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Mix Design of Geosynthetically Reinforced Geopolymer Concrete (GSRGPC/GPCC)

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Abstract: *This paper describes the Mix Design Method of Geosynthetically reinforced Geopolymer Concrete (GSRGPC or GPCC) primarily based on IS: 10262- 2009 for various mix strengths which are identified by performing rigorous trials-and- errors during experimental investigations. The experimental work includes the manufacturing and design process of Geopolymer concrete by using various materials such as Fly ash, Geosynthetics Fibers, Water, Alkaline Activated Solution (i.e. mixture of Na_2SiO_3 & NaOH) with various proportions, 13Molarity of NaOH and dosages of super-plasticizer as per practical requirements. The combination of ASTM Class F-fly ash and alkaline activated solution is used as cementatious material. This method of Mix Design can be adopted both for GPC and GPCC's. It is analyzed from the test results and a solved numerical example that the Indian standard mix design method itself may be used for the design of Geopolymer Concrete Composites with little-bit changes.*

Keywords*: Geopolymer Concrete Composites (GPCC), ASTM Class F-fly Ash, Alkaline Activated Solution, Super- Plasticizer dosages, Molarity*

I. Introduction

Geopolymer Concrete utilizes an alternative material including fly ash as binding material in place of Ordinary Portland cement. This fly ash reacts with alkaline solution (e.g., NaOH) and Sodium Silicate (Na_2SiO_3) to form a gel which binds the fine and coarse aggregates. Since Geopolymer concrete is the most emerging field, the guidelines from the Bureau of Indian Standards are yet to be formulated. Therefore an attempt has been made to find out an optimum mix for the Geopolymer concrete. Concrete cubes of size (150 x 150 x 150) mm were prepared and cured under thermostatically controlled oven for a temperature of 90^0 C for 7 day and up to 28 days. The compressive strength was found out at 7 and 28 days respectively and the results are compared. The optimum mix is (Fly ash: Fine aggregate: Coarse aggregate) i.e. with a solution (NaOH & Na_2SiO_3 combined together) to fly ash ratio of 0.35; as shown in Table no.14. High and early strength was obtained in the Geopolymer Concrete Composite mix. This work is presented in this paper dealt with a study investigating the Mix design procedure of GPCC matrixes analogous to the OPCC and similar to IS: 10262-2009 as a basic method [1and 14].

II. Literature Survey

Geopolymer cement (Davidovits, 1984, 2008, 2010) [2, 3, and 4] represents a broad range of materials characterized by networks of inorganic molecule. The fly ash which has high content of Silica (Si) and Alumina (Al) reacts with alkaline solution like Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na_2SiO_3) or Potassium Silicate (K_2SiO_3) and forms a gel which binds the fine and coarse aggregates. Geopolymer concrete do not require any water for matrix bonding, instead the Alkaline Solution reacts with Silicon and Aluminium present in the fly ash. The "polymerization process" involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals. The reaction of fly ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of (Si-O-Al-O)bonds, as follows:

"M n [-(SiO_2) z–AlO_2] n. wH_2O………….. (1) "

where M is a monovalent cations such as potassium or Sodium, the symbol – indicates the presence of a bond, n is the degree of polycondensation or polymerization and z is 1, 2,3 or higher, as reported earlier (Hardjito D., Wallah et al., 2004; Van Chanh Bui et al., 2008)[5-7].

III. Materials

III.I) Fly Ash-(as cementatious/source material) ASTM low calcium - type F -Fly ash is the residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases of thermal power plants. The important characteristics of fly ash are its particles are in spherical shape, which improves the flowability and reduces the water demand. The fly ash used in this experimentation is obtained from the silos of Thermal Power Station situated at Parali -Vaijanath, Dist. Beed, Maharashtra State, India; which is of low calcium, Class F type. The chemical composition of fly ash is shown in Table1, with its specific gravity 2.3, obtained from test reports of CSRL–STRUCTWEL LAB. Pune PVT. LTD., M.S., India.[8]

Table 1: Chemical Composition of Fly Ash

Sr. No.	Chemical constituents in % or Type of Test	Percentages As per Test Result%	Requirement as per IS:3812-2003 [8]			
			Part-I		Part-II	
			Siliceous fly ash	Calcareous fly ash	Siliceous fly ash	Calcareous fly ash
1	Silica content SiO_2	61.49	35.0 min.	25.0min.	35.0 min.	25.0min.
2	Alumina content(Al_2O_3)	31.34	----	----	----	----
	Ferric Oxide(Fe_2O_3)		----	----	----	----
3	Silica+ Alumina +Ferric Oxide	92.83	70 min.	50min.	70min.	50min.
4	Calcium Oxide(CaO)	1.92	----	----	----	----
5	Magnesium Oxide(MgO)	0.56	5max.	5max.	5max.	5max.
6	Sulphur Tri–oxide(SO_3)	0.51	3max.	3max.	5max.	5max.
7	Loss on Ignition(LOI)	0.49	5max.	5max.	7max.	7max.
8	Chloride	----	0.05max.	0.05max.	0.05max.	0.05max.

III.II) F.A. &C.A.:- Locally available Godavari (Paithan) river sand and Crushed Basaltic stones (from stone crushers near outskirts of Aurangabad city of Waluj premises) were used as F.A. and C.A.respectively; with C.A. of NMS as 20 mm and 12.5 mm having their physical properties as shown in Table 2 and their gradings are shown in Table 3 and 4 respectively.

Table 2: Physical Properties of Aggregates (F.A. &C.A.)[9]

Physical Properties	Coarse Aggregates(CA)		Fine Aggregates (FA)
	CA-I	CA-II	FA(Sand)
Type	Crushed	Crushed	Godavari sand
Maximum size	20mm	12.5mm	4.75mm
Specific Gravity	2.641	2.639	2.563
Water Absorption	0.58%	0.84%	1.58%
Moisture content	Nil	Nil	Nil

Table 3: Gradings of C.A.(in Saturated Surface Dry- conditions)

Sr.No.	IS Sieve sizes in mm	Cumulative percentage Passing for			
		CA-I 20mm	CA-II 12.5mm	Combined Aggregates CA-I :CA-II(65:35)	Required grading as per BIS 383:1970 [9]
1	40	100	100	100	100
2	25	100	100	100	---
3	20	87.50	100	89.90	90-100
4	16	6.80	100	39.42	--
5	12.5	0.40	96.5	35.04	--
6	10	0.00	76.40	27.75	25-35
7	4.75	0.00	0.96	0.35	0-10
8	2.36	0.00	0.00	0.00	---

Table 4: Grading of FA (Saturated Surface Dry- conditions) [9]

Sr.No.	IS Sieve size designation mm	Cumulative percentage Passing for Godavari river sand	Remarks
1	10	100	FM = 3.74 Confirming to ZoneII, IS 383-1970 [9] Specific Gravity-
2	4.75	92	
3	2.36	84.80	
4	1.18	59.90	
5	600μ	35.30	

6	300μ	10.60	2.61.
7	150μ	0.62	
8	75μ	0.10	
Total		374.32	

III.III) Alkaline Activated Solution (A.A.S.):-

III.III.I) Sodium Hydroxide (NaOH)- (Laboratory Grade):- in flake or pellets/solid form and its cost is mainly varied according to its purity and its main function is to activate the Sodium Silicate solution ;hence it is better to use it within economical purity i.e. up to the purity range from 94% to 96%.The concentrations of NaOH used was of 13Molar(as per previous research)[10]

III.III.II) **Sodium Silicate (Na_2SiO_3) Solution** : in Gel form (known as Water Glass) with a ratio of oxides between SiO_2 to Na_2O = 2 was used ;which were silicates which are supplied to the detergent company and textile industries as bonding agent; same type of silicates were used for this investigation for making Geopolymer concrete. The Chemical **C**ompositions of both NaOH and Na_2SiO_3 are presented in Table 5.

Table 5: Chemical Compositions of NaOH and Na_2SiO_3

Chemical Compositions of NaOH (Min. Assay)	**Percentages 97%**	**Chemical compositions Of Sodium Silicate (Na_2SiO_3) Solution Colour- light yellow liquid**	**Percentages**
Carbonate(Na_2O_3)	2	Na_2O (%)	16.37%
Chloride(Cl)	0.01	Si O_2 (%)	34.31
Sulphate(SO_2)	0.05	Ratio of Na_2O: SiO_2	1:2.09
Potassium(K)	0.1	Total Solids (%)	50.68
Silicate(Si_2O_3)	0.05	Water content H_2 (%)	49.32
Lead(Pb)	0.ooi	Appearance	Liquid(Gel)
Zink(Zn)	0.02	Boiling point	102^0c for 40% aq.soln
Specific gravity	1.16	Specific gravity	1.57
Colour	Colourless	Molecular Weight	184.04

III.III.III) Preparation of Sodium Hydroxide Solution: - (Sample case explained)
1 Mole of Sodium Hydroxide Solution = [40 gm Flakes of NaOH + Distilled Water]
(Since Molecular Weight of NaOH is 40 =1 LITRE Solution of NaOH} temp.rises to 70^0 to 80^0C.
Hence, it is suggested to prepare NaOH Solution 3 days prior to the casting of concrete cubes etc to avoid any contaminations during the mixing of ingredients of GPC. For e.g. for the preparation of 13M NaOH Solution = {520gms flakes of NaOH+750 ml water} steered solution and after cooling; add remaining quantity of water to make one litre complete solution. Always avoid direct contact with skin and eyes to avoid severe burns.
III.IV) Water:-Potable water which is available in laboratory was used for mixing purposes.
III.V) Geosynthetics Fibers (*Tensor SS40-Biaxial)*:-Since Geopolymer cement concrete is more brittle than conventional concrete, in these investigations Geosynthetics fibres (GGR Types only) are used to convert GPCC into more ductile/ elastic one. Geogrids fibres with aspect ratio (Lf/ hf *= 35.54/1.27 =28*) 28 to 50 is used with modulus of elasticity (E) in the range of 12000 -18000 MPa {MN/m^2} say 15000 MPa, Specific Gravity ranging from 1.22-1.38, melting point @ 260^0C., unit mass or weight/unit area-345-930 g/m^2, thickness ranges from 10-300 mils or generally 20 mils i.e.0.025 mmx20 = 0.5mm (since 1 mil = 0.025mm).The quantities of Geosynthetics fibres incorporated into GPC for experimentation was as per previous research[16]& as shown in Table 9.
III.VI) Super-plasticizers: -Sikament 610 ut.250 Kg (Naphthalene based) was used as super plasticizer/ an admixture, its Quality Assurance Certificate shown in Table 6.

Table 6: Quality Assurance Certificate

Property	**Specifications**		**Actual Results**	**Test Results**
	Min	**Max**		
Aspect	Dark Brown Lump Free Liquid		OK	PASS
pH Value	7.00	9.00	8.80	PASS
Specific Gravity	1.15	1.19	1.18	PASS
Solid content (% by wt.)	30.88	34.13	32.42	PASS
Chloride% by wt.	0.00	0.20	0.00	PASS

III.VII) Preparation of alkaline solution:

Prof. J. Davidovits, (Geopolymer Institute, France) has recommended that the sodium silicate solution and the sodium hydroxide solution were mixed together one day prior to the use in preparing the Geopolymer concrete. This is followed in this study. The ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5%.with the following chemical compositions of NaOH and Na_2SiO_3 as shown in Table no.7.

Table 7: Chemical Compositions of NaOH and Na_2SiO_3

Chemical Compositions of NaOH (Min. Assay)	**Percentages 97%**	**Chemical compositions of Sodium Silicate (Na_2SiO_3) Solution Colour- light yellow liquid**	**Percentages**
Carbonate(Na_2O_3)	2	Na_2O (%)	16.37%
Chloride(Cl)	0.01	SiO_2 (%)	34.31
Sulphate(SO_2)	0.05	Ratio of Na_2O: SiO_2	1:2.09
Potassium(K)	0.1	Total Solids (%)	50.68
Silicate(Si_2O_3)	0.05	Water content H_2O(%)	49.32
Lead(Pb)	0.ooi	Appearance	Liquid(Gel)
Zink(Zn)	0.02	Boiling point	102^0C for 40% aq.soln
Specific gravity	1.16	Specific gravity	1.57
Colour	Colourless	Molecular Weight	184.04

III.VIII) Mix Proportion of Geopolymer Concrete:- The mix ratio proposed by Dr. B. V.Rangan of Curtin University, Australia (Van Chanh Bui et al., 2008; Wallah & Rangan, 2006) [5-7] was taken as a base mix. Different mix proportions were used to find out the compressive strength for optimization as shown in Table no.14. The previous studies on Geopolymer concrete ((Van Chanh Bui et al., 2008; Wallah & Rangan, 2006) [5-6] used a mix proportion of fly ash: Fine Aggregate: Coarse Aggregate as {1:1.35:3.17} with a solution (NaOH & Na_2SiO_3 combined together) to fly ash ratio of 0.35. In this experimentations Seventeen (3 each) {16GPCC +1GPC} trail mixes were arrived by slightly modifying the quantities of fine and coarse aggregates. The proposed Optimized mix ratios are shown in table 15, and for all seventeen trial mixes, the solution to fly ash ratios and other details are shown their in the table. The exact quantities of ingredients for one cubic meter are presented in Table 8. Fly ash, C.A., F.A. are initially mixed together in dry state and then the liquid component of the mixture i.e. AAS is added to prepare wet mix until it gives homogeneous mix with or without super plasticizer as per workability requirements. Mix proportions and fiber quantities of Geopolymer concrete per cubic meter are given in Table 8 and Table 9 respectively.

Table 8: Mix proportion of Geopolymer concrete per cubic meter

Fly Ash	**NaOH(13M)**	**Na_2SiO_3**	**FA**	**CA**	**Extra water**	**Total Quantity of Ingredients (kg)**
310	54.25	54.25	744	1387.90	62.00	2612.401
1part	0.175 part	0.175 part	2.40 part	4.4771 part	0.20 part	Proportions [AAS/FA]=105/300 = 0.35

Table 9: Quantity of fibres for various mixes

Geosynthetics (Geo-grids only) fiber (%)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Fibre quantity (kg/m^3)	0.0	2.613	5.22	7.84	10.452	13.065	15.678	18.286	20.899
Super plasticizer[as per actual] (kg/m^3)	0.0	0.10	0.200	0.225	0.370	0.500	0.723	0.981	1.052

IV. Specified Basic Data

IV.I) Following is the specified Basic Data required for Mix Design of G P Concrete Composites (based on the experimental investigations performed).

(A) Obtain the Characteristic Compressive Strength of Geopolymer Concrete Composites at 24 hours(i.e. One Day) / 7 days Curing at a Temperature of 90^0 C = f_{ck}….

(B) Specified Maximum Size and Type of Fine Aggregates and CA to be used for these purposes….

(C) Specific Gravity of various ingredients of GPCC Mixes (like Fly Ash, FA, CA, AAS etc) to be used……

(D) Proper Selection of (as per requirements of target strength to be achieved)……..

(D1) Alkaline Activated Solution with suitable mass ratios amongst their ingredients,

(D2) Fly Ash to the Compressive strength Ratio,

(D3) Aggregates Sizes, Gradings of aggregates, Surface Texture, shape and other characteristics may produce secretes of different compressive strengths for the same ratios of ingredients and the relationship between strength and free Alkaline Activators are to be derived from experimental investigations, D4) Extra Water, Fly Ash to GPC Solids ratios should be preferably established for all these ingredients [11-13] through many trials and errors of ingredients used in laboratory.

The fly ash, fine aggregates and coarse aggregates were mixed first manually in a container specially Pan mixture and then the alkaline solution was added to prepare the Geopolymer concrete. The Geopolymer concrete was placed in 150 mm cube moulds in three layers and each layer was compacted by giving 25 blows with a tamping rod. The Geopolymer concrete was dark in colour with shiny appearance.

IV.I) Curing of Specimens:-

The previous studies on Geopolymer Concrete curing revealed that the Geopolymer concrete did not attain any strength at room temperature or by water curing. The Geopolymer concrete will harden at steam curing or hot air curing and the minimum curing period shall be 24 hours. After casting the specimens, they were kept in rest period in room temperature for 2 days. The term '*Rest Period'* was coined to indicate the time taken from the completion of casting of test specimen to curing at an elevated temperature. The Geopolymer concrete was demoulded and then placed in a thermostatically controlled oven for Curing for 24 hours i.e. One day / 7 days and /28 days at a temperature of 90^{O} C. The cubes were then allowed to cool in room temperature for 24 hours.

IV.II) Compressive Strength Test:-

The cube specimens were tested in a compressive testing machine having 2000kN capacity in accordance with the Bureau of Indian Standard test procedures. The compression test results are tabulated in Table 14 for 7 and 28 days.

IV.III) Results and discussion:-

The Geopolymer Concrete Composites showed high performance w.r.t. the strength. The Geopolymer concrete was a good workable mix. The increase in percentage of fine aggregates and coarse aggregates increased the compressive strength up to the optimum level. This may be due to the high bonding between the aggregates and alkaline solution. The compressive strength was found reduced beyond the optimum mix. This may be due to the increase in volume of voids between the aggregates. Thus the optimum mix can be found out from test results.

IV.IV) Approximate Estimation of Air Contents: - Approximate amount of entrapped air to be expected in normal i.e. non-air–entrained concrete is given in Table10.

Table-10: Approximate Estimation of Air Contents & sand required per cum of concrete

Nominal maximum size of aggregate in mm (NMSA)	**Entrapped Air, as % of volume of concrete**	**Nominal maximum size of coarse (NMSA)Aggregates**	**Sand as % of total aggregate by absolute volume**
10	3	10 mm	40
12.5	3	20 mm	35
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 is to be established from Table 10 as applicable, depending upon the NMS and type of aggregates.

Table 11: Adjustment of values in Water content and Sand % for other conditions.

As per Table 4, IS:383-1979	**Adjustments required in**	
Change in conditions Stipulated for Tables	Water content	% sand in Total Aggregate
For sand conforming to, Grading Zone – I or Zone IV of	0	1.5% for Zone I
For sand conforming to Grading Zone – III		-1.5% for Zone III
For sand conforming to Grading Zone – IV		- 3% for Zone IV
Increase or decrease in the value of compacting factor by 0.1	± 3%	0
Each 0.05 increase or decrease in water-cement ratio	0	±1%
For rounded aggregates	-15 kg	-7%

IV.V) Calculations of Aggregates contents- The total Aggregate (TA) contents per unit volume of concrete may be calculated from the equation:-

"$\mathbf{V = \{(SO/S_{so}) + (S/S_s) + (F/S_F) + (1/P)\,(F_a / SF_a)\} \times (1/1000)}$……………**(2)"** &

"$\mathbf{V = \{(SO/S_{so}) + (S/S_s) + (F/S_F) + (1/\,1 - P)\,(C_a / SC_a)\} \times (1/1000)}$………(3)"

Where, V = Absolute volume of fresh concrete, which is = {Gross Volume -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,

SF = Specific Gravity of Fly Ash,
P = Ratio of (FA to TA) by Absolute Volume,
F_a, Ca = Total masses of FA and CA in (Kg) per m^3 of concrete respectively,
SF_a, SCa =Specific Gravity of (in SSD condition) of FA & CA respectively,
S_s =Specific Gravity of Sodium Silicate solution, and
S_{so} =Specific gravity of Sodium hydroxide solution.

V.VI. Illustrative Example For Mix Design Of Geopolymer Concrete Composites…..

This example is prepared for the illustration of the proposed mix design of Geopolymer Concrete Composites of say M_{35} grades as explained below---As per IS:10262-2009[1]

V.I) Design stipulations:-

Required Design stipulations	Experimental Results
a) Characteristics compressive strength required in the field at the Age of 7 days at 90^0 C temperatures curing…	35MPa
b) Maximum size of aggregates MSA (shape-Angular)	20 mm,
c) Sand i.e. FA conforming to	zone II,
d) S_{ss} = Specific Gravity of Sodium Silicate solution	1.57
e) S_{so} =Specific gravity of Sodium hydroxide solution	1.16
f) Degree of workability ……(compacting factor)	0.90
g) Degree of Quality Control…	Good
h)Type of exposure	Mild

5.2) Test Data for Materials: By performing tests as per requirements, the following data is established….

Table 12: Required Test Data

1) S_{FA} = Specific Gravity of Fly Ash	2.3
2)SF_a =Specific Gravity of FA at SSD condition	2. 563
3)SCa = Specific Gravity of CA at SSD condition	2.641
4)Water Absorption:	--------
1) of CA	0.75%
2) of FA	1.58%
5)Free moisture	--------
1)CA	Nil
2)FA	2.0%
3)Sieve Analysis is shown as above….F.A.	Lies in grading zone II Conforming to IS:383-1970[9]

V.III) Target mean strength (f 'ck): for mix design of specified characteristic cube strength at 7 days is given by

“ $f'_{ck} = f_{ck} + t.S$………………………...(4) ” [1]

Where fck is characteristic compressive strength at 7 days. As per IS: 456-2000 and IS: 1343-80, t = risk factor =1.65, S = Standard deviation= 4, keeping the above values,

“$f'ck = f_{ck} + t.S = f_{ck} + 1.65\ S = 35+1.65\ X4 = 41.6$MPa,

Where, S = assumed Standard deviation as per IS: 456-2000 [15] w.r.t. grade of concrete as shown below.

Table13: Assumed values of Standard deviation [15]

Grade of concrete	M10	M15	M20	M25	M30	M35	M40	M45	M50
Assumed Standard Deviation(S)	…..	3.5	…	4.00	….	….	5.00	…	…

Table14: Test results for Compressive Strength and Split Tensile Strength (7 days)(MPa)

I.D. OF Mix.	GPCC.Q (V_f = 0.0)	GPCC.P (V_f = 0.05)	GPCC.O (V_f = 0.1)	*GPCC.N* (V_f = 0.15)	*GPCC.M* (V_f = 0.2)	*GPCC.L* (V_f = .25)	GPCC.K (V_f = 0.3)	GPCC.J (V_f = 0.35)	*GPCC.I* (V_f = 0.4)
Compressive Strength	15	16	20	21	24	28	30	31	35
Split Tensile Strength	1.9	1.98	2.1	2.23	2.67	2.7	2.89	2.91	3.01
I.D. OF Mix.	GPCC.H (V_f=0.45)	GPCC.G (V_f= 0.50)	GPCC.F (V_f= 0.55)	*GPCC.E* (V_f= .60)	GPCC.D (V_f=0.65)	GPCC.C (V_f= .70)	GPCC.B (V_f= .75)	*GPCC.A* (V_f = 0.8)	
Compressive Strength	38	40	43	47	52	54	60	68	
Split Tensile Strength	3.21	3.31	3.5	3.70	4.03	4.04	4.5	4.8	

Table 15: Various Optimized Mix Proportions for Design of GSRGPC & GPC (As per actual requirements after many Trials)

Content	**GPCC.F**	**GPCC.L**	**GPCC.E**	**GPCC.N**	**GPCC.M**	**GPCC.A**	**GPCC.I**
Fly Ash	424	380	350	380	763.11	430	401
CA	1293.60	1293.60	1293.60	1293.60	964.0	1293.60	1293.60
Fine Sand(FA)	554.40	554.40	554.40	554.40	713	554.40	554.40
Water	42.46	40.88	42.46	40.88	14.2	38.06	39.42
NaOH Solution	36.40	40.89	36.40	40.89	83.0	48.95	45.06
Na_2SiO_3	91.0	102.22	91.0	102.22	207.3	122.36	112.65
Comp. Strength	43	28	47	21	24	68	35
AAS/FLY ASH	0.300	0.349	0.364	0.377	0.380	0.398	0.399
Total weight	2441.88	2440.88	2367.86	2440.88	2346.40	2438.06	2394.36
SS/SH	2.5	2.5	2.5	2.5	2.5	2.5	2.5
WATER/GPS	0.227	0.260	0.224	0.268	0.261	0.186	0.252
WATER /Fly Ash	0.1	0.107	0.121	0.107	0.0186	0.089	0.098
Content	GPCC.K	GPCC.B	GPCC.G	GPCC.C	GPCC.J	GPCC.H	GPCC.O
Fly Ash	702.12	580.02	670	555.00	590.21	487	450
CA	832.80	929.1	882.2	957.9	832.80	987.5	1018.0
Fine Sand(FA)	615.6	615.6	652.1	572.2	615.6	589.9	608.1
Water	28.2	44.2	28.3	44.2	28.2	44.2	44.2
NaOH Solution	82.2	68.5	82.2	68.5	82.2	68.5	68.5
Na_2SiO_3	205.5	171.1	205.5	171.1	205.5	171.1	171.1
Comp. Strength	30	60	40	54	31	38	20
AAS/FLY ASH	0.409	0.413	0.430	0.432	0.487	0.492	0.532
Total weight	2319.00	2466.70	2334.00	2368.9	2319.00	2343.80	2329.60
SS/SH	2.5	2.5	2.5	2.5	2.5	2.5	2.5
WATER/GPS	0.258	0.215	0.247	0.224	0.256	0.249	0.285

Content	**GPCC.Q**	**GPCC.P**	**GPCC.D**
Fly Ash	450	571.90	510
CA	1018.0	1011.75	1049.5
Fine Sand(FA)	608.1	581.56	613
Water	44.2	34.78	36.5
NaOH Solution	68.5	100	52.7
Na_2SiO_3	171.1	250	131.5
Comp. Strength	15	16	52
AAS/FLY ASH	0.570	0.612	0.650
Total weight	2329.60	2550.00	2301.10
SS/SH	2.5	2.5	3.50
WATER/GPS	0.304	0.298	0.224

V.IV) Solution procedure:-

V.IV.I) STEP-1: Selection of fly Ash Content (on y-axis) to the Compressive strength (on x-axis) is plotted as shown in Fig.1 (Obtained after numerous experimentations on samples of different Grades as shown in Table no15 which is designed by optimized mix proportions and as shown in the Fig.1, from which we can obtain the amount of Fly Ash required for M $_{35}$ grade GPCC is = 610 kg/m^3.

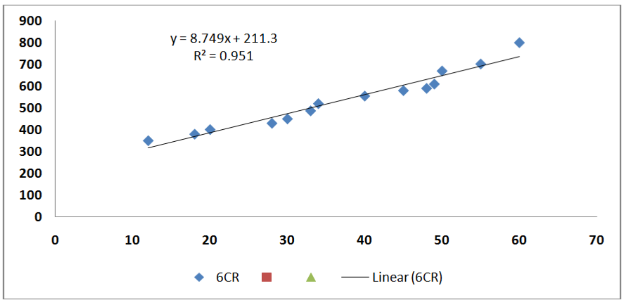

Figure 1:- Showing fly ash content to the compressive strength (From Table 6)

V.IV.II) Step-II:-Selection of [Alkaline Activator Solution / Fly Ash] Ratio (on y-axis) and the Compressive Stress (on x-axis) of GPCC. (From Fig.2)

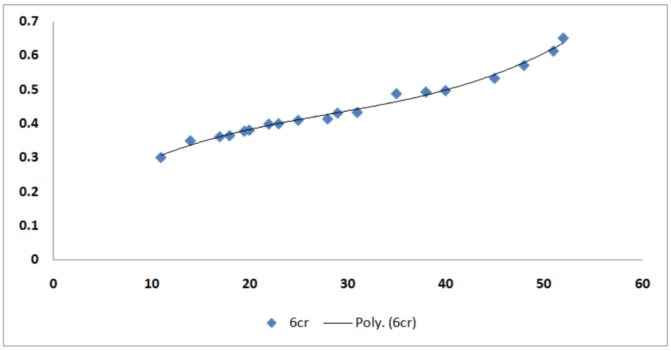

Figure 2-generalized relation between [alkaline activator solution to fly ash] ratio v/s compressive stresses of gpcc.

Generalized relation between Alkaline Activator (liquid) to Fly Ash Ratio v/s Compressive Stress of GPCC, as shown in Fig.2- (This is obtained after numerous experimentations on samples of different grades as shown in Table no.15). Thus the ratio of Alkaline Activator (liquid)/Fly Ash Ratio w.r.t Compressive Stress 41M Pa (target strength) of GPCC requirements is 0.51.

V.IV.III) Step-III:- Calculations of Solids and Water quantity in NaOH solution of Morality 13

Now, for the Compressive Stress of GPCC requirement, the ratio between Sodium Hydroxide/Sodium Silicate from Table 6 comes out to be… NaOH / Na_2SiO_3 = 1: 2.5, Total (1+2.5) parts = 3.5 parts

Now, Total amount of Alkaline Activator Solution = 0.51x Fly Ash Content = 0.51 x 610 = 311.10 Kg/m^3

Alkaline liquid = 311.10Kg/m^3, one part of this = 311.10/3.5 = 88.89 Kg/m^3 NaOH (SH) and remaining 2.5 parts = 2.5 x 88.89 =222.225 Kg/m^3 of Na_2SiO_3 (SS).

Amount of Sodium silicate Solution = 222.225 Kg/m^3

Amount of Sodium Hydroxide Solution = 88.89 kg/m^3

Morality of Sodium Hydroxide Solution to be used in the GPCC is 13 Molar in which 383 grams of NaOH solids are dissolved in 617 grams of water.

For 1000……383, for 100..=383x100/1000 = 38.3; now for 100…38.3 so for 88.89 = 88.89x38.3/100= Solids 34.04 kg/m^3, Water =137.12kg/m^3 i.e. [1000...671; then 100=617x100/1000 = 61.7; 100…61.7 then for 222.225 = 222.225x61.70/100 =137.1212kg/m^3].

Table 16: (from table no.15) {Sodium hydroxide to Sodium Silicate} ratio w.r.t. Compressive Strength

Compressive strength(MPa)	Sodium hydroxide	Sodium Silicate	Ratio of SS/SH
30	36.40	91.0	2.5
60	40.89	102.22	2.5
40	36.40	91.0	2.5
54	40.89	102.22	2.5
31	83.0	207.3	2.5
38	48.95	122.36	2.5
20	45.06	112.65	2.5
30	82.2	205.5	2.5
60	68.5	171.1	2.5
40	82.2	205.5	2.5
54	68.5	171.1	2.5
31	82.2	205.5	2.5
38	68.5	171.1	2.5
20	68.5	171.1	2.5
15	68.5	171.1	2.5
16	100	250	2.5
52	52.7	131.5	3.50

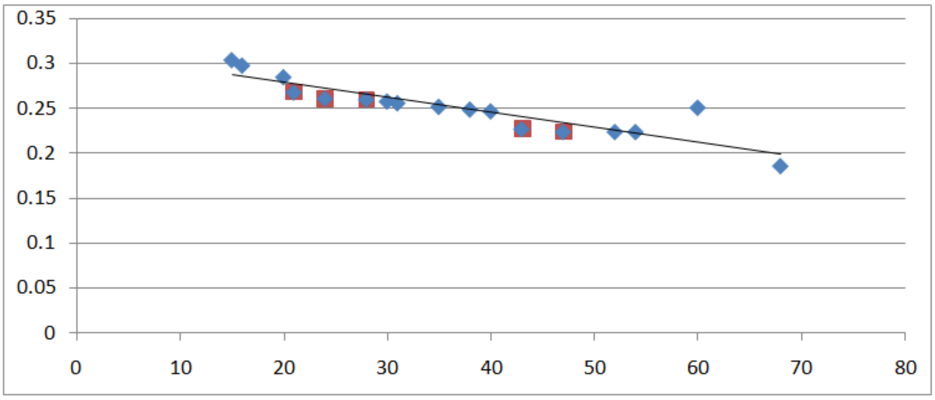

Figure 3:- shows the relationship between (WATER to GPS) v/s compressive strength [developed from Table no.15]

Fig.3 clearly shows that as [Water to GPS] ratio increases the Compressive strength of GPCC goes on decreasing which is very similar to W/C ratio of OPCC.

V.IV,IV) STEP-4:- Selection of Water Content – from table 2,for 20 mm MSA,Sand conforming to grading zone II, Water content per cubic meter of concrete = 186kg /m^3 and Sand content as percentage of Total aggregate by absolute volume 35%, as per table1. Based on the assumptions which are experienced during experimental investigations, we have…..

1) The maximum water content to be added extra is = 6% of [W/FA] ratio i.e.0.06 x {water / Fly Ash} ratio;

2) The minimum water content to be added extra is say 0.02 x {water / Fly Ash} Ratio. As per workability requirements of GPCC, extra water is required to be added, this is due to the fact that fly ash which is arrived from various plants having different water absorption capacities; hence in order to match, extra water is added. Amount of water to be added extra and considering it more than the minimum 0.02 % is say 0.03 x [water / fly ash ratio] = 0.03 x610 =18.3 kg/m^3 Fig. 4 – below shows the adjustments of values in sand content percentages plotted on y-axis as decrease in sand% v/s compressive stress on x-axis.

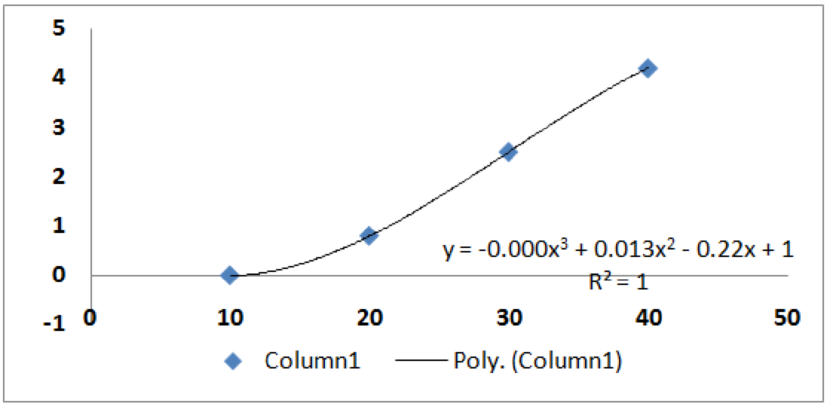

Figure 4- decrease in sand v/s compressive strength

From above fig.4, we have decrease in sand content is = 4.2%. Hence, required sand content as % of Total Aggregate by absolute volume = (35- 4.2) =30.8%

V.IV.IV) Estimation of Air Content:-Table17 shows the approximate air contents in GPCC

Table 17: Approximate Air Contents in GPCC

Nominal maximum size of aggregates in mm	Entrapped air as percentage of volume of concrete
10	3%
20	2%

V.IV.VI) STEP-5: Determination of Aggregate contents:- From Table 1,for the specified size of aggregates of 20mm,the amount of entrapped air in the fresh wet concrete is 2 %.Considering this ,and applying the equations (2) and (3),using data available, we have :

V = Absolute volume of fresh concrete = {Gross Volume -Volume of entrapped air} = (100-2) = 0.98.

SS = Sodium Silicate Solution = 222.225 Kg/m^3, SH = Sodium Hydroxide Solution = 88.89 Kg/m^3.

FA =Weight of Fly Ash = 610 Kg/m^3, S_{FA} = Specific Gravity of Fly Ash = 2.3,
P = Ratio of (FA to TA) $_{\text{by Absolute Volume}}$= 0.36, S_{FA} = Specific Gravity of FA in SSD condition = 2.563, Specific Gravity of CA in SSD condition, S_{CA}= 2.641, S_{SS} =Specific Gravity of Sodium Silicate solution = 1.57, S_{SH} =Specific gravity of Sodium hydroxide solution =1.16, on substituting the corresponding values in the equations (2) and (3) to obtain.

V.IV.VII) Fine aggregate contents:-

(100- 2%) = 0.98 = {(88.89/1.16) + (222.225 /1.57) + (610/2.3) + (1/ (0.308) (Fa/2.563)} x (1/1000)

0.98 x1000 = 483.391 +1.2667Fa; which yields Fa = 392.049 kg/m^3

V.IV.VIII) Coarse aggregate contents:-

0.98 = {(88.89/1.16) + (222.225 /1.57) + (610/2.3) + (1/ (1-0.308) (Ca / 2.61)}x(1/ 1000)

0.98 x1000 =483.394 +0.5537Ca; which yields Ca = 896.886kg/m^3

Table18: Mix Proportions

Sodium Silicate (SS)	Sodium Hydroxide Solution	Extra Water	Fly Ash	FA	CA
222.225 kg/m^3	88.89 kg/m^3	18.3 kg/m^3	610kg/m^3	392.049 kg/m^3	896.886 kg/m^3
0.51		0.03	1	0.643	1.470

V. Conclusions

1. Geopolymer concrete is modern invention in the world of Concrete Technology wherein the cement is 100% eliminated by industrial waste which contributes towards the global warming by reducing the use of cement and utilization of various by-products like fly ash.
2. From the literature survey on geopolymers, adopting the currently used technology to manufacture OPCC, a rigorous trial-error method was adopted to develop a process of manufacturing fly ash-based geopolymer concrete. The trial-and-error method thus yielded successful results for the manufacture of low-calcium (ASTM Class F) Fly Ash based Geopolymer concrete. Thus GPCC is an excellent alternative solution to the CO_2 producing OPCC.
3. In this study it is observed that Compressive Strength results obtained for GPCC are more than that of GPC & similarly tensile strength of the GPCC are also higher w.r.t the GPC.
4. 4) Since the nature of NaOH Gel is very sticky and the fly ash is very finer, therefore it is recommended to use these ingredients 10 to 20 % more than their Mix design values. It was observed that the Sodium Silicate solution delays the setting process at ambient temperature, hence heat curing is obvious so also it increases the compressive strength when heating is maintained at 90 ^{0} C for @ 24 hours to 48 hours.

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