

PAPER • OPEN ACCESS

## Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar

To cite this article: Ali Abdulhussein Shubbar *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **584** 012022

View the [article online](#) for updates and enhancements.

You may also like

- [Thermal and durability characteristics of optimized green concrete developed using slag powder and pond ash](#)  
Jeyaprakash Maheswaran, Maheswaran Chellapandian, Nakarajan Arunachelam et al.
- [Effect of GGBS and Nano Silica on the Mechanical Properties of Ternary Concrete](#)  
Manank Shah, Niragi Dave, Kaushal Vora et al.
- [Development of green cement mortar using industrial by-products](#)  
Raad Hashim, Mohammad Amir Khan, Mohammed Kadhum et al.



**ECS**  
The  
Electrochemical  
Society  
Advancing solid state &  
electrochemical science & technology

**DISCOVER**  
how sustainability  
intersects with  
electrochemistry & solid  
state science research

# Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar

Ali Abdulhussein Shubbar <sup>1,2,\*</sup>, Ali Al-Shaer <sup>1</sup>, Rasha Salah AlKizwini <sup>3</sup>, Khalid Hashim <sup>1</sup>, Hayder Al Hawesah <sup>1</sup> and Monower Sadique <sup>1</sup>

<sup>1</sup> Department of Civil Engineering, Liverpool John Moores University, UK

<sup>2</sup> Department of Civil Engineering, College of Engineering, University of Babylon, Iraq.

<sup>3</sup> Department of Environmental Engineering, College of Engineering, University of Babylon, Iraq.

\* Corresponding author: [alishubbar993@gmail.com](mailto:alishubbar993@gmail.com) , [A.A.Shubbar@2014.ljmu.ac.uk](mailto:A.A.Shubbar@2014.ljmu.ac.uk)

**Abstract.** The technique of replacing the cement with other alternative materials focus on the production of materials with similar performance and reduced environmental impacts relative to traditional cement. The main aim of this study is to investigate the effect of replacing the cement content with high volume of GGBS and PFA on the mechanical performance of cement mortar. Three mixtures were prepared with different percentages of GGBS and PFA (40%, 60% and 80%) as replacement of cement along with other mixture that made with 100% cement as a control mixture. In order to evaluate the performance of the cement mortars, compressive strength test after 7, 14 and 28 days of curing was used. The results indicated that after 7 days of curing, the increase of GGBS and PFA contents caused a reduction in the compressive strength in comparison with the control mixture. After 28 days of curing, the results indicated that the mixture incorporated 80% GGBS and PFA has higher compressive strength relative to the control mixture. Such findings will significantly contribute in reducing the cost of the produced mortar by reducing the amount of used cement and this consequently reduce the cement demands/manufacturing. Less production of cement will reduce the CO<sub>2</sub> emissions of the cement industry.

**Keywords:** GGBS; PFA; high volume; compressive strength.

## 1. Introduction

Cement is globally considered as the main binder in the production of concrete and mortar. However, the production of cement is associated with some negative environmental impacts such as the production of greenhouse gases and the consumption of natural resources [1-3]. The cement industry alone contribute to about 7% of the CO<sub>2</sub> in the atmosphere globally [4]. Therefore, there are extensive efforts around the world being undertaken with the aim of developing construction materials that are environmentally friendly and at the same time provide similar performance to traditional cement [5].

Among the known viable alternative materials to cement in different applications such as concrete and mortar production and soil stabilization are Ground Granulated Blast Furnace Slag (GGBS) and Pulverised Fuel Ash (PFA). GGBS is a by-product material of iron that is extracted from blast furnaces that are dried and ground in a rotating ball-mill into a very fine powder of GGBS [6]. PFA is a by-product produced from different coal-fired power stations [7].



Recently, many studies have been conducted to investigate the effect of using GGBS or PFA as partial replacement to cement. For example, Soriano et al. [8] investigated the effect of replacing the cement by 30% PFA on the compressive strength of cement mortars. The results indicated that the new blend provided better performance at both early and later ages relative to control mixture with 100% cement. Hawileh, et al.[9] investigated the effect of replacing the cement with up to 70% GGBS on the performance of reinforced concrete beams. The results indicated that the beams incorporated up to 70% GGBS have compressive strength similar to that of the control beams especially at later ages. The replacement of cement partially with GGBS and PFA can improve the mechanical and durability properties of cement mortar [10, 11]. Additionally, the production of mortars with lower cement content means that the negative environmental impact will be lower.

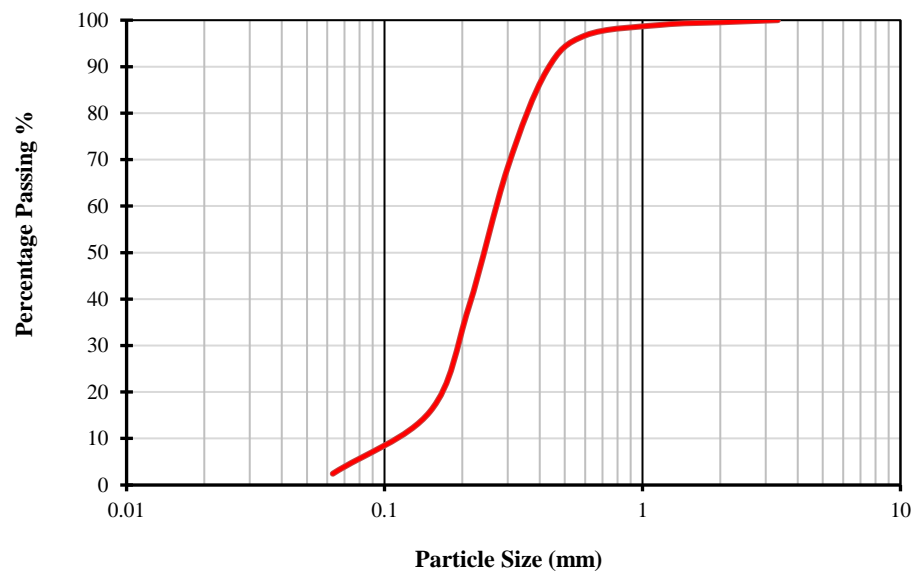
Although there are extensive research conducted by different researchers around the world to evaluate the effect of using GGBS and/or PFA on the performance of cement mortar, however, limited research investigated the replacement of cement with high volume (40-80%) of GGBS and PFA. Therefore, this paper presents the results of experimental work that has been conducted to study the effect of replacing the cement by high volume of GGBS and PFA (40, 60 and 80%) by weight on the compressive strength of cement mortar.

## 2. Materials and Methodology

### 2.1. Materials

#### 2.1.1. Sand

The sand used in this investigation was building sand with a specific gravity of 2.62. The particle size distribution of the sand is presented in Figure 1.



**Figure 1.** Particle size distribution of the sand.

### 2.1.2. Water

Tap water was used for all mixtures.

### 2.1.3. Binder Materials

The materials used in this investigation were Portland Cement (PC), Ground Granulated Blast Furnace Slag (GGBS) and Pulverised Fuel Ash (PFA). The cement was PC type CEM-II/A/LL 32.5-N. GGBS was supplied by Hanson Heidelberg Cement Group while PC and PFA supplied by CEMEX Ltd Company, Warwickshire, UK.

The elemental composition of PC, GGBS and PFA was analysed by an Energy Dispersive X-ray Florescence Spectrometer (EDXRF) type Shimadzu EDX-720. Table 1 shows the chemical compositions of the PC, GGBS and PFA.

**Table 1.** Chemical composition of PC, GGBS and PFA.

Item	PC	GGBS	PFA
CaO %	65.21	42.51	4.81
SiO <sub>2</sub> %	24.56	41.06	58.83
Al <sub>2</sub> O <sub>3</sub> %	1.70	5.12	18.83
Fe <sub>2</sub> O <sub>3</sub> %	1.64	-	5.54
MgO %	1.30	4.25	3.86
Na <sub>2</sub> O %	1.34	3.09	1.17
K <sub>2</sub> O %	0.82	0.69	2.04
SO <sub>3</sub> %	2.62	1.27	1.06
TiO <sub>2</sub> %	-	0.98	1.19
LOI %	0.28	0.37	2.67
pH	12.73	11.02	10.68
Specific Gravity	2.94	2.90	2.49

### 2.2. Mixing proportions

During this study, the cement was replaced partially with high volume of GGBS and PFA at different percentages: 40, 60 and 80%. Table 2 provide the mixing proportions of the ternary blending mixtures. The sand to binder ratio (S/B) and water to binder ratio (W/B) were fixed during this study as 2.5 and 0.4, respectively. Additionally, all the mixtures were compared with the control one of 100% PC.

**Table 2.** Mixing proportions of binder materials.

Mix ID	PC (%)	GGBS (%)	PFA (%)	S/B	W/B
M1	100	0	0	2.5	0.4
M2	60	20	20	2.5	0.4
M3	40	30	30	2.5	0.4
M4	20	40	40	2.5	0.4

### 2.3. Samples' preparation

All required materials to produce the mortars were firstly weighted, then the binder materials and the sand were mixed using Hobart N50-110 mixer for 5 minutes. Then the water was added and the wet mixture was further mixed for 5 minutes to form the cement mortar. The produced mortar was then moulded in the prism mould with the dimensions of 40 x 40 x 160 mm. After 24 hours, the mortar prisms

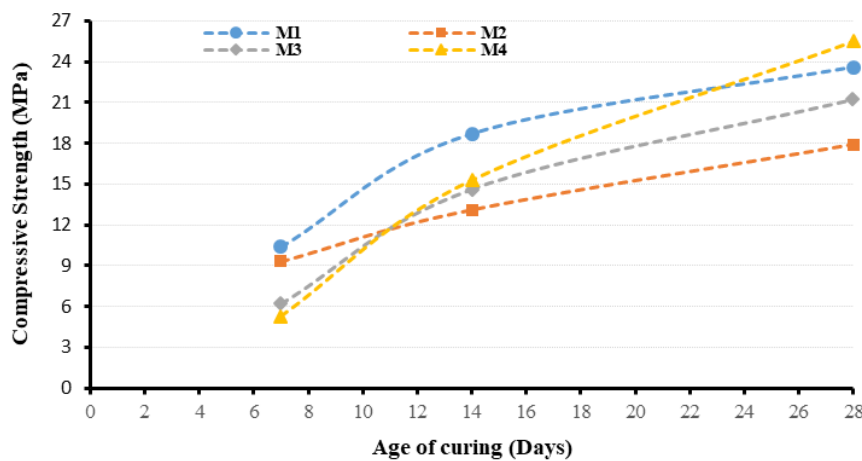
were demoulded and the samples were placed in small containers for water curing until the time of testing.

#### 2.4. Testing method

Compressive strength testing was conducted to evaluate the performance of the cement mortars according to BS EN 196-1[12]. Three samples of dimensions 40 x 40 x 160 mm were prepared for each mixing proportion and the test was carried out after 7, 14 and 28 days of curing.

### 3. Results and Discussion

The compressive strength of the cement mortars made from different combinations of PC, GGBS and PFA at different curing ages are presented in Figure 2.



**Figure 2.** Compressive strength development of different ternary blends and the control cement mixture.

It can be seen from Figure 2 that increase in the period of curing resulted in improved compressive strength for all the mixtures.

At the age of 7 days, the results indicated that with increasing the GGBS and PFA content in the mixture, the compressive strength decreased. This could be due to the slow acquisition of strength for mixtures with high volume of GGBS and PFA at initial curing ages [4, 13, 14]. Additionally, all the ternary mixtures showed lower compressive strength relative to the control mixture (M1). At this age of curing, the mixtures M2, M3 and M4 showed about 90%, 60% and 51% of the compressive strength of the control mixture, respectively.

At the age of 14 days, the results showed that the compressive strength of the cement mortars incorporated GGBS and PFA has been improved with increasing the GGBS and PFA content. However, all the mixtures provided lower compressive strength relative to the control mixture.

After 28 days of curing, the results indicated that the mixture M4 with 80% GGBS and PFA has higher compressive strength relative to the control mixture with an improvement of about 8%. On the other hand, the mixtures M2 and M3 showed about 76% and 90% of the compressive strength of the control mixture, respectively.

In summary, it is essential to extend the age of curing for mixture with high volume of GGBS and PFA to ensure the development of adequate compressive strength.

#### 4. Conclusion

The aim of this research was to investigate the effect of replacing the cement with high volume of GGBS and PFA on the compressive strength performance of cement mortar. Based on the obtained results, it can conclude that:

- Extending the period of curing resulted in enhanced compressive strength for all the mixtures. This could be due to the slow pozzolonic reaction for mortars with high percentage of GGBS and PFA that largely dependent on the formation of calcium hydroxide that requires time.
- At the age of 7 days, the results indicated that increasing the content of GGBS and PFA caused a reduction in the compressive strength of the cement mortar.
- After 14 days of curing, the results indicated that increasing the GGBS and PFA in the mixtures resulted in improved strength.
- At the age of 28 days, the results indicated that the mixture with 80% GGBS and PFA has higher compressive strength relative to the control mixture.
- Reducing the content of cement by 80% resulted in improved compressive strength of the cement mortars. Such replacement will significantly contribute to reduce cement content that consequently reduce the demand and production of cement. Therefore, the CO<sub>2</sub> emissions from the cement industry will be lower.

Finally, as the used by-product materials are gaining more values and the cost of these materials is increasing, therefore in order to produce sustainable binder materials with competitive financial cost, other waste materials should be investigated. For example, due to the huge production of municipal solid wastes [15-17], especially from water and wastewater facilities [18-26], the authors recommend to explore the possibility of using certain types of these wastes as cement replacement materials.

#### Acknowledgments

The corresponding author would like to acknowledge the financial support of this research by the Faculty of Engineering and Technology at Liverpool John Moores University (LJMU).

#### References

- [1] Karim M, Zain M, Jamil M, and 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*, vol. 49, pp. 894-902.
- [2] Shubbar A, Jafer H M, Dulaimi A, Atherton W, and Al-Rifaie A, 2017. "The Development of a Low Carbon Cementitious Material Produced from Cement, Ground Granulated Blast Furnace Slag and High Calcium Fly Ash". *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, vol. 11, no. 7, pp. 905-908.
- [3] Shubbar A A, Sadique M, Kot P, and Atherton W, 2019. "Future of clay-based construction materials – A review". *Construction and Building Materials*, vol. 210, pp. 172-187.
- [4] Shubbar A A, Jafer H, Dulaimi A, Hashim K, Atherton W, and Sadique M, 2018. "The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach". *Construction and Building Materials*, vol. 187, pp. 1051-1060.
- [5] Aprianti E, Shafiq P, Bahri S, and Farahani J N, 2015. "Supplementary cementitious materials origin from agricultural wastes – A review". *Construction and Building Materials*, vol. 74, pp. 176-187.
- [6] Grist E R, Paine K A, Heath A, Norman J, and Pinder H, 2015. "The environmental credentials of hydraulic lime-pozzolan concretes". *Journal of Cleaner Production*, vol. 93, pp. 26-37.
- [7] Aprianti E, 2017. "A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – a review part II". *Journal of Cleaner Production*, vol. 142, pp. 4178-4194.

- [8] Soriano L, Payá J, Monzó J, Borrachero M V, and Tashima M M, 2016. "High strength mortars using ordinary Portland cement–fly ash–fluid catalytic cracking catalyst residue ternary system (OPC/FA/FCC)". *Construction and Building Materials*, vol. 106, pp. 228-235.
- [9] Hawileh R A, Abdalla J A, Fardmanesh F, Shahsana P, and Khalili A, 2017. "Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement". *Archives of Civil and Mechanical Engineering*, vol. 17, no. 3, pp. 511-519.
- [10] Shubbar A, Atherton W, Jafer H M, Dulaimi A, and AL-Faluji D, 2017. "The Development of a New Cementitious Material Produced from Cement and GGBS". Presented at the The 3rd BUiD Doctoral Research Conference, the British University in Dubai, UAE, 13th May 2017.
- [11] Khalil E and Anwar M, 2015. "Carbonation of ternary cementitious concrete systems containing fly ash and silica fume". *Water Science*, vol. 29, no. 1, pp. 36-44.
- [12] BSI, "Methods of testing cement–Part 1: Determination of strength," British Standard Institute, London 2005.
- [13] Limbachiya V, Ganjian E, and Claisse P, 2016 "Strength, durability and leaching properties of concrete paving blocks incorporating GGBS and SF". *Construction and Building Materials*, vol. 113, pp. 273-279.
- [14] Attari A, McNally C, and Richardson M G, 2016. "A probabilistic assessment of the influence of age factor on the service life of concretes with limestone cement/GGBS binders". *Construction and Building Materials*, vol. 111, pp. 488-494.
- [15] Abdulredha M, Al Khaddar R, Jordan D, Kot P, Abdulridha A, and Hashim K, 2018 "Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression". *Waste Manag*, vol. 77, pp. 388-400, Jul 2018.
- [16] Abdulredha M, Al Khaddar R, Jordan D, and Hashim K, 2017. "The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition". *Procedia Engineering*, vol. 196, pp. 779-784.
- [17] Al-Jumeily D, Hashim K, Alkaddar R, Al-Tufaily M, and Lunn J, 2018. "Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the past to motivate the future)". presented at the 11th International Conference on the Developments in eSystems Engineering (DeSE), University of Cambridge, England, UK.
- [18] Alattabi A W, Harris C, Alkhaddar R, Alzeyadi A, and Hashim K, 2017. "Treatment of Residential Complexes' Wastewater using Environmentally Friendly Technology". *Procedia Engineering*, vol. 196, pp. 792-799.
- [19] Alattabi A W, Harris C B, Alkhaddar R M, Hashim K S, Ortoneda-Pedrola M, and Phipps D, 2017. "Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor". *Journal of Water Process Engineering*, vol. 20, pp. 207-216.
- [20] Hashim K S, 2017. "The innovative use of electrocoagulation-microwave techniques for the removal of pollutants from water," PhD thesis, Civil Engineering Liverpool John Moores University, UK.
- [21] Hashim K S, Al-Saati N H, Hussein A H, and Al-Saati Z N, 2018. "An Investigation into The Level of Heavy Metals Leaching from Canal-Dredged Sediment: A Case Study Metals Leaching from Dredged Sediment". presented at the 1st International Conference on Materials Engineering & Science, Istanbul Aydin University (IAU), Turkey.
- [22] Hashim K S et al., 2018. "Removal of phosphate from River water using a new baffle plates electrochemical reactor". *MethodsX*, vol. 5, pp. 1413-1418, 2018.
- [23] Hashim K S et al., 2018. "Electrocoagulation as a green technology for phosphate removal from River water". *Separation and Purification Technology*, vol. 210, pp. 135-144.
- [24] Hashim K S, Shaw S, Al Khaddar R, Ortoneda Pedrola M, and Phipps D, 2017. "Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach". *J Environ Manage*, vol. 197, pp. 80-88.
- [25] Hashim K S, Shaw A, Al Khaddar R, Pedrola M O, and Phipps D, 2017. "Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor". *Journal of Environmental Management*, vol. 189, pp. 98-108.

- [26] Hashim K S, Shaw A, R. Al Khaddar R, Pedrola M O, and Phipps D, 2017. "Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach". *J Environ Manage*, vol. 196, pp. 224-233.