Development of Eco-Friendly Geopolymer Concrete with Different Grade

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Abstract- Pollution caused by cement production is a major environmental issue throughout world. Geopolymer concrete is an alternative material to the cement as well as environment friendly material in the construction field. The geopolymer concrete is prepared without cement by using fly ash as base material and combination of sodium hydroxide and sodium silicate as an alkaline activator is 12 moles. Thus, silicate and alumina available in fly ash react with alkaline solution to produce alumina silicate gel that binds, the fine and coarse aggregates to produce a good concrete. The hot curing method, ambient and external exposure curing is proposed to adjust with the condition of cast in situ environment. The different grades of geopolymer concrete such as M 20, M 30, M 40, M 50 and M 60 developed and tested for density, workability and compressive strength to compared with cement concrete and proves GPC is an alternative eco-friendly concrete.

Indexed Terms- Fly ash, Alkaline solution, Geopolymer concrete, Compressive strength.

I. INTRODUCTION

Concrete is widely used as one of the important construction materials. Portland cement is the main component of making concrete. The cement industry becomes responsible for CO_2 emissions because the production one ton of Portland cement produces approximately one ton of CO_2 to the atmosphere (Davidovits, 1994; 1998). Many efforts are being made in order to reduce Portland cement in concrete by means of finding alternative cementing materials such as fly ash, silica fume, ground granulated blast furnace slag, rise husk ash and metakaolin. (Davidovits, 1998, Fernandez-Jimenez, A. M., and Palomo; Abdul Aleem.M. I., and Arumairaj.P.D; Nugteren.H.W). proposed an alkaline liquid that could be used to react with the silicon (Si) and aluminium (Al) to produce binders. Because the chemical reaction that takes place is a polymerization process, Davidovits coined the term “Geopolymer” to represent these binders. The Geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement.

II. GEOPOLYMER CONCRETE

The main constituents of geopolymers are the source materials and the alkaline liquids. The source materials for geopolymers based alumino-silicate should be rich in silicon and aluminium. These could be natural minerals such as kaolinite, clays, micas, and alousite etc. Alternatively by product materials such as fly ash, silica fume, slag, rice husk ash, red mud, etc. The alkaline liquids are formed soluble alkali metals that are usually sodium or potassium based. The combination of sodium hydroxide and sodium silicate is called alkaline liquids. It was found that the type of alkaline liquids is as significant factors affecting the mechanical and that the combination of silicate and sodium hydroxide gave the highest compressive strength (Duxson, 2007).

III. PREPARATION OF GEOPOLYMER CONCRETE MATERIALS USED

3.1 Fly ash

Low-calcium (ASTM Class F) fly ash obtained from the Mettur Thermal Power Station, (Tamilnadu) is used for this test. The SEM of fly ash (Figure 1) and its constituents are given in Table 1.

3.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS from the Toshaly Cements Pvt., Vishakhapatnam, (AndhraPradesh) is conforming to IS 12089 are used. The SEM of GGBS (Figure 2) and its constituents are given in Table 1.

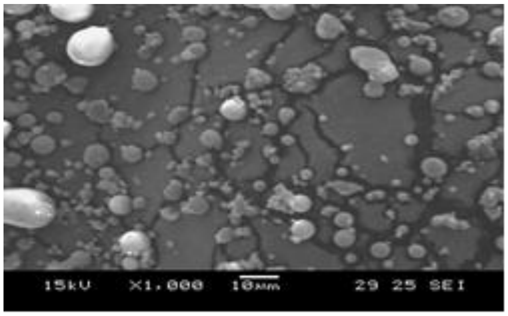

Fig. 1 SEM of Fly ash

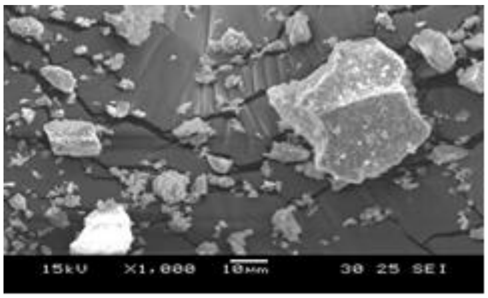

Fig. 2 SEM of GGBS

Table 1 Constitutes of Fly ash and GGBS

Element	Fly ash		GGBS	
	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)
Mg	1.36	1.57	5.05	5.24
Al	27.57	28.68	16.87	17.11
Si	66.61	66.57	42.24	43.15
K	3.14	2.25	1.69	1.13
Ca	1.32	0.92	34.15	33.36
Total	100		100	

3.3 Alkaline liquid

The alkaline liquid is prepared by mixing sodium silicate and sodium hydroxide solutions together at least 24 hours prior to use for thorough mixing and reaction. The sodium silicate solution is commercially available in different grades. The sodium silicate solution (Na_2SiO_3) with Sodium Hydroxide (NaOH) ratio by mass of 2.5 and fly ash to alkaline liquid ratio 0.45 are used (Hardjito.D., and Rangan.B.V). The sodium hydroxide with 97-98% purity in pellet form is commercially available. The solids dissolved in water to make a solution with required concentration of 12 M (mole) solutions are used to obtain varying grade of concrete. Since the molecular weight of Sodium Hydroxide is 40.

3.4 Aggregates

Coarse and fine aggregates are used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete. Specific gravity of fine and coarse aggregate are 2.66 and 2.70, fineness modulus of fine and coarse aggregate are 2.43 and 7.12 respectively.

3.5 Concrete

The fly ash, GGBS and alkaline solution are mixed to obtained 'geopolymer' in the ratio 0.45. The materials required for making geopolymer concrete is shown in Figure 3. The constituents of geopolymer concrete of 12 Molarity Sodium Hydroxide and others for M 20, M 30, M 40, M 50 and M 60 grade concrete is shown in Table 1.

Table1 Constituents of Geopolymer Concrete

DESCRIPTION	QUANTITY (kg/m^3)				
	M 20	M 30	M 40	M 50	M60
Fly Ash	436	410	356.25	510	264
GGBS	-	-	118.75	-	264
NaOH Solid	17.94	25.30	29.33	36.80	38.02
Water	38.12	27.40	31.77	28.91	29.87
Na_2SiO_3 Solution	140.14	131.50	152.75	164.30	169.71
Coarse aggregate	1308	1230	1260	1249.50	1214.40
Fine aggregate	654	676	665	637.50	607.20
Curing (24hrs)	60° C (Steam)	60° C (Hot air)	60° C (Hot air)	75° C (Hot air)	75° C (Hot air)
Super Plaster	-	-	2.68	3.65	4.32

3.6 Mixing, Casting and Curing

The geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the fine aggregates are first mixed together dry in 50-litre capacity pan mixer (Figure 4) for about three minutes. The course aggregates are prepared in Saturated-Surface-Dry (SSD) condition.The alkaline liquid andthe liquid component of the mixture added to the dry materials and the mixing continued usually for another four minutes.The workability of fresh concrete is measured by means of the conventional slump test. The Average slump measured is 100 mm (Figure 5). The fresh concrete could be handled up to 60 minutes without any sign of setting and without any degradation in the compressive strength.

Figure 3 Materials for GPC

Figure 4 Pan-Mixer

It is observed that a geopolymer concrete stick hard to the mould so oiling the moulds is very important to release each cube specimen, while cast in three layers by compacting manually. Each layer received 25 strokes of compaction by standard compaction rod for concrete. The geopolymer concrete is used to cast cubes of size 100x100x100mm and cylinders 100 mm diameter, 200 mm height as shown in Figure 6. Fresh fly ash-based geopolymer concrete is usually cohesive. After casting the specimens, they are kept for one day in rest period at room temperature. The term 'rest period' is coined to indicate the time taken from thecompletion of casting of test specimen to the start of curing at an elevated temperature (Kumaravel.S and Girija.P, 2014). After casting, the specimens are covered using vacuum bagging film. A steam boiler (Figure 7) is used to generate the steam at a specified temperature of 60^o C. The curing at 60^o C was done in the steam convert by the channel in steam curing chamber for 24 hours (Figure 8).

Figure 5 Measuring of Slump

Figure 6 Casting of Specimans

Figure 7 Steam Boilar

Figure 8 Curing Chamber

IV. TEST SETUP

The compressive strength machine of 1000 kN capacity is used to apply the axial force of compression. The 7- and 28-days compressive strength of geopolymer concrete cubes are given in Table 2. The different grade of concrete mix Ratio for M 20 is 1.0 :1.5: 3.0, M 30 is 1.0: 1.65:3.0, M 40 is 1.0:1.40:2.65, M 50 is 1: 1.25: 2.45 and M 60 is 1.0:1.15:2.30 respectively.

Table 2 Compressive Strength of Different Grade of Concrete Cubes

S.No	Grade of Concrete	Compressive Strength (N/mm^2)			
		7 Days		28 Days	
		CC	GPC	CC	GPC
1	M 20	18.75	24.75	24.50	28.00
2	M 30	27.34	36.24	34.00	38.50
3	M 40	36.50	45.95	46.50	48.00
4	M 50	48.65	56.74	57.25	59.00
5	M 60	54.75	63.25	65.50	66.67

V. MODULUS OF ELASTICITY

The Young's modulus of fly ash-based geopolymer concreteis determined as the secant modulus measured at the stress level equal to 40 percent of the average compressive strength of concrete cylinders of size 150 mm diameter and 300 mm height. Three of these cylinders are used to determine the elastic modulus. All the specimens are capped in accordance with the Indian Standard. The tests are performed in a 1000 kN capacity Universal Test Machine. One dial gauge are used to measure the axial deformation of the cylinder, while the other dial gauge is used to measure the longitudinal deformation of the test cylinder at top and bottom are used. The result of modulus of elasticity is shown in Table 3.

Table 3 Material Property for Concrete

Grade of Concrete	Beam Code	Stress in Concrete (N/mm^2)	Young Modulus in Concrete (N/mm^2)	Poisson ratio in Concrete
M 20	RCC	24.50	2.483×10^4	0.185
	GPC	27.85	2.606×10^4	0.186
M 30	RCC	34.50	2.930×10^4	0.174
	GPC	38.50	3.104×10^4	0.176
M 40	RCC	46.50	3.431×10^4	0.166
	GPC	48.00	3.442×10^4	0.165
M 50	RCC	57.50	3.681×10^4	0.161
	GPC	59.00	3.830×10^4	0.162
M 60	RCC	65.50	4.076×10^4	0.157
	GPC	66.67	4.615×10^4	0.159

VI. RESULTS AND DISSCUSSIONS

Geopolymer concrete is used Fly ash and GGBS with alkaline solution and the compressive strength of concrete is obtained. The density of geopolymer concrete is found as 2330 kg/m^3 which are less to that of cement concrete. The 28 days average compressive strength of geopolymer concrete cubes gives 26.36, 38.5, 48.0, 59.0 and 66.70 N/mm^2 respectively (Figure 9). These results obtained in geopolymer concrete are suited for structural applications. In a similar way to the compressive strength results, the modulus of elasticity increased with age. For alkaline binder ratio of 2.5, the elastic modulus increased with increasing curing temperature up to 60˚C and 75˚C. The geopolymer concrete possesses good compressive strength, elastic modulus and Poisson's ratio.

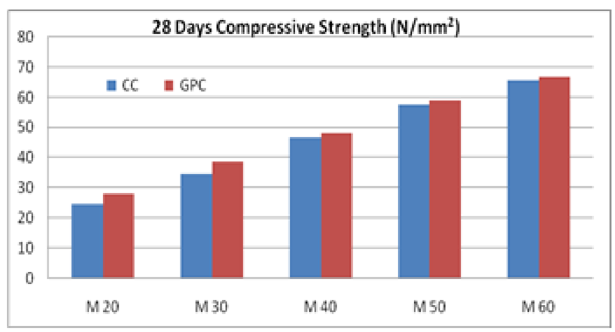

Figure 9 Compressive Strength of CC and GPC Cubes

CONCLUSION

The geopolymer concrete is made in NaOH molarity for 12 M. The ratio of alkaline solution /Fly ash is 0.45. The GGBS content 25% and 50%is replaced in fly ash. The alkaline binder ratio kept as 2.5.

a. The average compressive strength of cement concrete cubes were obtained as 23.5, 34.5,46.5, 57.5 and 65.5 N/mm^2. The geopolymer cubes were obtained as 26.36, 38.5, 48.0, 59.0 and 66.67 N/mm^2 respectively.

b. Geopolymer concrete has an excellent compressive strength and is quite suitable for structural applications.

c. The elastic modulus of GPC concrete increased with increasing curing temperature to a limit. The geopolymer concrete possesses good compressive strength, elastic modulus and Poisson's ratio.

d. The geopolymer concrete possesses good compressive strength and well-suited to manufacture precast concrete products. It is evident from the obtained results that the geopolymer concrete is encouraging.

e. Low calcium fly ash-based geopolymer concrete has an excellent compressive strength and is quite suitable for structural applications.

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