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To Study Strength Parameters of Fly Ash Based Geopolymer Concrete

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Abstract:* Utilization of concrete as a major construction material is a worldwide phenomenon & the concrete industry is the largest user of natural resources in the world. This use of concrete is driving the massive global production of cement, estimated at over 2.8 billion tones according to recent industry data .In this paper geopolymer concrete using alkaline liquid is prepared. Testing has done with different proportions and molarities. From this experimental work, it is concluded that due to the price of fly ash-based geopolymer concrete is estimated to be about 10 to 30 % cheaper than that of Portland cement concrete.The strength Geopolymer concrete gives high compressive strength in less time..The geopolymer concrete achieves 50% to 75% compressive strength within 1 day of heat curing. Because of the heat curing Geopolymer concrete have Rapid controllable setting and hardening.

***Keywords:* Geopolymer concrete, concrete, mix design, heat curing, portal and cement, etc.**

I. INTRODUCTION

Ordinary Portland cement production is under critical review due to high amount of carbon dioxide gas released to the atmosphere. In recent years, attempts to increase the utilization of fly ash to partially replace the use of Portland cement in concrete are gathering momentum. Most of this by-product material is currently dumped in landfills, thus creating a threat to the environment. Geopolymer concrete is a 'New' material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as fly ash, that are rich in Silicon (Si) and Aluminum (Al) are activated by alkaline liquids to produce the binder. Hence concrete with no cement is prepared. The rate of production of carbon dioxide released to the atmosphere during the production of Portland cement and fly ash, a by-product from power stations worldwide is increasing with the increasing demand on infrastructure development and hence needs proper attention and action to minimize the impact on the sustainability of our living environment.De-carbonation of limestone in the kiln during manufacturing of cement is responsible for the liberation of one ton of carbon dioxide to the atmosphere for each ton of Portland cement as can be seen from the following reaction equation:

$5\ CaCO_3 + 2\ SiO_2 \rightarrow 3\ CaO.SiO_2 + 2\ CaO.SiO_2 + 5\ CO_2$ … (1)

The production of Portland cement worldwide is increasing 3% annually. The current contribution of green house gas emission from the Portland cement production is about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere. Furthermore, Portland cement is also among the most energy-intensive construction materials after aluminum and steel. In this project, geoplymer concrete is prepared with alkaline liquid and shows various results obtained to prove it as alternative best arterial for construction.

II. METHODOLOGY

The aim of present paper is to study the physical, chemical and mechanical properties of ingredients of fly ash based geopolymer concrete. Also to study the structural behavior of geopolymer concrete regarding to tensile and compressive strength and design the concrete mix of geopolymer concrete as well as to compare the gepolymer concrete with ordinary Portland cement concrete according experimental analysis . This paper work is explained with the help of following points:

A. Introduction to Fly as based Geopolymer concrete.
B. Preparing the mix design for fly ash based geopolymer concrete with different proportions.
C. Testing the strength of concrete.
D. To study experimental analysis and to find optimum proportion for best concrete results.

III. MATERIAL USED

A. Fly Ash

Fly ash is the finer part of the Coal Combustion Products (CCP) captured by the electro-static precipitators in coal fired thermal power plants. Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Some of these cements were made near the small Italian town of Pozzuoli - which later gave its name to the term "pozzolan." About 600 million tones of fly ash was produced in year 2000 according to Manz (1989). This poses a major challenge in terms of their safe disposal preferably via bulk utilization in a commercially profitable manner. At present only about 20% of all fly ash gets productively used while the rest get dumped in landfills one way or the other.

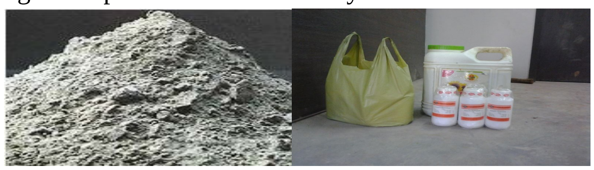


Fig.3.1 Fly ash and Alkaline liquid

B. Alkaline Liquids

1) *Sodium Hydroxide:* Generally the sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. Since our geopolymer concrete is homogenous material and its main process to activate the sodium silicate, so it is recommended to use the lowest cost i.e. up to 94% to 96% purity. In this investigation the sodium hydroxide pellets were used. Whose physical and chemical properties are given by the manufacturer is shown in Table 1 and 2.Sodium hydroxide pellets are taken and dissolved in the water at the rate of 16 molar concentrations. It is strongly recommended that the sodium hydroxide solution must be prepared 24 hours prior to use and also if it exceeds 36 hours it terminate to semi solid liquid state. So the prepared solution should be used within this time.
2) *Sodium Silicate:* Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation sodium silicate 2.0 (ratio between Na2O to SiO2) is used. As per the manufacture, silicates were supplied to the detergent company and textile industry as bonding agent. Same sodium silicate is used for the making of geopolymer concrete.

IV. PREPARATION OF ALKALINE LIQUID

A. Dissolution

Initially the vitreous component of the fly ash (aluminosilicate glass) in contact with the alkali solution Sodium Hydroxide and Sodium Silicate is dissolved, forming a series of complex ionic species;

B. Molarity Calculation

The solids must be dissolved in water to make a solution with the required concentration. The concentration of Sodium hydroxide solution can vary in different Molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 16 Molar consists of 16 x 40 = 640 grams of NaOH solids per litre of the water, were 40 is the molecular weight of NaOH. Note that the mass of water is the major component in both the alkaline solutions.The mass of NaOH solids was measured as 444 grams per kg of NaOH solution with a Concentration of 16 Molar. Similarly, the mass of NaOH solids per kg of the solution for other concentrations was measured as 10 Molar: 314 grams, 12 Molar: 361 grams, and 14 Molar: 404 grams .

Fig. 4.1 Preparation of mix

C. Alkaline Liquid

Sodium based alkaline solutions were used to react with the fly ash to produce the binder. Sodium-silicate solution was used for the concrete production. The chemical composition. Sodium hydroxide solution was prepared by dissolving sodium hydroxide pellets in water. The pellets are commercial grade with 97% purity thus 16 molar solutions were made by dissolving 444 grams of sodium hydroxide pellets in 556 g of water. The sodium hydroxide solution was prepared one day prior to the concrete batching to allow the exothermically heated liquid to cool to room temperature. The Sodium silicate solution and the sodium hydroxide solution were mixed just prior to the concrete batching. Generally alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate at the room temperature. When the solution mixed together the both solution start to react i.e. polymerization takes place it liberate large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent

V. MIX DESIGN

Geopolymer Concrete is obtained by mixing fly ash, alkaline liquid and aggregates and sometimes admixtures in required proportions. The strength, durability and other characteristics of geopolymer concrete depend upon the properties of its ingredients i.e. fly ash, aggregates, alkaline liquid and admixtures and their proportions in the mix, method of compaction and other controls during placing, compacting and curing. For preparing mix design of geopolymer concrete we have to carried out some tests for ingredients of geopolymer concrete i.e. for fly ash, for fine aggregates, for coarse aggregates, for chemicals etc

A. Data for Mix Design

The following basic data are required to be specified for design of a concrete mix:

1) Characteristic compressive strength of Geopolymer Concrete at 24 hours curing at the temperature of 60ºC (fck).
2) Maximum size and Type of Fine aggregate and Coarse Aggregate to be used.
3) Specific gravity of ingredients of concrete.
4) Selection of Alkaline liquid, Fly ash Ratio to the Compressive ratio.

Aggregates size, grading, surface texture, shape and other characteristics may produce secretes of different compressive strength for the same tiled ratio, the relationship between strength and free Alkaline liquid, Extra Water, Fly ash Ratio should preferably be established for the materials [7,8,9].

B. Estimation of Air Content

Approximate amount of entrapped air to be expected in normal (non-air-entrained) concrete is given in Table (6).

Table 6: Approximate of Air Content

Nominal Maximum size of aggregate in mm	Entrapped air, as percentage of volume of concrete
10	3
20	2

For the desired workability, the quantity of mixing per unit volume of concrete and the ratio of fine aggregate to total aggregate by absolute volume are to be estimated from Tables as applicable, depending upon the nominal maximum size and type of aggregates.

Nominal size of course aggregate	Sand as per percent of total Aggregate by absolute volume
10 mm	40
20 mm	35

Table 8: Adjustment of values in and sand percentage for zone factor i.e. fineness modulus

Change in condition	Adjustment in sand percentage
For sand conforming to grading	+1.5 % for zone I
Zone I, Zone III or Zone IV	-1.5 % for zone I

Table 4 of IS : 383-1970* 3.0 percent for Zone IV

C. Calculation of Aggregate Content

The total aggregate content per unit volume of concrete may be calculated from the following equations:

Fine Aggregate

$$V = \left[\frac{SO}{S_{SO}} + \frac{S}{S_S} + \frac{F}{S_F} + \frac{1\,F_a}{P\,SF_a}\right]\frac{1}{1000}$$ and

Course Aggregate

$$V = \left[\frac{SO}{S_{SO}} + \frac{S}{S_S} + \frac{F}{S_F} + \frac{1\,C_a}{(1-P\,SC_a)}\right]\frac{1}{1000}$$

Where ,

V = Absolute volume of fresh concrete , which is equal to gross volume minus the volume of entrapped air

S = Sodium Silicate Solution (kg) per m^3 of concrete

SO = Sodium Hydroxide Solution (kg) per m^3 of concrete

F = Weight of fly ash (kg) per m^3 of concrete

S_F = Specific gravity of Fly ash

P = Ratio of fine aggregate to total aggregate by absolute volume

F_a , C_a = Total masses of fine aggregate and coarse aggregate (kg) per m^3 of concrete

SF_a , SC_a = Specific gravity of saturated surface dry fine aggregate and coarse aggregate respectively

S_S = Specific gravity of Sodium Silicate Solution

S_{SO} = Specific gravity of Sodium Hydroxide Solution

1) Illustration: An example illustrating the mix design for a Geopolymer concrete of M 30 grade is given below:

D. Design Stipulations

1) Characteristic compressive strength required at age of 36hours at the temperature of 60ºC = 30 Mpa

2) Maximum size of aggregate (angular) = 20mm

3) Specific gravity of fly ash = 1.9

4) Specific gravity of coarse aggregate = 2.8

5) Specific gravity of fine aggregate = 2.78

6) Sand conforming = zone III

7) Specific gravity of NaOH = 1.45

8) Specific gravity of Na_2SiO_3 = 1.58

9) Solution

a) Selection of Fly Ash to the Compressive Ratio: Taking the amount of fly ash for M30 grade =500 Kg/m3

b) Selection of Alkaline Liquid Ratio:

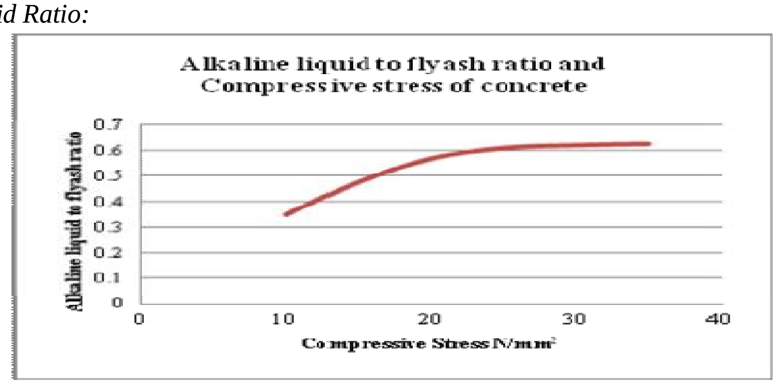


Figure 2. Generalized relation between free alkaline liquid to fly ash ratio and compressive strength of concrete:-The ratio between Sodium hydroxide to sodium silicate is 1 : 2.5 From the table (9)The amount of alkaline liquid required accordance to compressive stress from the Figure2.

c) The amount of Alkaline liquid = 0.61 x fly ash content =0.61 x 500 = 305 Kg/m3
Amount of Sodium silicate Solution = 217.86 Kg/m3
Amount of Sodium Hydroxide Solution = 87.14 kg/m3

d) Morality to be used in the concrete is 16 molar in which 444 grams of NaOH solids dissolved in 556 grams of water.
Solids = 38.69 kg/m3
Water = 48.45 kg/m3
Sodium hydroxide to sodium silicate ratio accordance to compressive Strength are selected from table 9. i.e. " 1:2.5 "

e) Selection of Water Content: The maximum water content and the minimum water content to be added extra is 0.06 and 0.02 water to fly ash ratio respectively. According to workability extra water can be added this is due to fly ash is arrived from various plant which have different properties in absorption of water in order to match extra water is added. Amount of water add extra 0.03 to water fly ash ratio = 0.03 x 500 = 15 kg/m3

f) Determination of Aggregate Content: The total aggregate content per unit volume of concrete may be calculated from the following equations:

Fine Aggregate

$$V = \left[\frac{SO}{S_{SO}} + \frac{S}{S_S} + \frac{F}{S_F} + \frac{1\,F_a}{P\,SF_a}\right]\frac{1}{1000}$$

Fa = 486.86 Kg / m^3

Course Aggregate

$$V = \left[\frac{SO}{S_{SO}} + \frac{S}{S_S} + \frac{F}{S_F} + \frac{1\,C_a}{(1-P\,SC_a)}\right]\frac{1}{1000}$$

Ca = 1011.17 Kg / m^3

VI. EXPERIMENTAL ANALYSIS

A. Compression Test Results of Indian Standard Method

1) Is Trail 1

DAYS	LOAD			STRENGTH			AVG. STRENGTH	WEIGHT		
	CUBE 1	CUBE 2	CUBE 3	CUBE 1	CUBE 2	CUBE 3		CUBE 1	CUBE 2	CUBE 3
3	284.4	325.13	252.68	12.64	14.45	11.23	12.77	8902	8879	8850
7	661.95	672.75	627.07	29.42	29.90	27.87	29.06	8864	8937.5	9006.5
28	866.93	925.43	908.33	38.53	41.13	40.37	40.01	8970	9036	8956

2) Is Trail 2

DAYS	LOAD			STRENGTH			AVG. STRENGTH	WEIGHT		
	CUBE 1	CUBE 2	CUBE 3	CUBE 1	CUBE 2	CUBE 3		CUBE 1	CUBE 2	CUBE 3

3	322.88	380.30	314.55	14.35	16.89	13.98	15.07	8850	8685	8982
7	693.9	699.98	635.18	30.84	31.11	28.23	30.06	8638	8763	8602
28	1020	975.15	957.82	45.33	43.34	42.57	43.74	8765	8425	8562

B. Compression Test Results of DOE Method

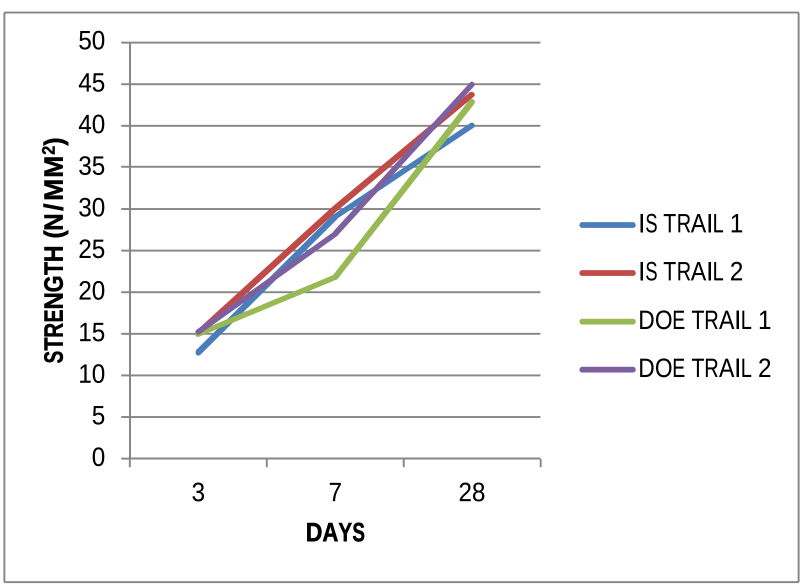
1) Doe Trail 1:

DAYS	LOAD			STRENGTH			AVG. STRENGTH	WEIGHT		
	CUBE 1	CUBE 2	CUBE 3	CUBE 1	CUBE 2	CUBE 3		CUBE 1	CUBE 2	CUBE 3
3	277.88	372.15	359.55	12.35	16.54	15.98	14.95	8865	8952	8636
7	502.88	465.98	505.8	22.35	20.71	22.48	21.84	8850	8854	8469
28	940	931.5	1021	41.77	41.40	45.37	42.84	8836	8789	8948

2) Doe Trail 2:

DAYS	LOAD			STRENGTH			AVG. STRENGTH	WEIGHT		
	CUBE 1	CUBE 2	CUBE 3	CUBE 1	CUBE 2	CUBE 3		CUBE 1	CUBE 2	CUBE 3
3	303.58	344.02	375.3	13.67	15.29	16.68	15.21	8965	9035	8991
7	638.33	562.05	629.1	28.37	24.98	27.96	27.00	9080	8768	8985
28	1004.63	980.78	1047.6	44.65	43.59	46.56	44.93	8956	8865	8796

C. Results Graph as Per Is-10262-2009 & DOE Method



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the graph at 3rd day the IS trial (2) got maximum compressive strength then it increases gradually. At 28 th day the DOE trial (2) got maximum strength. Hence the DOE trial (2) result is taken for the comparison with geopolymer concrete.

D. Geopolymer Concrete Results of Compression for 16 M

1) For M 500:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	415.5	-	18.46	-	19.46	7.200	-
3	645.0	661.0	28.67	29.38	29.03	7.320	7.360
7	843.0	915.5	37.46	40.68	39.07	7.460	7.500
14	947.5	926.5	42.11	41.17	41.64	7.580	7.520
28	981.0	1056.5	43.60	46.95	45.28	7.720	7.620

2) For M 550:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	435.5	-	19.35	-	19.35	7.680	-
3	529.5	448.0	23.53	20.10	21.82	7.700	7.460
7	547.5	543.5	24.33	24.16	24.24	7.480	7.260
14	632	673	28.08	29.91	29.00	7.400	7.260
28	743	747	33.04	33.22	33.13	7.540	7.480

3) For M 600:

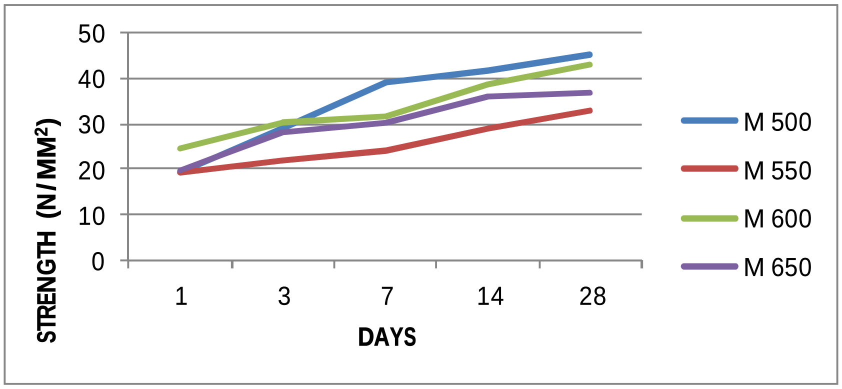
DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	556.5	-	24.73	-	24.73	7.400	-
3	697.0	664.93	30.97	29.91	30.44	7.440	7.420
7	713.0	684.9	31.68	31.47	31.58	7.280	7.320
14	905.0	809.5	40.22	36.98	38.60	7.460	7.440
28	987.5	946.0	43.89	42.04	42.97	7.420	7.460

4) For M 650:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	446.50	-	19.84	-	19.84	7.330	-

3	595.0	670.50	26.44	29.80	28.12	7.340	7.360
7	672.75	693.9	29.90	30.84	30.37	7.000	7.060
14	844	781	37.51	34.71	36.11	6.760	6.820
28	854	810	37.95	36.00	36.97	6.800	6.760

E. Results Graph of Fly Ash Based Geopolymer Concrete of 16m



F. Compressive Strength: In experimental work for geopolymer concrete design we have taken IS method for mix design. In which four trials are taken with 16 molar sodium hydroxide concentration i.e. M 500,M 550,M 600,M 650. In which we have changed the variation in the fly ash content. In this we have taken tests for 1,3,7,14,28th days. At 1st day mix M 600 got the maximum strength but after 28th day it gets lower strength than M 500. The compressive strength of M 500 after 28 days is 45.28 N/mm^2.

G. Geopolymer Concrete Results of Tensile Strength For 16 M

1) For M 500:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
21	161	181	7.15	8.04	7.60	11.76	11.60

2) For M 550:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
21	153	175.5	6.80	7.80	7.30	11.12	11.22

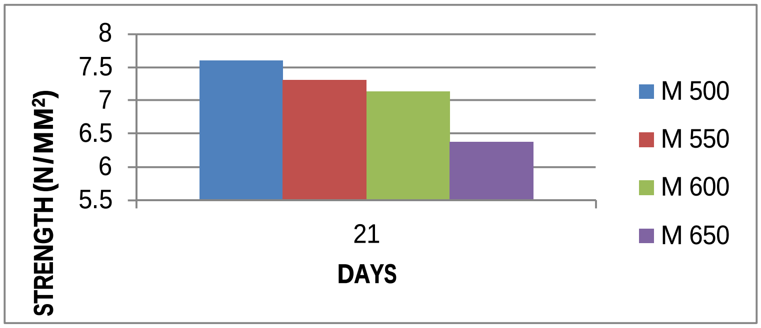
3) For M 600:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
21	169.5	151.5	7.53	6.73	7.13	11.60	11.02

4) For M 650:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
21	132.5	154.5	5.88	6.86	6.37	11.22	11.84

H. Results Graph of Fly Ash Based Geopolymer Concrete of 16m Tensile Strength



From the of tensile strength we get that the strength of M500 is 7.6 N /mm^2 at 21st day which is higher than other proportion .For the ordinary concrete it is 3 to 5 N /mm^2

I. Replacing Molarity of NAOH 16 M To 10 M

For 16 Molar solution, the mass of NaOH solid was measured as 444 grams per kg of NaOH solution. Similarly, for 10 Molar, the mass of NaOH solid was measured as 314 grams per kg of NaOH solution.

J. Geopolymer Concrete Results of Compression for 10 M

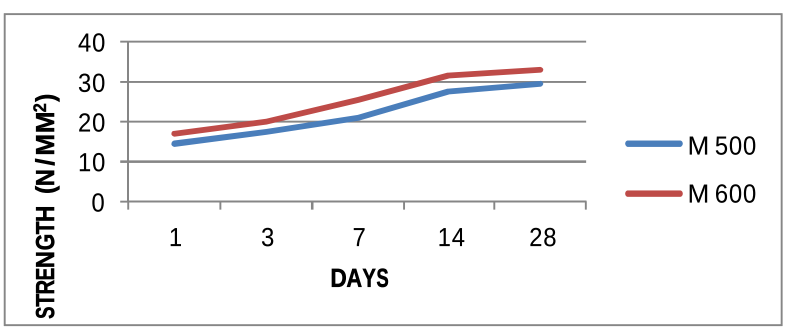
1) For M 500:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	328.5	-	14.60	-	14.60	7.440	-
3	402	387.5	17.86	17.22	17.54	7.820	7.500
7	436	514.5	19.38	22.87	21.12	7.920	7.680
14	624	590	28.53	26.22	27.38	7.600	7.500
28	645.5	690	28.69	30.66	29.68	7.640	7.380

2) For M 600:

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRAIL 1	TRAIL 2	TRAIL 1	TRAIL 2		TRAIL 1	TRAIL 2
1	382	-	16.97	-	16.97	7.300	-
3	424	470	18.84	20.88	19.86	7.140	7.360
7	598.0	547.50	26.57	24.33	25.45	7.220	7.380
14	719	714	31.95	31.73	31.84	8.100	7.200
28	728	758	32.34	33.69	33.02	7.400	7.380

K. Results Graph Of Fly Ash Based Geopolymer Concrete 10m



VII. CONCLUSIONS

Based on test results, the following conclusions are drawn:

A. From the point of view of Carbon Credit the price of fly ash-based geopolymer concrete is estimated to be about 10 to 30 % cheaper than that of Portland cement concrete

B. The strength Geopolymer concrete gives high compressive strength in less time.

C. The geopolymer concrete achieves 50% to 75% compressive strength within 1 day of heat curing.

D. Because of the heat curing Geopolymer concrete have Rapid controllable setting and hardening.

E. The tensile strength of geopolymer concrete is comparatively more than the ordinary concrete, it is 7.60 N / mm^2 for M 30 design strength of geopolymer concrete.

F. The strength of geopolymer concrete increases with increase in morality of sodium hydroxide solution.

G. The geopolymer concrete is lighter in weight as compared to ordinary concrete.

H. Individually geopolymer concrete is costly due to the alkaline liquid (sodium silicate & sodium hydroxide) but if we consider the Carbon Credit the geopolymer concrete is economical.

I. The strength of geopolymer concrete increases with increase in curing temperature as well as duration.

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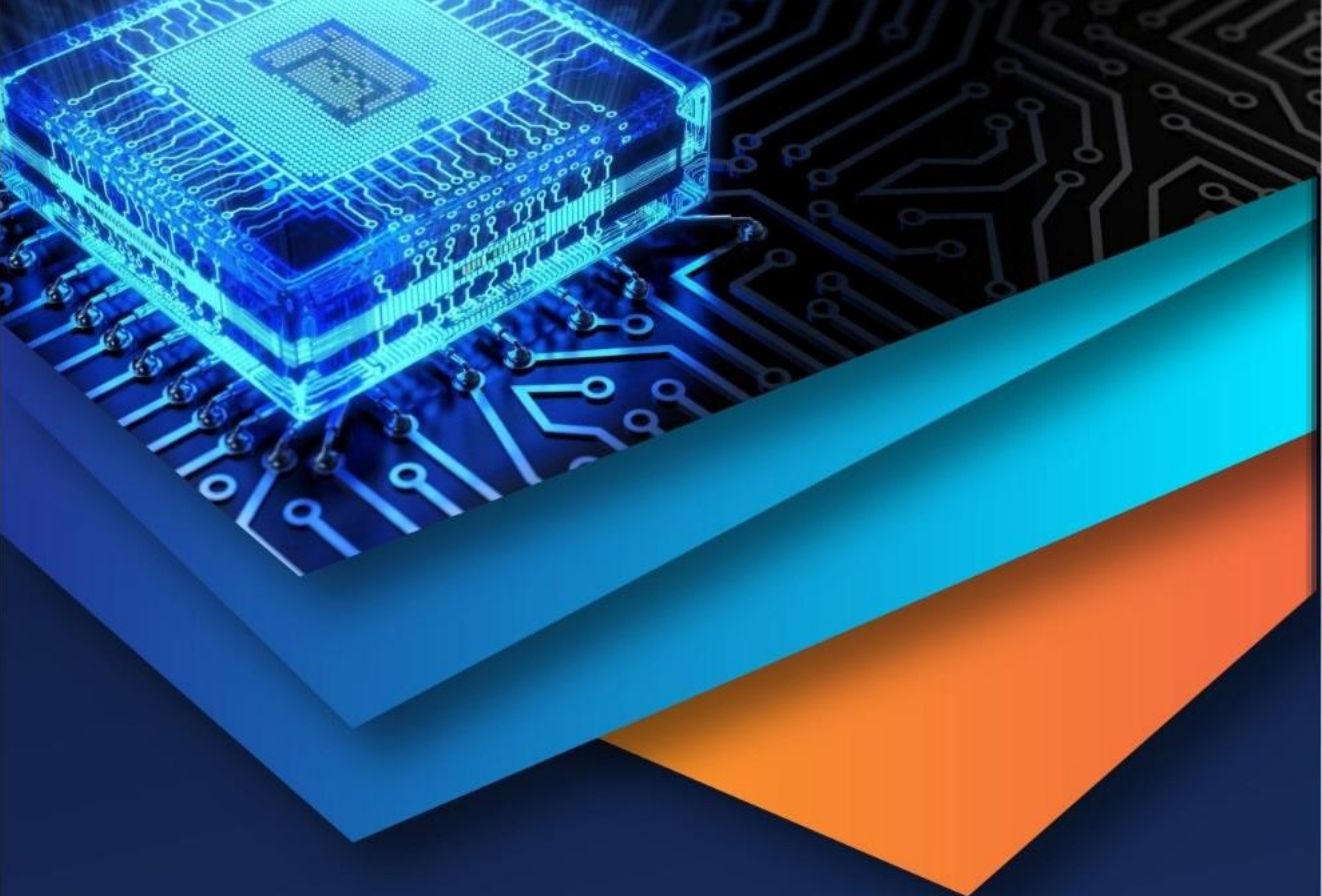

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