Sustainable Concrete Construction Using Pulverized Fly Ash as a Partial Replacement of Portland Cement

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Abstract

The use of Binary Cement concrete incorporating Supplementary Cementitious Material (SCM) has been increased to reduce the cement consumption in construction industry. The cement production is the major source for the generation of Green House Gases (GHG) and there is an increasing pressure to reduce its consumption to avoid further Global Warming, Climate Changes etc. In this research, Pulverised Fly Ash was used as a partial replacement to cement in concrete. The Portland cement was partially replaced by PFA in three different percentages and was cured in sealed bags at room temperature of 20 oC to minimise the loss of moisture. Due to low early age strength gain of concrete containing GGBS and PFA, their use in the fast track construction and post tensioned concrete where they are exposed to high early age loads is limited. To overcome this problem, the water/cement ratio of the concrete produced was kept low to achieve higher early age and ultimate strength which also adds to the durability properties of concrete. To achieve the maximum workability, superplasticiser was used.

The strength development characteristics of the blended concrete has been compared with control mix having no PFA The compressive strengths of blended concrete for various levels of cement replacement has been observed as nearly the same as the control concrete mix.

1. INTRODUCTION

According to the Brundtland commission (1987) Sustainable development is the development of the present generation for their needs without jeopardising those of future generations. The main aim of the research is to minimise the embodied CO2 (ECO2) of structural concrete. Concrete is an important structural material composed of cement, aggregate and water. During the last century concrete technology has gained importance, due to which researchers are developing methods for making concrete.

In concrete, cement is the main constituent and due to the limit on the availability of natural minerals used for making cement and due to the emission of CO2 produced in the manufacturing of cement, research is focussed on partially replacing Portland cement in concrete by ground granulated blast furnace slag (GGBS) and silica fume. Processing of this by-products into quality materials avoids the need to landfill.

According to The Concrete Centre (2010), the amount of embodied CO_2 (ECO_2) of concrete, is a function of the cement content in the mix designs. Hence more production of concrete will lead to more cement consumption and generation of CO_2. To reduce cement contents in concrete, various Supplementary Cementitious Material (SCM) are used which include Pulverized Fly Ash (PFA) as well.

The extensive emission of Green House Gases (GHG), due to industrialization and use of fossil fuels in automobiles has led to Global Warming, Climate Changes and other environmental degradations, which has further intensified the need for sustainable development. (Struble.L. and Godfrey.J. (2004)). Embodied CO_2 (ECO_2), is the measure of the amount of CO_2 emissions generated from the energy needed for the raw material extraction, processing, transportation, assembling, installation, disassembly and deconstruction for any system over the duration of a product's life (Sustainable concrete (2011)). According to ScotAsh (2005), the production of one tonne of Portland cement requires about 4 GJ of energy and results in 0.89 to 1.1 tonnes of CO2, depending upon the type of process used. About half of the CO2 emissions are due the calcination of lime-stone, with the remainder due to the combustion of fossil fuels in energy production.

To offset the negative impacts of the cement production and reduce the cost of concrete, construction industry and concrete technologist around the world has been attempting to explore cementitious and pozzalonic material. In this context, Ground Granulated Blast Furnace Slag (GGBFS) and Pulverized Fly Ash (PFA) has been extensively used during last two decades. Poon (2000) used Low Calcium High Volume Fly Ash (HVFA) for high strength concrete and achieved a 28 days compressive strength of 83 MPa. The High loss on Ignition (LoI) value for Fly Ash severely affects the compressive strength and creep of concrete when used as replacement of cement in concrete. The unburnt ash particles increase the water requirement and reduces the compressive strength as well. To reduce this impact, High Range Water Reducers (HRWR) have been used. (Berry & Malhorta (1980)).

According to Thomas (2010) the use of fly ash as supplementary cementing material in concrete has been known from the start of last century but the first research in fly ash was conducted at the university of California by Davis *et al*1937), and the first significant utilization of fly ash in concrete began with the construction of the Hungry Horse Dam in Montana in 1948. The production of the material has been changed to reduce the gaseous emissions in recent years but has not affected the nature of PFA except it has increased the loss on ignition (LOI). The standards and specification of PFA are covered under BS EN 450-1(2012).

PFA has been used widely as cementitious material in construction industry. Dhir (1986) found that PFA fineness affects the strength of concrete and the strength of PFA concrete is reduced by using coarser PFA. In order to take care of the effect of PFA fineness on strength they developed a simple procedure of varying the water content, cement content or both. Kayali and Ahmed (2013) prepared concrete mixes by replacing PC with different percentages of Fly ash. The water/cement ratio was 0.38 for all the concrete mixes and the total amount of cementitious material content was kept constant for all the mixes and was equal to 450 kg/m^3. The concrete samples were cured with fog for seven days and then they were air dried till the age of 28 days for testing. They reported that there was a decrease in the compressive strength of concrete made with fly ash and this decrease was increased with the replacement level of fly ash.

Fly ash has been extensively used a partial replacement to cement in concrete, firstly to reduce the cement consumption in concrete and thereby making it relatively sustainable material and secondly increasing the mechanical properties of concrete in fresh and hardened forms Malhotra and Mehta(2005).

In this research, the effects of the partial replacement of cement with PFA on strength development of concrete cured at room temperature of 20^o in sealed plastic bags to minimise the loss of moisture. The use of PFA in concrete tends to slow down the early age strength which limits its use in the fast track construction and post tensioned concrete which are subjected to high early loads. Early age strength of concrete containing PFA can be increased by reducing the water/cement ratio.

2. RESEARCH SIGNIFICANCE

There is limited research work undertaken on effect of compressive strength and strength development characteristics of concrete incorporating PFA. The non-uniform physical properties of PFA found in various parts of the world also affects the performance of concrete produced. It is expected that the results of the research will add to the existing data on use of blended cement in concrete and its performance under controlled curing condition. The early age strength of blended concrete is relatively less than the normal concrete, which restricts its use in many important projects. Based on various trial mixing, the optimal level of water cement ratio, chemical admixtures and replacement of cement by PFA has been established. This will help in further research in standardizing the properties and mixing of the concrete made with blended cements.

3. EXPERIMENTAL PROGRAM

3.1 Material

3.1.1 Pulverised Fly Ash (PFA)

PFA conforming to BS-EN 450-1(2012) was used as binary cement component in the production of concrete. PFA used in the concrete is commercially available in the UK and is classified as CEM IV according to BS EN 197-1 (2011). Typical physical and chemical properties, provided by the supplier of PFA used, are presented in Table 1 and Table 2 respectively.

Table 1 Physical properties of PFA

Odour	Virtually None
Particle Density (Specific Gravity)	1.8 to 2.4
Solubility in water	Less than 2%
Bulk density	1.1 to 1.7 g/cm^3
Alkalinity - pH	9 to 12 when damp
Dielectric Constant	1.9-2.6

Table 2 Chemical properties of PFA

Component	Typical % by weight
SiO_2	45 to 51
Al_2O_3	27 to 32

Fe_2O_3	7 to 11
CaO	1to 5
MgO	1 to 4
K_2O	1 to 5
Na_2O	0.8 to 1.7
TiO_2	0.8 to 1.1
SO_3	0.3 to 1.3
Cl	0.05 to 0.15

3.1.2 Portland cement

Ordinary Portland cement (OPC) used conformed to BS EN 197-1 (2011) and was classified as CEM-I. The Portland cement was stored in the laboratory to avoid exposure to humidity.

3.1.3 Superplasticiser (SP)

High performance liquid superplasticizers conforming to BS-EN 934-2, to achieve the required workability.

3.1.4 Aggregates

Graded natural sand with a maximum particle size of 5 mm and complying with the requirements of BS EN 12620-1 (2009), was used as fine aggregate in the concrete mixes. Thames valley natural aggregates of lime stone were used as coarse aggregate in the concrete mixes. The maximum size of the aggregate used was 20 mm.

3.2 Concrete Mix Proportions

Concrete was designed to achieve an equal 28 days compressive strength of 40 MPa and the strengths of 10 MPa after 16 hours and 25 MPa after 38 hours to meet the practical requirement of post tensioned concrete beams. The concrete mix proportions are shown in Table 1. To achieve a practical level of workability and cohesion, suitable for pumping, concrete was designed for a target slump of 200 mm. Superplasticiser was used to minimise water and cement contents to achieve low free w/c ratio.

Table 1 Concrete Mix Proportions

Constituent Materials, Kg/m³									
Free Water	Cement Constituents				Aggregates		w/c Ratio	Super plasticiser	Calculated Density
Litres	PC	FA	GGBS	SF	Coarse	Fine		ml/100kg cement	kg/m³
CEM I (100PC), PC 375 kg/m3 @w/c 0.40									

150	375	-	-	-	1370	520	0.40	500	2415
90PC/10PFA@w/c0.4									
154	345	40	-	-	1360	515	0.40	525	2410
80PC/20PFA@w/c0.35									
150	345	85	-	-	1230	635	0.375	925	2410
70PC/30PFA@w/c0.28									
135	340	145	-	-	1180	635	0.35	1300	2425

3.2 Test Samples:

Two batches of concrete were made for each concrete mix, to cast samples. 100 mm cubes were cast for each mix to measure the compressive strength development according to the British standard test method BS EN 12390-3 (2009), at the age of 1, 2, 3,5,7,14,28 and 56 days.

3.3 Curing Environments

Concrete samples were cured soon after casting at a room temperature of 20oC ± 2 oC. The concrete samples were demoulded after 24 hours and then they were sealed in plastic bags for curing. The concrete cubes were sealed in bags to minimise the loss of moisture from concrete.

4. Results & Discussion

The strength for various mixes of concrete are shown in Table 4.

Table 2 Concrete Compressive strength development

	Compressive cube strength, MPa Age at test, days							
	1	**2**	**3**	**5**	**7**	**14**	**28**	**56**
CEM I,(100PC)375 kg/m^3@ w/c 0.40								
	17.0	25.0	34.0	41.0	45.5	46.5	51.5	57.5
90PC/10PFA@ w/c 0.40								
	13.0	22.0	25.5	26.5	29.0	31.5	41.0	44.5
80PC/20PFA@ w/c 0.35								
	16.5	24.0	25.5	28.0	30.5	38.5	42.5	46.0
70PC/30PFA@ w/c 0.28								
	20.0		34.0	38.5	41.0	46.0	55.0	65.0

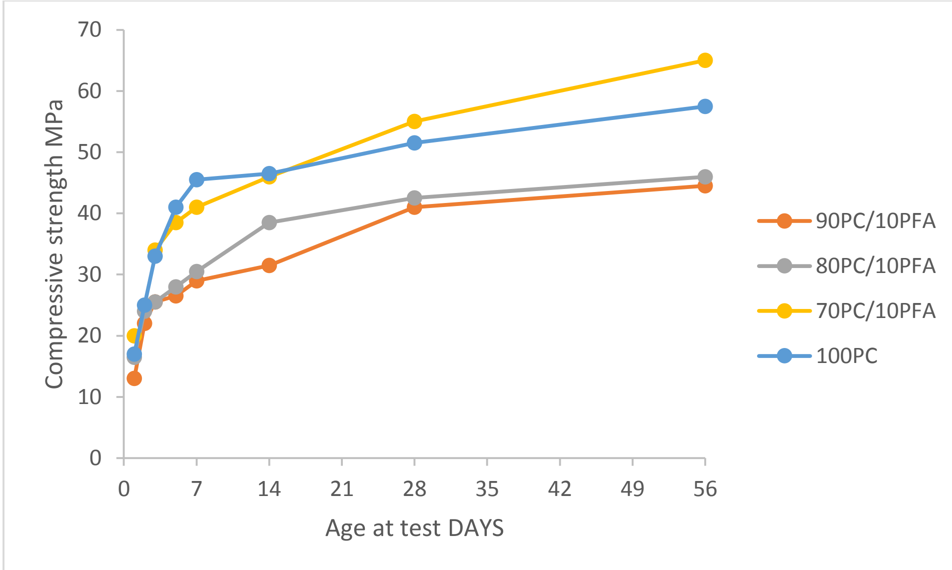

Figure 4 Compressive Strength Development

Strength development for PFA concrete mixes 90PC/10PFA, 80PC/20PFA and 70PC/30PFA cured under the regime explained above are compared in Figure 1.

PFA concrete has shown that the early age strength development is slow due to the apparent slow pozzolanic reactions between PFA and the lime (Ca(OH)2) generated by the PC concrete. The strength of 90PC/10PFA, 80PC/20PFA and 70PC/30PFA concrete mixes are 25.5 MPa, 25.5 MPa and 34 MPa respectively at the age of 3 day as compared to 34 MPa for the, 100PC-control concrete mix. At 14 days of age the strengths increased to 31.5 MPa, 38.5 MPa, 46MPa and 46.5 MPa respectively. At 28 days of age, these strengths further improve to 41MPa, 42.5 MPa, 55 MPa and 51.5 MPa respectively. The difference in the compressive strengths at 28 days for PFA concrete and 100PC concrete is relatively less. For 70PC/30PFA at w/c ratio of 0.28, the blended concrete has achieved the maximum 56 days compressive strength of 65MPa, as compared to 57.5 MPa for 100PC with no Fly Ash. The strength gain in PFA concrete is maximum during 28 and 56 days of age.

5. CONCLUSION

- Partial replacement of cement by PFA up to 30% has little impact on the compressive strength at 56 days when compared with samples having no PFA, as the compressive strength achieved has a reasonable value for use in structural works. This can offer greater opportunity for saving of cement and CO2 emissions, thereby making concrete relatively sustainable.
- The strength development of PFA concrete is relatively slow in the beginning up to 7 days and then increases with relatively high rate. The optimum strength is achieved at 56 days instead of 28 days of age.
- The results shows that there are significant reductions in the rate of strength gain of concrete cured under winter curing conditions (7 ^{o}C), as compared to those of summer curing and under water (20 ^{o}C). In winter conditions, for concrete containing PFA up to 30 %, special care should be taken regarding temperature increase of the curing environment at the early age to gain enough strength. This can be achieved at covering the concrete in sealed conditions. The heating of concrete buildings, to increase the temperature for curing is a common practice in cold areas.

- The strength development under the summer conditions and under water is almost the same for PFA concrete.
- From comparison of the compressive strength development of PFA concrete results between the ages of 28 and 56 days, it is evident that the strength gain is relatively more during this period as compared to the 100% PC, with no PFA. It is more advisable to use the specified strength of PFA concrete at 56 days, as already suggested by earlier research on the blended concrete.

6. REFERENCES

British Standards Institution (2009). *BS EN 12390-3: 2009. Testing hardened concrete. Part 3: Compressive strength of test specimens.* London: British Standards Institute.

British standard institute (2012) BS EN 450-1:2012: *Fly ash for concrete, definition, specification and conformity criteria*: London: British Standard Institute.

British standard institute (2011) *BS EN 197-1:2011: Composition, specifications and conformity criteria for common cements:* London: British Standard Institute.

British standard institute (2009) BS EN 12620-1:2009: *Aggregates for concrete:* London: British Standard Institute.

Brundtland Commission (1987) 'Our Common Future'. *Technical report, World Commission on Environment and Development (WCED)*, Oxford university press, 1987.

Davis, R.E., Carlson, R.W., Kelly, J.W. and Davis, H.E. (1937). 'Properties of cements and concretes containing fly ash.' *Journal of the American Concrete Institute*, Vol. 33, pp. 577-611.

Dhir,R.K (1986) *Pulverised-fuel ash*, Concrete Technology and Design, Cement Replacement Materials, Surrey University Press, London, Vol. 33 , Ch. 7, pp. 197-255.

Kayali.O., Ahmed,M.S (2013) *Assessment of high volume replacement fly ash concrete – Concept of performance index*, Construction and Building Materials ,39,pp71-76,Elsevier.

Malhotra, V.M. and Mehta, P.K(2005), *High-Performance, High-Volume Fly Ash Concrete. Supplementary Cementing Materials for Sustainable Development* , Ottawa, Canada, 2005, 124 pages.

Poon, C.S(2000) Study on high strength concrete prepared with large volumes of low calcium fly ash. Cement Concrete Res 2000;30(3):447–55.

ScotAsh (2005) 'ScotAsh and The Environment Quality Sustainable construction Products' [online], Available at: www.scotash.com/pdfs/scotash0605.pdf. (Accessed 5th Feb, 2010).

Struble.L. and Godfrey.J. (2004) '*How Sustainable Is Concrete*' Proceedings of the International Workshop on Sustainable Development and Concrete Technology Beijing, China, May 20–21, 2004: Centre for Transportation Research and Education, Iowa State University Ames, Iowa, USA, pp. 201-211.

Thomas, M, D.A (2010) '*Optimizing Fly Ash Content for Sustainability, Durability, and Constructability*' University of New Brunswick, Department of Civil Engineering, Canada.

United Kingdom Quality Ash Association (2004) 'The power behind PFA' Technical data sheet.