Studies on Mix Design of Sustainable Geo-Polymer Concrete

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ABSTRACT
Geo-polymer is an eco-friendly binding material alternative to ordinary Portland cement. Geo-polymer concrete is obtained by mixing the ingredients such as sodium hydroxide solution, sodium silicate solution, fly ash, grounded granulated blast furnace slag and, fine aggregate and coarse aggregate and cured suitably. The blend of sodium hydroxide solution and sodium silicate solution is termed as alkaline liquid. This paper deals with attaining sustainable Geo-polymer concrete by using the combination of manufactured sand and pond ash a fine aggregate material replacing conventional natural river sand and using ambient curing for its strength development. The optimization of mix is achieved by Taguchi's optimization technique.

Keywords
Sustainable, Geo-Polymer Concrete, Alkaline liquid, Binder, Ambient Curing..

1. INTRODUCTION
Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder for binding fine and coarse aggregates to produce concrete. In 1978, Davidovits proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geo-polymers. The silicon and the aluminum in the low-calcium fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geo-polymer paste that binds the aggregates and other un-reacted materials.

Since early 1980s, lots of research on the development, manufacture, behavior, and applications of Low-Calcium Fly Ash-Based Geo-polymer Concrete has been carried out worldwide. where concrete was manufactured without usage of Portland cement; instead, we use the low-calcium fly ash from a coal burning power station which is a waste material and is harmful for environment is used as a source material to make the binder necessary to manufacture concrete. An important ingredient in the conventional concrete is the Portland cement. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere whereas the use of geo-polymer concrete reduces the carbon footage considerably as compared to Portland cement concrete. The main motive behind the development of sustainable geo-polymer concrete is to make geo-polymer concrete more greener by using ambient curing techniques by blending ground granulated blast furnace slag with fly ash as a binder material for gaining of strength in the concrete and to replace conventional fine aggregate consisting of river sand with a blend of pond ash and manufactured sand which has a reduced carbon footage as compared to conventional geo-polymer concrete. The designed mix is optimized with Taguchi's principles foe achieving economy and the desired characteristics of geo-polymer concrete.

2. LITERATURE REVIEW
In the works carried out by Kolli.Ramujee et.al[1] is to develop the mix design for Geo-polymer concrete in different grades of concrete that is low, medium and higher grades. They have considered the design parameters as alkaline liquid to fly ash ratio and water to geo polymer solids ratio. seven different mixes for each grade is casted, tested and optimized. Based on results they have suggested water to binder ratio of 0.27, 0.21 & 0.158 and alkaline to Binder ratios of 0.5, 0.40, and 0.35 are suggested for M20, M40, & M60 Respectively.

M.I. Abdul Aleem et al[2] made an attempt to find out an optimum mix for the Geo-polymer concrete and they have casted concrete cubes of size 150 x 150 x 150 mm and cured under Steam curing for 24 hours. The compressive strength was found out at 7 days and 28 days. The results are compared. The optimum mix is Fly ash: Fine aggregate: Coarse aggregate (1:1.5:3.3) with a solution (NaoH& Na_2SiO_3 combined together) to fly ash ratio of 0.35. High and early strength was obtained in the Geo-polymer concrete mix.

Madheswaran C.K et.al[3] studied the variation of strength for different grades of geo polymer concrete by varying the molarities of sodium hydroxide. Different molarities of NaoH (3M, 5M, 7M) are taken to prepare different mixes and cured in the ambient temperature. GPC mix formulations with compressive strength ranging from 15 to 52 M pa have been developed. The specimens are tested for their compressive strength at the age of 7 and 28 days. The compressive strength of GPC increased with increasing concentration of NaoH. The GPC produced for different combination of FA & GGBS are able to produce structural concrete of higher grade by self-curing only.

T.V.Srinivas Murthy et.al[4] have replaced fully OPC by GGBS and alkaline liquids are used as the binding materials. They have casted cubes, cylinder and prisms to determine the strength properties. The curing is carried out in oven at 65degree C and carried out the tests. The results are compared with conventional concrete. Thus higher the concentration of NaoH and higher the ratio of sodium hydroxide to sodium silicate higher is the compressive strength of GGBS based GPC. To improve the workability addition of naphthalene sulphonate based super plasticizer of about 4% of the binding material (GGBS) mass is used. The test results shows the use of GGBS based GPC the compressive, split, flexural strength increased by 13.82%,18.23%,30.19% as compare to conventional concrete.

P. Nath et.al[5] have aimed to achieve fly ash-based geopolymer concretes suitable for ambient curing condition. Class F fly ash was used as the base material and the binding materials used are sodium hydroxide and sodium silicate solutions. Grounded blast furnace slag was added in different proportions to the mix to enhance the early age properties of concrete. Setting times of geo-polymer pastes, workability of fresh concrete and compressive strength after curing at 20-23ºC were investigated. Setting time and compressive strength of geo-polymers varied with the variation of alkaline activator to fly ash ratio and sodium silicate to sodium hydroxide ratio in the alkaline activator solution. With the increase of alkaline activator solution in the mix from 35% to 45% of total binder, the setting time increased and compressive strength decreased. Alkaline activator solution with SS/SH ratio of 2.5 achieved lesser slump and setting time than those with 1.5 and 2.

3. AIM OF INVESTIGATION

Earlier researchers have investigated in making geopolymer concrete more greener by adopting ambient curing for the development of strength in geo-polymer concrete. They could do this by partially replacing class F fly ash with GGBS along with hundred percent replacement of river sand with manufactured sand. In this investigation we are attempting to make geopolymer concrete more sustainable by partially replacing the manufactured sand with pond ash which is a waste product generated in thermal power plant in addition to partially replacing class F fly ash with GGBS along with hundred percent replacement of river sand with manufactured sand and pond ash. Mix design of M-30 grade geo-polymer concrete is made and it is optimized using Taguchi's principles and its strength properties is evaluated.

4. METHODOLOGY

1. To determine properties of materials:
   The propertied of following materials are determined as listed below:

   i) Fly ash:
   Fly ash is the alumino silicate source material used for the synthesis of geo-polymeric binder Fly ash was obtained from the silos of Raichur Thermal Power Station, Karnataka, INDIA was used for the experimental work. The Fly ash was of low calcium Fly ash which confirms to class F of ASTM standards. The percentage of fly ash passing through 45µm IS Sieve was found to be 95% and its specific gravity was 2.20

   ii) Ground Granulated Blast Furnace Slag:
   Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the steel industry. Blast furnace slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The percentage of GGBS passing through 45µm IS Sieve was found to be 97% and its specific gravity was 2.93.

   iii) Sodium Hydroxide:
   Sodium hydroxide flakes used in this investigation is of commercial grade with 97% purity.

   iv) Sodium Silicate solution:
   Sodium Silicate solution used in this investigation is of commercial grade with 97% purity.

   v) Manufactured Sand:
   Manufactures sand confirms to Grade II from the sieve analysis test. Its Specific Gravity was found to be 2.55, Its Fineness Modulus was found to be 2.67, its loose density was found to be 1666.882 kg/m^3 and its dry compacted density was found to be 1912.201 kg/m^3.

   vi) Pond Ash:
   Pond ash was obtained from Raichur Thermal power plant. It's Specific Gravity was found to be 2.087, Its Fineness Modulus was found to be 2.105 and it confirms to grading zone III from sieve analysis test.

   vii) Coarse Aggregate:
   Coarse aggregate used is of 12.5 mm nominal size and its specific gravity was found to be 2.602. it also passed the tests of aggregate impact value and aggregate crushing value.

   viii) Super Plasticizer:
   Conplast-SP-430 grade super plasticizer was used in this mix and its dosage was 1.5% of the mass of binder material comprising of Fly ash and GGBS.

2. Trial mix of M-30 grade sustainable geopolymer concrete.
   The GPC mix design used in the study was based on Rangan method[6] for M30 grade of concrete. The mix proportions for casting the concrete specimens are calculated with fine aggregate comprising of 60% M-sand and 40% Pond ash. The alkaline to binder ratio is taken as 0.55 and molarities of sodium hydroxide is taken as 14M. While the rest of the components are varied according to the requirements of optimization method. A sample calculations for a mix design using Rangan method is shown in Table-4.2.1

Table-4.2.1

MIX PROPORTION FOR ONE METER CUBE OF GPC	
Sodium silicate	170.32kg
Sodium hydroxide solution	68.12 kg
Extra water required	75kg
Fly ash	346.84 kg
GGBS	86.71 kg
Fine Aggregate(M-sand)	456.19kg
Pond ash	304.13kg
Coarse aggregate	967.68 kg
Super plasticizer	6.7kg

3. Optimization of trial mix by Taguchi's principle.

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Parameters considered for mix design is as listed in Table 4.3.1

Table-4.3.1

Code	Factor/parameter	Unit of measurement
A	Alkaline liquid	kg/m3
B	Binder	kg/m3
C	Coarse aggregates	kg/m3
D	Manufactured sand	kg/m3
E	Pondash	kg/m3
F	Water	kg/m3

For the selected six parameters with two degrees of freedom for each parameter, total degree of freedom is 12. Hence the minimum number of experiments to be performed is 13. The three levels of control factors is as shown in Table-4.3.2

Table -4.3.2 Table of Control Factors with factor levels

LeveLs	Alkaline liquids (kg/m^3)	Binders (kg/m^3)	C.A (kg/m^3)	M-Sand (kg/m^3)	Pond ash (kg/m^3)	Water kg/m^3
	A	B	C	D	E	F
1	230.10	418.38	933.81	440.22	293.49	72.38
2	238.45	433.55	967.68	456.19	304.13	75.00
3	246.80	448.72	1001.55	472.16	314.77	77.63

The value of this 3 levels is obtained by varying 3.5 % positive and negative for the obtained mix design. The orthogonal ray selected for the experiments is L18 (3^6).

4. Determining the strength characteristics of optimized mix. The GPC was casted in cubes of side 150 mm. Compaction factor test was done for each experimental mix and 28 days cube compression test were conducted and the results are tabulated as shown in Table-4.4.1

Table-4.4.1 : Compressive strength and Compaction Factor values

Experiment No	Compressive strength	Compaction Factor
1	38.36	0.68
2	39.25	0.70
3	39.10	0.65
4	39.70	0.60
5	32.88	0.66
6	37.18	0.62
7	35.25	0.70
8	38.36	0.68
9	40.14	0.67
10	33.47	0.64
11	31.40	0.67
12	35.23	0.64
13	34.07	0.63
14	31.40	0.60
15	39.68	0.60
16	38.66	0.64
17	40.88	0.65
18	40.14	0.61

Table 4.4.2 Mean calculation for results obtained for 28days for μ^2							
		1	2	3	4	5	6
Level 1		226.47	216.81	236.39	221.86	219.51	218.91
	X1	37.747	36.135	39.39	36.97	36.585	36.48
Level 2		213.85	214.91	209.86	229.44	214.17	228.83
	X2	35.64	35.81	34.97	38.24	35.69	38.13
Level 3		224.83	233.43	218.8	213.85	231.47	217.41
	X3	37.47	38.905	36.46	35.64	38.57	36.235

Table-4.4.3 : Calculation of mean for factors and levels

Signal- to –noise ratios at 28days results							
	STD DEV	**1**	**2**	**3**	**4**	**5**	**6**
	Σ	2.540	3.279	0.946	3.418	2.644	3.340
Level 1	**Σ^2**	6.456	10.757	0.895	11.688	6.992	11.162
	μ^2	1424.68	1305.738	1551.57	1366.78	1338.46	1330.79
	S/N	23.43	20.84	32.38	20.67	22.82	20.76
	Σ	3.182	3.550	3.054	2.92	4.276	3.337
Level 2	**σ^2**	10.128	12.607	9.33	8.545	18.286	11.14
	μ^2	1270.20	1282.35	1223.36	1462.29	1274.13	1453.89
	S/N	20.983	20.07	21.17	22.33	18.430	21.156
	Σ	3.832	2.032	3.461	3.182	1.975	3.088
Level 3	**σ^2**	14.69	4.132	11.98	10.128	3.904	9.54
	μ^2	1404.00	1513.59	1329.81	1270.20	1487.6	1312.97
	S/N	19.80	25.63	20.45	20.98	25.80	21.387

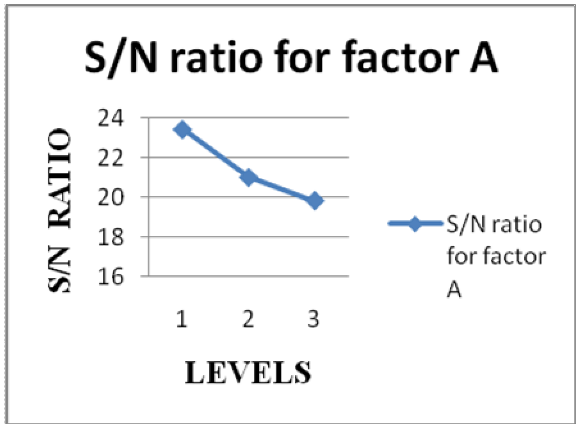

Figure-1

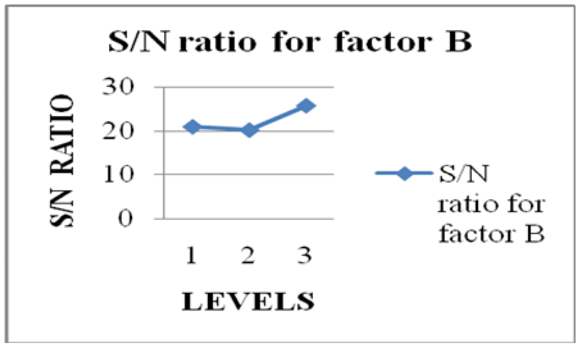

Figure-2

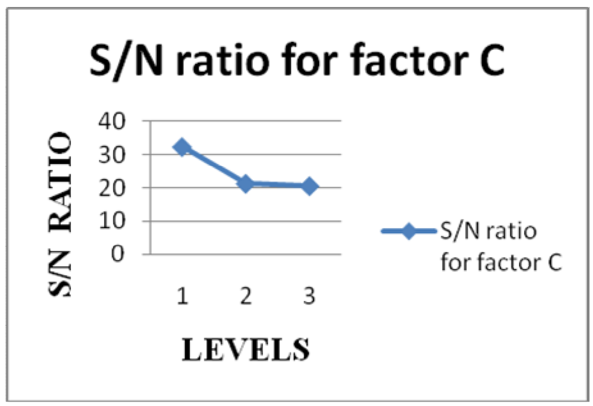

Figure-3

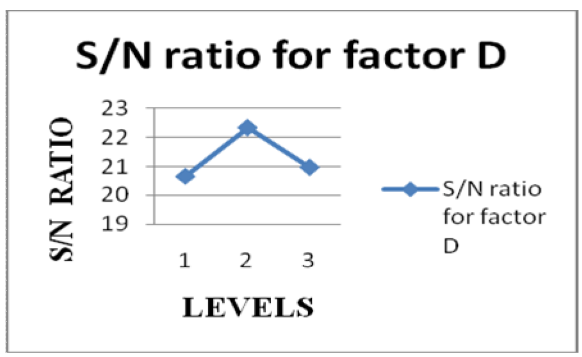

Figure-4

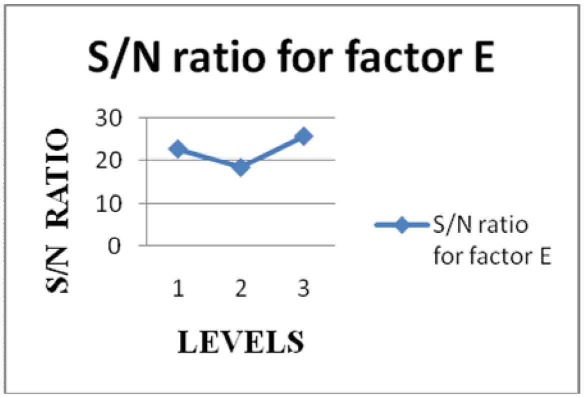

Figure-5

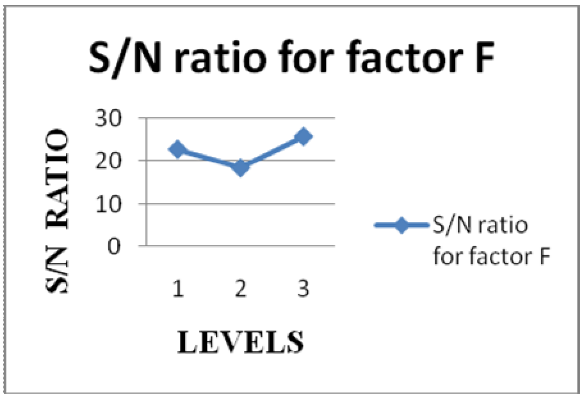

Figure 6 Response curves to find the optimum levels

Table-4.4.4 : indicating the factor level for which S/N ratios are highest

Sl no	Code	Factor/parameter	Level	Qty in kg/m3
1	A	Alkaline Liquids	1	230.10
2	B	Binder	3	448.72
3	C	Coarse aggregates	1	933.81
4	D	M-sand	2	456.19
5	E	Pond ash	3	314.77
6	F	Water	3	77.63

5. RESULTS AND DISCUSSIONS

1. The compressive strength obtained was referred for different levels. Each factor containing 3levels were selected from there reference orthogonal array each level has 6set of results for which mean was calculated. Therefore each factor had 3 sets of mean values tabulated in the Table4.4.3.

2. For each observation the deviation from the mean value was calculated .Sample variance(σ^2) and standard deviation(σ) were calculated for each factorcontaining 3 levels.

3. The standard deviation and mean values were used for the calculation of signal to noise ratio (S/N) (η) for analyzing the results. Nominal-the-best is the type of S/N ratio chosen for this static problem. This type arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable.

4. These ratios can be represented graphically in figures 1 to 6, which show the change in performance characteristic with variation in process parameter's levels, the 3 levels are plotted on the x-axis and the S/N ratios are plotted on the y-axis. For the level1 is better for factor A(Alkaline liquid),level3for factor B(Binder),level 1for factor C (Coarse aggregate), level 2 is better for factor D(M-sand),level 3 is better for factor E (Pond ash), level 3 for factor F(Water). The optimum mix design is tabulated in the Table 4.4.4.

5. The compressive strength of the trial verification test at the end of 28 days was 36.4 M Pa. This value is higher than the M-30 grade mix .

6. CONCLUSIONS

Sustainable Geo-polymer concrete has been achieved in a sequential procedure starting with the trial mixes designed by the Rangan method of mix design which is regarded as a simple mix design. Rangan method gives the calculation of quantity of materials used in the mix design but the dosage of super plasticizer are finalized using trial and error. About 60% of M-sand and 40% of pond ash as sand replacement is found to be the optimum amount in order to get a favorable strength. Compressive strength of concrete increases with increasing the concentration of sodium hydroxide. Use of GGBS about 20% by mass of fly ash in a geo-polymer concrete, increases the strength of concrete and cured under ambient curing There by making it as sustainable geo-polymer concrete.

REFERENCES

[1] Kolli.Ramujee, Member, Dr.M.Potharaju "Development of mix design for low calcium based geopolymer concrete in low, medium and higher grades -indian scenario" Volume 1, Issue 1, July-December (2013), pp. 15-25

[2] M.I. Abdul Aleem and P.D. Arumairaj "Optimum mix for the geopolymer concrete" Indian Journal of Science and Technology Vol. 5 No. 3 (Mar 2012) ISSN: 0974- 6846.

[3] Madheswaran C. K, Gnanasundar G, Gopalakrishnan. N "Effect of molarity in geopolymer concrete" International journal of civil and structural engineering volume 4, no 2, 2013.

[4] T.V. Srinivas Murthy, Dr. Ajeet Kumar Rai "Geopolymer concrete, an earth friendly concrete, very promising in the

industry" ISSN 0976 – 6316(Online)Volume 5, Issue 7, July (2014), pp. 113-122.

[5] P. Nath, P. K. Sarker " Geopolymer concrete for ambient curing condition" Department of Civil Engineering, Curtin University, Kent Street, Bentley, WA, 6102, Australia

[6] R. Anuradha, V. Sreevidyaa, R. Venkatasubramania and B.V. Rangan "Modified guidelines for geopolymer concrete mix design using indian standard" Asian journal of civil engineering (building and housing) vol. 13, no. 3 (2012) pages 353-364asian journal of civil