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Production of Ternary Blend Binder as an Alternative to Portland Cement

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Abstract. Environmental pollution and the relatively high cost of waste disposal have been a major focus for scientists around the world, leading researchers to find a solution to reuse waste materials in different applications. Additionally, landfills are considered one of the biggest crisis facing the Iraqi government. Therefore, this study aims to present a new ternary mixture that consists of OPC in addition to Pulverized Fuel Ash (PFA), Ground Granulated Blast Furnace Slag (GGBS) by utilizing it as a partial substitution of cement. A new ternary mortar mixtures containing four substitution levels of cement with GGBS and PFA (0%, 30 %, 50% and 70% by weight) were carried out. The Ultrasonic Pulse Velocity (UPV) and compressive strength tests were adopted to show the influence of GGBS and PFA on mechanical features of cement mortar. Findings indicated that, the compressive strength values were reduced with increasing the GGBS and PFA proportions at all curing ages. For 70% replacement, the compressive strength values were the lowest values comparison with that for control specimens. In contrast, the GGBS and PFA had a negative and positive impacts on the UPV of mortar depending on the substitution ratio. At 30 % substitution levels, the velocity value was enhanced, while other substitution ratios affected negatively on the UPV values.

1. Introduction

The consequences of greenhouse gas emissions have been the concern of governments, scientists and companies due to its direct influence to global warming. Rates of carbon dioxide (CO_2) emissions are still rising up rapidly and the fear of irreversible changes is looming over these parties [1]. Thus, for the environment to be maintained, carbon dioxide emissions should be minimized [2]. One of the contributors to such phenomena is the cement industry [3–12]. In general, the percentage of 5-8% of total CO_2 produced by the man-kind [12–22]. While on the other hand the construction industry is showing a rapid growth which directly influence the demand of production of Portland cement as the cementitious material is an essential substance for concrete structures [23–25]. The research on studying Supplementary Cementitious Materials (SCM) that would aid the parties concerned to decrease the negative influence of the production of Portland cement on cost and environment has been continuously encouraged and growing to conduct studies [26]. It was found that multiple industries generate waste materials that could be turned to by-products and used as SCMs by cement companies, industries such as the agriculture, steel and the coal industries could produces substances like rice husk ash (RHA), GGBS, and PFA [27,28]. Literature has showed lack of studies conducted on the influences of utilizing ternary blends that contains both GGBS and PFA in the mix with Ordinary Portland Cement [28].

Ground granulated blast-furnace slag (GGBS) is an extracted by-product from the steel factories or plants, specifically from the blast furnaces that are utilized to produce iron [29]. The formation of GGBS takes place once the blast furnace slag goes through rapid quenching which would eventually turn into glassy calcium-magnesium aluminosilicate granules. These granules can be later grinded to a certain degree of fine powder that would be optimum for use based on the requirements of usage [23,28]. GGBS contains two phases, the glassy phase which is responsible of the cementitious features within the material and the crystalline phased which allows the hydration of the material once its exposed to moisture in the mix with cement [30]. The usage of GGBS as a substitution of cement in partial percentages has yielded improved durability of specimens as higher strength levels has been recorded in the later ages and increased persistence to environmental abrasive wearing conditions [29].

PFA also alternatively called Fly ash (FA), is another supplementary cementitious material extracted from the coal industry. Pulverized coal once combusted in burning power plant would release residue, subsequently electrostatic or mechanical precipitators are used to capture the residue that flies out among the flue gas stream during the burning process [25]. PFA acts as a pozzolanic material due to its chemical features composition. This allows PFA to be used as a substitution of cement partially in concrete structures [31]. Studies have showed that the usage of PFA in a mix as a substitution of cement outcomes into lower hydration heat which was advantageous for dams construction [25], reduction of permeability in concrete that would protect the concrete from abrasive conditions therefore the durability is improved , and increased workability [31].

The shift for more eco-friendly/durable mixtures and the availability of pozzolanic admixtures has driven experiments and studies for binary and ternary blends for cement replacement. One of these ternary blends is the mixture of GGBS and PFA, this is due to the registered promising and improving mechanical and chemical features of the concrete mix after the inclusion of these materials together and separately [1]. After reviewing the literature, it was found that there are multiple studies on the influence of GGBS and PFA on cement binder, however, the majority of the studies experimented the influence of these materials separately. Kamau et al. [32] conducted a substitution experiment of cement with ternary blends using both GGBS and PFA in the mix and investigated the influence on the strength of specimens. The percentages of substitution were 0%, 5%, 7.5%, 10%, 15%, 20%, 25%, and 30%. It was concluded that both materials complement each other performance in the blend. The using of GGBS increased the strength of PFA, and the workability of GGBS enhanced by PFA. The compressive strength of samples showed an advantage over the binary and 0% substitution in lower levels of substitution and otherwise in higher level of substitution samples. More limitations were recorded as well, as the density of binary and 0% substitution samples were better than of the ternary blend. Tensile strength recorded lower levels as well than binary mixes. A following up study by the same author, Kamau and Ahmed [33] investigated the use of ternary blends over the induvial binary mixes in challenging environments that would hinder the durability of concrete. The author found in MgSO4 environments, the use of GGBS and PFA as ternary blends has an advantage when the substitution of cement is 30%. Higher levels of substitution showed preservation in both Na2SO4 and MgSO4 environments. Sern et al. [1] did a further study on ternary blend with a goal of observing the influence of using more waste materials in the mix of the binder.

2. Work Methodology

2.1. Materials

2.1.1. Binders. PFA, GGBS, and Portland Cement (PC) were the components utilized in this inquiry. The cement is PC kind CEM-II / A / LL 32.5-N. Hanson Heidelberg Cement Group supplied GGBS whereas CEMEX ltd Corporation, Warwickshire, United Kingdom provided PFA and PC.

An Energy Dispersive X-ray Florescence Spectrometer (EDXRF) model Shimadzu EDX-720 evaluated the fundamental structure of PFA, GGBS and PC. The chemical compositions of the PFA, GGBS and PC are shown in Table 1.

Table 1. Chemical analysing of PFA, GGBS and PC.

Item	PC	GGBS	PFA
CaO	$6521x10^{-2}$	$4251x10^{-2}$	$481x10^{-2}$
SiO_2	$2456x10^{-2}$	$4106x10^{-2}$	$5883x10^{-2}$
Al_2O_3	$170x10^{-2}$	$512x10^{-2}$	$1883x10^{-2}$
Fe_2O_3	$164x10^{-2}$	-	$54x10^{-2}$
MgO	$130x10^{-2}$	$425x10^{-2}$	$386x10^{-2}$
Na_2O	$134x10^{-2}$	$309x10^{-2}$	$117x10^{-2}$
K_2O	$82x10^{-2}$	$69x10^{-2}$	$204x10^{-2}$
SO_3	$262x10^{-2}$	$127x10^{-2}$	$106x10^{-2}$
TiO_2	-	$98x10^{-2}$	$119x10^{-2}$
LOI	$28x10^{-2}$	$37x10^{-2}$	$267x10^{-2}$
pH	$1273x10^{-2}$	$1102x10^{-2}$	$1068x10^{-2}$
Specific Gravity	$294x10^{-2}$	$290x10^{-2}$	$249x10^{-2}$

2.1.2. Mixing Water. Standard potable water (from tap) has been utilized for sample mixing.

2.1.3. Aggregates. Coarse and Fine aggregate depending on (BS 882: 1992) has been utilized in this project, obtainable in the "Liverpool" zone. The sieving test analysing is placed in Table (2).

Table 2. The sieve analysis of aggregates

Sieve Size (mm)	% Passing on every Sieve				
	(O/A) Limits	% Passing of the Specimen	Additional Limits		
			C	M	F
4.76	100	95	-	-	-
2.36	89-100	81.2	-	-	-
1.18	60-100	67.2	60-100	65-100	80-100
0.6	30-100	47.9	30-90	45-100	70-100
0.3	15-100	20.8	15-54	25-80	55-100
0.15	5-70	6.6	5-40	5-48	5-70

Coarse= C, Medium=M, Fine=F

2.2. Mix Proportions

The cement pastes, mortars and concrete mixes were prepared maintaining the levels of substitution of (GGBS +PFA) of (0, 30, 50, 70) % by weight of cement. A reference cement paste, mortar and concrete mix were also prepared for comparison. The blends were used to identified the optimum substitution ratios of (GGBS +PFA) as a ternary blending binder. Table 3 demonstrated the mix ratios utilized in this project. The sand/binder proportion (S/B) and water/binder (W/B) were, 2.5 and 0.4, respectively.

Table 3. Mix Design

Mix ID	OPC %	PFA %	GGBS %	S/B	W/B
RF	100	0	0	2.5	0.4
M1	70	15	15	2.5	0.4
M2	50	25	25	2.5	0.4
M3	30	35	35	2.5	0.4

2.3 **Testes**

1) Depending on BS EN 196-1, the test of compressive strength for all the mix has been performed (Two samples with sizes of 4x4x16 cm were generated at every curing period for each mixing ratio. Three points of loading of the prism samples split each sample into two sections and the average of 4 parts have been taken to indicate the final magnitudes of compressive strength).
2) The tests of UPV for all selected mix have been performed depending on BS 1881-203. (Three specimens with dimensions of 100x100x100 mm have been produced for each blending proportion at every period of curing).

3. Results and discussion

3.1 Compressive strength findings

The findings of the compressive strength for different blends are demonstrated in Figure 1. It could be realized from Figure 1 that extending the age of curing for different blends led to enhance the compressive strength performance of mortars. As shown in Figure 1, the compressive strength of mortar decreased with increasing the levels of substitution of OPC by GGBS and PFA at different curing periods.

At the age of 7 days, the substitution of OPC by 30% GGBS+PFA, 50% GGBS+PFA and 70% GGBS+PFA led to reduce the compressive strength by about 31%, 54% and 64%, respectively relative to the control blend (RF). Moving to the age of 14 days, the reduction in the compressive strength for the blend M1 was lower than that at the age of 7 days. This could be due to the low reactivity of GGBS and PFA at early ages that improves with extending the age of curing [5–7,17]. On the other hand, the mixes M3 and M2 demonstrated similar performance to that at the age of 7 days. After 28 days of curing, the mix M1 demonstrated about 74% of the compressive strength of the RF, while the mixes M3 and M2 demonstrated only about 48% and 39% of the compressive strength of the RF sample.

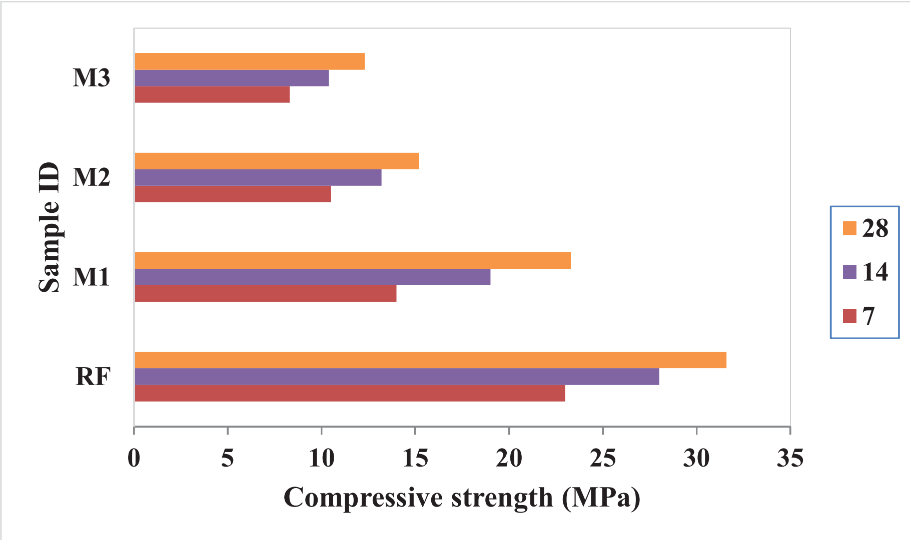

Figure 1. Compressive strength findings

3.2 UPV findings

The findings of the UPV test for different blends and for different periods of curing are presented in Figure 2. Figure 2 clearly demonstrations that extending the curing period for different mixtures led in improving the UPV values for all blends. The findings shows that extending the curing age for all mixtures helped in improving the UPV values of all blends. After 7 days of curing, the mixture M1 indicated an improvement in the UPV value relative to the RF mixture by about 0.3 %, while the mixtures M2 and M3 demonstrated a reduction in the UPV by nearly 9% and 20%, respectively. At the 14 curing days, the mixture M1 demonstrated similar finding to that of 7 days, while the UPV values of M2 and M3 improved by 8% and 10%, respectively. The findings of the UPV test after 28 days of curing indicated improvement in the UPV value for mixture M1 relative to RF by approximately 1%.

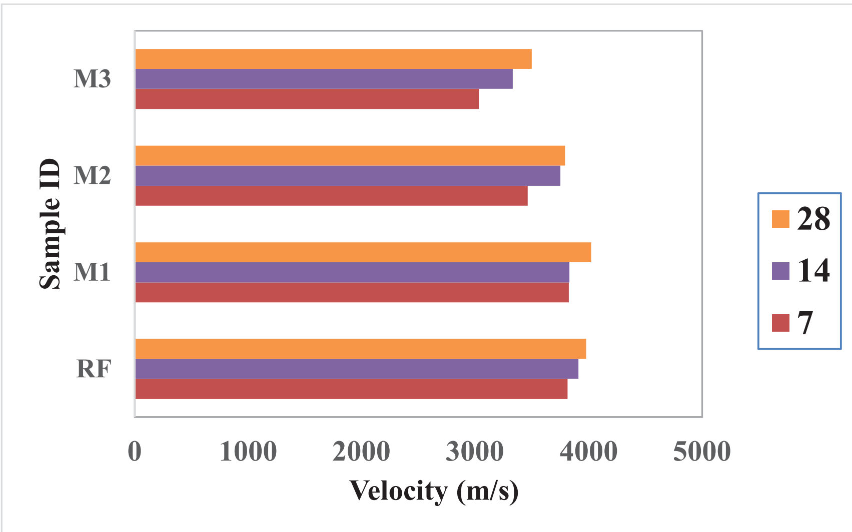

Figure 2. UPV findings.

4. Conclusion

The main goal of this investigation is to explore the features of cement mortar incorporated various percentages of PFA and GGBS. Depending on the obtained outcome, the next conclusions were collected.

- Extending the age of curing for all mixtures led to improve the UPV and compressive strength performances.
- The magnitudes of compressive strength of all the ternary mixtures were lesser than that of the RF at all ages.
- At all ages, the mixture M1 indicated better UPV values relative to the RF mixture.
- Accumulative the PFA and GGBS amount led to reduce the compressive strength at all ages.
- The mixture M2 showed comparable UPV value relative to the RF mixture after 28 days of curing.

Authors recommended utilizing other waste or by-products materials, for example stainless steel powder, silica fume, paper waste, crude oil wastes, agricultural waste [34–54], industrial wastes [55–57], municipal solid wastes [58] as well as water and wastewater planes waste [59–62] to improve the produced mortar. Utilisation of such materials in reinforced concrete beams is also considered as worthy issue [63].

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