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Experimental Investigations of Partial Replacement of OPC with PFA and GGBS in cement mortar

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Abstract. Production of cement has been identified as a major source of carbon dioxide, particulates, and other gases, where it was reported that the production of one ton of OPC could produce one ton of CO_2. These gases and particulates exert significant effects on human health and the environment. Therefore, the supplementary cementitious materials (SCMs) are becoming sustainable concrete in comparison with ordinary Portland cement (OPC) by decreasing the consumption of cement and carbon dioxide emissions. This experimental study is to focus on the effect of partial replacement in cement by pulverized fly ash (PFA) and ground granulated blast furnace slag (GGBS). Four mixes were used with different values of PFA and GGBS and they tested at 1, 2, and 4 weeks. The compressive strength of these specimens was carried out by a compression test. The test results revealed that increasing the ratios of PFA and GGBS replacement results in a decrease in the compressive strength of specimens. The decrease in compressive strength of SCMs mortar ranged from 20 to 30%, and they could be an acceptable value.

1. Introduction

In today's world, concrete plays a vital role in the construction industry, and the most important ingredient of the concrete is ordinary Portland cement (OPC) [1, 2]. However, the production of cement has become a growing concern as a large amount of carbon dioxide (CO_2), particulates, and other gases are released into the atmosphere during this process [3-5]. For example, the available literature confirms that the cement industry contributes by about 6% to 8% of the total concentration of CO_2 in the atmosphere [6, 7]. In simple words, it is estimated that producing one ton of OPC could produce one ton of CO_2. These gases and particulates caused severe changes in the average weather temperature, and the climate in general, where it has been proved that the produced gases from the cement industry contribute to climate change and global warming. The latter phenomena threaten public health through maximining water pollution [8-12], and the lack of rain in some parts of the world [13-16]. Moreover, the concrete plants produce large amounts of wastewaters that have a very high concentration of suspended particles and very high pH level (up to 11) and turbidity [17-19], which threat the aquatic life in the receiving water bodies [19-21]. Therefore, the negative impacts of the cement and concrete industries on the public health and the environment, efficient management plans along with expressive wastewater treatments, such as filtration [22-26], combined methods [27-30], coagulation [31-40], and electro-chemical methods [41-46] and disposal options [47-49].

Recently, a number of researchers were directed to find alternative cementitious materials that replace a part of cement, such as fly ash (FA) and ground granulated blast furnace slab (GGBS) [50]. Using these mineral admixtures as a partial cement replacement could reduce costs, conserve energy, and minimize the emission of gases. Ground granulated blast furnace slab (GGBS) and Pulverised Fly Ash (PFA) are commonly used in partial replacement of OPC due to their pozzolanic properties. Thus, using these materials makes a significant contribution to the characteristics properties of the cement mortar [50, 51].
In this study, the pulverized fly ash (PFA) and ground granulated blast furnace slab (GGBS) were assessed with ordinary Portland cement (OPC). The main goal of this study is to examine the effects of using these materials on the compressive strength of the cement mortar at different curing ages (1, 2, and 4 weeks).

2. Experimental program

Many tests have been conducted to compare the compression strength of the cement mortar made by partial replacement of OPC with PFA and GGBS. Mix design and the percentages of PFA and GGBS that used in tests are disused later.

2.1. Materials

In this study, the PFA and GGBS were used as binder materials. Fly ashes, which is called pulverized fuel ash (PFA) in the UK, are by-products of the burning of pulverized coals in electricity generation plants. The carbon and volatile materials are burned off when the pulverized coals are burnt in the combustion chamber. Then some materials are fused to form the ash which is driven out of the boiler. This ash is collected by some filtration equipment, and after molten materials cool. This ash solidifies as sphere-shaped glassy particles known as Fly Ash that generally have an average size of 0.5-300 µm, which is slightly larger than the size of the particles of OPC. The ground granulated blast furnace slag (GGBS) is the waste of the iron and steel industries; this material has a glassy granular structure with large grain sizes. Thus, it is subjected, after the drying process, to a grinding process to minimize their sizes into fine powders. Normally, GGBS is used when there is a need to obtain a durable concrete structure with the OPC. In this study, the Ordinary Portland cement (OPC) was utilized as the basic binder due to its good adhesive characteristics that serve its bonding with other components of the mixture. The cement used in this work was examined according to BS-EN 196-2:2013. The physical and chemical properties of geopolymer binders are listed in Table 1. These properties of cement, PFA, and GGBS are fulfilled to BS-EN 197-1:2011, BS-EN 450-1:2012, and BS-EN 15167-1:2006, respectively. Local clean river sands were utilized as fine aggregates. (particle sizes < 5mm). The particle size distributions, and chlorides and sulphates contents were measured according to the BS-EN 12620:2002+A1:2008. Also, the portable water (free from organics) was used for mixtures as well as for the curing of samples.

Table 1. Properties of geopolymer binders.

Particulars (%)	PFA	GGBS
Chemical composition		
SiO_2	65,6	30,61
Al_2O_3	28,0	16,24
Fe_2O_3	3,0	0,584
CaO	1,0	34,48
MgO	1,0	6,79
TiO_2	0,5	0,0
SO_3	0,2	1,85
Losses during ignition	0,29	2,1
Physical Properties		
Specific gravity	2,13	2,9
Fineness (m^2/kg)	360,0	400,0

2.2. Test methods
To measure the compressive strength of cement mortar, three cubes (100x100x100 mm) were cast and tested for each case. The considerable cases include testing the cubes by using only OPC, and then with the different replacement ratio of PFA and GGBS. All cubes were kept in appropriate condition and after 1 week of casting, they demolded and placed in water for curing. Later, the compressive strength was measured at the ages of 1, 2, and 4 weeks.

2.3. Mix Design
The mix design procedure adopted in the present work involves choosing the amount of cement, water, fine aggregate, and mineral admixture materials in a mortar mixture. The fine aggregate was chosen to fit the standard grading curves. The water to binder (cement+fly ash + GGBS) ratio is taken 0.4 for all the mixes. While the proportion of sand to binder was one part of cement to 2.5 parts of sand. The weight of each component/ingredients and the mix design proportion is listed in Table 2. It should be mentioned that the compression test applied to these specimens to exam the characteristics of cement mortar. Normally, cubes of 100x100x100 mm can be used to investigate the properties of cement mortar with PFA and GGBS. These samples were tested using a compression machine after 1, 2, and 4 weeks of curing. The testing load was applied gradually until the specimens fail. The compressive strength of samples can be computed by dividing the applied load on the area of the cube that is exposed to load (100*100 mm).

Table 2. Components of mix proportions

Cement (OPC)	(PFA)	(GGBS)
100 %	0 %	0 %
70 %	15 %	15 %
50 %	25 %	25 %
30 %	35 %	35%

3. Results
The results of the compressive strength tests of cement mortar with partial replacement of PFA and GGBS at various percentages at different curing periods are presented in Tables (1) and Figures 1 and 2.

Table 3. Compressive strengths at age 1, 2, and 4 weeks.

Test No.	OPC %	PFA %	GGBS %	Average of compressive strength (MPa) at		
				1 week	2 weeks	4 weeks
1	100	0	0	10.4	11.4	13.7
2	70	15	15	9.4	10.3	11.2
3	50	25	25	5.8	8.5	9.0
4	30	35	35	5.2	6.4	7.0

Key observations from these results are:
(i): It can be seen that using a partial replacement of PFA and GGBS in mixes results in a reduction in the compressive strengths of cementitious mortar. It could be noticed that mix 2 shows less decrease in the compressive strength when compared with those of 3 and 4. For example, at 1 week of curing, the reduction of compressive strength for the three mixes in comparison with the first mix was 10%, 44%, and 50 % respectively (Figure 2).
On the other hand, it can be noticed, for example, that using 50% a partial replacement material dropped the compressive strength of mortar by around half at 1 week, but this ratio decreased to be 20% at 28 curings. This means that PFA and GGBS are inactive material at an early age and they need time to interact with the components of a cement. To sum up, the partial replacement of PFA and GGBS can be done between 20 to 30% to get good strength and reduce environmental pollution. This can be attributed to the fact that the SCMs reduces the compressive strength of cementitious mortar which is a

significant factor in production gel (C-S-H) in mortar. Because of these react after hydration of cement and use the hydration products, $Ca(OH)_2$ to active and start the hydration of PFA and GGBS.
(ii): The results exhibit higher compressive strength for samples are curing 4 weeks. This can be explained by the fact that the curing age affects gain and increase of C-S-H that leads to reduce the volume of internal voids or porosity in the structure of mortar that in turn affects the density of concrete and increase of compressive strength of these mixes. For example, the percentages increase in compressive strength for mix 4 at 2 and 4 weeks were 23% and 35% respectively compared with the same samples at 1 week.

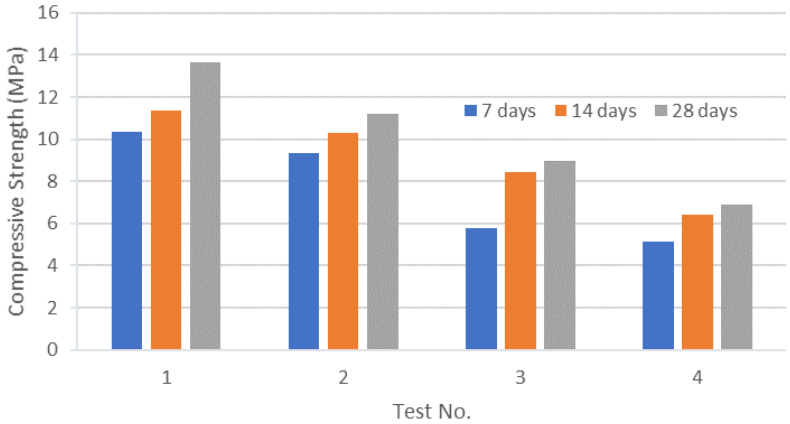

Figure 1. Compressive Strength for mixes at ages 1, 2, and 4 weeks.

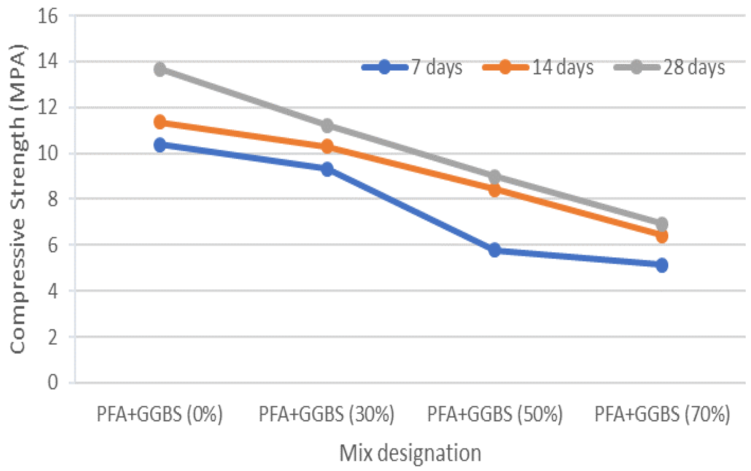

Figure 2. Effect of partial replacement of PFA and GGBS on compressive strength

The present work investigated the compressive for the concrete samples for 4 weeks, therefore more studies are required to investigate longer ages and compare the results with the traditional concrete samples of the same ages. Embedded sensors could be used for this purpose [52, 53], because of sensors shown good quality data in many fields, such as water quality [54] and communications [55].

4. Conclusions
Based on the results of this study, it can be drawn some points and as follows:
1. The partial replacement of PFA and GGBS of OPC in mortars decreases in compressive strength when an increase in percentage.
2. Increase the curing period is essential to obtain higher values of compressive strength when additional material is used in the mix.
3. Using 20 – 30 % as partial replacement of cement could be acceptable values, where increase this value leads to a drop in compressive strength of the concrete.

For future extension of this study more ages must be investigated because the present work investigated the compressive for the concrete samples for only 4 weeks. Embedded sensors could be used for this purpose because sensors have shown good quality data in many fields of civil and environmental engineering.

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