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Development of Fly Ash based Geopolymer High Performance Concrete

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***Abstract:** This paper provided the mix proportioning for development of geopolymer high performance concrete by using processed fly ash. Alkaline binder ratio was used as 0.35, 0.30, 0.25 and 0.20. Alkaline activators such as sodium hydroxide and sodium silicate were used. Molarity for sodium hydroxide solution was maintained as 12M. Processed fly ash with fineness of 638 m^2/kg was used. Target compressive strength was considered more than 65 MPa. Oven heat curing was provided for cast samples at 90°C and tested for average compressive strength after 3 hours, 8 hours and 24 hours heat curing period. Experimental results indicated that as the alkaline binder ratio reduces, the compressive strength also decreases.*
***Keywords:** Geopolymer high performance concrete, Fly ash, Alkaline binder ratio, Compressive strength.*

I. INTRODUCTION

The development of geopolymer concrete is part of a broader trend in the construction industry towards more sustainable and environmentally friendly materials. Continued research and collaboration between academia, industry and standard setting bodies are crucial for the widespread adoption of geopolymer concrete in mainstream construction practices. Fly ash, a by-product of coal combustion, emerged as one of the primary materials for geopolymer concrete. Researchers explored the reactivity of fly ash with alkaline solutions, leading to the development of fly ash based geopolymers. This marked a crucial step in the evolution of geopolymer technology. Geopolymer High Performance Concrete (GHPC) is an innovative and advanced construction material that represents a significant departure from traditional Portland cement based concrete. Unlike conventional concrete, which relies on Portland cement as a binder, GHPC utilizes geopolymers as the binding agent. Geopolymers are inorganic, amorphous materials formed through the chemical reaction of alumino silicate materials with alkaline activators. The challenges such as the availability of suitable raw materials, standardization and widespread acceptance in the construction industry need to be addressed for the broader adoption of geopolymer high performance concrete. Ongoing research and development efforts aim to further optimize the formulation, production processes and application of this innovative concrete technology.

Davidovits, a French chemist, discovered that alkali solution and aluminosilicate compounds reacted to make alkali aluminosilicate compounds. These compounds showed good binding properties and resembled the calcium silicate hydrate (C-S-H) gel that forms in OPC concrete. An alkaline solution (Na/K-silicates/hydroxides) can be used to activate alumino-silicate source materials, such as FA or GGBS, to produce binders and prepare Geopolymer. GPs have good mechanical qualities, strong acid resistance, and stability even after being exposed to high temperatures [1]. Precursors and reaction state are crucial in determining how end products are formed and, consequently, what characteristics they have. The parameters that have the most influence include the Si/Al ratio, types of alkali activators, network modifier content (Na or Ca), alkali molarity, curing conditions, and additives. The following summarizes a few published studies on the impact of reaction parameters and sources. Reports are available regarding the impact of alkali activator concentration on Geopolymer generated from various sources, including FA, GGBS, metakaolin, rice husk ash, waste clay brick powder, combining FA and GGBS, and one-part GPC [3]-[13].

II. MATERIALS AND METHODOLOGY

A. Fly Ash

Fly ash is a fine, powdery, and predominantly siliceous or alumino silicate material that is a by-product of coal combustion in thermal power plants. It is one of the primary raw materials used in the production of geopolymer concrete. Utilizing fly ash in geopolymer concrete has environmental benefits, as it repurposes a waste product (fly ash) and reduces the need for traditional Portland cement, which is a significant contributor to carbon dioxide emissions. The processed fly ash having fineness 638 m2/kg procured from Dirk India Pvt. Ltd., Nashik region was used for present experimental investigation.

B. Sodium Hydroxide solution

Sodium Hydroxide in the form flakes were used for present experimental investigation with purity of 96% as minimum assay.

C. Sodium Silicate solution

Sodium Silicate in the form liquid was used for present investigation with weight ratio of Na2O: SiO2 as 1:2.17 was used.

D. Coarse Aggregate and Fine Aggregate

Well graded Coarse Aggregate (CA) of sizes 20 mm and 10 mm were used in percentage combinations of 60:40 for present experimental investigation with specific gravity of 2.7 and 2.68 respectively. Fine aggregate with Fineness Modulus as 2.7 and specific gravity as 2.63 was used.

E. Water

Potable water was used for present experimental investigation.

F. Superplasticizer

Naphthalene based superplasticizer was used for present experimental investigation to improve the workability of geopolymer concrete mixes.

G. Ingredients for Geopolymer high Performance Concrete mix Proportioning

Following ingredient quantities are obtained as per the mix proportioning designed for alkaline binder ratios of 0.35, 0.30, 0.25 and 0.20 in development of fly ash based geopolymer high performance concrete. Degree of workability, fineness of fly ash and weather temperature plays an important role in determination of total water quantity including extra water. The required proportions with different ingredients for different alkaline binder ratios were shown in Table 1.

TABLE I
QUANTITIES REQUIRED FOR 1 CUM OF GHPC WITH DIFFERENT ALKALINE BINDER RATIOS

Ingredients	Fly ash binder	NaOH solution	Na_2SiO_3 solution	FA (sand)	CA	Total water	(AL/B) ratio
Quantity [kg/cum]	600	105.1	105.1	618	1147	117.75	0.35
		90.5	90.5	623	1156	139.65	0.30
		75	75	625	1163	156.61	0.25
		60	60	630	1171	173.29	0.20

III.EXPERIMENTAL WORK

For present experimental work, geopolymer concrete mixes were prepared by using drum pan mixer and table vibrator with cube mold sizes of 150 x 150 x 150 mm and 100 x 100 x 100 mm for measurement of compressive strength under Compression Testing Machine (CTM) with capacity 3000 kN.

A. Preparation of Sodium Hydroxide and Sodium Silicate solution

Sodium Hydroxide solution with required Molarity was prepared with required quantity of water one day before to cast of geopolymer concrete samples. Care must be taken for preparation of Sodium Hydroxide solution as large amount of heat is evolved during preparation.

Sodium Silicate solution in the form of liquid was used and mixed carefully with other ingredients.

B. Geopolymer concrete mixes preparation

All ingredients were weight out individually and mixed in rotating drum pan mixer carefully with required quantity of superplasticizer as per mix design calculations.

C. Workability of fresh geopolymer concrete mixes

Workability for fresh geopolymer concrete mixes for alkaline binder ratios were measured by using flow table apparatus as shown in Fig. 1 below. Workability of fresh geopolymer concrete mixes measured as per BIS:5512 and BIS:1727.

Fig. 1 Flow table apparatus with fresh geopolymer concrete mix.

IV. RESULTS AND DISCUSSIONS

For present experimental investigation, GHPC have developed by using processed fly ash. Experimental results were studied with variation of alkaline binder ratios.

A. Experimental test results of GHPC for alkaline binder ratios

GHPC have developed by using processed fly ash with alkaline binder ratios as 0.35, 0.30, 0.25 and 0.20 as per the mix proportioning method developed. After measuring the workability by flow table apparatus, freshly mix geopolymer concrete mixes were cast with cube mold sizes of 150 x 150 x 150 mm, 100 x 100 x 100 mm and demolded after 24 hours of rest period. The cast samples were provided with oven heat curing. Geopolymer samples were tested for compressive strength after 3 hours, 8 hours and 24 hours of heat curing period under Compression Testing Machine (CTM). Experimental results were represented in tabular form for different alkaline binder ratios. As a result, Fig. 2 depicts the geopolymer concrete samples tested under CTM.

Fig. 2 Compression testing machine with geopolymer concrete samples

The experimental test results have shown in Table 2 as below.

TABLE III
EXPERIMENTAL TEST RESULTS OF GHPC FOR DIFFERENT AL/B RATIOS

Sr. No.	Observation	Mixes without superplasticizer				Mixes with Superplasticizer			
1	Alkaline Binder ratios	0.35	0.30	0.25	0.20	0.35	0.30	0.25	0.20
2	Heat curing temperature	90°C	90°C	90°C	90°C	90°C	90°C	90°C	90°C
3	Minimum mass density (kg/cum)	2489	2536	2543	2570	2540	2569	2550	2589
4	Average compressive strength at 3 hours oven heat curing (MPa)	20.75	18.43	21.42	21.41	24.53	22.40	19.41	17.80
5	Average compressive strength at 8 hours oven heat curing (MPa)	40.23	41.58	39.12	37.42	45.53	44.12	37.45	37.10
6	Average compressive strength at 24 hours oven heat curing (MPa)	71.23	69.45	65.40	62.57	73.30	70.22	68.57	59.23

The experimental test results have shown graphically in Fig. 3, Fig. 4 and Fig. 5 as below.

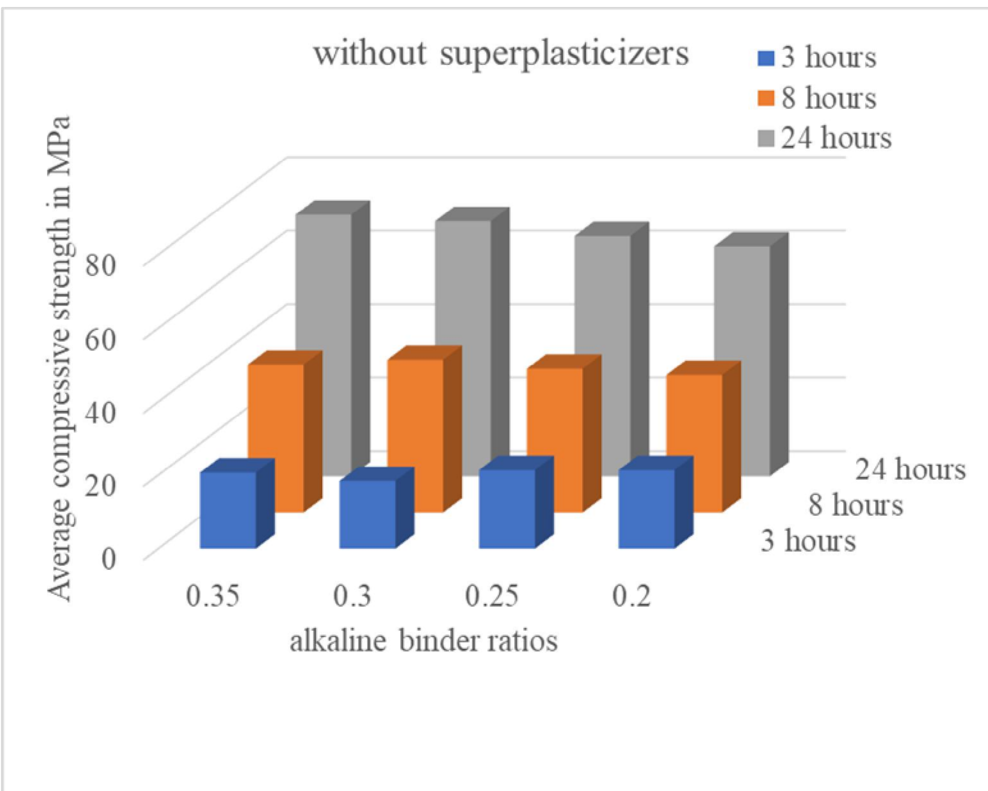

Fig. 3 Compressive strength for different alkaline binder ratios

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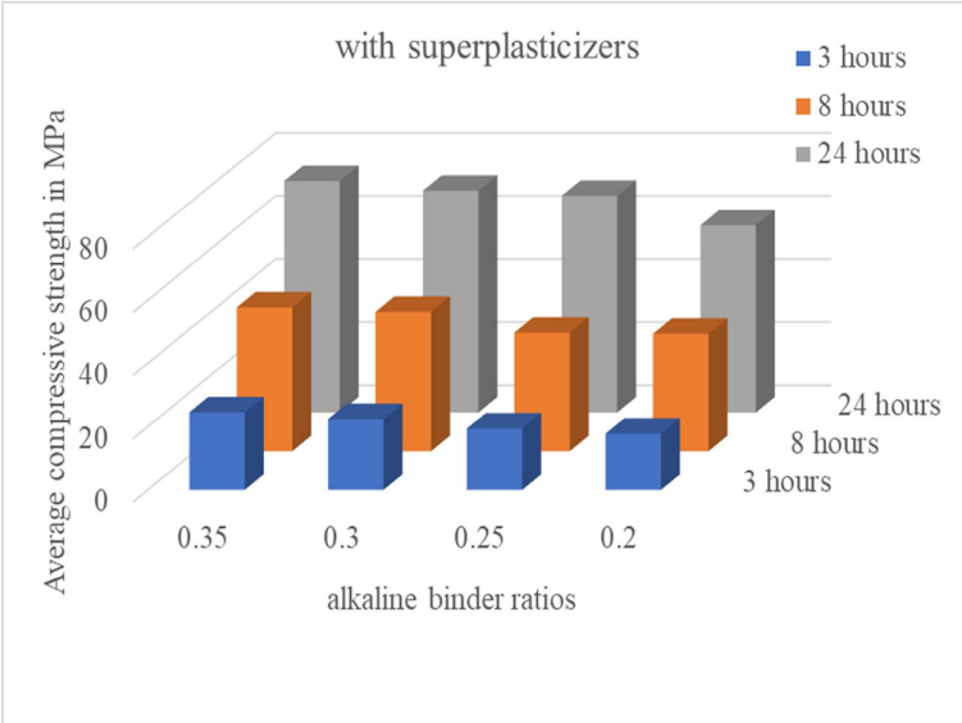

Fig. 4 Compressive strength for different alkaline binder ratios

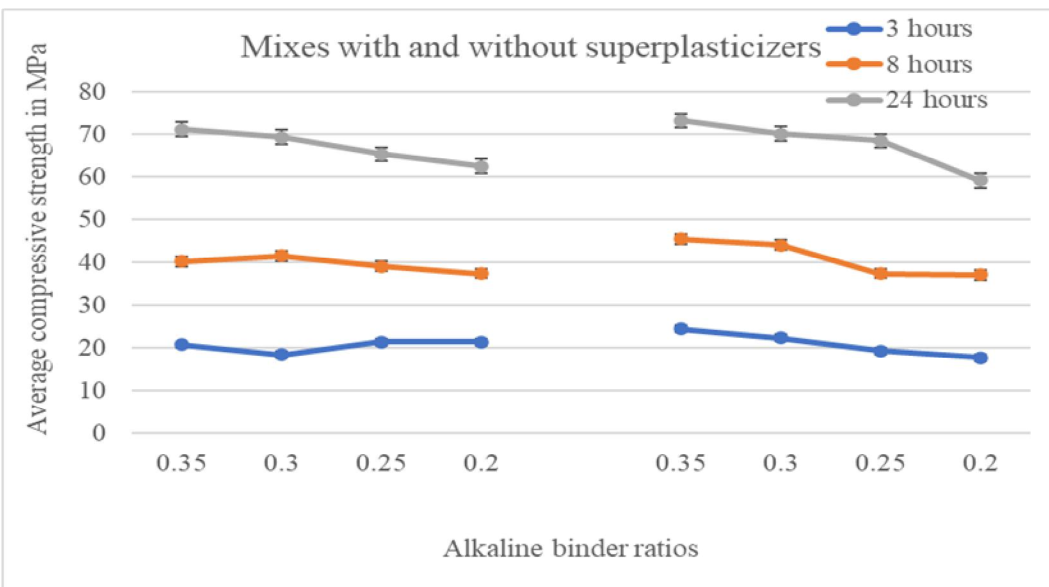

Fig. 5 Comparison of compressive strength with and without superplasticizers

V. CONCLUSIONS

The From the experimental investigation, the test results concluded in following ways as below.

The geopolymer high performance concrete [GHPC] have developed with compressive strength more than 65 MPa by using processed fly ash for alkaline binder ratios such as 0.35, 0.30 and 0.25.

Superplasticizer have used for enhancing workability purpose only. It does not contribute any compressive strength enhancement considerably in development of GHPC.

It was observed that as the alkaline binder ratio reduces, compressive strength also decreases.

Fineness of processed fly ash also considered an important parameter for strength development of GHPC.

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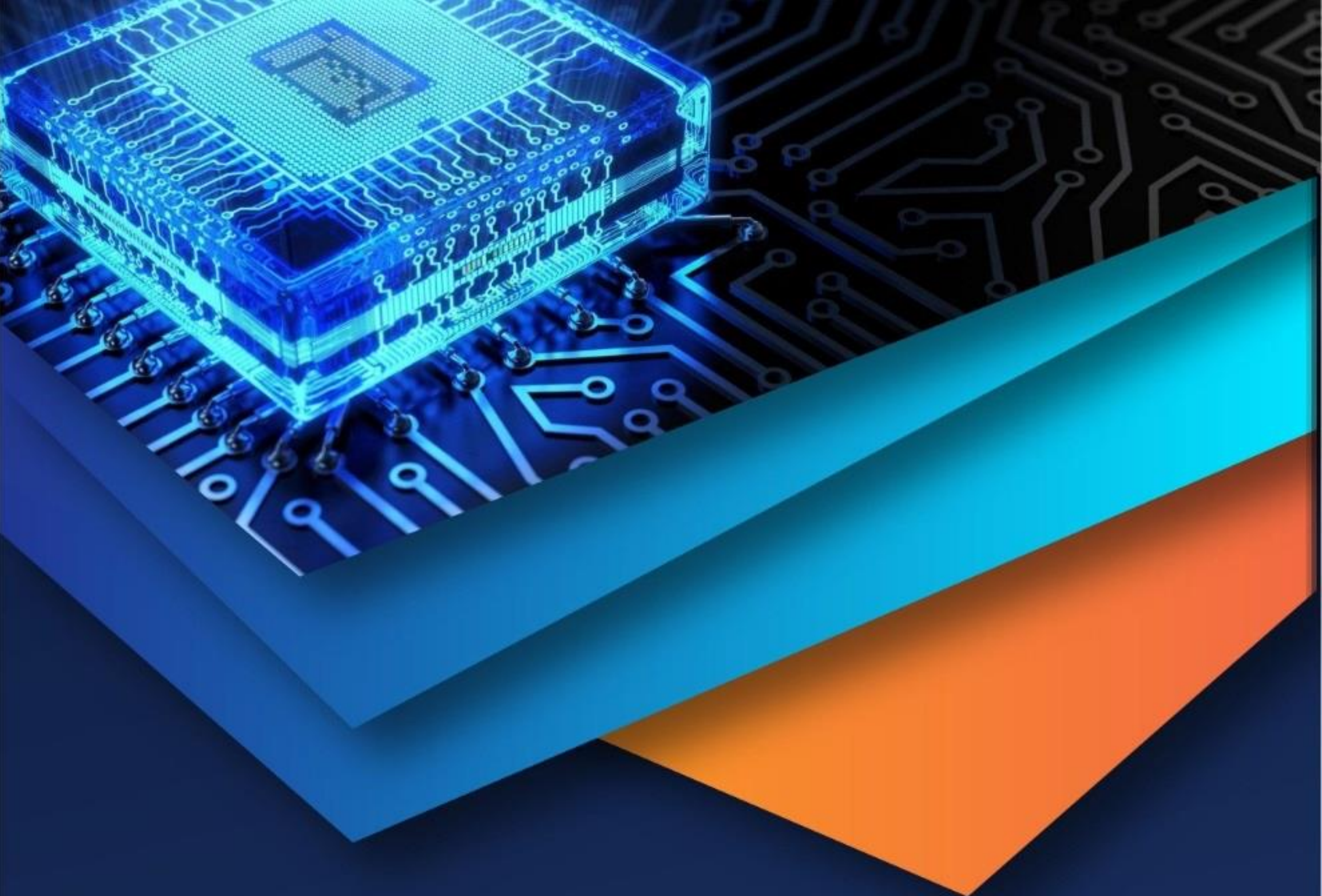

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