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EFFECT OF WATER-TO-GEOPOLYMER BINDER RATIO ON THE PRODUCTION OF FLY ASH BASED GEOPOLYMER CONCRETE

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Abstract-: Geopolymer is a new invention in the world of concrete in which cement is totally replaced by pozzolanic material that is rich in silica and alumina like fly ash and activated by alkaline liquids to act as a binder in the concrete. Experimental investigation has been carried out to study the effect of water-to-geopolymer binder ratio on workability in terms of flow and compressive strength tested after heat curing in oven at 900C for 8 hours duration. Activated liquid to fly ash ratio of 0.35 by mass was maintained constant on the basis of past research. Sodium silicate solution with Na_2O = 16.37%, SiO_2 = 34.35% and H_2O = 49.28% and 13 mole concentrated sodium hydroxide solution were used as alkaline activators. Test results show that the flow of geopolymer concrete increases with increase in the water-to-geopolymer binder ratio. But the compressive strength decreases with increase in water-to-geopolymer binder ratio similar to water/cement ratio in cement concrete.

Keywords *-Fly ash, Geopolymer concrete, Flow, Heat-cured, Compressive Strength.*

I. INTRODUCTION

Concrete is the world's most important construction material. Every year the production of Portland cement is increasing with the increasing demand of construction. Therefore the rate of production of carbon dioxide released to the atmosphere is also increasing. Each ton of Portland cement releases a ton of carbon dioxide into the atmosphere [1]. 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 [1-2]. On the other side, fly ash is the waste material of coal based thermal power plant, available abundantly but pose disposal problem. Several hectors of valuable land is acquired by thermal power plants for the disposal of fly ash. As it 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 [2]. In India more than 100 million tons of fly ash is produced annually, out of which 17 – 20 % fly ash is utilized either in concrete as a part replacement of cement or workability improving admixture or 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. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete. The concrete made with such industrial wastes is eco-friendly and hence called as "Green concrete". Some fly ash is utilizes in the production of Portland Pozzolana cement or part replacement of cement in 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].

The pozzolanic activity of fly ash is due to the presence of finely divided glassy silica and lime that produce calcium silicate hydrates. The calcium hydroxide $Ca(OH)_2$ provides the right environment for pozzolanic action. The process is very slow and the particle sizes below 45 micron are responsible for the pozzolanic reaction and higher size particles act as a filler material. Therefore the replacement of cement by fly ash is possible up to certain extent. For complete replacement of cement by fly ash and to achieve higher strength within a short period of time, it is possible to activate the fly ash by using the alkaline solutions [3-4]. Geopolymer concrete is a new material in which cement is totally replaced by the pozzolanic materials that is rich in Silicon (Si) and Aluminium (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature. The chemical process involved in this case is polymerization [4].

Review of literature indicated that the activation of fly ash or other similar materials can be modeled in two ways as suggested by [9]. In the first model, the material containing essentially silicon and calcium like class 'C' fly ash, is activated by low to mild concentration of alkaline solution resulting into calcium silicate hydrate (C-S-H). In the second model, the material that is rich in silica and alumina, like class 'F' fly ash, when reacts with highly alkaline solutions form inorganic alumino-silicate product known as geopolymer. The development of geopolymer concrete can provide a solution to produce greener concrete for sustainable development.

II. EXPERIMENTAL PROGRAM

Experimental work is designed to study the effect of water-to-geopolymer binder ratio on flow and compressive strength of geopolymer concrete for constant solution-to-fly ash ratio of 0.35.

a. 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 I shows chemical composition of fly ash. 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 II and grading of coarse aggregates and fine aggregate are given in table III and IV respectively.

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 V and VI respectively. Concentration of sodium hydroxide was fixed at 13M as per past research (Patankar S.V., Jamkar S. S., 2007).

TABLE I: CHEMICAL COMPOSITION OF FLY ASH

Sr. No.	Chemical Composition	Percentage
1	SiO_2	77.10
2	Al_2O_3	17.71
3	Fe_2O_3	1.21
4	MgO	0.90
5	SO_3	2.20
6	Na_2O	0.80
7	CaO	0.62
8	Total chlorides	0.03
9	Loss of ignition	0.87

TABLE II: PROPERTIES OF AGGREGATES

Physical properties	Coarse Aggregate		Fine Aggregate
	CA-I	CA-II	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 III: GRADING OF COARSE AGGREGATES

Sr. No.	IS Sieve size mm	Cumulative Percentage Passing for			
		CA-I 20mm	CA-II 12.5mm	Combined Aggregate 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	--

TABLE IV: GRADING OF FINE AGGREGATE

Sr. No.	IS Sieve size designation mm	Cumulative Percentage Passing for	Remark
		River Sand	Fineness modulus = 3.16
1	10	100	
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	
8	0.075	0.10	

TABLE V: CHEMICAL COMPOSITION OF SODIUM HYDROXIDE

Chemical Compositions	Percentage
Sodium hydroxide (Min. assay)	97
Carbonate	2
Chloride	0.01
Sulphate	0.05
Potassium	0.1
Silicate	0.05
Zinc	0.02

TABLE VI: CHEMICAL COMPOSITION OF SODIUM SILICATE

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

b. Preparation of Sodium Hydroxide Solution

For the preparation of one-mole sodium hydroxide solution, flakes of sodium hydroxide weighing 40gms were added in distilled water so as to make one-liter solution, where 40 is the molecular weight of NaOH. After dissolving the flakes of NaOH, the temperature of solution rise up to 70 to 80^{0}C, therefore in the present investigation, sodium hydroxide solution was prepared three days prior to the casting of concrete cubes so as to avoid any contamination during the mixing of ingredients of geopolymer concrete.

For preparation of 13M NaOH solution, 520gms of NaOH flakes were added in 750ml water and steered the solution and after cooling add remaining quantity of water so as to make one liter solution. During preparation, avoid direct contact of sodium hydroxide solution with skin and eyes. It may cause severe burn.

c. Preparation of Geopolymer Concrete Mixes

Quantities of ingredients of geopolymer concrete are calculated by considering solution-to-fly ash ratio of 0.35 and 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 Na_2O of 16.37%, SiO_2 of 34.35% and H_2O of 49.28% were maintained constant (Patankar and Jamkar, 2007, 2008).

Table VII shows the materials required per cubic meter of geopolymer concrete by changing quantity of water. Column 2 shows the total quantity of water considered for mix proportioning including water present in solution and extra water required if any. Column 3, 4, 5, 6 and 7 show the quantities of fly ash, sodium hydroxide and sodium silicate solution and fine and coarse aggregate required per cubic meter of geopolymer concrete. Column 8 shows the extra water added in the mix. Similarly 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). 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 seven days of casting.

Six water-to-geopolymer binder ratios (0.40, 0.35, 0.30, 0.25, 0.20, and 0.16) are considered by changing the quantities of water for fixed quantity of geopolymer binder as 450 Kg/m^3. First mix proportion is calculated for water-to-geopolymer binder ratio of 0.40 and quantity of water is considered as 180 Kg/m^3 then quantities of other materials are calculated. Table VII shows the materials required for different water-to-geopolymer binder ratios by changing quantity of water.

TABLE VII: DETAILS OF THE MIXTURES FOR DIFFERENT WATER-TO-GEOPOLYMER BINDER RATIOS

W/GPB	Total Quantity of Water Kg/m^3	Fly ash Kg/m^3	NaOH Kg/m^3	Na_2SiO_3 Kg/m^3	Aggregates Fine Kg/m^3	Aggregates Coarse Kg/m^3	Extra Water Added Kg/m^3
1	2	3	4	5	6	7	8
0.16	72	334	58.45	58.45	648.85	1373.15	0.00
0.20	90	334	58.45	58.45	632.75	1329.09	18.74
0.25	112.5	334	58.45	58.45	613.42	1298.18	41.23
0.30	135	334	58.45	58.45	593.95	1256.96	63.74
0.35	157.5	334	58.45	58.45	574.34	1215.47	86.24
0.40	180	334	58.45	58.45	555.21	1174.98	108.84

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 VIII shows the effect of water-to-geopolymer binder ratio by changing quantity of water without disturbing the mix proportion on workability by slump cone test, compaction factor test and flow table test, mass density and compressive strength of geopolymer concrete. In the table, 2nd column shows the identification mark in which W-0.35 indicates the mix with different W/GPB ratio. 3rd, 4th and 5th column show the workability by slump, compaction factor and flow respectively. 6th column shows the dry mass density of hardened geopolymer concrete cubes after 8 hours of heating. 7th column shows the column shows the average compressive strength taken on three samples. This test was conducted 3 days after completion of specified period of heating.

During the measurement of workability of geopolymer concrete by slump cone, compaction factor and flow table test, following points have been observed;

1) For viscous mix, the concrete subside slowly for long time after lifting the slump cone which prose difficulties in measuring actual slump value.
2) For less viscous but flowable mix, the slurry part flows from bottom of slump cone during placing of geopolymer concrete which affect the slump value.
3) Similarly in compaction factor test, geopolymer concrete was not flow freely through hopper but moves discontinuously due to viscous nature and ultimately affect the weight of partially compacted concrete. TABLE 8 clearly shows the similar values of compaction factor for all type of geopolymer mixes.
4) But due to small height, flow table test gives fairly good values of workability. So in the present investigation, workability was measured by flow table test only.

TABLE VIII: EFFECT OF WATER-TO-GEOPOLYMER BINDER RATIO ON WORKABILITY AND COMPRESSIVE STRENGTH

Sr. No.	I. mark	Workability			Mass Density	Average Compressive Strength
		Slump	C.F.	Flow		
		mm		%	Kg/m^3	MPa
1	2	3	4	5	6	7
1	W-0.40	235	0.986	170.40	2524.44	17.56
2	W-0.35	205	0.986	114.40	2482.96	35.33
3	W-0.30	190	0.956	78.40	2496.29	41.78
4	W-0.25	175	0.958	29.60	2543.70	61.33
5	W-0.20	0.00	0.781	0.00	2411.11	47.11
6	W-0.16	--	--	--	--	--

a. Workability of geopolymer concrete

Water-to-geopolymer binder ratio is the ratio of the total quantity of water (quantity of water present in solution and extra water added in the mix) to the geopolymer binder (quantities of fly ash, sodium silicate and sodium hydroxide solutions). Figure 1 shows the effect of water-to-geopolymer binder ratio on workability in terms of flow of fly ash based geopolymer concrete by changing the quantity of water. It is observed that the flow increases with increase in water-to-geopolymer binder ratio by maintaining other parameters constant. At water-to-geopolymer binder ratio of 0.40, the mix was flow just like self compacting concrete but after few minutes the slurry part separated out from rest of the mix due to presence of excess amount of water. Just after lifting the mould, all the concrete subside rapidly but spread for long time. One more thing was pointed out, is that the spread diameter of geopolymer concrete mix after jolting is similar to that of mix without jolting just after few minutes.

At water-to-geopolymer binder ratio of 0.35 and 0.30, the mix was cohesive and viscous but flow slowly for long time. Before jolting, the geopolymer concrete mix was spread just like a self compacting concrete but slurry part did not separated out and it takes more time than binder ratio of 0.40. At water-to-geopolymer binder ratio of 0.25, the mix was very viscous and takes more time for mixing. At water-to-geopolymer binder ratio of 0.20, the mix was dry, and during mixing, fly ash stick to the surface of aggregate and form large size particles which separated out from each other so difficult to compact. It is also observed that the surface is rough and honey combed when demoulding. At water-to-geopolymer binder ratio of 0.16, the mix was very dry and not workable.

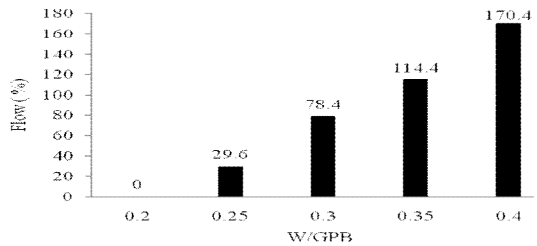

Figure 1: Effect of water-to-geopolymer binder ratio by changing quantity of water on flow of geopolymer concrete

b. Compressive strength of geopolymer concrete

Figure 2 shows the effect of water-to-geopolymer binder ratio by changing the quantity of water on compressive strength of geopolymer concrete with all other test variables were held constant. It is observed that the compressive strength of geopolymer concrete decreases with increase in water-to-geopolymer binder ratio by changing the quantity of water. That means compressive strength of geopolymer concrete is inversely proportional to the water-to-geopolymer binder ratio similar to that of water-to-cement ration in cement concrete.

At water-to-geopolymer binder ratio of 0.40, the cubes were wet even after 48 hours of casting and also observe wet surface even after heating in oven at 90^{0}C for 8 hours. That means the quantity of water present in the mix is much more than required. Similarly, at water-to-geopolymer binder ratio of 0.20, the mix was dry and difficult to compact properly which gives rough surface with reduced strength. At water-to-geopolymer binder ratio of 0.25, the mix was very viscous and stiff but achieves higher strength than higher ratio. It was also observed that the compressive strength reduces with increase in water-to-geopolymer binder ratio by increasing quantity of water. That means the quantity of water plays vital role only in improvement of workability by reducing viscous nature of mix but shows adverse effect on strength. Secondly water come out during polymerization process as clearly seen from chemical reaction equation (1). So quantity of water should be maintained as low as possible.

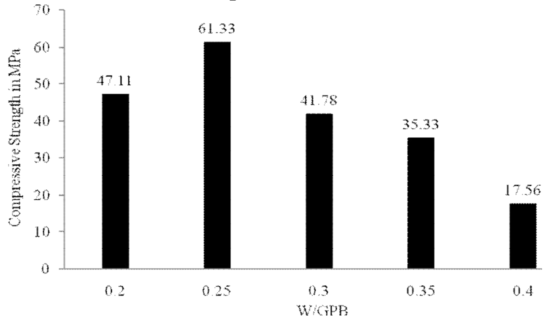

Figure 2: Effect of water - to - geopolymer binder ratio on compressive strength of geopolymer concrete

CONCLUSIONS

This paper presented the effect of water-to-geopolymer binder ratio on the development of fly ash based geopolymer concrete. Based on the experimental work, following conclusions are drawn;

- The flow of geopolymer concrete increases with increase in water-to-geopolymer binder ratio by changing quantity of water.
- Geopolymer concrete is more and more viscous with decrease in water-to-geopolymer binder ratios due to reduction in quantity of water in the mixes.

- The compressive strength of geopolymer concrete is inversely proportional to the water-to-geopolymer binder ratio similar to that of water-to-cement ratio in cement concrete.
- Suitable range of water-to-geopolymer binder ratio is in the range of 0.25 to 0.35. Higher ratio gives segregated mix while lower ratio gives viscous and dry mix.

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