Strength Development of Fly Ash based Geopolymer Concrete

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Abstract:- In recent time, the importance and use of fly ash in concrete has grown so much that it has almost become a common ingredient in concrete, particularly for making high strength and high performance concrete. Extensive research has been done all over the world on the benefits that could be accrued in the utilization of fly ash as a supplementary cementitious material. High volume fly ash concrete as a subject of current interest all over the world. The use of fly ash a concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control. In India alone, we produce about 100 million tons of fly ash per year, the disposal of which has become a serious environmental problem. The effective utilization of fly ash in concrete making is, therefore attracting serious considerations of concrete technologies and government departments.

Keywords:- Fly ash, ASTM Class F fly ash, Alkaline liquid, Geo polymer concrete

1. INTRODUCTION

Geo polymer concrete show several advantages and disadvantages over conventional concrete. Now a days the concrete is one of the most widely used construction material, it is usually associated with Portland cement as the main component for making the concrete. The demand for concrete as a construction material is increasing day by day. The several efforts are in progress to reduce the use of Portland cement in concrete in order to address the global warming issues. In this respect the geo polymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement.

The scope of this project work is explained with the help of methodology, research strategy and research design.

1.1 Methodology

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

1) Introduction to fly as based Geo polymer concrete.

2) To study the physical, chemical & mechanical properties of ingredients.

3) Preparing the mix design for fly ash based geo polymer concrete with different proportions.

4) Preparing blocks, cylinders & beams of concrete.

5) Testing the compressive and tensile strength of concrete.

6) To study experimental analysis and to find optimum proportion for best concrete results.

2. RESEARCH STRATEGY

Considering the research objectives of the work, the focus is on empirical evidence of the use of concrete in India in the recent years. In order to give an actual and overall picture of the use of Geo polymer concrete in India, the research needs a strategy that can effectively provide depth of information. Therefore a research strategy combines study of properties of geo polymer concrete, material used for making it, actual mix design of geo polymer concrete adopted to acquire integrated and in-depth data. The data and material needed in this research is mainly obtained by three methods: The theoretical framework of Fly ash based Geo- polymer concrete is derived from literature including previous studies and research, the publications of the related agencies, social institution and academic organizations.

3. MATERIAL USED

Geopolymer is an inorganic allumino-silicate polymer synthesized from predominantly silicon (Si) and alluminum (Al) materials of geological origin or by-product materials such as fly ash. The term geopolymer was introduced by Davidovits to represent the mineral polymers resulting from geochemistry. The process involves a chemical reaction under highly alkaline conditions on Si-Al minerals, yielding polymeric Si-O-Al-O bonds in amorphous form. It has been reported that geopolymer material does not suffer from alkali-aggregate reaction even in the presence of high alkalinity and possesses excellent fire resistant. Geopolymer is used as the binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, the aggregates occupy the largest volume, i.e. about 75-80 % by mass, in geopolymer concrete. The silicon and the alluminium in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials. Geopolymer-based materials are environmentally friendly, and need only moderate energy to produce. They can be made using industrial by-products, such as fly ash, as the source material. In geopolymer concrete, the geopolymer paste serves to bind the coarse and fine aggregates, and any un-reacted material. Geopolymer concrete can be utilized to manufacture precast concrete structural and non-structural elements, to make concrete pavements, to immobilize toxic wastes, and to produce concrete products that are resistant to heat and aggressive environments.

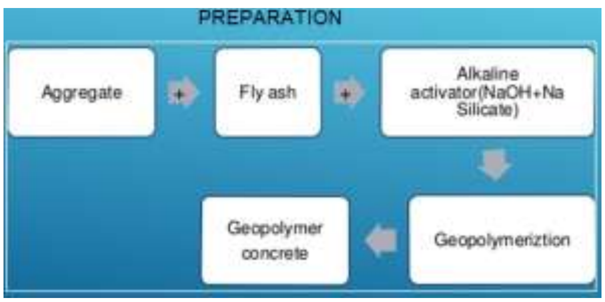

Fig. 1: Preparation of concrete

Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Rather, the binder is produced by the reaction of an alkaline liquid with a source material that is rich in silica and alumina. Geo polymers were developed as a result of research into heat resistant materials after a series of catastrophic fires. The research yielded non-flammable and non-combustible geopolymer resins and binders. Geopolymer is being studied extensively and shows promise as a greener alternative to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer. It has been found that geopolymer concrete has good engineering properties.

3.1 Fly Ash

Fly ash is divided mainly into two categories based mainly on its calcium content. ASTM Class F fly ash is low in calcium and mainly pozzolanic (i.e., they react with calcium hydroxide in moist condition to produce cementitious compounds), whereas class C fly ash has higher fraction of calcium oxides, which give them cementitious characteristics. Class C fly ash is often marketed directly in many countries and finds easy application in concrete as a part replacement of cement. Class F fly ash (most Indian fly ash fall in this category) is primarily used as a cement replacement under certain conditions of quality in terms of chemical composition, particle size distribution and loss on ignition (which is an indicator of carbon content).

Table 1: Chemical Composition Class F Fly Ash

Oxides	Quantity (%)
SiO_2	50.18
Al_2O_3	26.31
Fe_2O_3	13.68
CaO	2.63
MgO	1.29
SO_3	0.02
Na_2O	0.32
K_2O	0.53
TiO	1.66
SrO	0.30
P_2O_5	1.55
Mn_2O_3	0.09

The use of fly ash has additional environment advantages. The annual production of fly ash in Australia in 2007 was approximately 14.5 million tonnes of which only 2.3 million tonnes were utilized in beneficial ways; principally for the partial replacement of Portland cement . Development of geopolymer technology and applications would see a further increase in the beneficial use of fly ash, similar to what has been observed in the last 14 years with the use of fly ash in concrete and other building materials.

3.2 Alkaline Liquids

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 2 & 3.

Table 2: Physical Properties Sodium hydroxide

Colour less	Specific Gravity
20%	1.22
30%	1.33
40%	1.43
50%	1.53

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.

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 Na_2O to SiO_2) 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. The chemical properties and the physical properties of the silicates are given the manufacture is shown as below:-

Table 3: physical properties of the silicates

Assay	-97%
Min Carbonate (Na_2CO_3)	-2% Max
Chloride (Cl)	-0.01% Max
Sulphate (SO_2)	-0.05% Max
Lead (Pb)	-0.001% Max
Iron (Fe)	-0.001% Max
Potassium (K)	-0.1% Max
Zinc (Zn)	-0.02% Max

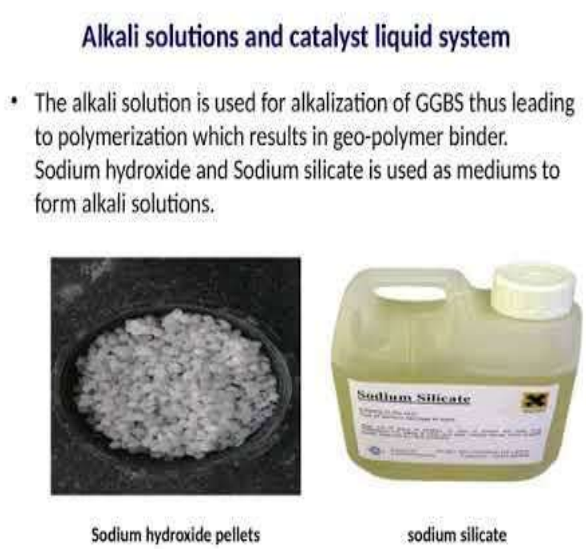

Fig. 2: Alkali solutions

3.4 Preparation of Alkaline Liquid

Dissolution:- Initially the vitreous component of the fly ash (allumino silicate glass) in contact with the alkali solution **Sodium Hydroxide** and **Sodium Silicate** is dissolved, forming a series of complex ionic species.

3.3 Morality 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 Noah solids in a solution varies depending on the concentration of the solution. For instance, Noah solution with a concentration of 16 Molar consists of 16 x 40 = 640 grams of Noah solids per liter of the water, were 40 is the molecular weight of Noah. Note that the mass of water is the major component in both the alkaline solutions. The mass of Noah solids was measured as 444 grams per kg of Noah solution with a Concentration of 16 Molar. Similarly, the mass of Noah 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. 3: Mixing of contents

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 .

Fig. 4: Alkaline liquid is get ready as binding agent

Polymerization

These small molecules present in the dissolution can join each other and form large molecules that precipitate in the form of gel, in which some degree of short range structural order can be identified (10). The composition and structure of this alkali alumina silicate gel depends essentially on the size, structure and concentration of the ionic species present in the medium, as well as on the synthesis temperature on the curing time, and the pH of the mixture. The hypothetical evolution of this gel would be to form some sort of zeolite crystal. However, due to the very low “alkaline solution / fly ash” ratio used in the synthesis of this type of materials (or prevailing under experimental conditions), this evolution is extremely slow. The studies done up to today concerning the manufacturing of mortars and/or concretes of activated fly ash following the alkaline process (without Portland cement) turned out into very promising results. The above mentioned studies have demonstrated for example that the properties of the concrete of alkali activated fly ash are influenced, like those of the conventional concrete, by a set of factors related to the dosing of the mixture and to the conditions of the curing process. Nevertheless, these new concrete can manage to develop very high mechanical strength within a few hours. These strengths continue to grow more slowly with time. Also, the mentioned studies have manifested the high potential of these materials that could be used in the near future in the construction industry, especially in the precast industry. This is the reason why the goal of this work is focused on the establishment of some engineering properties for this type of materials (mechanical strength development, matrix-steel adherence and shrinkage). Finally, there is a specific case of an industrial application of these new concrete for the manufacturing of pre-stressed mono-block sleeper son railroads.

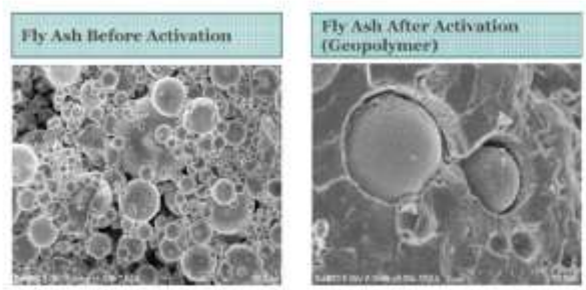

Fig. 5: Fly ash before and after activation

4. EXPERIMENTAL ANALYSIS

Proportions

AS PER IS-10262-2009 & DOE METHOD

Table 4: I.S. and DOE trials

TYPE	CEMENT (kg/M^3)	FINE AGGR. (kg//M^3)	COURSE AGGR. (kg//M^3)	WATER (kg//M^3)
IS TRIAL 1	475	661	1255	189
RATIO	1	1.38	2.63	0.39
IS TRIAL 2	525	645	1229	189
RATIO	1	1.21	2.33	0.35
DOE TRIAL 1	410	588	1396	205
RATIO	1	1.42	3.39	0.49
DOE TRIAL 2	456	574	1364	205
RATIO	1	1.26	3.00	0.45

Proportions

AS PER MODIFIED GUIELINE FOR GEOPOLYMER CONRETE MIX DESIGN USING INDIAN STANDARD (IS-10262-2009):-

Table 5: Grade and ratio

GRADE	FLY ASH (kg//M³)	FINE AGGR. (kg//M³)	COURSE AGGR. (kg//M³)	ALKALINE LIQUID		EXTRA WATER (kg//M³)
				SODIUM SILICATE (kg//M³)	SODIUM HYDROXIDE (kg//M³)	
M 500	500	487	1011	217.86	87.14	15
RATIO	1	0.96	2.01	0.60		0.03
M 550	550	445.2	924.65	239.64	95.86	16.5
RATIO	1	0.80	1.67	0.60		0.03
M 600	600	403.53	838.10	261.43	104.57	18
RATIO	1	0.63	1.32	0.60		0.03
M 650	650	361.87	751.58	283.21	113.28	19.5
RATIO	1	0.55	1.15	0.60		0.03

Compression test results of Indian standard method:-

Table 6: Compression Test IS Trial 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	284.5	325.14	252.69	12.65	14.46	11.24	12.78	8903	8879	8851
7	661.96	672.76	627.08	29.43	29.91	27.88	29.07	8865	8938	9006
28	866.93	925.43	908.33	38.53	41.13	40.37	40.01	8970	9037	8957

Table 7: Compression Test IS Trial 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	322.89	380.31	314.56	14.36	16.90	13.99	15.08	8851	8686	8983
7	693.9	699.99	635.19	30.85	31.12	28.24	30.07	8639	8764	8603
28	1021	975.16	957.83	45.34	43.35	42.58	43.75	8766	8426	8563

Compression test results of doe method

Table 8: Compression Test DOE Trial 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	277.89	372.16	359.56	12.36	16.55	15.99	14.96	8866	8953	8637
7	502.89	465.99	505.9	22.36	20.72	22.49	21.85	8851	8855	8470
28	941	931.6	1022	41.78	41.41	45.38	42.85	8837	8790	8949

Table 9: Compression Test DOE Trial 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	303.59	344.03	375.4	13.68	15.30	16.69	15.22	8966	9036	8992
7	638.34	562.06	629.2	28.38	24.99	27.97	27.01	9081	8769	8986
28	1004.7	980.79	1047.7	44.66	43.60	46.57	44.94	8957	8866	8797

RESULTS GRAPH AS PER IS-10262-2009 & DOE METHOD

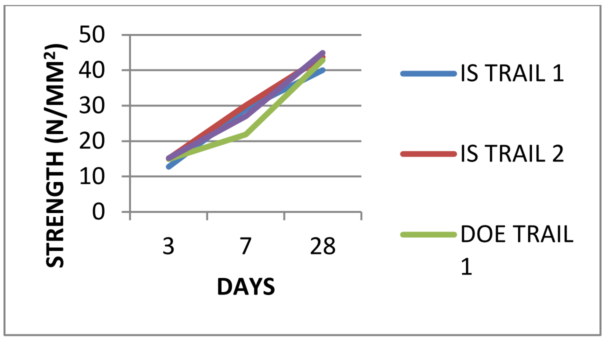

Chart 1: IS-10262-2009 & DOE Method

In experimental work for ordinary concrete design we have taken IS method and DOE method for mix design. In which two trials of each methods have done and the best one strength result is taken for comparison with geopolymer concrete. From the graph at 3rd day the IS trial (2) got maximum compressive strength then it increases gradually. At 28 the day the DOE trial (2) got maximum strength. Hence the DOE trial (2) result is taken for the comparison with geopolymer concrete.

GEOPOLYMER CONCRETE RESULTS OF COMPRESSION FOR 16 M:-

Table 10: Geopolymer Concrete Results of Compression for 16 M for M 500

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
1	415.6	-	18.47	-	19.47	7.210	-
3	645.01	661.01	28.68	29.39	29.04	7.330	7.370
7	843.01	915.6	37.47	40.69	39.08	7.460	7.510
14	947.6	926.6	42.12	41.18	41.65	7.590	7.530
28	981.01	1056.6	43.61	46.96	45.29	7.730	7.640

Table 11: Geopolymer Concrete Results of Compression for 16 M for M 550

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 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

Table 12: Geopolymer Concrete Results of Compression for 16 M for M 600

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
1	556.5	-	24.75	-	24.74	7.410	-
3	697.5	664.95	30.98	29.90	30.45	7.450	7.430
7	713.5	684.90	31.69	31.48	31.59	7.290	7.330
14	905.5	809.55	40.23	36.99	38.61	7.470	7.450
28	987.5	946.05	43.88	42.05	42.98	7.430	7.470

Table 13: Geopolymer Concrete Results of Compression for 16 M for M 650

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
1	446.5	-	19.85	-	19.83	7.340	-
3	595.0	670.55	26.45	29.81	28.14	7.350	7.370
7	672.5	693.8	29.93	30.83	30.39	7.010	7.070
14	844.5	781.5	37.54	34.73	36.12	6.770	6.830
28	854.5	810.5	37.96	36.05	36.98	6.810	6.770

RESULTS GRAPH OF FLY ASH BASED GEOPOLYMER CONCRETE OF 16M COMPRESSIVE STRENGTH:-

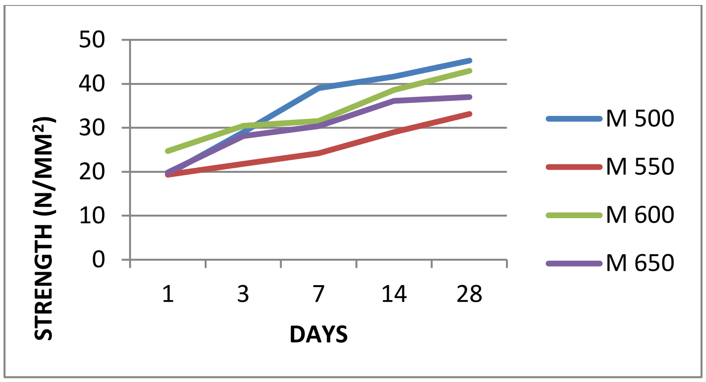

Chart 2: Fly Ash Based Geopolymer Concrete of 16M Compressive Strength

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

GEOPOLYMER CONCRETE RESULTS OF TENSILE STRENGTH FOR 16 M

Table 14: Geopolymer Concrete Results of Tensile Strength for 16 M for M 500

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
21	161.5	181.5	7.20	8.05	7.65	11.80	11.65

Table 15: Geopolymer Concrete Results of Tensile Strength for 16 M for M 550

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
21	155	175.5	6.85	7.85	7.35	11.14	11.24

Table 16: Geopolymer Concrete Results of Tensile Strength for 16 M for M 600

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
21	170.5	152.5	7.55	6.75	7.15	11.65	11.05

Table 17: Geopolymer Concrete Results of Tensile Strength for 16 M for M 650

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT (kg)	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
21	133.5	155.5	5.89	6.87	6.38	11.23	11.85

RESULTS GRAPH OF FLY ASH BASED GEOPOLYMER CONCRETE OF 16M TENSILE STRENGTH

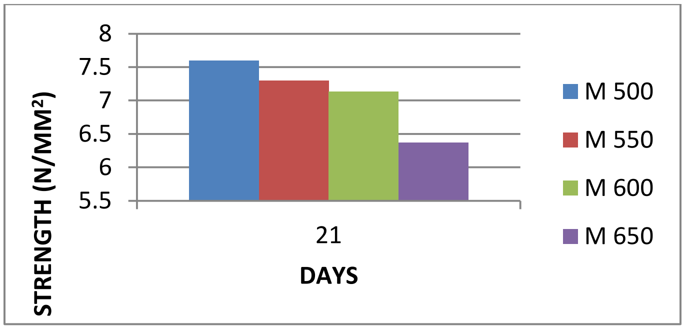

Chart 3: Fly Ash Based Geopolymer Concrete of 16M Tensile Strength

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

REPLACING MOLARITY OF NAOH 16 M TO 10 M:-

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

Table 18: Geopolymer Concrete Results of Compression for 10 M for M 500

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
1	329.5	-	14.62	-	14.61	7.450	-
3	403	388	17.85	17.23	17.55	7.830	7.510
7	436.5	515	19.37	22.88	21.13	7.930	7.690
14	624.5	590.5	28.54	26.23	27.39	7.610	7.510
28	645.5	690.5	28.68	30.67	29.69	7.650	7.390

Table 19: Geopolymer Concrete Results of Compression for 10 M for M 600

DAYS	LOAD		STRENGTH		AVG. STRENGTH	WEIGHT	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2		TRIAL 1	TRIAL 2
1	382.5	-	16.98	-	16.98	7.301	-
3	424.3	470.1	18.85	20.89	19.87	7.141	7.361
7	598.1	547.50	26.58	24.34	25.46	7.221	7.383
14	719.1	714.5	31.96	31.74	31.85	8.102	7.201
28	728.2	758.4	32.35	33.68	33.03	7.403	7.382

RESULTS GRAPH OF FLY ASH BASED GEOPOLYMER CONCRETE 10M:-

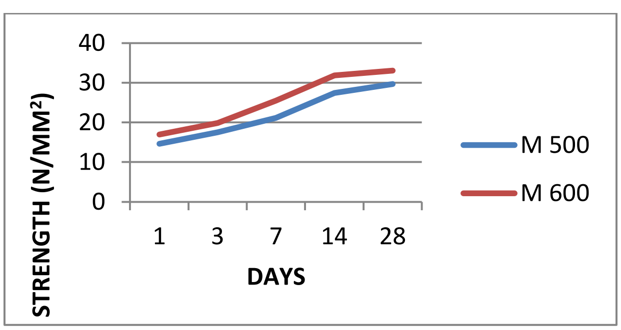

Chart 4: Fly Ash Based Geopolymer Concrete 10M

For the further work, we have taken the 2 proportions M 500 and M 600. In which we have replaced the morality of Noah from 16 molar to 10 molar for checking the variation in compressive strengths. From the graph of compressive strength we can say that the strength of concrete decreases with the morality of Noah decreases.

5. CONCLUSIONS

Geopolymer concrete cubes and cylinders were made and tested. The test result were compared with the prediction of the methods of calculations available for Portland cement concrete and the design provision given in the Indian Standard for concrete structure.

Based on test results, the following conclusions are drawn:

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

2. 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.
3. The strength of geopolymer concrete increases with increase in molarity of sodium hydroxide solution.
4. The geopolymer concrete is lighter in weight as compared to ordinary concrete.
5. 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.
6. The strength of geopolymer concrete increases with increase in curing temperature as well as duration.

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