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ENGINEERING PROPERTIES OF CONCRETE MADE WITH PULVERISED FLY ASH

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Abstract - This research work reports the potential of using Pulverised Fuel Ash (PFA) as a partial substitute for Portland Cement (PC) in the development of concrete. PFA is a by-product of the combustion of pulverized coal in electric power generating plants. Its use in concrete will alleviate the environmental concern for PFA disposal and ease the growing shortage and increasingly high cost of PC. In order to investigate the cement replacement potential of PFA, six types of mixes, at varying PFA replacement levels were designed— 5%, 10%, 15%, 20%, 25% and 30%; all with a water binding ratio of 0.6 and tested at 7, 14, and 28 days. The testing programme included material characterization; the determination of slump value and compressive strength. The results showed that the addition of PFA to the concrete mix causes the compressive strength to reduce at early age and that the slump values increased as the quantity of PFA increased in the mix.

Index Terms - Pulverised Fuel Ash, Slump, Concrete, Compressive Strength

I. INTRODUCTION

Due to the increasing demand for environmentally friendly and low cost construction materials; by-products from power plants and steel production are now being utilised as cement replacement materials in the construction industry. An example of such a material, is Pulverised Fuel Ash (PFA), which is a by-product of coal combustion from power plants and is currently being stock-piled in open field landfill sites; thus having a negative impact on the environment. PFA has similar properties to Portland Cement (PC) owing to the available calcium content (CaO) [1] and so has the potential to be used as pozzolan for the partial replacement of cement. Replacing PC in concrete with PFA, will reduce the pollutant emissions, such as Carbon Dioxide and Nitrogen Oxide that are given off in the production of PC; thus helping to reduce greenhouse gases [2]. There have been a number of reports of the use of PFA in concrete. Motamedi et al [3] reported that if the percentage of PFA used in PC replacement exceeds 20% of the total weight, the final UCS decreases. Openshaw [4] and Snelson et al [5] reported the same UCS reduction when the PFA content exceeds an optimum amount. Maslehuddin [6] carried out investigations to evaluate the compressive strength, development and corrosion-resisting characteristics of concrete mixes in which PFA was used as an admixture and from the results concluded that addition of Fly Ash as an admixture, increases the early age compressive strength and long-term corrosion-resisting characteristics of concrete. The superior performance of these mixes compared to plain concrete mixes was attributed to the increase in densification of the paste structure which is a result of the pozzolanic action between the Fly Ash and the calcium hydroxide that is from the hydration of cement. Jiang and Malhotra [7] tested Fly Ash of several different compositions, at 55% replacement. They demonstrated a strong positive correlation between lime content and compressive strength at all ages, although more notably at later ages.

This research reports on the results of the investigation on the slump value and strength of concrete made by the partial replacement of up to 30% of the PC in conventional concrete with PFA. The use of a cement replacement material such PFA in the production of concrete will increase environmental sustainability, by the reducing the high energy usage and carbon dioxide emissions that occur during cement production process. The paper will have a high impact on the Engineering and Scientific communities involved in alternative construction material development. The future impacts of this paper are for international development, through the development of techniques that will be transferable.

II. MATERIALS

A. Pulverised Fuel Ash

The Pulverised Fuel Ash (PFA) used within this research work was supplied by a local contractor and its manufacture conformed to BS EN 450-1 [8]. PFA is a by-product from coal-fired powered stations and is produced when pulverised coal is fed into the boilers and burnt at very high temperatures. The chemical composition and certain physical properties of PFA can be seen in Table 1.

Table 1 - Chemical composition and some physical properties of PFA

Chemical constituent PFA	Percentage
Silicon dioxide (SiO_2)	59·04
Aluminium oxide (Al_2O_3)	34·08
Iron oxide (Fe_2O_3)	2·0
Lime (CaO)	0·22
Sulphur trioxide (SO_3)	0·05
Magnesium oxide (MgO)	0·43
Alkalis (Na_2O, K_2O)	1·26
Loss on ignition	0·63
Characteristic of PFA	**Test result**
Lime reactivity; average compressive strength (MPa)	6·59
Specific gravity	2·058
Fineness: specific surface area (m^2/N)	35·48
Drying shrinkage (mm)	0·06
Soundness by autoclave test expansion of specimen (mm)	0·01

B. Portland Cement

The Portland Cement (PC) used throughout this research was manufactured in accordance with BS 197-1 [9] and supplied by Lafarge Cement UK. The minimum compressive strength of the PC is 32.5 N/mm^2. The physical properties and Oxide/chemical composition of the PC are shown in Table 2.

Table 2 - Physical properties and Oxide/chemical composition of the PC

Properties	
Insoluble Residue	0.5
Bulk Density (kg/m³)	1400
Relative Density	3.1
Blaine fineness (m^2/kg)	365
Colour	Grey
Oxide	**%**
SiO_2	20.00
Al_2O_3	6.00
Fe_2O_3	3.00
MgO	4.21
MnO	0.03 - 1.11
SO_3	2.30
Loss on Ignition	0.8
Chemical (%)	
Cl	0.03
Free lime	1.32
Bogue's composition	
Tricalcium aluminate (C_3A)	6.48
Tricalcium silicate (C_3S)	70.58
Dicalcium silicate (C_2S)	6.09
Tetracalcium alumunate-ferrite (C_4AF)	6.45

C. Limestone Aggregates

The limestone aggregate used throughout this investigation were sizes 10mm and 20mm. The limestone aggregates were supplied by a local quarry and complied with the requirements of BS EN 12620 [11]. Some geometrical, mechanical and physical properties of the limestone aggregate can be seen in Oti and Kinuthia [10].

D. Sand

The sand used throughout this study was natural sea-dredged sand from the Bristol Channel. Some geometrical, mechanical and physical properties of the sand can be seen in Oti and Kinuthia [10]. The sieve analysis of the sand was performed in accordance with BS EN 933-1: [12] and the results are given in Table 3.

Table 3 - Sieve analysis of the limestone aggregate and sand

Sieve Sizs (mm)	Sand	Limestone 10/4.
31.5	100	100
16	100	100
8	100	77
4	100	2
2	83	0.3
1	54	0.28
0.5	21.8	0.19
0.25	6	0.14
0.125	1.2	0.1

III. METHODOLOGY

The control mix for the concrete in the current research work was designed using a PC content of 374 kg/m3. The water/binder ratio was 0.5, with a slump value of 7mm. In order to investigate the cement replacement potential of Fly Ash, the investigation used up to 30% Fly Ash to replace the PC in the control mix, in various combinations as shown in Table 4. The intention is to maintain a specified consistency but to obtain usable concrete, irrespective of consistency, using Fly Ash and, if possible, without using superplasticisers, which is more cost-effective. The first mix to be referred to as JO1, is the control mix. For the second mix (JO2), the PC in the control concrete was be replaced with 5% Fly Ash. In the third mix (JO3), the PC in the control concrete was be replaced with 10% Fly Ash. For the forth mix (JO4), the PC in the control concrete was be replaced with 15% Fly Ash. In the fifth mix (JO5), the PC in the control concrete was be replaced with 20% Fly Ash. For the sixth mix (JO6), the PC in the control concrete was replaced with 25% Fly Ash. The final mix (JO7), was produced by replacing the PC in the control concrete with 30% Fly Ash.

Table 4 - The mix composition

Mix Code	Binder (kg)		Coarse Aggregate (kg)		Sand	Water
	PC	PFA	20./10	10./4	(kg)	(kg)
JO1 (Control)	5.69	0	11.94	5.12	11.52	2.97
JO2	5.40	0.29	11.94	5.12	11.52	2.97
JO3	5.12	0.59	11.94	5.12	11.52	2.97
JO4	4.84	0.85	11.94	5.12	11.52	2.97
JO5	4.55	1.14	11.94	5.12	11.52	2.97
JO6	4.27	1.42	11.94	5.12	11.52	2.97
JO7	3.98	1.71	11.94	5.12	11.52	2.97

Cube (100 mm × 100 mm × 100 mm) test specimens were used in the production of all the concrete. For all mix compositions, the test specimens, were prepared in accordance with BS EN 206 [13], BS EN 12350-1 [14] and BS EN 12390-1 [15]. The consistency of the fresh concrete was measured using slump test in accordance with BS EN 12350-2 [16]. De-moulding of the test specimens was done after 24 hours. The curing of the test specimens were carried out in accordance with BS EN 12390-2 [17]. All the cube specimens were tested for 7, 14 and 28 day compressive strength in accordance with BS EN 12390-3 [18] and BS EN 12390-4 [19]. For all mix compositions, the results reported are the average obtained from five individual specimens for compressive strength.

RESULTS

The results for the slump for each of the mixes are presented in Figure 1. It can be seen that the more PFA there is in the mix, the higher the slump value, suggesting that more PFA gives a wetter mix.

The slump values varies from 7mm slump for mix JO1 with no PFA in the mix, to 50mm for JO7; giving an early indication as to the behaviour of the concrete in a fresh state. The trend is relatively constant throughout the range of mixes, however, two anomaly points were observed. Mix JO4 shows a lower slump from the linear trend-line of the other mixes; as does JO7, which shows no increase in slump value compared to JO5, even though additional 5% PFA was added to the mix.

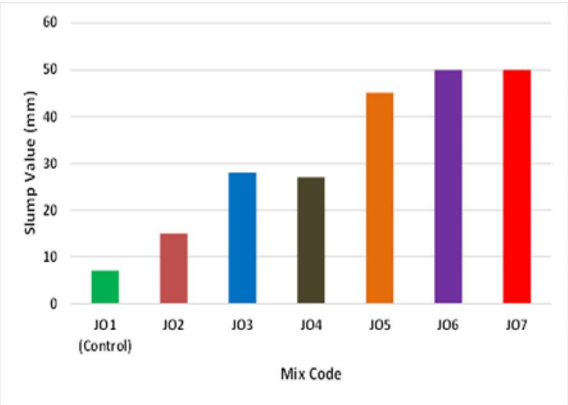

Figure 1 - Slump value for all mixes

Figure 2 shows the results of the compressive strength test for 7, 14 and 28 days. There was a progressive increase in strength values for all the mix compositions with age. The highest 7 day strength observed was, JO1 which was the control mix; while the lowest strength was observed for mix JO7, where PC in the control mix was replaced by 30% PFA. Increasing the PFA content of a concrete mix caused a reduction in compressive strength in early age.

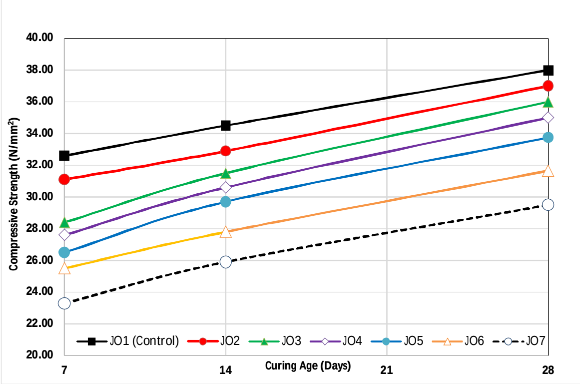

Figure 2 - Compressive Strength for all mixes

DISCUSSION

There were some observed variations in the slump values of the various mixes with the addition of PFA. A continual trend of increasing slump values developed for every percentage increase in the amount of PFA in the concrete mix, except in mixes JO4 and JO7. In compliance with BS EN 12350 [16], the seven mixes produced can be categorised, resulting in JO1 being not classified (i.e. below 10mm), JO2 to JO4 being classed as S1 and JO5 to JO7 being classed as S2. The increase in slump values with PFA addition may be attributed to the extremely spherical particle shape of PFA which may act as miniature ball bearings within the concrete mix, thus providing a lubricant effect [10]. Using the PFA would make the consistency of the concrete mixes flow more easily on site and so speed up the construction process. Mixes JO6 and JO7 had the largest slump values making the concrete wetter. These mixes also had the highest PFA content as the water content was identical in all mixes. The results showed that PFA can be used not only as a cement replacement material but also as a substitute for water content.

The variations observed with regards to the compressive strength were a progressive increase in strength values for each mix composition, as the curing age increased. Mix JO1, the control mix, attained a higher strength at 28 days. This higher strength gain may be due to the gradual formation of the calcium silicate hydrate gel (C-S-H gel) in the hydration process. The more PFA in the mix, the lower the overall strength of the mix. PFA was found to have an increased effect on concrete strength development at later age. To further understand the long term effect of adding PFA to concrete, it is necessary to test the strength at later age (beyond 28 days).

CONCLUSIONS

The investigation carried out in the current study has demonstrated the potential of replacing up to 30% of

PC with PFA. The key conclusions that can be drawn from this investigation are summarised in the following list:

1) There was variation in the slump values of the concrete mixes with the addition of PFA. The lowest slump value was observed from the control mix while the highest slump value was observed from mixes JO6 and JO7, these are the mixes where 25% and 30% of the PC in the control mix was replaced with PFA.
2) The results of the compressive strength test showed that the highest strength value was obtained for the control mix while lowest strength was obtained from the concrete where 30% of the PC in the control concrete was replaced with PFA.

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