Role of Supplementary Cementitious Materials in enhancing Concrete Properties

Mehwish Asad [1], Ayub Elahi [1], Huma Pervaiz [2], Usman Ali Naeem[1], Sidra Iftekhar [1], Muhammad Bilal Asif [1], Amber Taseer [3], Ayyaz Tajammal Mirza[4], , Naeem Ejaz [1]

[1]University of Engineering and Technology Taxila, Pakistan
[2] National University of Sciences and Technology Islamabad, Pakistan
[3]Engineer Directorate, GHQ, Rawalpindi, Pakistan
[4]United Nations Development Programme, Tajikistan
mehwish.asad@uettaxila.edu.pk

Abstract: Importance of pulverised fuel ash and ground granulated blast furnace slag cannot be denied. In this research work, experimentation was carried out to assess various fresh and harden properties of concretes by adding supplementary cementitious materials in both binary and ternary systems. Various concrete samples with mix ratio1:2:4 were prepared to have constant water-binder ratio of 0.50. The test variables included the type and the amount of the supplementary cementitious materials such as class 'F' pulverized fuel ash (PFA) and ground granulated blast furnace slag (GGBS). Portland cement was replaced with PFA and GGBS up to a level of 60%. Hence, total eight mixes were prepared. The fresh characteristics were investigated in terms of slump, whereas, the harden properties were assessed from the compressive strength. Among all mixes PF46 mix (40% Portland cement + 60% fly ash) named PF (46) showed highest slump showing effect of PFA on workability of concrete. The addition of high volumes of supplementary cementitious materials decreased the compressive strength at early age but this difference was reduced considerably for long term (91 days) results.
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1. Introduction

Concrete is used more than any other man-made material in the world (Lomborg, Bjørn, 2001). As of 2006, about 7.5 billion cubic metres of concrete are made each year, more than one cubic metre for every person on Earth (Minerals commodity summary – cement, 2007). It forms the backbone of nation's infrastructure and has influenced almost everything we encounter in daily life. Clinker, cement, and concrete production represent a set of processes characterized by high CO_2 emissions, huge energy consumption, and intensive utilization of natural resources (Italcementi Group, Bergamo, 2006). Concrete usually contains a small amount of some chemical admixture, and it often contains a mineral admixture replacing some portion of the cement. A typical concrete formulation contains a large amount of coarse and fine aggregate, a moderate amount of cement and water, and a small amount of admixture (Leslie and Jonathan, 2005).

Portland cement (PC) has become the dominant binder used in concrete for construction. Annual worldwide PC production is approaching three Gega-tones. Due to its versatility and durability portland cement concrete is receiving increasing recognition due to usage of local materials in its manufacturing. However, Portland cement is not without problems (Neville, 1995). Because such vast quantities are produced, manufacturing of Portland cement consumes 10–11 EJ of energy annually, approximately 2–3% of global primary energy use. Furthermore, Portland cement production results in approximately 0.87 tons of carbon dioxide for every tone of cement produced, this accounts for 5% of manmade CO_2 emissions.

The cement industry is under pressure to reduce both energy use and greenhouse gas emissions and is actively seeking alternatives to this familiar and reliable material. Coupled with the interest in seeking low-energy, low-CO_2 binders is an interest in finding re-use for waste materials from other industries. Portland cement concrete has the ability to accommodate a wide variety of waste materials used as supplementary cementing materials, including fly ash from coal combustion, ground granulated blast furnace slag from iron production, and silica fume from ferrosilicon production [(Neville, 1998), (Osborne, 1986), (Paillere, 1986), (Roy, 1989)]. However, these are used to replace only a portion of the cement in concrete. Additional motivation for exploring alternatives to PC can be derived from its shortcomings in certain applications and environments.

Utilisation of waste materials in construction industries has become one of the issues of researchers over the last few years because of the advantages such as reducing the use of natural resources and the elimination of the wastes stored at waste storage areas without harming to the environment. In recent years, focus is turning to natural and industrial wastes and by-products that have previously received little or no attention. These materials have dual problems of disposal and health hazards. Reutilization of industrial by-products as supplementary cementitious materials has been a thrust area of research, both ecologically and economically, in recent decades.

2. Research significance

The utilization of ground granulated blast-furnace slag (GGBS) and Class F Fly Ash (PFA) in concrete as a partial replacement of PC is well established. Generally the long-term strength and durability of concrete containing GGBS and PFA becomes equal to or exceeds that of PC concrete

In this study, test variables included the type and the amount of the supplementary cementitious materials such as PFA and GGBS. These materials, when used as, can improve either or both the strength and durability properties of concrete. Concretes with these supplementary cementitious materials are used extensively throughout the world. Some of the major users are power, gas, oil and nuclear industries. The applications of such concretes are increasing with the passage of time due to their superior structural performance, environmental friendliness and low impact on energy utilization. Also industries in developing countries like Pakistan are switching from power to coal combustion techniques resulting in excess amount of PFA in future. In this study PC was replaced with PFA up to 60% and GGBS up to a level of 60%.

3. Research Methodology

3.1 Materials

PC complying with BS EN 197-1 (2000) CEM 1 42.5 N [10], PFA equivalent to BS 3892: Part 1, 1997 [11] and GGBS manufactured according to ASTM-C-989-97b (British Standards, 1992) were used as binders. The chemical composition and physical properties of these materials are reported in Table 1. Coarse aggregates were obtained from local sources in Margalla. Table 2, shows the properties of aggregates used in this study .Fine aggregates were obtained from the local sources in Lawrence Pur. Table 3 shows properties of natural sand used in this study .Again as the concrete mixes were proportioned based on the saturated surface dry (SSD) condition, in order to make sure that the accurate amount of water was used for coarse aggregate; the specific gravity was tested prior to the experimental investigation. Tap water from mains supply was used throughout this research work to cast and cure samples.

Table 1: Chemical composition and physical properties of binders

Chemical composition (%)	**PC**	**PFA**	**GGBS**
Silicon dioxide (SiO_2)	20.54	50.7	35.76
Aluminum oxide (Al_2O_3)	6.06	28.80	13.96
Ferric oxide (Fe_2O_3)	2.77	8.8	0.25
Calcium oxide (CaO)	64.49	2.38	41.21
Magnesium oxide (MgO)	1.72	1.39	8.18
Sodium oxide (Na_2O)	0.14	0.84	-
Potassium oxide (K_2O)	0.61	2.4	-
Sulphur trioxide (SO_3)	3.03	0.9	-
Loss on ignition	0.64	3.79	0.64
Physical properties			
Specific gravity	3.18	2.52	2.91
Specific surface (m^2/kg)	322	340	600

Table 2: Properties of natural sand used

Specific gravity	2.72
Fineness modulus	2.27

Table 3: Properties of Coarse aggregates used

Specific gravity	2.69
Fineness modulus	5.91

3.2 Mix Proportioning

Different concrete samples with mix ratio1:2:4 were prepared to have constant water-binder ratio of 0.50.

Different mix proportions are summarized in table 4.

Table 4: Mix proportions

Mix ID	**w/ b**	**% of binder materials**		
		PC	**PFA**	**GGBS**
PC 100%	0.5	100	0	0
PG-46	0.5	40	0	60
OF-46	0.5	40	60	0
PGF-451	0.5	40	10	50
PGF-442	0.5	40	20	40
PGF-433	0.5	40	30	30
PGF-424	0.5	40	40	20
PGF-415	0.5	40	50	10

3.3 Preparation of Concrete Specimens

The concrete was manufactured by following the procedure in BS 1881: Part 125 using a 100 kg capacity ground base mounted mixer shown in Fig. 1. Twelve cubes of size 100×100×100 mm were manufactured to determine the compressive strength at different ages for each mix. Standard procedures were used to manufacture the sets of specimens BS 1881. Part 108 . The moulds were covered with a polythene sheet after casting test specimens in order to prevent the evaporation of moisture from the concrete and left in the lab at 20 °C

(±1 °C). The specimens were demoulded 24 h after casting and placed in a water bath at 20 °C (±1 °C). After 3 days of water curing, they were removed from the water bath, sealed in polythene sheets and placed in a room at a constant temperature of 20 °C (±1 °C) and 55% (±1%) relative humidity until the samples were ready for testing.

Fig 1: Mixer used for concrete mix

3.4 Test Carried Out

3.4.1 Workability of concrete

The workability of concrete was measured in terms of slump, noted immediately after manufacturing the concrete. The slump test was carried out in accordance with BS EN 12350: Part 2, 2000; these results are reported in table 5.

Table 5: Workability (Slump)

Mix ID	Slump (mm)
PC 100%	0.00
PG-46	0.00
OF-46	26
PGF-451	0.00
PGF-442	05
PGF-433	15
PGF-424	24
PGF-415	07

3.4.2 Compressive strength

The compressive strength of the concrete was determined by crushing three cubes of 100x100x100 mm size at the age of 3, 7, 28, 56 and 91 days for each mix using a compression testing machine with a rate of loading of 50kN/min. The test was carried out according to BS 4550-3.4:1978.

4. Results

4.1 Compressive Strength

The compressive strength of various mixes reported in Table 6 and compressive strength in relation to the reference mix (100% PC) are reported in Table 7.

Table 6 shows that addition of fly ash and GGBS as supplementary cementitious materials in concrete mixes cause the decrease in the compressive strength of concrete at early ages and this difference decreased with age due to pozzolanic action due to fly ash, thus, strength development in this case is more than conventional concrete after 28days. With SCMs, lower early age and adequate later age strengths achieved.

Table 6: Compressive strength of various concrete mixes

Mix ID	Compressive strength (MPa)				
	3 days	7 days	28 days	56 days	91 days
PC 100%	24	25.5	35.5	39	41
PG-46	10.5	21	24.5	29.5	32
PF-46	9	14	21	35	40
PGF-451	8	15.5	26.5	39.5	43
PGF-442	8	15	26	31	36.5
PGF-433	7	15	20.5	32.5	37.5
PGF-424	6	12.5	20	28.5	34.5
PGF-415	11.5	19	20.5	30.5	37

Table 7: Strength of mixes relative to the control mix at each test age

Mix ID	Compressive strength (%) at different ages relative to control mix (PC 100%)				
	3 days	7 days	28 days	56 days	91 days
PC100%	100	100	100	100	100
PG-46	43.75	82.36	69.01	75.64	78.05
PF-46	37.5	54.90	59.15	89.74	97.56
PGF-451	33.33	60.78	74.64	101.28	104.88
PGF-442	33.33	58.82	73.23	79.48	89.02
PGF-433	29.16	58.82	57.74	83.33	91.46
PGF-424	25	49.01	56.33	73.07	84.15
PGF-415	47.91	74.50	57.74	78.20	90.24

Table 7 shows that the incorporation of high volumes of PFA and GGBS in the concrete mixes produced a lower strength value at the early age. However, at later ages, the strength was either greater or comparable to the specimen named PC 100%. Although, as the gain in strength after 28 days is well pronounced for Mix 4 (PF-46) and greater than that of the PFA and GGBS concrete at all stages, from cost point view, it can be suggested that combination of 40% PC, 50% GGBS and 10% of PFA can be beneficially used to improve the compressive strength of concrete

With the W/B ratio kept constant at 0.5, the compressive strength was detrimentally affected by the replacement of PC with both PFA and GGBS at all stages up to 56 days. It was possible to enhance the long-term compressive strength of both PFA and GGBS mixes, but there was a decrease in compressive strength at early ages It is evident from the Fig.2, shown below, that the concrete containing SCMs having low early strength as compared to that of PC 100% having no SCMs. But on the other hand for Mix 2(PG-46) and Mix 3(PF-46), the gain in strength beyond 28 days is progressing. As for PF – 46, there has been found an appreciable increase in the compressive strength beyond 28 days.

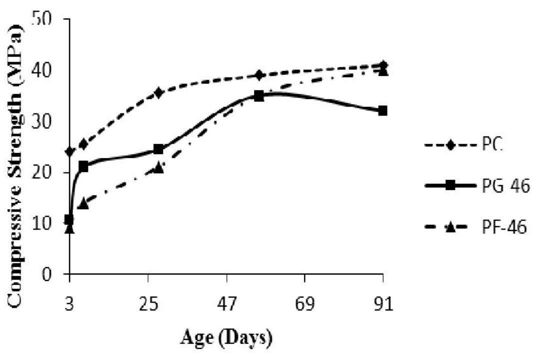

Fig 2: Compressive strength development of binary mixes containing PFA and GGBS

The Fig.3 is the comparison of supplementary materials when they are used in proportion PGF-451 (40%PC and 10% PFA and 50% GGBS).and PGF-415 (40%PC and 50% PFA and 10% GGBS) .As shown above. This Graph Clearly Shows That the gain in strength in the mix having PGF-451is the greater than that of PGF-415

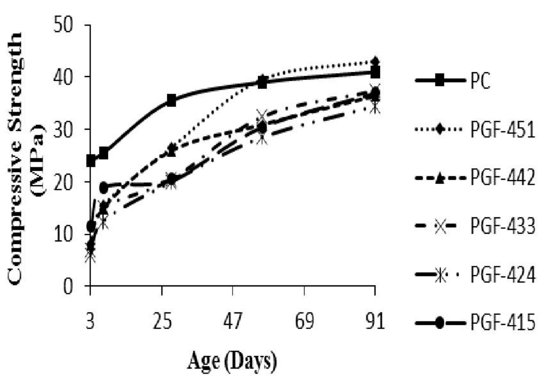

Fig. 3: Compressive strength development of ternary mixes containing PFA and GGBS

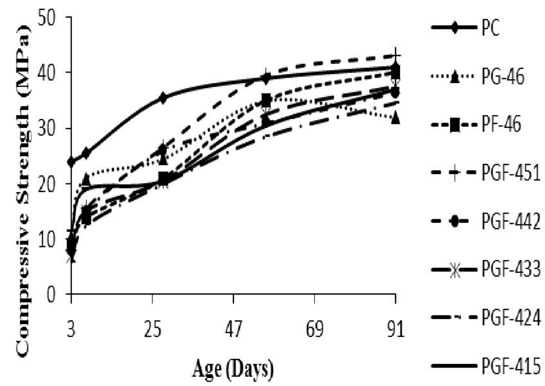

Fig. 4. Compressive strength development of binary and ternary mixes containing PFA and GGBS

Fig.4 illustrated the compressive strength of ternary mix (PGF – 451), containing GGBS 50% and PFA 10%, was observed to be greater than the binary mixes. The use of the SCMs increases the surface area for the hydration process to be carried out efficiently. The increase in the strength of ternary mixes could be attributed to the improvement in the bond between the hydrated cement matrix and the aggregate (Maage, 1986). This is due to the conversion of calcium hydroxide, which tends to form on the surface of aggregate particles to calcium silicate hydrate. As the average particle size of PFA is very small compared to those of the other binder particles, it contributes to the grain refinement of the ternary mixes of PFA and GGBS.

5. Conclusions

1. The incorporation of high volumes of FA and GGBS in the concrete mixes produced a lower strength value at the early age. However, at later ages, the strength was either greater or comparable to the specimen named PC 100%. Although, as the gain in strength after 28 days is well pronounced for Mix 3 (PF-46) and greater than that of the FA and GGBS concrete at all stages, from cost point view, it can be suggested that combination of 40% PC, 50% GGBS and 10% of FA can be beneficially used to improve the compressive strength of concrete.
2. With the W/B ratio kept constant at 0.5, generally the compressive strength was detrimentally affected by the replacement of PC with both FA and GGBS at all stages up to 91 days. It was possible to enhance the long-term compressive strength of both FA and GGBS mixes, but there was a decrease in compressive strength at early ages.
3. The results of the tests carried out on concrete containing FA and GGBS in large volumes clearly illustrated that some mix combinations are superior to

others for the property of compressive strength presented in this research work. Clearly this would mean that combination of different CRMs and the exact choice of these combinations should be based on the physical properties relevant the strength and performance expected from the concrete.

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