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An Experimental Study on Fly ash - based Geopolymer Concrete

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Abstract: This paper presents the progress of the research on making geopolymer concrete using fly-ash (VTPS-Vijayawada).The work aims at making and studying the different properties of geo-polymer concrete using this fly-ash and other ingredients like sand, coarse aggregate, sodium hydroxide and sodium silicate solution in different proportions. The actual compressive strength of the concrete depends on various parameters such as the ratio of the activator solution to fly-ash, molarities of the alkaline solution, ratio of the activator chemicals, curing temperature etc. some of the observations in making geopolymer concrete in the lab were presented in this paper.

1. INTRODUCTION

Fly-ash or coal ash has been partly used to replace cement in concrete industry for a long period because it contributes the beneficial properties to concrete. Fly-ash often incorporated in to the ordinary Portland cement as a value adding filler. In this system fly-ash is not highly reactive, but has been shown to improve properties such as workability and durability. Up to 55% of the cement binder can be replaced with fly-ash to make normal or high performance concrete. The idea to make concrete without manufacture cement has been purchased but not yet succeeded.

Geo-polymer, a new material gradually earns an interest from material scientists. Fly-ash is to replace totally manufactured cement to make concrete-like material. This will turn the construction material to the new era. Geo-polymer is an inorganic alumina-silicate polymer synthesized from predominantly silicon and aluminum material of geological origin or by-product materials such as fly-ash. Fly-ash based geo-polymer is made by mixing fly ash with sodium silicate solution and highly caustic hydroxide solution and cured at room temperature or at higher temperature.

Geo-polymer was first used by Davidovits {7}. Utilization of such a material to produce the valuable-added products is of considerable commercial interest.

The exact mechanism by which geo-polymer setting and hardening occur is not fully understood. Most proposed mechanisms consist of a dissolution, transportation or poly-condensation. Temperature environment is considered as the most factors that affects to any polymerization. The purpose of this research is to study the effect of mixing temperature and curing temperature on the compressive strength of mortars.Rangan.B.V.et al., [6] carried significant research work on geopolymer concrete using fly ash, sodium silicate and sodium hydroxide solutions. The authors have reported higher strength and better durability of geo polymer concrete than Portland cement concrete. J.S.J.vanDeventeretal., [3] have reported that mechanical properties and microstructure of Na-based metakaolin geo polymer are highly depended on composition of the alumino silicate gel particularly, alkali content and silica content. Raijiwala.D.B.etal. [5] studied on geopolymer concrete using the Ukai thermal power plant fly ash, Gujarat. Test results indicate GPC with higher concentration of sodium hydroxide in alkaline solution exhibited more compressive strength than lower concentration of NaOH. It is also concluded that GPC specimens cured at 60^0C show higher compressive strength than specimens cured at room temperature.

2. EXPERIMENTAL PROGRAM

In this work, low calcium (ASTM Class F) fly ash–based geopolymer is used as the binder material, instead of Portland or any other hydraulic cement paste, to produce concrete. The fly-ash based geo-polymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete. The manufacture of geo-polymer concrete is carried out using the usual concrete technology methods as in the case of OPC concrete. The silicon and the aluminum in the low-calcium fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geo-polymer paste that binds the aggregates and other un-reacted materials.

2.1 Materials

Table1 Chemical composition of Fly ash (%) &Metakaolin (%)

S.No	Parameters MK	% of mass	Parameters FA	% of mass
1	Loss on ignition	0.72	Loss on ignition	0.65
2	Al_20_3	41.95	Al_20_3	24.50
3	$Si0_2$	51.34	$Si0_2$	66.80

4	Fe_20_3	0.52	Fe_20_3	4.0
5	Cao	0.34	Cao	1.50
6	MgO		MgO	0.45
7	Na_20		Na_20	0.22
8	K_20		K_20	0.3

Materials includes Fly ash (F.A), Metakaolin(MK), Sand, Coarse aggregates, Alkaline liquid (AL), water, super plasticizer (SP).In the batches of fly ash, the molar Si-to-Al ratio was about 1-3. A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. The commercial grade sodium hydroxide (97%-100% purity) solution was prepared by dissolving the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar (M) and sodium silicate solution (Na_20=18.2%,$Si0_2$=36.7%,H_20=45.1%) were used as the alkali activators.

2.2 Mixture Proportions

Based on the limited past research on GP pastes available in the literature and the experience gained during the preliminary experimental work the following ranges were selected for the constituents of the mixtures used in the present study.

i. Low calcium (ASTM ClassF) dry fly ash is used as the base material

ii. Metakaolin as blending material to the base material Fly ash

iii. In general, ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, of 0.4-2.5 is being adopted by several researchers. This ratio was fixed at 2.5 for mixes because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution.

iv. Molarity of sodium hydroxide solution in the range of 8M to 14M

v. Ratio of activator solution-to-fly ash, by mass, is 0.35

vi. Coarse and fine aggregates are approximately 77% of entire mixture, by mass.

vii. Super plasticizer - 0% - 2% of fly ash, by mass

viii. Extra water when added in mass

2.3 Mixing, Casting and Curing

All materials were mixed manually in the laboratory at room temperature. The total experimental program is divided into two parts. In the first part, the aggregates were mixed homogeneously with the base material fly ash and in the second stage of program fly ash (50% by mass) is replaced with metakaolin. To the above said dry mixes, the alkaline solution which was made one day before and super plasticizer were added. The sodium hydroxide and sodium silicate solutions were first mixed with each other and stirred to obtain a homogeneous mixture of the solutions before adding them to solids. A pan type concrete mixture was used for obtaining uniform mixture .Fig1(c) shows typical dry mixture of solids that was used to make the cube (100x100x100mm) specimens.

(a) Na_2SiO_3 solution

(b) NaOH pellets

(c) Dry mixing of fly ash and aggregates

Fig. 1

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The fresh geopolymer concrete was used to cast cubes of size 100mm x 100mm x 100mm to determine its compressive strength. The specimens were prepared according to the method followed by Hardjito et al., [4]. Each cube specimen was cast in three layers by compacting manually as well as by using vibrating table. The specimens were wrapped by plastic sheet to prevent loss of moisture and placed in an oven. Since the process of geo polymerization needs curing at high temperature, these specimens were cured at two different temperatures 60^0C and 90^0C for 24 hrs in the oven as shown in Fig.2 (b).The specimens were temperature cured for 24hrs and then left to open air in the laboratory until testing

(a) Slump of fresh GPC,

(b) Oven Curing

(c) Testing of Cubes

Fig.2

3. TEST RESULTS

The effects of various parameters on compressive and tensile strengths of GPC are discussed by considering ratio of alkaline solution to fly ash and alkaline solution to (fly ash + metakaoline), by mass, as 0.35. The following parameters were considered in the present study.

i. Concentration of sodium hydroxide solution in molar

ii. Curing temperature

All the specimens were tested for compressive and tensile strengths using the compression testing machine of 200t capacity. The cubes were tested at the age of 7 and 28 days.Fig.2(C) shows the testing of cubes cured at 90^0C . The test results of cube and cylindrical specimens are presented in Table 1 and 2.The addition of naphthalene sulphonate-based super plasticizer, up to1.5% of fly ash by mass, to Mf series & Mfm series improves the workability of the fresh geopolymer concrete.

Table. 2 Details of Mixtures

Mix No	**Aggregates**				**Fly Ash (kg)**	**Meta Kaoline (kg)**	**NaoH**		**Sodium Silicate (kg)**	**Added Water (kg)**	**Super Plasticizer (kg)**	**Sodium silicate / NaOH**
	20mm (kg)	12mm (kg)	7mm (kg)	Sand (kg)			Mass (Kg)	Molarity				
Mf1	260	350	610	628	408		41	8	103	20.1	6.1	1
Mf2	260	350	610	628	408		41	14	103	20.1	6.1	1
Mf3	260	350	610	628	408		41	8	103	20.1	6.1	2.5
Mf4	260	350	610	628	408		41	14	103	20.1	6.1	2.5
Mfm1	260	350	610	628	204	204	41	8	103	20.1	6.1	1
Mfm2	260	350	610	628	204	204	41	14	103	20.1	6.1	1
Mfm3	260	350	610	628	204	204	41	8	103	20.1	6.1	2.5
Mfm4	260	350	610	628	204	204	41	14	103	20.1	6.1	2.5

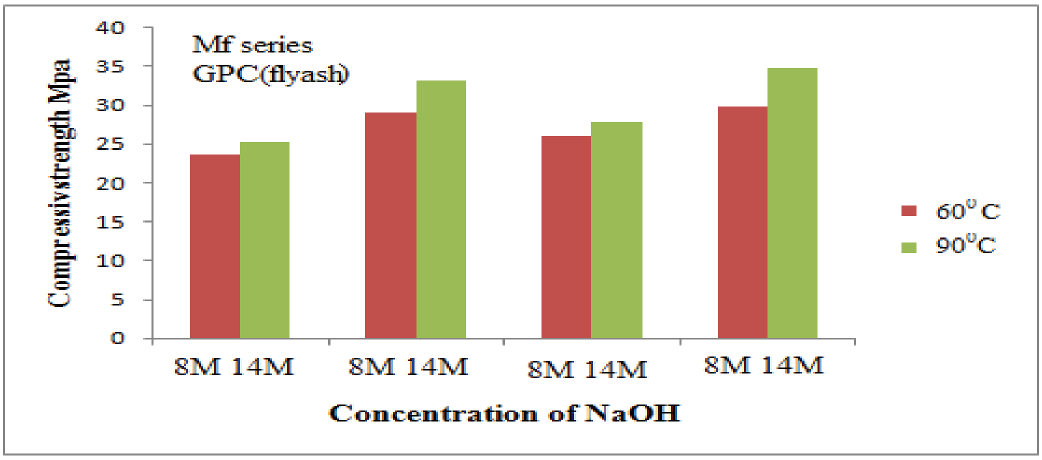

Fig. 3. Effect of Curing Temperature and Concentration of NaOH on Specimens tested at the age of 7 days

Table.3 Test results of Fly ash based GPC

Mix	Concentration of NaOH	Sodium silicate /Sodium hydroxide	Compressive strength Cured at 60^0Cfor 24hrs N/mm^2		Compressive strength Cured at 90^0Cfor 24hrs N/mm^2		Tensile Strength (N/mm^2) 60^0C 90^0C	
			7d	28d	7d	28d	28d	28d
Mf1	8M	1	23.7	29.3	25.2	29	3.29	4.02
Mf2	14M	1	26	31.2	27.9	33.3	3.45	4.4
Mf3	8M	2.5	29	35.8	33.2	39.2	3.67	4.86
Mf4	14M	2.5	29.8	36.5	34.76	42	3.9	4.9
Mfm1	8M	1	23.7	30.8	28	33.04	3.74	4.2
Mfm2	14M	1	29.3	34.2	35.8	42.2	4.24	5.14
Mfm3	8M	2.5	33.6	40.3	38.2	45.25	4.25	5.36
Mfm4	14M	2.5	34.3	41.3	40.86	49.4	4.6	5.75

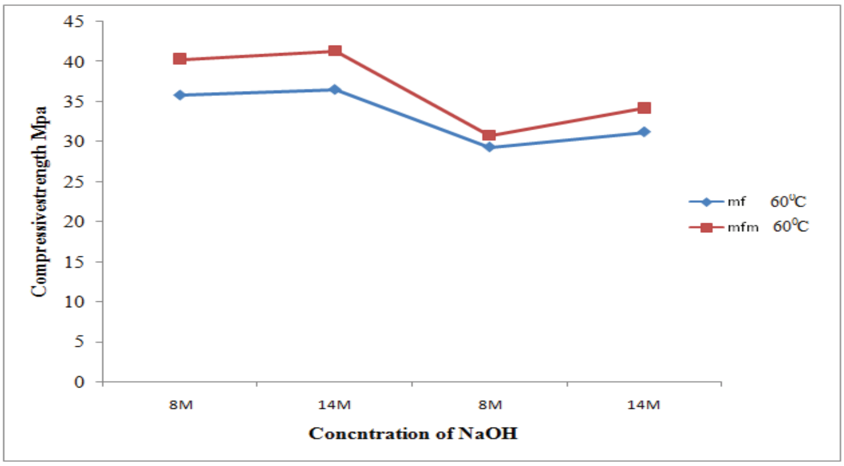

Fig. 4. Influence of blending Fly ash with Metakaolin on Compressive strength of cubes tested at the age of 28 days

3.1Concentration of sodium hydroxide solution in molar

Two different molarities 8M and14M of sodium hydroxide were used. Compressive strength result shows that higher concentration of NaOH yields higher compressive strength. 7 days and 28 days compressive strength of the mixture 3 are 33.2Mpa and 39.2Mpa and for mixture 4 are 34.8Mpa and 42.0Mpa respectively for Mf series as shown in Table 3.

3.2 Ratio of Sodium silicate solution-to-Sodium hydroxide solution

The effect of ratio of sodium silicate solution-to- sodium hydroxide solution by mass, on compressive strength of concrete can be seen by comparing results of Mf 1&3 as well as 2&4.For mixtures 1 &3, though the concentration of NaoH solution (8M) is the same, in mixture 3, sodium silicate solution-to- sodium hydroxide solution ratio is higher than that of mixture 1.This change increased the compressive strength of mixture 3.The effect of such alkaline solution is shown in Table.3. Similar behavior is also observed in mixtures Mfm1-to-Mfm4.

3.3 Curing Temperature

Comparative results of compressive strengths of concretes are shown in Table.3.It was found that in both the mixtures(Mf & Mfm), the specimens cured at 60^0C exhibited low compressive strengths compared to specimens cured at 90^0C.From this it can be inferred that as the curing temperature increases, the compressive strength of fly ash-based GPC mixtures increases.

3.4 Compressive strength and split tensile strength

Table.3 &Figures 3 &4 clearly indicate that the influence of parameters like concentration of NaOH solution in terms of molarity, ratio of sodium silicate solution-to–sodium hydroxide solution and curing temperature(keeping curing timing constant i.e. 24hrs) on the compressive as well as tensile strengths of GPC mixtures. As the concentration of NaOH solution in terms of molarity increased from 8M to 14M, the compressive strengths in both the series (Mf &Mfm) also increases. The GPC mixtures show higher values for 7d and 28 days of compressive and tensile strengths for sodium silicate solution-to–sodium hydroxide solution ratio 2.5. Cubes cured at 90^0C yielded higher compressive strengths compared to specimens cured at 60^0C. Out of all 8 types of mixtures presented in the Table.3, the mixture Mfm4 shows larger values of compressive and tensile strengths. The reason for this increase in values may be attributed to the blending of fly ash with another type of mineral admixture, metakaolin. From Table.1 it can be observed that metakaolin possesses higher Al_2O_3 content than fly ash.

4. CONCLUSIONS

1. Higher concentration of sodium hydroxide solution results in higher compressive strength of Geo Polymer Concrete.
2. The higher the ratio of sodium silicate-to-sodium hydroxide by mass, the higher is the compressive strength.
3. As the curing temperature increases, the compressive strength of fly based geo- polymer concrete also increases.
4. The addition of metakaolin to the base material fly ash (blending of fly ash with metakaolin) improves the compressive strength values.

5. DESIGNATIONS

Mf: GPC prepared with fly ash alone
Mfm: GPC prepared by blending fly ash with Metakaolin

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