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Effect of Supplementary Cementitious Materials on Properties of Concrete

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Abstract
An experimental investigation was carried out to evaluate fresh and harden properties of concretes containing supplementary cementitious materials in both binary and ternary systems. Different 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' fly ash (FA) and ground granulated blast furnace slag (GGBS). Portland cement was replaced with FA and GGBS up to a level of 60%. Hence, total eight mixes were prepared. The fresh characteristics were investigated in terms of slump whilst the harden properties were assessed from the compressive strength. Among all mixes OF46 mix (40% ordinary Portland cement + 60% fly ash) named OF (46) showed highest slump showing effect of FA on workability 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 (56 days) results.

Keywords
Compressive strength, Fly ash, Ground granulated blast furnace slag, workability

1. Introduction

The role of concrete as critical material for modern society cannot be overestimated. Concrete forms the backbone of our nation's infrastructure and has impacted almost everything we encounter in daily life. Concrete is the most widely used synthetic product in the world and is second only to water as the world's most utilized substance. 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 [2002; Italcementi Group, 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 [Struble and Godfrey, 2005].

Most of these constituents are themselves manufactured products, by-products, or materials extracted by mining. In order to assess the environmental impact of concrete manufacture, it is necessary to consider the impact of each separate constituent. The aggregates are usually obtained by mining. The coarse and fine aggregates are usually mined separately. Occasionally aggregate is obtained as a by-product of some other process (e.g., slag or recycled concrete). Aggregates may be crushed and possibly washed. They are usually separated into various size fractions and reconstituted so as to satisfy the grading requirements. They may need to be dried. A modest amount of energy is involved in all these processes. To reduce mainly the natural resource consumptions different production chains whose by-products can substitute natural materials mixed with cement and/or concrete are investigated and, then, modeled. Hence, concrete and by-products production chains are jointly modeled to evaluate comprehensive and environmental benefits, the effective design of linked production chains, and to compare different economical and technical solutions. For instance, materials resulting from building demolition are proved to be effective also in terms of reduction of landfill space consumption.

Sustainable construction requires a critical review of prevailing practices, techniques and sources of raw materials. 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.

This study test variables included the type and the amount of the supplementary cementitious materials such as class F Fly ash (FA) by-product of Power Station and ground granulated blast furnace slag (GGBS) by-product of Steel Mills. 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.

After development of such types of blended cement, it will be very beneficial for the construction industry. So construction industry will improve economically and technically in countries like Pakistan. The cost of all projects will decrease tremendously, as the supplementary cementitious materials have much low cost as compared to cement. As supplementary cementitious materials are the by- products. The quantities of these by- products will increase in future because industries in countries like Pakistan are switching from Power to coal combustion techniques. Hence this research will positively affect the life of a common man and consequently improve the national economy/social sector.

In this study Portland cement was replaced with FA up to 60% and GGBS up to a level of 60%.This project is a real time application that provides a platform to understand these materials in term of sustainable development, with the help of this research the amount of carbon dioxide (produced because of the manufacturing of cement) will reduce. A large amount of Fly ash and steel slag (industry by-products) will be possible to import abroad as our neighbor countries have this practice. Increase the life time of reinforced concrete structures. Many new performance based specifications for durability of concrete will be established which will be beneficial to local construction industry .Local construction industry will produce special ingredients to make the concrete structures much durable.

2. Research Methodology

2.1 Materials

Ordinary Portland cement complying with BS EN 197-1 (2000) CEM 1 42.5 N, FA equivalent to BS 3892: Part 1, 1997 and GGBS manufactured according to ASTM-C-989-97bb 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 (%)	**OPC**	**FA**	**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

2.2 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	**FA**	**GGBS**
PC 100%	0.5	100	0	0
OG-46	0.5	40	0	60
OF-46	0.5	40	60	0
OGF-451	0.5	40	10	50
OGF-442	0.5	40	20	40
OGF-433	0.5	40	30	30
OGF-424	0.5	40	40	20
OGF-415	0.5	40	50	10

2.3 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

2.4 Test Carried Out

2.4.1 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)
OPC 100%	0.00
OG-46	0.00
OF-46	26
OGF-451	0.00
OGF-442	05
OGF-433	15
OGF-424	24
OGF-415	07

2.4.2 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 and 56 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% OPC) 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 increases it later 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
OPC 100%	48	51	71	78
OG-46	21	42	49	59
OF-46	18	28	42	70
OGF-451	16	31	53	79
OGF-442	16	30	52	62
OGF-433	14	30	41	65
OGF-424	12	25	40	57
OGF-415	23	38	41	61

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 (OPC 100%)			
	3 days	7 days	28 days	56 days
OPC100%	100	100	100	100
OG-46	43.75	82.36	69.01	75.64
OF-46	37.5	54.90	59.15	89.74
OGF-451	33.33	60.78	74.64	101.28
OGF-442	33.33	58.82	73.23	79.48
OGF-433	29.16	58.82	57.74	83.33
OGF-424	25	49.01	56.33	73.07
OGF-415	47.91	74.50	57.74	78.20

Table7 shows that 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 OPC 100%. Although, as the gain in strength after 28 days is well pronounced for Mix 4 (OF-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% OPC, 50% GGBS and 10% of FA 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 OPC with both FA and GGBS at all stages up to 56 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 It is evident from the Fig.2, shown below, that the concrete containing SCMs having low early strength as compared to that of OPC 100% having no SCMs. But on the other hand for

Mix 2(OG-46) and Mix 3(OF-46), the gain in strength beyond 28 days is progressing. As for OF – 46, there has been found an appreciable increase in the compressive strength beyond 28 days.

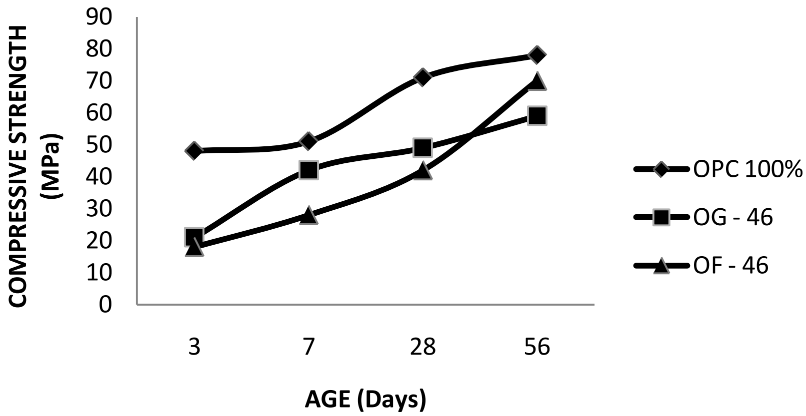

Fig 2: Compressive strength development of binary mixes containing FA and GGBS

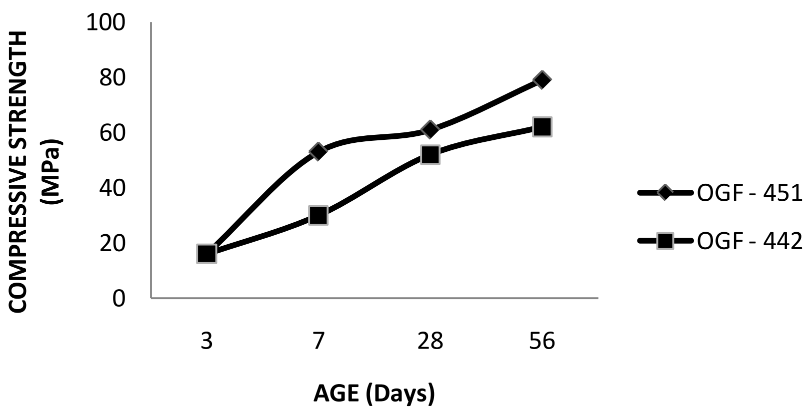

Fig.3: Compressive strength development of ternary mixes containing FA and GGBS

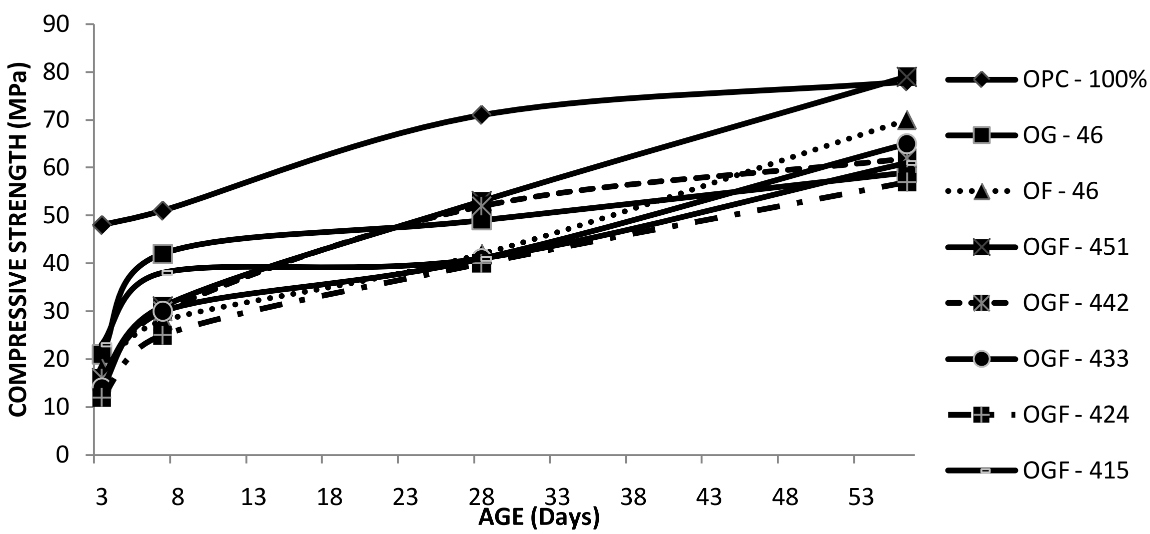

Fig. 4. Compressive strength development of binary and ternary mixes containing FA and GGBS

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

Fig.4 illustrated the compressive strength of ternary mix (OGF – 451), containing GGBS 50% and FA 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 FA is very small compared to those of the other binder particles, it contributes to the grain refinement of the ternary mixes of FA and GGBS.

5. Recommendations and Conclusions

5.1 Recommendations

The replacement of cement by SCMs has substantial advantages, not only increased durability and service life of concrete, but also additional ecological benefits. Therefore, every time we specify a concrete mix for a particular design, we should ask ourselves, or the concrete mix design specialist, if more fly ash can be utilized.

Although this research has indicated the limits in which OPC can be replaced with SCMs to beneficially produce durable concrete without detrimentally affecting the strength of concrete, the following further research is recommended in order to broaden the use of SCMs in ordinary concrete.

1. In the study the SCMs considered are taken from one source. However, as the properties of SCMs vary from source to source, further research should be carried out to evaluate the effects of SCMs from different sources on the performance of ordinary concrete.
2. Effect of age and water-binder ratio on size and dispersion of pores in ordinary Portland concrete should be studied.
3. As the pore structure affects the behavior of cement-based material perhaps more than any other characteristic of the material. It governs the physical and chemical resistance of cement-based material to deterioration, that is, durability, strength, thermal conductivity, and other mechanical properties. Permeability is affected by interconnected pores, whereas ultimately compressive strength is affected by all types of pores. So a detailed study should be made on the permeability of concrete containing SCMs.
4. In spite of the non linear behavior of concrete, an estimate of modulus of elasticity is necessary for computing the design stresses under load in simple elements, and moments and deflections in complicated structures. In addition to this, the modulus of elasticity also affects the serviceability and structural performance of reinforced structures. Therefore, there is a need to investigate the elastic modulus of ordinary concrete containing high volumes of SCMs.
5. Due to the relative more complex morphology of SCMs when compared to cement particles, the drying shrinkage mechanism of concrete containing SCMs could be different from that of concrete containing only OPC. Hence, a detailed study on the drying shrinkage properties is required.
6. There is need to investigate the influence of acidic medium (i.e., 1% of H_2SO_4 in water curing tank) on the strength of concrete cubes on different ages like 28 days and 56 days, after the curing in water tank. And also the measure of deterioration of the concrete, after the attack of acidic medium, should be studied for further durability checks.

5.2 Conclusion

1. Throughout the world, the waste disposal costs have escalated greatly. At the same time, the concrete construction industry has realized that the coal fly ash and the blast furnace slag is relatively inexpensive and widely available by-products that can be used for partial cement replacement to achieve excellent workability in fresh concrete mixtures.
2. Higher amounts of SCMs are recommended when there is a concern for thermal cracking, alkali-silica expansion and sulfate attack. Such high proportions of SCMs are not favorable by the construction industries due to a slower rate of strength development at early age.
3. The high-volume concrete offers a holistic solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and at reduced or no additional cost, and at the same time reducing the environmental impact of three industries that are vital to economic development namely the cement industry, coal-fired power industry and the steel manufacturing industry. The technology of high-volume concrete containing SCMs is especially significant for country like Pakistan, where, given the limited amount of financial and natural resources, the huge demand for concrete needed for infrastructure and mega construction can be easily met in a cost-effective and ecological manner.

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