Fly ash based geopolymer concrete-Material/parameters Guidelines

Mr.Kamble V.S.[1], Prof.Nagendra M.V.[2], Dr. Shinde D.N.[3]

[1]*Student department of civil engineering P.V.P.I.T.budhagaon,Sangli,Maharashtra,India.*

[2]*Associate Professor, department of civil engineering,P.V.P.I.T.budhagaon,Sangli,Maharashtra,India.*

[3]*Professor and P.G. Co-ordinator,department of civil engineering P.V.P.I.T.budhagaon,Sangli,Maharashtra,India.*

---***---

Abstract

Geopolymer is a new development in the world of concrete in which cement is totally replaced by pozzoloanic materials like fly ash and activated by highly alkaline solutions to act as a binder in the concrete mix. For the selection of suitable ingredients of geopolymer concrete to achieve desire strength at required workability, an experimental investigation has been carried out for the gradation of geopolymer concrete and a mix design procedure is proposed on the basis of quantity and fineness of fly ash, quantity of water, grading of fine aggregate, fine to total aggregate ratio. Sodium silicate solution with Na2O = 16.37 %, SiO2 = 34.35 % and H2O = 49.28 % and sodium hydroxide solution having 13M , 10M 15M concentration were obtained throughout the experiment. Water-to-geopolymer binder ratio of 0.40, alkaline solution-to-fly ash ratio of 0.35 and sodium silicate-to-sodium hydroxide ratio of 2.0 by mass were fixed on the basis of workability and cube compressive strength. Workability of geopolymer concrete was measured by flow table apparatus and cubes of 150 mm .side were cast and tested for compressive strength after specified period of oven heating. The temperature of oven heating was maintained at 60 °C for 24 h duration and tested 7 days after heating. It is observed that the results of workability and compressive strength are well match with the required degree of workability and compressive strength. So, proposed method is used to design normal and standard geopolymer concrete.

Key Words **-**Geopolymer concrete , Mix design ,Fly ash alkaline solution,Compressive strength.

1.INTRODUCTION

Use of concrete is globally accepted due to ease in operation, mechanical properties and low cost of production as compared to other construction materials. An important ingredient in the conventional concrete is the Portland cement. Production of Portland cement is increasing due to the increasing demand of construction industries. Therefore the rate of production of carbon dioxide released to the atmosphere during the production of Portland cement is also increasing. Generally for each ton of Portland cement production, releases a ton of carbon dioxide in the atmosphere . The greenhouse 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. .Moreover, cement production also consumessignificant amount of natural resources. Therefore to reduce the pollution, it is necessary to reduce or replace the cement from concrete by other cementitious materials like fly ash, blast furnace slag, rice husk ash, etc. Fly ash is a by-product of pulverized coal blown into a fire furnace of an electricity generating thermal power plant. According to the survey, the total fly ash production in the world is about 780 million tons per year but utilization is only about 17–20 %. In India more than 220 million tons of Fly ash is produced annually. Out of this, only 35–50 % fly ash is utilized either in the production of Portland pozzoloana cement, workability improving admixture in concrete or in stabilization of soil. Most of the fly ash is disposed off as a waste material that covers several hectares of valuable land. Therefore for complete replacement of cement by fly ash and to achieve the higher strength within a short period of curing, Davodavits suggested the activation process of pozzolanic material that are rich in silica and alumina like fly ash with alkaline elements at certain elevated temperature. Fly ash when comes in contact with highly alkaline solutions forms inorganic alumina–silicate polymer product yielding polymeric Si–O–Al– O bonds known as Geopolymer . To produce concrete of desired strength, various mix proportioning methods are used on the basis of type of work, types, availability and properties of material, field conditions and workability and durability requirements. Rangan [16] have proposed the mix design procedure for production of fly ash based geopolymer concrete whereas Anuradha [1] have presented modified guidelines for mix design of geopolymer concrete using Indian standard code. As geopolymer concrete is a new material in which cement is totally replaced by fly ash and activated by alkaline solutions. Chemical composition, fineness and density of fly ashes are different from cement. Similarly, in cement concrete, water Plays main role during hydration process while water cement out during polymerization process a sin case of geopolymer concrete .Therefore it is necessary to develop a new mix design procedure for geopolymer concrete to achieve desired strength at required workability. So, in the present investigation, geopolymer concrete mix design procedure is proposed on the basis of quantity and fineness of fly ash to achieve desired strength quantity of water to achieve required degree of workability grading of fine aggregate and fineness-to-total aggregate ratio by maintaining solution-to-fly ash ratio by mass of 0.35 , water-togeopolymer binder ratio of 0.40 , sodium silicate-to-sodium hydroxide ratio by mass of 2.0 and tested after oven heating at a temperature 60 °C for duration of 24 h and tested after test period of 7 days 14 days 28 days

2. EXPERIMENTAL WORK

2.1. MATERIALS

In the proposed mix proportioning method, low calcium processed fly ash of thermal power plant was used as source material. The laboratory grade sodium hydroxide in flake form (97.8 % purity) and sodium silicate (50.72 % solids) solutions are used as alkaline activators. Locally available river sand is used as fine aggregate and locally available 20 and 12.5 mm sizes crushed basalt stones are used as coarse aggregates.

2.2.PARAMETERS CONSIDERED FOR MIX PROPORTIONING OF GEOPOLYMER CONCRETE

For the development of fly ash based geopolymer concrete mix design method, detailed investigations have been carried out and following parameters were selected on the basis of workability and compressive strength.

2.2.1.FLY ASH

Quantity and fineness of fly ash plays an important role in the activation process of geopolymer. It was already pointed out that the strength of geopolymer concrete increases with increase in quantity and fineness of fly ash,. Similarly higher fineness shows higher workability and strength with early duration of heating. So, the main emphasis is given on quantity and fineness of fly ash in the development of mix proportioning procedure of geopolymer concrete. So, in the proposed mix design procedure, quantity of fly ash is selected on the basis of fineness of fly ash and target strength.

2.2.2.ALKALINE ACTIVATORS

In the present investigation, sodium based alkaline activators are used. Single activator either sodium hydroxide or sodium silicate alone is not much effective as clearly seen. So, the combination of sodium hydroxide and sodium silicate solutions are used for the activation of fly ash based geopolymer concrete. It is observed that the compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of fresh mix. Due to increase in concentration of sodium hydroxide solution in terms of molarity (M) makes the concrete more brittle with increased compressive strength. Secondly, the cost of sodium hydroxide solid is high and preparation is very caustic.

Similarly to achieve desired degree of workability, extra water is required which ultimately reduce the concentration of sodium hydroxide solution. So, the concentration of sodium hydroxide was maintained at 13 M while concentration of sodium silicate solution contains Na2O of 16.37 %, SiO2 of 34.35 % and H2O of 49.72 % is used as alkaline solutions. Similarly, sodium silicate-tosodium hydroxide ratio by mass was maintained at 2 which set cubes within 24 h after casting and gives fairly good results of compressive strength.

2.2.3.WATER

From the chemical reaction, it was observe that the water comes out from the mix during the polymerization process. The role of water in the geopolymer mix is to make workable concrete in plastic state and do not contribute towards the strength in hardened state. Similarly the demand of water increases with increase in fineness of source material for same degree of workability. So, the minimum quantity of water required to achieve desired workability is selected on the basis of degree of workability, fineness of fly ash and grading of fine aggregate .

2.2.4.AGGREGATE

Aggregates are inert mineral material used as filler in concrete which occupies 70–85 % volume. So, in the preparation of geopolymer concrete, fine and coarse aggregates are mixed in such a way that it gives least voids in the concrete mass. This was done by grading of fine aggregate and selecting suitable fine-to-total aggregate ratio. Workability of geopolymer concrete is also affected by grading of fine aggregate similar to cement concrete. So, on the basis of grading of fine aggregate, fine-to-total aggregate ratio is selected in the proposed mix proportionating method.

2.2.5.CURING

For the development of geopolymer concrete, temperature and duration of heating plays an important role in the activation process. In the present investigation, cubes were de molded after 24 h of casting and then place in an oven for heating at 60 °C for a period of 24 h. After specified degree of heating, oven is switched off and cubes are allowed to cool down to room temperature in an oven itself. Then compression test is carried out on geopolymer concrete cubes after a test period of 7 days. Test period is the period considered in between testing cubes for compressive strength and placing it in normal room temperature after heating. is observed that the compressive strength of geopolymer concrete increases with increase in duration and test period. From the design point of view, 24 h of oven curing at 60 °C and tested after a period of 7 days was fixed as per past research.

2.2.6.WATER TO GEOPOLYMER BINDER RATIO

Water-to-geopolymer binder ratio The ratio of total water (i.e. water present in solution and extra water if required) to material involve in polymerization process (i.e. fly ash and sodium silicate and sodium hydroxide solutions) plays an important role in the activation. process. Rangan suggested the water-to-geopolymer solid ratio in which only solid content in solution and fly ash is considered. But the calculation is tedious and water present in solution indicates the concentration of solution itself. So, in the present investigation, water-to-geopolymer binder ratio is considered. From the investigation, it is observed that thecompressive strength reduces with increase in water-togeopolymer binder ratio similar to water-to-cement ratio in cement concrete. At water-to-geopolymer binder ratio of 0.35, the mix was very stiff and at 0.40, the mix was segregated. Similarly water come out during polymerization process and does not contribute anything to the strength. So, water-to-geopolymer binder ratio is maintained at 0.40 which gives better results of workability and compressive strength.

2.2.7. SOLUTION TO FLY ASH RATIO

As solution (i.e. sodium silicate + sodium hydroxide) to fly ash ratio increases, strength is also increases. But the rate of gain of strength is not much significant beyond solution to fly ash ratio of 0.35. Similarly the mix was more and more viscous with higher ratios and unit cost is also increases. So, in the present mix design method, solution-to-fly ash ratio was maintained at 0.35

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 for 3–4 min so as to give homogeneous mix. It was found that the fresh fly ash based geopolymer concrete was viscous, cohesive and dark in color. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by flow table apparatus as per IS 5512-1983 and IS 1727-1967. Concrete cubes of side 150 mm are casted in three layers. Each layer is well compacted by tamping rod of diameter 16 mm. All cubes were place on table vibrator and vibrated for 2 min for proper compaction of concrete. After compaction of concrete, the top surface was leveled by using trowel. After 24 h of casting, all cubes were de molded 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. Three cubes were cast and tested for compressive strength for each curing period.

4. METHOD PROPOSED FOR MIX PROPORTIONING (FOR M20 GRADE OF CONCRETE)

4.1. DATA REQUIRED FOR MIX DESIGN

1. Characteristic compressive strength of Geopolymer Concrete (fck)

2. Fineness of fly ash in terms of specific surface in m2/kg 3. Workability in terms of flow

4. Oven curing (heating) 60 °C for 24 h and tested after 7 days

5.Fineness modulus of fine aggregate

6. Water absorption and water content in fine and coarse aggregate.

Following design steps are used to select the suitable mix proportion of fly ash based geopolymer concrete.

5. DESIGN STEPS

5.1. TARGET MEAN STRENGTH (FCK)

for Mix Design Fck ¼fck þ1:65 S ð1Þ The standard deviation, S for each grade of geopolymer concrete shall be calculated, separately on the basis of minimum 30 test samples. With reference to IS 456-2000, the value of S is assumed as per Table 1 in the first instant as mentioned in clause 9. 2. 4.

5.2. SELECTION OF QUANTITY OF FLY-ASH (F)

Quantity of fly ash selected based on target mean strength and fineness of fly ash at solution-to-fly ash ratio of 0.35

5.3. CALCULATION OF THE QUANTITY OF ALKALINE ACTIVATORS

Based on the quantity of fly ash (F) determined in the previous step, the amount of total solution is obtained using solution-to-fly ash ratio of 0.35 by mass. After that, quantity of sodium silicate and sodium hydroxide is decided using sodium silicate-to-sodium hydroxide ratio of 1 by mass.

5. 4. CALCULATION OF THE SOLID CONTENT IN ALKALINE SOLUTION

Calculation of Total Solid Content in Alkaline Solution Calculate solid content in sodium silicate and sodium hydroxide solution on the basis of percentage solid present in each solution.

5.5. SELECTION OF QUANTITY OF WATER

Selection of Quantity of Water Workability of geopolymer concrete is depending on total quantity of water including water present in both alkaline solutions and the degree of workability. Select the total quantity of water required to achieve desired workability based on fineness of fly ash.

5.6. CORRECTION IN WATER CONTENT

In concrete, volume occupied by fine and coarse aggregate is about 70–85% of total volume. Similarly, finer particles have large surface area as compared to coarser one and hence required more water to produce workablemix.IS10262 suggested some correction in water content for the mix proportioning of cement concrete on the basis of grading of fine aggregate. in geopolymer concrete role of water is to make workable concrete. So, it is recommended to apply same correction to geo- polymer concrete in the proposed mix design on the basis of grading zones of fine aggregate. on the basis of grading zones of fine aggregate.

5.7. CALCULATION OF ADDITIONAL QUANTITY OF WATER

In geopolymer concrete, alkaline solutions are used which contains certain quantity of water on the basis of their concentration. But to meet workability requirements, additional water may be added in the mix externally which is calculated as: Additional quantity of water; if required = Total quantity of water - Water present in alkaline solutions.

5.8.CALCULATION OF FINE AND COARSE AGGREGATE CONTENT

Aggregate Contents is obtained using following relations: Total quantity of aggregate = Wet Density of Geopolymer concrete – {Quantity of Geopolymer Binder + Additional water; if any} Sand content = {Fine-to-total aggregate content in %] x {Total quantity of aggregate} Coarse aggregate content ={Total quantity of aggregate} –{ Sand content }.

5.9.ACTUAL QUANTITY OF MATERIAL REQUIRED ON THE BASIS OF FIELD CONDITION.

The above mix proportion has been arrived on the assumption that aggregates are saturated and surface dry. For any deviation from this condition i.e. when aggregates are moist or air dry or bone dry, correction has to be applied on quantity of mixing water as well to the aggregates.

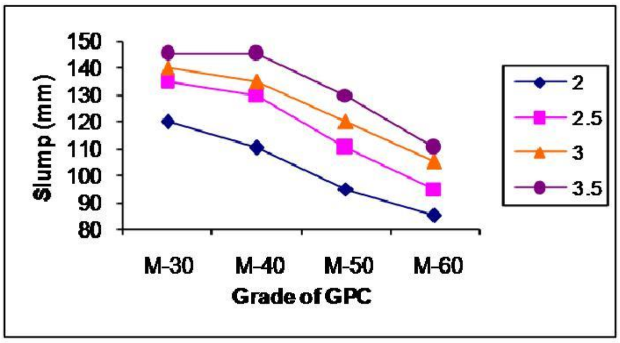
6.RESULT AND DISCUSSION

It was found that the fresh fly ash-based geopolymer concrete was viscous, cohesive and dark in color and glassy appearance. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by flow table apparatus as per IS 5512-1983 and IS 1727-1967. Freshly mixed geopolymer concrete is viscous in nature and water comes out during polymerization process, methods like slump cone test is not suitable to measure workability as concrete subside for long time while in compaction factor test, concrete cannot flow freely. So, flow table test is recommended for workability measurement of geopolymer concrete After measuring workability, concrete cubes of side 150 mm were cast in three layers and each is properly compacted similar to cement concrete. Then after 24 h of casting, all cubes were demoulded and weight was taken for the calculation of mass density. Average weight of three cubes was considered for calculation of mass density. It is observed that the average mass.

Table-1:slump values for various grades of GPC

Grade	$Na_2SiO_3/NaOH$	Slump	Grade	$Na_2SiO_3/NaOH$	Slump
M30	2.5	135	M30	3.5	145
M40	2.5	130	M40	3.5	140
M50	2.5	110	M50	3.5	130
M60	2.5	95	M60	3.5	110

Chart -1: graph of slump and concrete grade



7. CONCLUSION

This paper proposed the guidelines for the design of fly ash based geopolymer concrete of ordinary and standard grade on the basis of quantity and fineness of fly ash, quantity of water and grading of fine aggregate by maintaining water-to-geopolymer binder ratio of 0.40, solution-to-fly ash ratio of 0.35, and sodium silicate-to-sodium hydroxide ratio of 2 with concentration of sodium hydroxide as 13 M. Heat curing was done at 60 °C for duration of 24 h and tested after 7 days after oven heating. Experimental results of M20, M25, M30, M35 and M40 grades of geopolymer concrete mixes using proposed method of mix design shows promising results of workability and compressive strength. So, these guidelines help in design of fly ash based geopolymer concrete of Ordinary and Standard Grades as mentioned in IS 456: 2000.

8.REFERENCES

1. ShankarH.Sanni,KhadiranaikarR.B.(Nov.2012) *"performance of geopolymer concrete under severe environmental conditions"* international journal of structural engineering.
2. M.I.Abdulalim,P.D.Arumairaj(Feb.2012)*"Geopolymer a review"*International journal of engineering sciences and emerging technologies.
3. Prabir K. Sarker (Jan.2013)*"Fracture properties of geopolymer concrete cured in ambient temperature"* Materials and Design 44.
4. l.krishnan l,s. karthikeyan, s.nathiya, k.suganya,knowledge institute of technology, salem.(June.2014)*"Geopolymer concrete an ecofriendly construction material"* international journal of research in engineering and technology vol.03.
5. 15. Vaibhav A. Kalmegh, Dr. P.P.Saklecha, Prof.R.S.Kedar-2015. "*Experimntal Study on Geopolymer concrete with fly ash*".
6. 16. Mohammed Areeb Qidwai -2015."*to study the properties of geopolymer concrete using ggbs*".
7. Sarker PK (2009)*"analysis of geopolymer concrete"*mater struct.
8. Lloyd N and rangan(june 2010)*"Geopolymer concrete with fly ash"*second international conference on sustainable construction materials and technologies.
9. Saint Quentin france(2010)*"What is geopolymer by institute of geopolyemer"*
10. Olivia, Monita and Nikraz(2011)*"Properties of fly ash geopolymer concrete designed by Taguchi method"*,Journel of engineering and technology research vol.3.
11. Mohd Mustafa Al Bakri, H. Mohammed, H. Kamarudin(Jan.2011) *"Review on fly ash-based geopolymer concrete without Portland cement"* Journal of Engineering and Technology Research Vol. 3(1)