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Analysis on the Strength and Durability of High Strength GGBS Based Geopolymer Concrete

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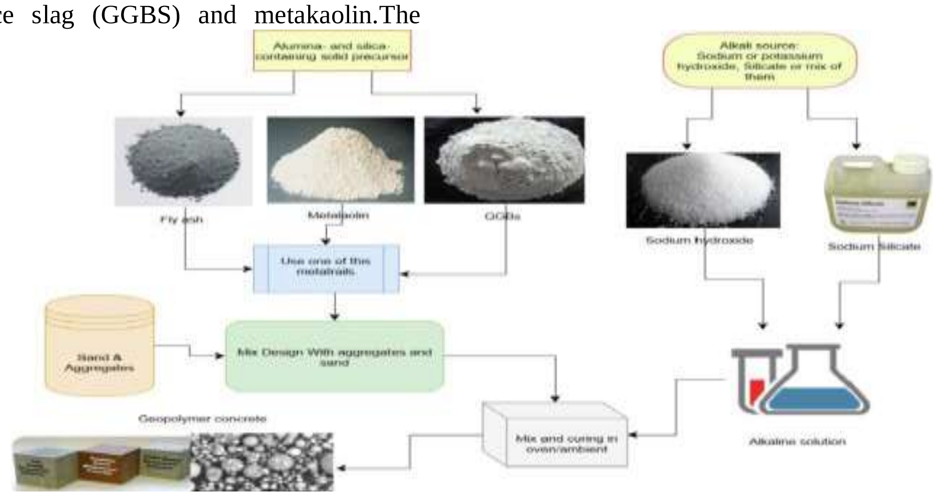
ABSTRACT: It is very well known that production of cement clinkers is highly expensive and ecologically and environmentally harmful due to hazardous emissions. Hence the next option is to search for alternative cement binders. In recent years, three alternative cements, namely, Geopolymer (GP) cements, eco-cements and sulfoaluminate cements have come. In this study M60 grade of concrete was used. Different samples were prepared in order to study different properties of TVC, GPC and FGPC. Glass fiber was also used in the study. Cubes of size 150x150x150mm and cylinders of 150x200mm were casted. 3 samples were tested and average was found out in order to get accurate result. Tests performed in this study are: compressive strength test, split tensile test, acid resistant test and chloride test.

KEYWORDS: GPC (geopolymer concrete),TVC (Traditional Vibrated Concrete),FGPC .(Fiber geopolymer concrete) GGBS (Ground granulated blast furnace slag)

I. INTRODUCTION

Geopolymer was developed to replace conventional cement and utilization of industrial waste like fly ash, rice husk, ground granulated blast furnace slag (GGBS) and metakaolin.The thermal power plants using coal produces fly ash and steel plants produces GGBS which has to be dumped requiring large areas. GPC addresses the above issues in making concrete as a sustainable material.GPC doesn’t require any cement, thereby while producing cement avoiding pollution of the environment.

The reaction of a solid alumina silicate with a highly concentrated aqueous alkali hydroxide or silicate solution produces a synthetic alkali alumina silicate material generically called a ‘GP’. These materials can provide comparable performance to traditional cementitious binders in a range of applications, but with the added advantage of significantly reduced GHC emissions. Depending on the raw material selection and processing conditions, GPs can exhibit a wide variety of properties and characteristics, including high compressive strength, low shrinkage, fast or slow setting, acid resistance, fire resistance and low thermal conductivity. Geopolymeric gels and composites are also commonly referred to as ‘low-temperature alumina silicate glass’, ‘alkali-activated cement’,‘geocement’,‘alkali-bonded ceramic’,‘inorganicpolymerconcrete’,and ‘hydroceramic’.



II. OBJECTIVE OF WORK

Utilization of GPC in structural elements requires justification with respect to mix design and strength properties hence it is required to conduct laboratory investigation with respect to the above behaviour.

The objectives of the present research work are:

• To develop M60 grade of GPC and TVC, (Rangan's method for GPC and for TVC Perumal's method).

• To study the mechanical properties of GPC by conducting different strength tests.

• To conduct the durability studies on GPC & TVC.

• To conduct study on GPC and TVC by using glass fiber and compare their properties.

III. METHODOLOGY

Many parameters are involved in the production of GPC, out of which alkaline liquid mineral admixtures ratio and super plasticizer are important. Sulphonated Naphthalene based dispersing agents are adopted as super plasticizers to obtain better mechanical properties of GPC. Low calcium fly ash gives better results from the point of view of chemical composition. GGBS is used to fill the voids between fly ash and fine aggregate and this helps in the degree of particle aggregation, nature and quantity of impurities and basic particle size. Sodium hydroxide and sodium silicate solutions used as alkaline liquids react with fly ash and GGBS to form the geopolymer gel binding the aggregates to produce GPC. The final product was cured in steam curing chamber at 60°C for 24 hours. Based on review of literature, Rangan's method [30] has been adopted to produce M60 GPC. TVC mix design has been carried out using Perumal's method [28].

3.1 MATERIALS CHARACTERISTICS

- **Ground granulated blast furnace slag (GGBS):-**

The molten slag from the furnace is rapidly chilled by quenching in water to form glassy sand like material. GGBS is produced by grinding the granulated slag to less than 45µm size to obtain a fineness of 400-600 m^2/kg.

- **Silica fume**:-

SF (also known as micro silica or condensed SF) is a by-product of the ferrosilicon and silicon alloy industry. SF Is a high performance pozzolanic with unique chemical and physical properties that enable cement based systems and mix designs to achieve higher levels of performance and durability.

- **Fly ash** :-

It is well known that FA is a by-product of coal fired power plants resulting from the combustion of the finely ground coal used as fuel in the generation of electric power.

- **Alkaline liquids:-**

Sodium silicate gel (Na2SiO3) and sodium hydroxide (NaOH) solutions used for fly ash activation is shown in fig 3.3 Sodium hydroxide solution of 8, 12 and 14 Molar was prepared by mixing the pellets with water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8×40 = 320 grams of NaOH solids (in pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The Sodium silicate and Sodium hydroxide solution were mixed 24hrs prior to usage.

- **Superplasticizers:-**

Super plasticizers are capable of reducing water contents by about 30 percent. However it is to be noted that full efficiency of super plasticizer can be got only when it is added to a mix that has as initial slump of 20 to 30 mm. Addition of super plasticizer to stiff concrete mix reduces its water reducing efficiency. Depending on the solid content of the mix, a dosage of 1 to 3 percent by weight is recommended. For the present investigation, a super plasticizer namely CONPLAST SP 430 has been used for obtaining workable concrete at low a/m ratio. CONPLAST SP 430 complies with IS 9103: 1999 [20] and BS: 5075 part 3 and ASTM C 494, TYPE 'B' as a HR WRA. CONPLAST SP 430 is based on Sulphonated naphthalene formaldehyde (NSF) condensates with chloride content.

- **Aggregates** :-

The aggregates are important constituents of any concrete and generally occupy 70 to 80 percent of the volume of the concrete .

- **Water** :-

In the case of GPC, where the hydration is replaced by the chemical process of polymerization, the water is not utilized for chemical reactions. Instead, they get released during the process of polymerization and helps in attaining the necessary workability in the mix.

- **Fibres :-**

Generally fibres will be added to concrete to enhance ductility, tensile strength and energy absorption of the member / structure.

2.2 GPC MIX DESIGN

Ingredients Required:-

The range of ingredients for M60 concrete based on Rangan's [30] is listed below.

Fly ash – Low calcium (ASTM Class F)
GGBS– 10% of fly ash
Ratio of Na_2SiO_3 Solution to NaOH Solution, by mass – 0.4 to 2.5
Molarity of NaOH Solution – 8M to 14M.
Alkaline liquid to Binders ratio – 0.3 and 0.45.
Aggregates – 75 to 80% of mass of concrete
Super plasticizer – 2.5 to 3% of fly ash and GGBS

GPC mix design based on trial mix design and the following quantities are arrived for M60 concrete as given in table below

Table 1 – Trial Mixes (GPC)

Materials	Mass, kg/m3			
	Mix1, Al/Fa=0.3	**Mix2, Al/Fa=0.35**	**Mix3, Al/Fa=0.4**	**Mix4, Al/Fa=0.45**
Coarse aggregates	1295	1295	1295	1295
Fine sand	555	555	555	555
Fly ash	382	366	355	342
GGBS	42	40	39	38
Na_2SiO_3 solution	90	103	112	122
NaOH solution	36	41	44	48
Super plasticizer	3%	3%	3%	3%
Extra water	3%	3%	3%	3%

Table 2- Final Proportion of GPC & TVC Concrete

<table>
<tr><th>Binder</th><th>FA</th><th>CA</th><th>NaOH</th><th>Na_2SiO_3</th><th>water</th><th>Super plasticizer</th><th rowspan="3">Mix ratio for GPC</th></tr>
<tr><td>406</td><td>555</td><td>1295</td><td>41</td><td>103</td><td>16.24</td><td>3%</td></tr>
<tr><td>1</td><td>1.37</td><td>3.19</td><td>0.1</td><td>0.25</td><td>0.04</td><td>0.03</td></tr>
<tr><td colspan="8"></td></tr>
<tr><th>Binder</th><th>FA</th><th>CA</th><th>Water</th><th colspan="3">Super plasticizer</th><th rowspan="3">Mix ratio for TVC</th></tr>
<tr><td>417</td><td>716</td><td>1050</td><td>150</td><td colspan="3">2.5%</td></tr>
<tr><td>1</td><td>1.72</td><td>2.51</td><td>0.36</td><td colspan="3">0.025</td></tr>
</table>

The present investigation shows that high strength GPC mix proportioning can be done on similar guide lines given by Rangan's method. On the same mix glass fiber 1% was added and specimens were prepared to study the difference

3.3 SPECIMEN PREPARATION AND MIXING

Cubical moulds of size 150X150X150 mm, cylindrical moulds of size 150×300mm were used to prepare specimen of GPC and TVC. Fly ash, GGBS and aggregates were mixed dry in the 100 kg capacity pan mixer for 3 minutes. The alkaline solution that was prepared one day prior with super plasticizer and extra water were added into the blend and mixed for 4 minutes.

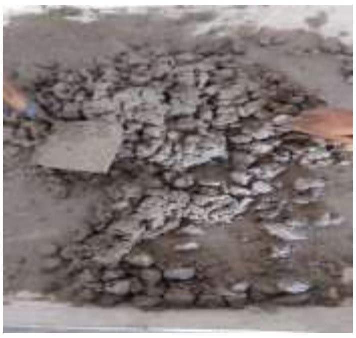




Fig2 Mixing Fly ash & GGBS **Fig 3 Mixing of concrete** **Fig 4 Casting of cubes**

IV. TESTS ON CONCRETE

4.1 Compressive Strength Test:-

The test specimens for compressive strength of cube are 150mmx 150mm x 150mm .The test specimens were cast in respective cast iron steel moulds. The mould specimens were applied with oil in all inner surfaces for easy removal of specimens during demoulding. Fresh concrete is filled in moulds in three equal layers. The mould is vibrated on a vibrating table to release the air trapped in the mix. The time of vibration was judged by the visual appearance of individual mixes to ensure full compaction. After casting, the specimens were demoulded after lapse of 24 hours and placed in the normal atmospheric condition.

4.2 Split Tensile Test:-

Splitting tensile strength is the measure of tensile strength of the concrete which is determined by splitting the cylinder across its diameter. This is an indirect test method to determine the tensile strength of concrete of test specimen of cylinders. The load was applied using compression testing machine. Testing was carried out as per IS 516-1959. Figure 4.13 shows the typical split tensile test on cylinder. Split tensile strength is determined on 7th day 14th day and 28th day.

4.3 Acid Resistance Test:-

The acid resistance was carried out on cube specimen at the age of 28 days curing. The cube specimen were weighed and immersed in water diluted with 2N, 10% by weight of hydrochloric acid for 6 weeks. Alternate drying and wetting of cubes were carried out for every 2 days. The specimens were taken out from solution and surface of cubes were cleaned. The average percentage loss of weight and the compressive strengths were calculated.

Fig.5Cubes immersed in 2N 10% HCl


Fig. 6Cubes after immersion in 2N 10% HCl

V. RESULT AND DISCUSSION

5.1 Cube Compressive Strength Test:-

The GPC, TVC and FGPC specimens were tested for 7, 14 and 28 day's compressive strength as per IS 516: 1959 [18].

Table 3 Results of Cube Compressive Strength

S.NO	DAYS	TVC	MEAN(MPa)	GPC	MEAN(MPa)	FGPC	MEAN(MPa)
1	7	25.24	25.68	62.45	62.8	63.41	63.21
2		26.36		62.54		63.24	
3		25.45		63.41		62.98	

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4	14	60.11	59.96	66.23	66.97	67.88	67.88
5		59.87		67.24		67.64	
6		59.91		67.45		68.14	
7	28	70.21	70.64	73.64	73.5	74.12	74.48
8		71.57		73.91		74.45	
9		70.14		72.95		74.87	

5.5 Split Tensile Strength

For M60 grade concrete the split tensile strength results of GPC, TVC and FGPC are tabulated in the table

Table 4. Results of Split Tensile Test Strength

S.NO	DAYS	TVC	MEAN(MPa)	GPC	MEAN(MPa)	FGPC	MEAN(MPa)
1	7	3.98	3.98	3.54	3.54	3.64	3.62
2		3.96		3.51		3.62	
3		4.01		3.57		3.61	
4	14	4.11	4.22	3.71	3.69	3.72	3.75
5		4.31		3.69		3.74	
6		4.25		3.67		3.79	
7	28	4.77	4.54	3.82	3.85	3.84	3.88
8		4.46		3.87		3.89	
9		4.41		3.86		3.91	

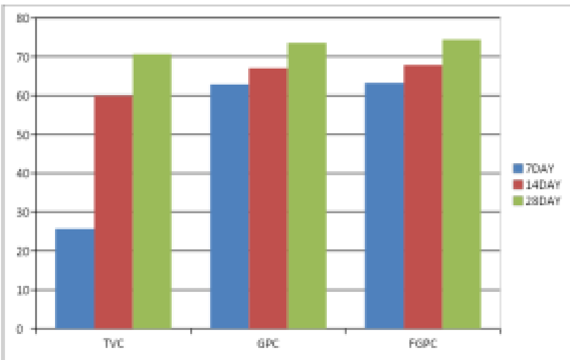

Fig 7 Results of Cube Compressive Strength

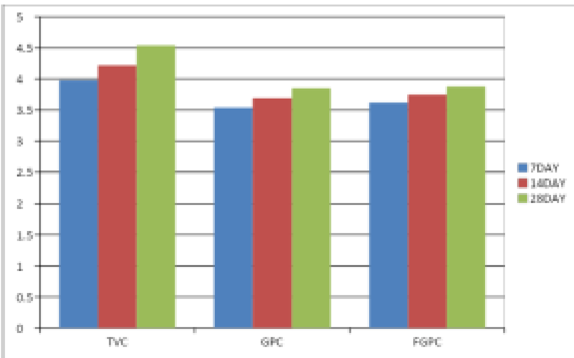

Fig 8 Results of Cube Split Tensile Strength

5.3 Acid Resistance Test:-

The average compressive strengths of GPC and TVC is decreasing with increasing in number of days and GPC is more consistent than TVC as the number of days increases while the weight loss is more consistent for GPC than TVC with increasing in number of days.

Table 6. – Results of GPC cubes immersed in HCl

No. of days of curing in HCL	Average weight loss (%)	Average compressive strength (N/mm^2)
7	-1.10	67
14	-0.99	65
21	-0.65	55

Table 7. - Results of TVC cubes immersed in HCl

No. of days of curing in HCL	Average weight loss (%)	Average compressive strength (N/mm^2)
7	**0.65**	67
14	**0.57**	65
21	**0.57**	51

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Table 8. - Results of FGPC cubes immersed in HCl

No. of days of curing in HCL	Average weight loss (%)	Average compressive strength (N/mm^2)
7	-1.09	66
14	-0.98	64
21	-0.64	54

VI. CONCLUSION

This chapter summarizes the overall conclusions drawn from this study. Various properties for TVC, GPC and FGPC concrete mixes were evaluated. Various tests like slump test, compaction factor test, density test, compressive test, split tensile test, acid resistant test and chloride test were performed. Based on these test salient features were found out.

- GPC is around 62% more than OPC in 7 days but at 28 days the strength difference between GPC and TVC is only 5%. Hence GPC is attaining early strength but the improvement of strength after 7days is less.
- The compressive strengths of GPC were more than TVC and the weight loss is negligible in TVC.
- The visual inspection of the cubes clearly indicates that GPC has better resistance than TVC
- Tensile strength of GPC is 20% less than TVC.
- Rapid development of tensile strength is achieved
- The addition of fibres (glass), considerable increase in compressive strength is observed.

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