Comparative Study of Physico-Mechanical Properties of Partial replacement of Cement by Fly Ash and Fly-Ash Geopolymer Paste

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Abstract: This study investigates the effect of partial replacement of Ordinary Portland Cement (OPC) with Fly Ash (FA) on the physico-mechanical properties of the paste. Specimen were prepared with OPC (%): FA (%) ratios of 100:0, 90:10, 80:20, 70:30 and 0:100.Comparision were studied in terms of compressive strength, bulk density, apparent porosity. Incorporation of fly ash to OPC decreases the compressive strength and Bulk Density of the paste with increasing amount of replacement. Geopolymer Specimens were observed to have early gain in mechanical strength.

***IndexTerms* – OPC, Fly Ash, Geopolymers**

I. Introduction

As the process of growth and development progress, the demand for construction materials is also ever increasing and the consumption rate of Portland cement is second only to water [1]. The global warming which is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2) contributes about 65% of global warming [2]. It is a known fact that one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [3]. It has been estimated that around 5% of the total man – made CO_2 emission is due to the production of Portland cement clinker and the figure is expected to rise up to 6% by the year 2015 [4]. Geopolymer, as an alternative binder to the Portland cement, shows considerable promise for application in concrete industry. Any pozzolanic compound or source of silica and alumina such as fly ash (FA), ground granulated blast furnace slags (GGBFS) with strong alkali solutions such as potassium hydroxide (KOH), sodium hydroxide (NaOH) and soluble silicates (in most cases) such as sodium silicate where the dissolved $Al2O_3$ and SiO_2 species undergoes geopolymerisation to form a three-dimensional amorphous aluminosilicate network with strength similar or higher than that of OPC concrete geopolymer [5].

The fact that there is abundance of industrial by-products generated in various industries that was found to be suitable to use as geopolymer source materials thrive the idea of potential replacement of traditional OPC binders [6].Fly ash (FA), an industrial by-products of coal burning power plant industry, makes up of 75–80% of global annual ash production yielded geopolymer concrete with better mechanical and durability properties as compared to OPC concrete [7–12].

II. Experiment Procedure

2.1 Materials and Methods

a) Cement

Ordinary Portaland Cement of 43 Grade (Ultratech Cement) was used in the study. The Specific Gravity of cement was found out to be 3.15 with initial setting time of 54 min. and final setting time of 251 minutes. Standard Consistency value of 31% were noted. Test on cement were carried out as per IS 1269-1987.

b) Fly Ash

Low calcium class F fly ash (Fig.1) were procured from Kolaghat Thermal Power Plant. Kolaghat, West Bengal, India.

Table 1 Chemical composition of Fly ash used (% mass)

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	LOI
Percentage (%)	56.01	29.8	3.58	1.75	2.36	0.30	0.73	0.61	Nil	0.44	0.40

LOI – Loss on ignition

The sum total of SiO_2, Al_2O_3 and Fe_2O_3 equaled to 89.39%. Calcium oxide (CaO) content was less than 10%. Hence, as per ASTM C 618-03, it can be classified as class F fly ash.

c) Alkaline Activators

The alkaline activating solution used in the manufacture of fly ash based geopolymer composites was a mixture of sodium hydroxide solids, sodium silicate solution and water. Sodium hydroxide (NaOH) solids were laboratory grade in pallet form with 98% purity having a specific gravity of 2.15. Sodium silicate (Na_2SiO_3) solution had a chemical composition of Na_2O=8%, SiO_2=26.5% and H_2O=65.5% and bulk density of 1410 Kg/m^3. Both the chemicals were supplied by LobaChemie Ltd, India.

2.2 Specimen Nomenclature and Mix –Proportions

The specimens prepared for studying the physico-mechanical properties are OPC paste, partial replacements of OPC with FA and geopolymer pastes. The size of the specimens were (50×50×50 mm) and the mix proportions of the specimens are given in Table 2. The nomenclature of the specimen were given in alphanumeric system where the alphabets “C” and “F” denotes Cement and Fly Ash respectively and the numeric denotes the percentage of the each components.C100 and F100 represents OPC paste and Fly Ash geopolymer paste. For serial no. 1 to 4, the specimen are casted in the cube mold and demolded the next day and kept in a dry shade until the day of testing. For specimen F100, alkaline solutions of required quantities of NaOH pallets and water were mixed depending on the desired Na_2O content of the activator to make sodium hydroxide solution. It was then mixed with required quantity of sodium silicate solution for a desired SiO_2 content. The resulting activator solution was left in ambient temperature for one day before using in the preparation of geopolymer mix. Fly ash are than mixed with activator solution and cast into the mould and oven dried at 80°c for 24 hours.

Table 2 Details of test specimens

Sl. No.	Specimen ID	Cement (%)	Fly ash (%)	Water/Binder ratio	$\%Na_2O$	$\%SiO_2$
1.	C100	100%	0%	0.31	-	-
2.	C90	90%	10%	0.31	-	-
3.	C80	80%	20%	0.31	-	-
4.	C70	70%	30%	0.31	-	-
5.	F100	0%	100%	0.34	8.0%	6.5%

2.3 Test Procedure

a) Compressive Strength

The direct compressive strength of hardened geopolymer specimens was determined at the age of 7 ,14 and 28 days by 2000kN capacity Compression Testing Machine. In each case, three identical specimens were tested in accordance to ASTM C-109-02 and the average values reported as compressive strength. A typical test setup for compressive strength is shown in Figure 1.

Fig. 1 Compression Testing Machine

b) Bulk Density and Apparent Porosity

The bulk density and apparent porosity were determined for 28 days old specimens. The following procedure was followed for the test.

i. The specimens are dried in a ventilated oven for 24 hours at a temperature of 105˚C.
ii. Weight of the dried specimens are measured and recorded as $\mathbf{W_d}$.
iii. Specimens are then soaked in water for 24 hours.
iv. After removal from water, specimens are suspended by a thin wire inside water and its weight recorded as **Wi.**
v. The specimens are then wiped dry and its weight measured in saturated surface dry condition as **Ws.**

The bulk density and apparent porosity of the specimens are determined using the relationships given below:

$$\textbf{Dry density (Kg/m3)} = \frac{Wd}{Ws-Wi}\times 1000 \quad (1)$$

$$\textbf{Apparent porosity (\%)} = \frac{Ws-Wd}{Ws-Wi}\times 100 \quad (2)$$

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c) Water absorption

The volume of pore space in a specimen matrix, as distinct from the ease with which a fluid can penetrate it is termed as absorption. Water absorption is usually measured by drying a specimen to a constant mass, immersing it in water, and measuring its increase in mass as a percentage of dry mass. The procedure followed for determination of water absorption of geopolymer specimens was in accordance to ASTM C-642. 28 days old specimens were dried at 105°C for 24 hours and immersed in water after measuring its weight. The specimens were then removed from water and wiped clean and immediately weighted in saturated surface dry (SSD) condition to find increase in weight

III. RESULTS AND DISCUSSIONS

a) Compressive Strength

It was observed that the control specimen C100 has the highest compressive strength of 44.57 MPa and the geopolymer paste F100 has the lowest compressive strength of 27.38MPa after 28 days. It is observed that as the partial replacement of cement by Fly Ash from (10 – 30) %, there is decrease in the compressive strength of the specimen from (41.29-25.78) MPa. Similar trends were also observed on 7 days and 14 days specimens. However, for geopolymer specimen F100, 7 days, 14 days and 28 days strength were almost similar indicating the early development of mechanical strength in the geopolymers.

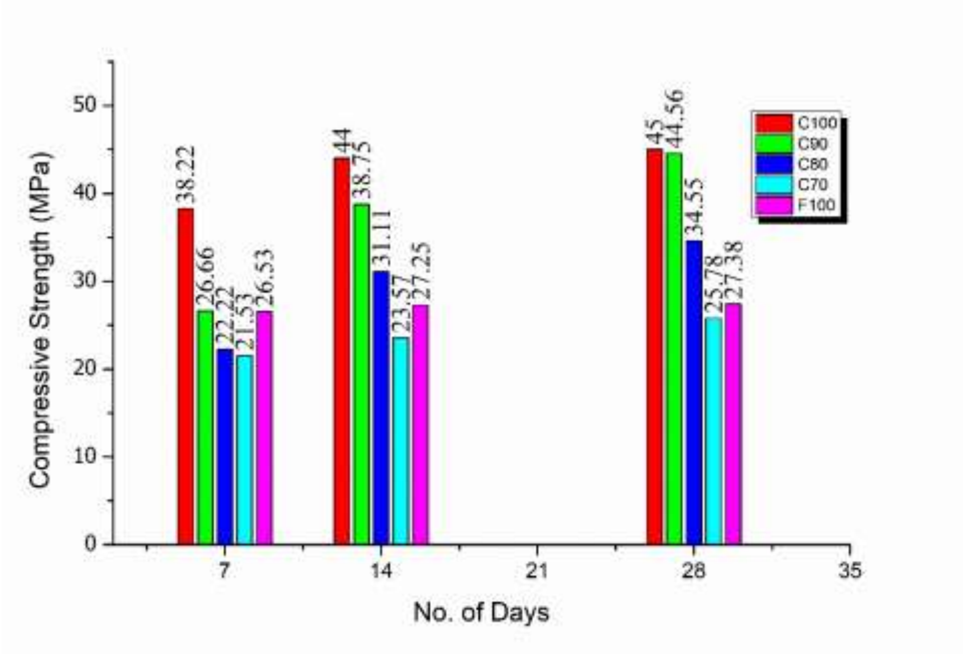
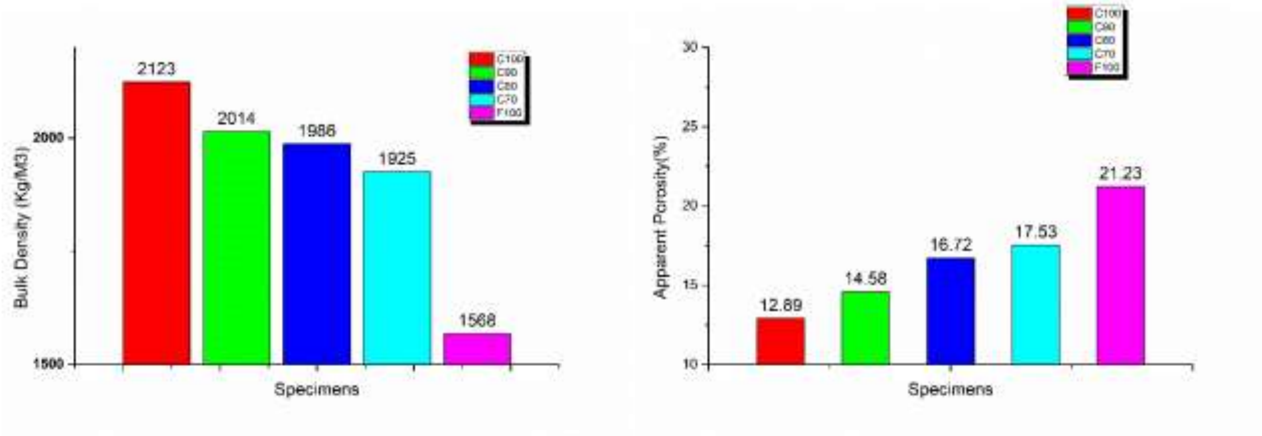


Fig. 2 Compressive Strength of specimens

b) Bulk Density and Apparent Porosity



(a) (b)

Fig. 3 Bulk Density and Apparent Porosity of the Specimen

It was observed in Fig, 3 (a) that the bulk density of cement paste specimen C100 is maximum with 2123 Kg/M^3 and the bulk density of geopolymer paste specimen F100 is minimum with 1568 Kg/M^3. Bulk density of cement paste C100 is more due to less porosity in the specimen. Bulk density of Pozzolanic cement paste specimen C90 is found to be lower than cement paste specimen C100 since the void of the specimen increases with increase in fly ash content. Therefore, the bulk density in specimen C80 and C70 also decreases with increase in fly ash content respectively.F100 specimen gives the lowest bulk density due to the low amount of alkali (8% Na_2O) in the activator solution which may not be sufficient to breakdown the fly ash completely to form geopolymer gel. From Fig.3 (b), it can be noticed that cement paste C100 has the lowest porosity of only 12.89%. Pozzolanic Cement paste specimen C90 shows slightly higher porosity than C100.The porosity of pozzolanic cement paste increases with increase in fly ash content in specimen C80 and C70 respectively.

c) Water Absorption

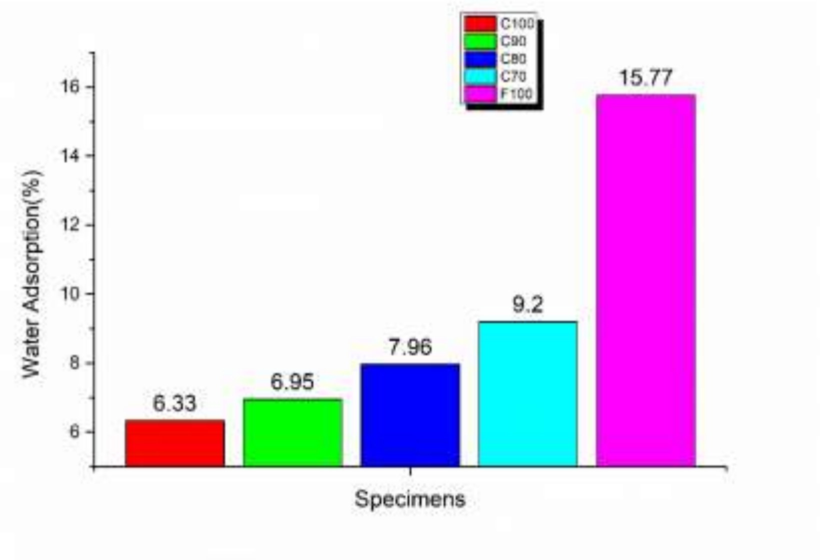


Fig. 4 Water absorption of the Specimen

Water absorption test is simple test but has a lot of significance. Figure 4 present the water absorption values for the specimens. It can be observed that cement paste specimen C100 has very low water absorption of 6.33%.The water absorption of pozzolanic cement paste is recoreded higher than C100 due to its higher amount of void content. GP specimen also recorded highest porosity and this is the reason for higher water absorption . In the geopolymer, the properties can be improved by increasing the quantity of Na_2O and SiO_2 in the activator solution.

IV. CONCLUSIONS

Compressive strength of cement mortar in the present work is comparatively higher than those of geopolymer specimens. However, geopolymer specimen can give sufficient strength for construction work even at the age of 7 days. For geopolymer mortar and concrete, the strength can even be increased. The bulk density of cement mortar is higher than those of cement paste and geopolymer specimens studied in the project work. However, the bulk density of geopolymer paste specimen increases with increase in Na_2O content. Apparent porosity of geopolymer paste specimens are higher in comparison to those of cement mortar and cement paste due to incomplete breakdown of fly ash particles and hence lesser formation of geopolymer gel. Among the specimens in the present study, water absorption of geopolymer specimens are higher which can be attributed to its higher porosity.

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