mortars during the hydration reactivity.

B. Compressive Strength

1) The BBCM Optimization

The compressive strengths of the mortars for different percentage combinations of GGBS and OPC with different curing ages are shown graphically in Fig. 3. It can be seen that at the age of 7 days, only OG10, OG20 and OG25 showed an improvement in the compressive strength by about 2% for OG10 and OG25 and 4% for OG20 relative to the control mix with 100% OPC (R). However, the addition of 30% and 35% GGBS caused a reduction in the compressive strength by about 3.6% and 5.1% respectively. Moreover, the replacement of OPC by 40%, 45% and 50% GGBS, caused significant reductions in the compressive strength ranging between 12.7% and 15.6%. This can be attributed to the slow acquisition of strength at initial curing ages for the mixes containing 40% or more GGBS.

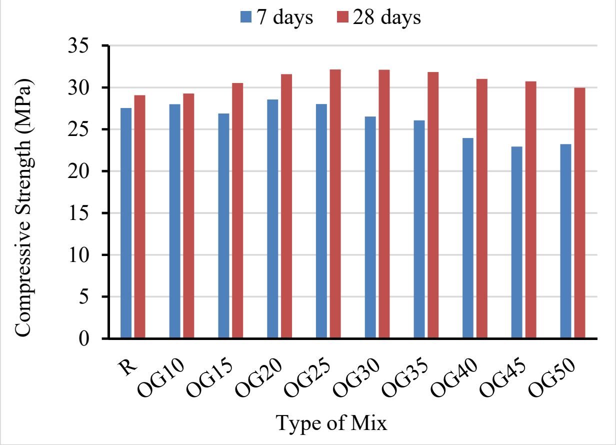

Fig. 3 The effect of GGBS on compressive strength at 7 and 28 days

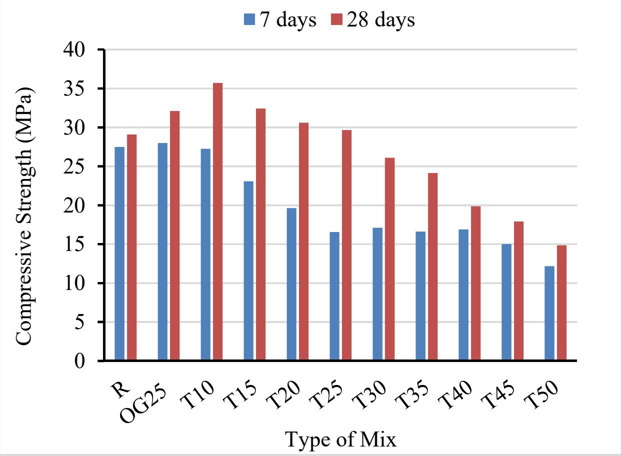

Fig. 4 The effect of HCFA on compressive strength at 7 and 28 days

Regarding the 28 days curing, all the mixes containing GGBS have shown an improvement in the compressive strength relative to the control mix. This means that with increasing the age of curing, the inclusion of GGBS in the mixes has enhanced the compressive strength. This result agreed with the findings of Mangamma et al. [6] and Cheng et al. [10]. Therefore, as OG25 has provided the highest compressive strength with 32.2MPa, it was considered as the optimum BBCM that will be used for producing the TBCM.

2) The TBCM Optimization

The compressive strengths of the TBCM mortars produced from different percentage combinations of OG25 and HCFA with different curing ages are shown in Fig. 4. It can be seen from Fig. 4 that at the age of 7 days, all the TBCM mixes have shown a lower compressive strength than the control mix and the BBCM. This can be attributed to the coarse particles of the HCFA that could retard the performance of the mortars during the hydration process. At the age of 28 days, the addition of 10, 15, 20 and 25% of HCFA to the optimum BBCM improved the compressive strength by 22.7, 11.3, 5.2 and 2.1% respectively. However, the replacement of optimum BBCM with more than 25% HCFA have indicated a reduction in the compressive strength up to 50% for the 50% replacement relative to the control mix.. On the other hand, the mixes T30, T35, T40, T45 and T50 have shown a reduction in the compressive strength ranging from 10.3% for T30 to almost 50% for T50 in comparison to the reference mix. This could be due to increase the water/binder ratio to improve the workability, as HCFA needs more water. In this study, the TBCM with 25% HCFA was considered to be the optimum, as it indicated better compressive strength than the control mix and at the same time has reduced the amount of cement by 44%. Such replacement will contribute to reduce the CO2 emissions and at the same time provide better compressive strength at suitable curing times.

V. CONCLUSION

The aim of this study was to investigate the influence of utilising GGBS and HCFA as a partial replacement for OPC and to produce a low carbon cementitious material with comparable compressive strength to OPC. According to the results of the experimental investigation, it can conclude that:

- Mortar containing GGBS and HCFA is considerably affected by the age of curing. Curing for more than 7 days is vital for the strength development of the mortars.
- At the age of 7 days, the mortars with 10, 20 and 25% GGBS have shown increment in the compressive strength in comparison to the control mix (R). However, the mortars with 30, 35, 40, 45, and 50% of GGBS have caused noticeable reductions in the compressive strength relative to the control mix.
- At the age of 28 days, all the mixes containing GGBS have indicted an improvement in the compressive strength relative to the control mix.
- The optimum BBCM was the mix with 25% GGBS and 75% OPC which has a compressive strength of 32.2MPa at the age of 28 days.
- Regarding the ternary blending, at the age of 7 days, all the TBCM mixes have shown a reduction in the compressive strength relative to both the control mix and the optimum BBCM.

- At the age of 28 days, the addition of HCFA up to 25% to the optimum BBCM have improved the compressive strength However, the replacement of optimum BBCM with 30% or more of have indicated a reduction in the compressive strength ranging from 10.3% to almost 50% for 30% and 50% replacement respectively.
- The TBCM with 25% HCFA and 75% optimum BBCM is considered to be the optimised mix as it showed better compressive strength than the control mix and at the same time has reduced the amount of cement by 44%.

ACKNOWLEDGMENT

The first author would like to acknowledge the financial support provided by Mr. Abd AL-Hussein Shubbar, together with Babylon and Kerbala Universities in Iraq for proving the funding for the present research. The authors would like to thank the Hanson Heidelberg Cement Group for the free supply of GGBS for this research.

REFERENCES

[1] 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.
[2] Mcleod, R. S., 2005. Newbuilder. (Online) Available at: http://www.uaecement.com/articles/ordinary_portland_cement.pdf (Accessed 12 6 2017).
[3] Jafer, H. M., Atherton, W. & Ruddock, F., 2015. Assessing the Potential of a Waste Material for Cement Replacement and the Effect of Its Fineness in Soft Soil Stabilisation. Manchester, the University of Salford.
[4] 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.
[5] Grist, E. R. et al., 2015. The environmental credentials of hydraulic lime-pozzolan concretes. Journal of Cleaner Production, Volume 93, pp. 26-37.
[6] 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.
[7] Ghosh, A. & Subbarao, C., 2007. Strength Characteristics of Class F Fly Ash Modified with Lime and Gypsum. JOURNAL OF Geotechnical and Geoenvironmental Engineering, 133(7), pp. 757-766.
[8] Dulaimi, A., Nageim, H. A., Ruddock, F. & Seton, L., 2016. New developments with cold asphalt concrete binder course mixtures containing binary blended cementitious filler (BBCF). Construction and Building Materials, Volume 124, pp. 414-423.
[9] 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.
[10] 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.