GEOPOLYMER CONCRETE-A BEST SOLUTION TO CEMENT CONCRETE IN HOT CLIMATE

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Abstract : Government stops the construction activities in most of the states during summer season due to scaring of water. Large quantity of water is required for casting and curing of concrete. This problem can be solved by replacing cement totally from concrete by industrial waste like fly ash which is activated by alkaline solutions to produce geopolymer concrete. So, in the present investigation, suitability of geopolymer concrete instead of cement concrete is studded on the basis of mechanical strength for different test period. Geopolymer concrete is produced by using fly ash which is activated by solutions of 13 M concentrated sodium hydroxide and sodium silicate solution contains 16.45% Na2O, 34.35% SiO2 and 49.20% H2O. Concrete cubes of side 150mmwere cast at solutions-to-fly ash ratio of 0.40. All specimens were cured in oven at 40^0C, 60^0C in oven while some cubes were place in natural sunlight in summer season for test period of 3, 7 and 28 days. Strength results of cement concrete of M25 grade and geopolymer concrete of same grade were compared for specified period of curing. It is observed that the geopolymer concrete gives better result of compressive strength at all period even at natural sunlight curing as compared to cement concrete with water curing. Geopolymer concrete is the best alternative to cement concrete specifically in summer season which need only 45 to 55% water for casting and no water for curing.

***Index Terms* - Cement concrete, Geopolymer concrete, workability, curing types, curing period, Compressive strength.**

I. INTRODUCTION

Concrete is one of the most suitable and affordable structural materials in the world of construction. Compared to the other construction materials, concrete has numerous advantages such as abundant resources, easy operation, mechanical properties, durability, and low cost of production. These characteristics enable concrete to be widely employed in the field of civil engineering. But due to high energy and raw material consumption, environmental pollution during the production of cement, high dead weight of structural element and most important is the requirement of water for casting and curing of concrete hampers the image of the concrete as a sustainable material. Even though to meet the demand of infrastructural development in the countries, technocrats are totally depend on cement concrete. As per European Cement Association, the total consumption of concrete reaches to 3 ton per person per year. The green house gas emission from the production of Portland cement is about 1.35 billion tons annually, which is about 7% of the total greenhouse gas emissions [1-3].

On the other side, fly ash is the waste material of coal based thermal power plant, available abundantly but create disposal problem. Several hectors of valuable land is acquired by thermal power plants for its disposal. As fly ash is light in weight and easily flies, creates severe health problems like asthma, bronchitis, etc. The survey shows the total production of fly ash in the world is about 780 Million tons per year after 2010 [4-5]. In India more than 200 million tons of fly ash is produced annually, out of which 35-50% fly ash is utilized either in concrete as a part replacement of cement or workability improving admixture and in stabilization of soil [6-7]. There are environmental benefits in reducing the use of Portland cement in concrete, and using a cementitious material, such as fly ash, silica fume, ground granulated blast furnace slag, Metakeoline, rice husk ash, etc. as a partial substitute. The concrete made with such industrial wastes is ecofriendly and hence called as "Green concrete". In recent years, attempts have been made to replace the cement by more than 50% with fly ash in concrete to produce high volume fly ash concrete [8-12].

For casting of concrete, 175 liters to 200 liters of water per cubic meter of concrete is required [13-16]. Similarly large amount of water is required for curing depending on types of curing. Therefore, central and state government banned construction activities in summer season.

To solve these problems partially, geopolymer concrete is the best alternative to cement concrete specifically in hot climate. In geopolymer concrete, cement is totally replaced by pozzolanic materials like fly ash and activated by alkaline activators [17]. Only 40 to 60% water is required for casting of geopolymer concrete as compared to cement concrete and no water required for curing. Similarly in summer season, the average temperature is more than 40^0C in most of the states of India which is favourable condition for polymerization of geopolymer concrete. That's why the aim of present investigation is to check the suitability of fly ash based geopolymer concrete in summer season.

II. EXPERIMENTAL PROGRAM

Experimental work is designed to study the effect of curing temperature and testing period on strength of fly ash based geopolymer concrete.

2.1 Materials

In the present experimental work, low calcium fly ash obtained from coal based Thermal Power plant at Eklahare, Nasik was used as source material. The residue of fly ash retained on 45µm IS sieve was reported as 7.67%. Table 1and 2 show the physical properties and chemical composition of fly ash respectively. Locally available river sand was used as fine aggregate and crushed basalt stones of nominal maximum size of 20mm and 12.5mm were used as coarse aggregate. The properties of aggregates are given in table and grading of coarse aggregates and fine aggregate are given in table 4 and 5 respectively.

Table 1: Physical properties of fly ash

Sr. No.	**Physical properties**	**Fly Ash**	**Specification as per IS 3812-1981**
1	Colour	Light gray	----
2	Residue retained on 45 µm	07.67 %	34 % maximum
3	Specific Surface Area (Blaine)	589 m^2/kg	320 m^2/kg
4	Specific gravity	2.25	----
5	Moisture content	0.45 %	2 % maximum
6	Autoclave expansion	0.024%	0.8 %
7	Lime Reactivity- N/mm^2	8.2	----

Table 2: Chemical compositions of fly ash

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	CaO	Total chlorides	Loss of ignition
Percentage	77.10	17.71	01.21	0.90	2.20	0.80	0.62	0.03	0.87

Table 3: Properties of aggregates

Physical properties	**Coarse Aggregate**		**Fine Aggregate**
	CA-I (12.5mm)	**CA-II (20 mm)**	**FA(Sand)**
Type	Crushed	Crushed	River sand
Maximum Size	20mm	12.5mm	4.75mm
Specific Gravity	2.641	2.639	2.563
Water Absorption	0.59%	0.82%	1.56%
Moisture Content	Nil	Nil	Nil

Table 4: Grading of fine aggregate

Sr. No.	**Sieve size mm**	**Cumulative Percentage Passing for River Sand**	**Remark**
1	10	100	Fineness modulus (F.M.) = 2.77. Conforming to grading zone II as per IS 383-1970
2	4.75	92	
3	2.36	84.80	
4	1.18	59.90	
5	0.600	35.30	
6	0.300	10.60	
7	0.150	0.60	

Table5: grading of coarse aggregates

Sr. No.	**Sieve size Mm**	**Cumulative Percentage Passing for**			
		CA-I 20 mm	**CA-II 12.5 mm**	**CA-I : CA-II 65 : 35**	**Required grading as per IS 383:1970**
1	40	100	100	100	100
2	25	100	100	100	--
3	20	84.40	100	89.86	90-100
4	16	06.80	100	39.42	--
5	12.5	0.40	96.50	34.04	--
6	10	0.00	76.40	26.74	25-35
7	4.75	0.00	0.90	0.32	0-10
8	2.36	0.00	0.00	0.00	--

The laboratory grade sodium hydroxide in flake form and sodium silicate solution were used as alkaline activators. The chemical compositions of both activators are given in table 6 and 7 respectively. Concentration of sodium hydroxide was fixed at 13M as per past research (Patankar S.V., Jamkar S. S., 2007) [14-15].

Table 6: Chemical composition of sodium hydroxide

Chemical Compositions	Sodium hydroxide	Carbonate	Chloride	Sulphate	Potassium	Silicate	Zinc
Percentage	97	2	0.01	0.05	0.1	0.05	0.02

Table 7: Chemical composition of sodium silicate

Chemical Compositions	Na_2O	SiO_2	Ratio of Na_2O : SiO_2	Total solid	Water content
Percentage	16.37	34.31	1:209	50.68	49.32

2.2 Mix Proportion

Geopolymer concrete mix is design for M20, M25, M30 and M35 grades concrete for medium workability as suggested by Patankar *et al.* [16]. Water-to-binder ratio is considered as 0.35 while sodium silicate-to-sodium hydroxide ratio by mass of 1. Moreover, concentration of sodium hydroxide in terms of molarity of 13, and concentration of Sodium silicate solution with Na2O of 16.37%, SiO2 of 34.35% and H2O of 49.28% were maintained constant Patankar et al.[18]. Table 8 shows the materials required per cubic meter of geopolymer concrete.

TABLE 8: Quantities of materials required for 1m^3 for different grades of geopolymer concrete

Grade	**W/GPB**	**GPB kg**	**Fly Ash kg**	**TAS kg**	**Fine Aggregate kg**	**Coarse Aggregate kg**	**Extra Water kg**
M 20	118.20	378	280	98	727	1351	64
M25	118.20	445	330	115	708	1314	53
M 30	108.35	513	380	133	691	1282	34
M 35	108.35	594	440	154	667	1239	20
GPB = [Fly ash + (Na_2sio_3 + NaOH) solution), TAS = Total Alkaline Solution of Na_2sio_3 & NaOH							

2.3 Preparation of Geopolymer Concrete Mixes

Preparation of geopolymer concrete is similar to that of cement concrete. Two types of coarse aggregates, sand and fly ash were mixed in dry state. Then add prepared mixture solution of sodium hydroxide and sodium silicate along with extra water based on water-to-geopolymer binder ratio and mix thoroughly so as to give homogeneous mix. It was found that the fresh fly ash-based geopolymer concrete was viscous, cohesive and dark in colour. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by flow table apparatus similar to cement concrete as per IS:1199-1959. Then concrete cubes of side 150 mm were cast in three layers. Each layer was well compacted by tamping rod of diameter 20 mm and then moulds were placed on table vibrator for few seconds so as to give proper compaction. Level the top surface of each mould and cover with steel plate. After 24 hours of casting, all cubes were demoulded and then placed in an oven for thermal curing (heating) for specified period as per past research. To avoid the sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature in an oven itself. Three cubes were cast for each mix and tested for compressive strength after specified period of curing. Similarly, some cubes after de-moulding were directly placed in natural sunlight for curing and tested for compressive strength at the age of for 3, 7 and 28 days.

III RESULT AND DISCUSSIONS

Results of workability in terms of flow and compressive strength of fly ash based geopolymer concrete are presented in the following paragraphs.

Table 8 shows the results of workability in terms of flow, wet density of cubes just after de-moulding and compressive strength of geopolymer concrete cured in oven at 90^{0}C for a period of 8 hours and tested after 3 days of test period, 60^{0}C for a period of 24 hours and tested after 7 days of test period, and 40^{0}C for a period of 24 hours and tested after 28 days of test period. In the present work, test period considered as the period taken after removing cubes from oven up to testing of cubes for compressive strength.

Table 9: Workability and compressive strength results of geopolymer concrete using oven curing.

Grade of Concrete	**Workability in terms of flow (%)**	**Wet Density kg/m^3**	**Compressive strength after oven heating for specified duration and test period, MPa**		
			90^{0}C, 8 hours, 3days	***60^{0}C, 24 hour, 7 days***	***40^{0}C, 24 hours, 28 days***
M20	77.86	2558.52	28.67	27.89	26.22
M25	61.61	2582.22	33.74	33.33	30.11
M30	57.55	2601.48	40.00	39.56	36.78
M35	59.17	2610.37	45.15	43.56	41.44

3.1 Workability of geopolymer concrete

The workability of geopolymer concrete is carried out by flow table test which gives comparatively good results than slump cone test due to viscous nature of geopolymer concrete in fresh state. Table 9 shows the results of workability in terms of flow. It was observed that the mix was cohesive for all grades of geopolymer concrete mixes and flow results are within limits as considered in mix design.

3.2 Compressive strength of geopolymer concrete

Table 9 shows the results of compressive strength of geopolymer concrete for different grades of geopolymer concrete cured in oven for specified duration of heating and test period. It is observed that the curing temperature and duration of heating plays important role in achieving desired strength for same grade of concrete. Lower temperature required long curing period. For all grades of concrete, 900C temperature for only 8 hours duration is sufficient to achieved desired strength just after 3 days of test period.

Table 10 shows the results of compressive strength of geopolymer concrete for different grades of geopolymer concrete placed directly in sunlight for different test period (3, 7 and 28 days) in cured in oven for specified duration of heating and test period. In India, average temperature during summer season is around 39 to 42 degree centigrade in most of places. This is most favorable condition for construction project using geopolymer concrete. That's why; it is decided to check the strength of geopolymer concrete in hot environment without heating.

Table 10: Workability and compressive strength results for different grades of geopolymer concrete for natural sunlight curing.

Grade of Concrete	**Workability in terms of flow (%)**	**Wet Density kg/m^3**	**Compressive strength, MPa** *Natural sunlight curing at an average temperature of 41^{0}C and tested after*		
			3 days	7 days	28 days
M20	77.86	2551.15	7.33	15.44	22.56
M25	61.61	2568.11	9.67	19.56	26.89
M30	47.55	2587.14	11.78	20.89	32.00
M35	29.17	2581.82	15.18	26.43	35.78

Fig.1 shows the effect of curing period on compressive strength of fly ash based geopolymer concrete without heat curing. It is observed that the 27 to 36% strength can be achieved after 3 days of natural sunlight curing, while at the age of 7 days, it was achieved up to 65% strength which is slightly less than the strength achieved by cement concrete using water curing. Similarly, compressive strength of geopolymer concrete using oven heating at 40^{0}C for 24 hours and tested after 28 days of test period is 12-14% higher than that of cubes placed in natural sunlight for same curing period. That means natural sunlight curing is possible for geopolymer concrete if ambient temperature is more than 35^{0}C as suggested by Rangan[]. That means geopolymer concrete can be used without heating directly on site.

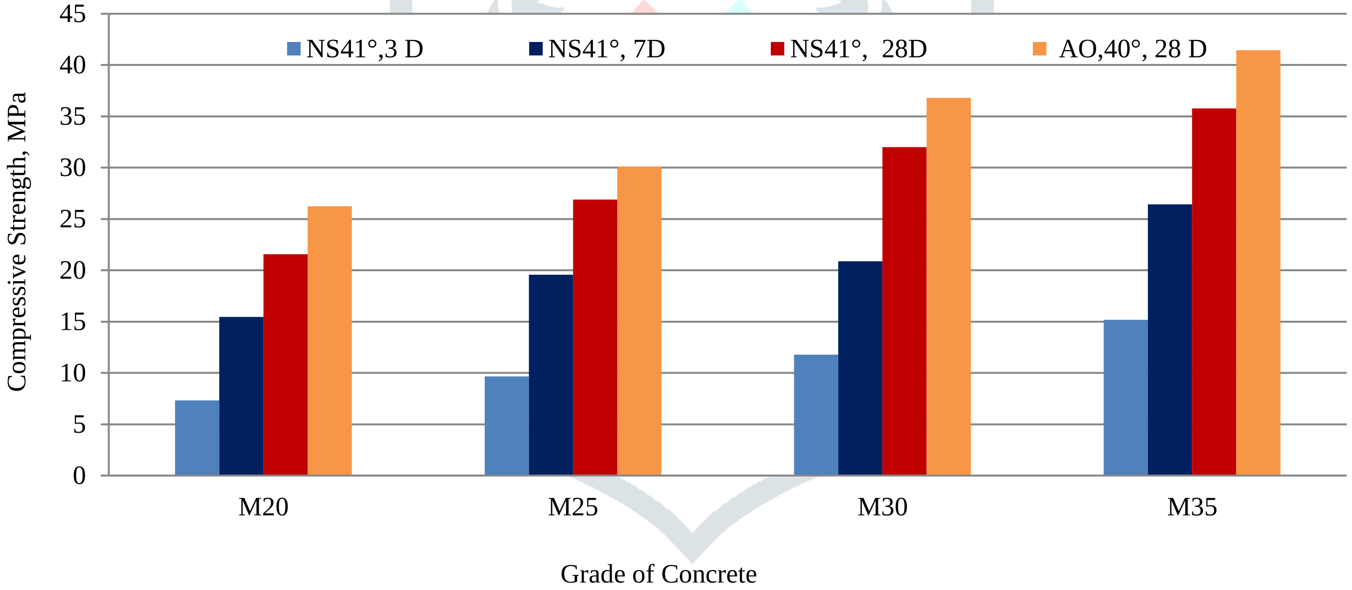

Figure1: Effect of duration of natural sunlight curing for different grades of geopolymer concrete.

To check the suitability of geopolymer concrete on site, M30 grade geopolymer concrete was used in the construction of plain geopolymer concrete (125 mm thick) and Reinforced Geopolymer Raft Slab of area 1200 sq. ft. (250 mm thick) along with 21 footing was constructed for Happy Thoughts Building in Kopargaon, district Ahmednagar, Maharasthtra, India on 12/04/2012. Compressive strength was tested by using rebound hammer after 3, 7 and 28 days. The 28 days compressive strength was observed to be 41.5 MPa without any heat treatment. Till date, there is no problem for the whole (Basement + Ground + First floor) structure which was completed in the year 2014.

Fig. 2, 3, 4 and 5 shows the photographs of Footing, plain geopolymer concrete, Raft foundation and non destructive testing of raft foundation of existing structure respectively.

Figure 2: Geopolymer concrete (M30 grade) placed in isolated Footing.

Figure 3: Photograph of Raft slab using fly ash based geopolymer concrete

Figure 4: Photograph of different Footings made by geopolymer concrete.

Figure 5: Photograph of NDT of geopolymer concrete of Raft slab.

IV CONCLUSION

This paper highlighted the suitability of fly ash based geopolymer concrete without heat curing specifically in hot weather condition. Geopolymer concrete is more environmental friendly and has the potential to replace cement completely by industrial waste like fly ash and to reduce pollution due cement production. It is not only use in laboratory work but also on actual construction sites. One more important thing is to use geopolymer concrete in summer season where ambient temperature is in between 35 to 45^{0}C and it required only 40-60% water for casting and no water for curing. Hence no need to ban the construction due to water crises in summer season and also help to increase employment to poor people in summer season.

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