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A Study on the Fresh and Hardened Properties of Fly-Ash Based Glass Fiber Reinforced Geopolymer Concrete

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Abstract: The production of cement consumes natural resources and lot of energy. Minimization of the use of cement leads to sustainability. This paper is a part of experimental investigation on the behavior of fly ash based Geo-polymer Concrete (GPC) with & with-out alkali resistant glass fibers. The variables of the study include Sodium Silicate to Sodium Hydroxide ratio, Molarities of Sodium Hydroxide (8M,12M & 14M), curing method, curing temperatures (30^{0}C, 60°C & 90°C), curing periods (4, 6 & 8 hours) and Fiber content. Fresh and hardened state properties like workability, density, compressive strength, split tensile strength, flexural strength and modulus of elasticity were studied under elevated temperature and ambient curing conditions. The results show that the mechanical properties of the Geo- Polymer Concrete improve with the increase of molarity of NaOH, Curing time, curing temperature, and Sodium Silicate to sodium hydroxide ratio. The design compressive strength was achieved through ambient curing for one day and the optimum fiber content was arrived at based on the mechanical properties of GPC.

***Keywords:** Geo-Polymer Concrete (GPC), Sodium Hydroxide, Sodium Silicate, Molarity, Fly ash, Curing type, Alkali Resistant Glass Fibers*

1. Introduction

In the recent years, demand for the Ordinary Portland Cement (OPC) has increased enormously due to rapid urbanization and extensive use of OPC concrete as a construction material. But the limestone resources were decreasing day by day. Also, increased production of cement resulted in increased emissions of CO_2 into the atmosphere and 7% of the CO_2 emitted into the environment is from OPC production. This in turn causes Global warming. Production of cement is increasing annually by 3%. Huge amount of power is consumed during the cement production. There is a need for eco-friendly concrete which minimizes the environmental pollution. So search for the alternative material to OPC has started in the recent decades. On the other hand, several million tonnes of fly ash is produced every year worldwide by thermal power production. Dumping of fly ash in open places is increasing the wastage and causing air pollution. Davidovits (1988)[5] found that the combination of the source material or by-product material like fly ash with alkaline solutions produce a binder which can be used for making concrete. He named this concrete as Geo-polymer Concrete. In order to reduce the environmental pollution by emission of CO_2 through cement production, to conserve the power and to utilize fly ash, geo-polymer concrete was used as an alternative to OPC Concrete. As per the research work done in the past, it was established that the addition of fibers improved the properties and performance of conventional hardened concrete. Jaganadha Rao and Khan (2009)[10] concluded from their experimental investigations on glass fiber reinforced high strength recycled aggregate concrete that the fiber reinforced specimens failed after sustaining the failure load for a period of time indicating gradual ductile failure unlike brittle failure of plain concrete. Steel and glass fibers produce greater impact, abrasion and crack resistance in the concrete and show improved deformability. However a little works is reported on the effect of these fibers on the geo-polymer concrete. Alkali Resistant (A.R) glass fibers were used in the present work to study the properties of glass fiber reinforced fly ash based Geo-Polymer concrete.

Malhotra (2002) [11] mentioned in his paper that carbon dioxide (CO_2) emission is a critical factor for the industries, including the cement industries, as the greenhouse effect created by the emissions is considered to produce an increase in the global temperature that may result in climate changes. Davidovits (1988)[5], proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash and rice husk ash. Anuradha et al. (2012) [2], suggested a mix design procedure for fly ash based geo-polymer concrete relevant to Indian standards (IS-10262) [8].

Hardjito and Rangan (2005)[6], have shown that the compressive strength of geopolymer concrete decreases as the water to geopolymer solids ratio by mass increases and the trend is analogous to the well-known effect of water-to-cement ratio on the compressive strength of OPC concrete. Bhikshma et. al. (2011) [4]investigated on the hardened state properties of geo-polymer concrete with ASTM – Class F Fly ash and found that the geo-polymer concrete has excellent compressive strength, suffers very low drying shrinkage along with excellent resistance to sulphate and acid attack.

Songa et al.(2005) [16],investigated the strength potential of nylon-fiber reinforced concrete versus poly-propylene fiber reinforced concrete, at a fiber content of 0.6 kg/m^3 and concluded that the nylon fibers improved mechanical properties compared to polypropylene fibers. Yeol Choi et al (2005)[19], established the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC) at 7, 28 and 90 days. The test results indicated that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by 20 to 50% and also the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of the compressive strength.

Vijai.K et al. – 2012[17] carried out studies on glass fiber reinforced fly ash based geo-polymer concrete. In their work, fly ash was partially replaced (10%) with cement to reduce the delay in setting time. The optimum percentage of fibers was found to be 0.03% by volume of concrete at which the compressive strength, split tensile strength, and flexural strength of GPC are maximum. Sathish Kumar et al. (2012)[14], studied behavior of glass fiber fly ash based geo-polymer concrete and found that the values of compressive strength, split tensile strength and flexural strength are maximum at an optimum percentage of 0.02% of glass fibers by volume of concrete. Shaik Jabiulla and Neeraja(2015) [15] studied the performance of Metakaoline and fly ash based Geopolymer concrete and concluded that fly ash and metakaoline in equal proportions contributed to the maximum strength while inclusion of metakaoline reduced the workability. Abideng, et. al (2014)[1] concluded from their experimental investigations that the addition of oil palm ash by 5% improved the compressive strength of Geopolymer concrete.

Vladimir, et. al. [18] conducted studies on pressure compacted geopolymer concrete and concluded that the pressure during curing has significant effect on the homogeneity and strength characteristics of geopolymers. Marín-López et. al. (2009) [12] found that the strengths of concrete based on metakaolin geopolymer were higher than those in the concrete based on portland cement besides its higher thermal insulation.

2. Significance of the Work:

The depleting natural resources and environmental consciousness have led to the research on alternative materials to cement as production of cement uses natural resources and a lot of energy, apart from the liberation of huge quantities of Carbon dioxide. The disposal of industrial waste like fly ash has also become a major problem. One of the best possible solutions to tackle these two problems is Geopolymer Concrete. The present experimental work aims to investigate the behavior of glass fiber reinforced geo-polymer concrete with fly ash as the base material. An effort was made to achieve the design strength of the plain and glass fibered geo-polymer concrete by elevated temperature curing as well as ambient curing.

3. Experimental Investigation

3.1. Materials Used

3.1.1. Fine Aggregate: The locally available natural river sand confirming to grading Zone-III of table 4 of IS 383-1970[6] with specific gravity 2.66 and Fineness Modulus 2.25 was used as fine aggregate.

3.1.2. Coarse aggregate: Machine crushed granite confirming to IS: 383-1970, obtained from the local quarry, consisting of 60% - 20 mm maximum size aggregates and 40%- 10mm maximum size aggregate was used. The specific gravity of coarse aggregate was determined as 2.76 and the properties are shown in Table1a.

3.1.3. Fly Ash: Fly ash was obtained from Bhupalapally Thermal Power Station, near Warangal in Telangana State. The fly ash was classified as ASTM– F [3], i.e., Low–Calcium Fly ash (CaO<5%) with a specific gravity of 2.30. The properties are shown in Table 1b.

3.1.4. Sodium Hydroxide: Available as flakes in the local market was used and solution was prepared (Plate 1).

3.1.5. Sodium Silicate: Sodium Silicate **a**vailable as a solution in the local market was used (Plate 2).

3.1.6. Water: Locally available potable water was used.

3.1.7. Super Plasticizer: Conplast SP-430 by FOSROC Chemicals was used.

3.1.8. Glass Fibers: The properties of Alkali resistant glass fibers (CEMFIL) used in this investigation are given in Table 1c and the fibers are shown in Plate 3.

Plate1: Sodium Hydroxide Flakes

Plate2: Sodiumsilicate solution

Plate 3: Alkali Resistant Glass Fibers

***Table 1b:** Properties of Fly Ash*

Physical property	**Result**
Specific Gravity	2.76
Fineness Modulus	7.31
Flakiness index	5.67%
Elongation index	5.42%
Aggregate impact value	13.89%
Aggregate Crushing value	13.99%

***Table 1a:** Properties of coarse Aggregate*

S No	Test parameter	Result (%)
1	Silica as SiO_2	52.48
2	Alumina as Al_2O_3	24.22
3	Iron as Fe_2O_3	3.81
4	Calcium as Cao	4.97
5	Magnesium as MgO	1.57
6	Sodium as Na_2O	0.12
7	Potassium as K_2O	0.46
8	Titanium as TiO_2	0.31
9	Sulphates as SO_3	2.91
10	Loss on ignition	2.35

***Table 1c:** Properties of Glass Fibers*

Fiber type	Anti-crack HD glass fiber
Diameter in Microns	14
Length in mm	12
Number of fibers (million/kg)	212
Density in kg/m^3	2600
Elastic modulus(GPa)	72
Tensile strength MPa)	1700

3.2. Methodology

By varying the selected parameters, different mixes were prepared and three 100mm cubes were cast for each mix. Tilted drum mixer was used for mixing concrete in which dry mixing of all the ingredients is done for 3 to 4 minutes. Later the solution was added and wet mixing was continued for another 5 minutes. The method of mixing was as suggested by Rangan[13]. The specimens were then cast in the moulds. Casting work was followed by curing of the specimens in hot air oven and ambient curing. This process was continued till an optimum mix was arrived at depending on the design compressive strength and workability. For the optimum mix, small cylinders (100mm dia, 200mm height), big cylinders (150mm dia, 300mm height) and prisms(500mm x 100mm x 100mm) were cast to find split-tensile strength, modulus of elasticity and flexural strength respectively. Optimum percentage of fibers to be added to the mix was obtained by varying the fiber content in steps of 0.01% by volume of concrete as reported by JagannadhaRao and Ahmed Khan[10].

3.3. Details of Parameters Chosen

i. Alkaline Liquid to Fly ash ratio (A/F ratio) was varied in the range of 0.6 to 0.5 in steps of 0.05.
ii. Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass (S/H ratio), was varied in the range of 1.5 to 2.5 in steps of 0.5.
iii. Molarity (M) of sodium hydroxide (NaOH) solution; 8M, 12M and 14M were used in this investigation.
iv. Curing time in the hot air oven was varied from 4 hours to 8 hours in steps of 2 hours.
v. Curing temperature in the hot oven was varied from 30^oC to 90^oC in steps of 30^oC.
vi. Super - plasticizer was varied from 0% to 3% by mass of fly ash in steps of 1%.
vii. Rest period is kept constant at one day so as to allow the fresh concrete to set before curing. Rest period is the period between the casting of specimens and start of the curing process.

4. Test Results

GPC of grade M-30 was designed using the mix design procedure suggested by Anuradha, et. al[2]. The details of the optimum mix proportion based on compressive strength are shown in Table 2. Optimum mix with the required workability was obtained without using any extra water or super plasticizer. Fresh and hardened state properties of GPC are given in Table 3 while Table 4 shows the percentage increase in the properties of GPC with fiber content compared to plain GPC.

***Table 2:** Details of Optimum Mix for Plain Geo-Polymer Concrete (All quantities are in kg/m^3)*

Mix-	Sodium	Sodium	Fly ash	Fine	Coarse Agg	A/F	S/H	Curing	Curing	Molarity of

ID	Silicate	Hydroxide		Agg			Ratio	Ratio	Time	Temp.	NaOH
					20mm	10mm					
GPC	190	95	570	610.5	314.4	190	0.5	2	4 hours	60^0C	14M

***Table 3:** Fresh and Hardened properties of Glass fiber reinforced Geo-polymer Concrete for Hot Air Cured Specimens*

Mix-ID	Percentage of Glass Fibers by volume of concrete	Slump 'cm'	Ambient Curing for one day	Hot Air Curing for 4hours – 60^0C				Unit Weight kN/m^3
			Compressive Strength (MPa)	Compressive Strength (MPa)	Split-Tensile Strength (MPa)	Flexural Strength (MPa)	Modulus Of Elasticity (MPa)	
GPC	0 .00	16	32.7	49.0	6.70	6.60	0.48 x 10^5	23.85
GPC-1	0.01	14.5	33.0	50.3	6.85	7.37	0.51 x 10^5	23.76
GPC-2	0.02	12	34.1	52.0	8.02	7.94	0.53 x 10^5	23.59
GPC-3	0.03	8.9	31.9	48.9	6.38	6.37	0.50 x 10^5	23.47

***Table 4:** Comparison of properties between Plain and Glass Fibered Geo-polymer Concrete*

Property	Percentage Increase In Property Compared To Plain Geo-Polymer Concrete			
	GPC	GPC-1	GPC-2	GPC-3
Compressive strength	---	2.65	6.12	- 0.20
Split-Tensile Strength	---	10.93	19.70	- 4.89
Flexural Strength	---	11.65	20.22	- 2.84
Modulus Of Elasticity	---	13.37	17.75	3.52

5.0. Discussion of Results

5.1 Effect of parameters chosen on the plain geo-polymer concrete :

5.1.1. Alkaline liquid to fly ash (A/F) Ratio: There was a decrease in slump with decrease in (A/F) ratio (Fig.1). As the (A/F) ratio was decreased from 0.6 to 0.5, compressive strength increased (Fig.2). This trend may be due to the decrease in the water content of the mix with decrease in the (A/F) ratio.

5.1.2. Molarity of Sodium Hydroxide: The compressive strength increased with increase in the molarity (M) of sodium hydroxide (NaOH) solution (Fig.3). This is due to the fact that the concentration of NaOH solution increases with the increasing molarity and thus decreases water content.

5.1.3 Sodium silicate to sodium hydroxide(S/H) ratio:

Higher the S/H ratio by mass, higher was the compressive strength (Fig.4). The sodium silicate solution being viscous, the workability of the mix increases without segregation. However, S/H ratio beyond 2.5 increased fluidity and thus affected setting time of GPC.

5.1.4. Curing Temperature and Curing Time: With the increase in the curing temperature and curing time, the compressive strength was found to increase (Fig. 5 & 6). Curing time and temperature can be selected as per the requirement of the design strength as the strength depends on the curing temperature and time when all other ingredients of the mix remain unchanged.

5.1.5. Curing Type: Curing is done in two different ways; hot air curing by oven and ambient curing.

Though the strength increased with increased curing temperature and time, the increase was not appreciable beyond 60^0C temperature and 4 hours curing time. Hence, optimum strength was noted as the strength corresponding to hot air curing for 4 hours at 60^0C. However, design strength is just achieved in case of ambient cured specimens also (Fig.3). Therefore it is noted that for M30 concrete ambient curing is sufficient.

5.1.6. Super plasticizer: Addition of super plasticizer more than 2% by mass of fly ash affected the compressive strength and increased the slump of geo-polymer concrete (Fig.7 &8).

5.1.7. Rest period: The compressive strength is increased by about 10% with a rest period of one day.

Based on the above studies, an optimum mix proportion of plain GPC was obtained. Fibers are introduced in the optimum GPC and optimum fiber content was arrived at.

5.2. Comparison of properties for plain GPC and glass fibered GPC: The fibers were added in percentages of 0.01%, 0.02% and 0.03% by volume of concrete to the optimum mix of GPC. There is a marginal increase in the compressive strength of GPC as the fiber content increased to 0.02% while there is a decrease as the fiber content increased beyond 0.02%. There is a considerable increase in the flexural and split tensile strengths as fiber content increased up to 0.02%, the maximum increase being around 20%. All these strengths are reduced when 0.03% of fibers are introduced in the concrete. This is due to the balling effect of fibers (Plate 4).

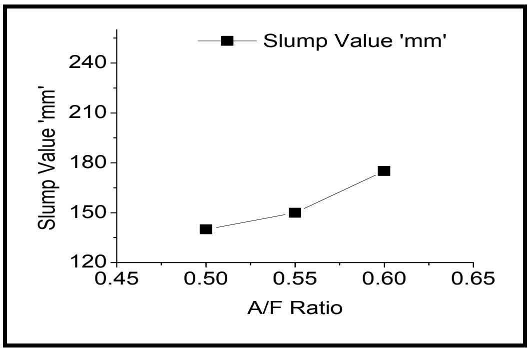

Fig1. *Variation of workability (in slump) of fresh Concrete with Alkaline Liquid (to) Flyash ratio*

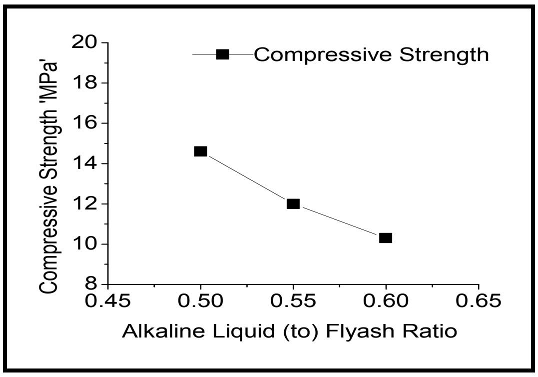

Fig2. *Variation of compressive strength of Concrete with Alkaline Liquid (to) Flyash ratio*

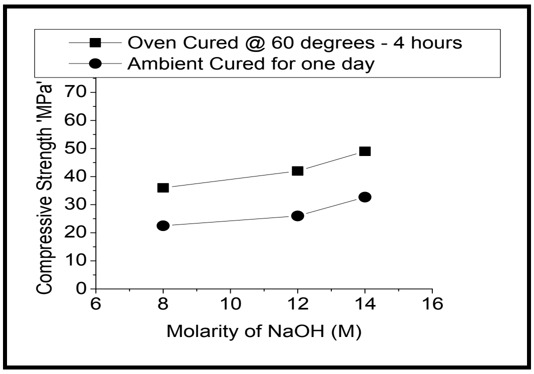

Fig3. *Variation of compressive strength of Oven & Ambient cured specimens with Molarity*

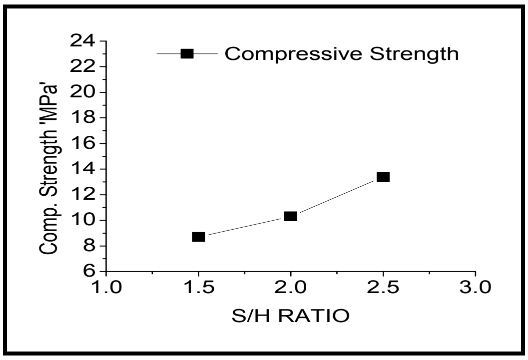

Fig4. *Variation of compressive strength of concrete with Sodium Silicate to Sodium Hydroxide (S/H) ratio*

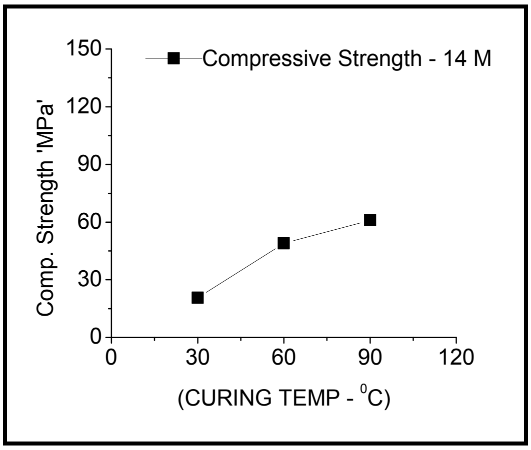

Fig5. *Variation of compressive strength with curing temperature*

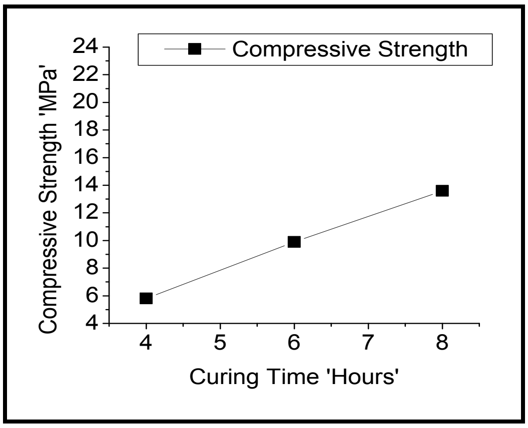

Fig6. *Variation of compressive strength with curing time*

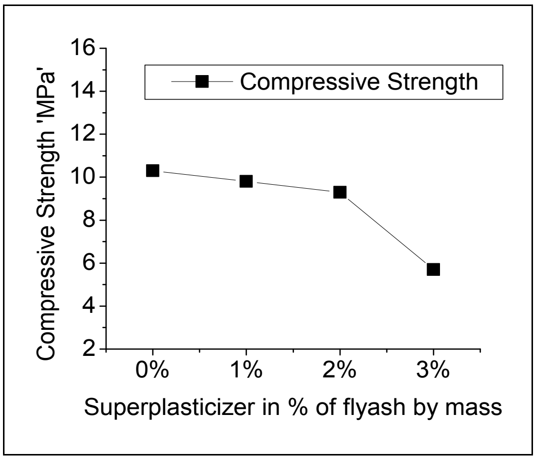

Fig7. *Variation of Compressive Strength with super plasticizer dosage*

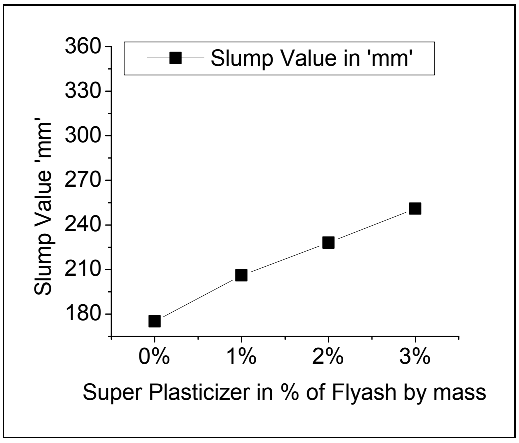

Fig8. *Variation of slump with super-plasticizer Dosage*

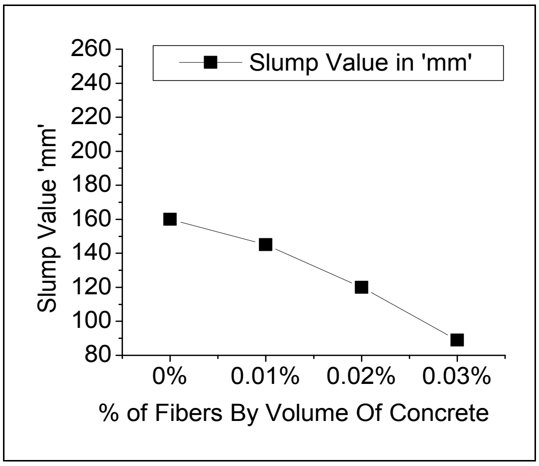

Fig9. *Variation of slump values with % of fibers*

5.2.1 Fresh properties: Addition of fibers slightly reduced the workability of concrete (Fig.9), but it did not show any adverse effect on the mechanical properties of Fiber Reinforced Geo-Polymer Concrete upto 0.02% of fibers by volume of concrete. Fiber percentage beyond 0.02% caused balling effect of fibers (Plate4) and considerably reduced workability.

5.2.2. Hardened properties:

5.2.2.1 Compressive Strength : At 0.02% fibers by volume of concrete (GPC – 2),the compressive strength increased marginally by 6.12% compared to that of plain GPC (Fig.10) for both hot air curing as well as ambient curing.

5.2.2.2 Split Tensile and Flexural Strengths : Split tensile strength is found to increase by 19.7% while flexural strength increased by 20.22 % at 0.02% fibers (Fig.11).The fiber distribution was uniform till 0.02% by volume of concrete that contributed to the higher strength and deformability characteristics of GPC (Plates 5, 6 and 7). From 0.03% of fibers by volume of concrete(GPC-3), the strength started decreasing and mix became harsh, making the compaction difficult. This may be due to the interlocking of fibers that lead to balling effect (plate 4), hindering the free movement of ingredients in the mix.

5.2.2.3 Density: Density of GPC got reduced marginally with the addition of fibers due to the lower density of glass fibers (Fig.12). However, the density values of GPC are comparable to that of OPC Concrete.

5.2.2.4 Young's Modulus: The Young's Modulus values are also observed to decrease beyond 0.02% fibers, the maximum increase being 17.77% (Fig.13) compared to plain GPC. However, the Young's Modulus value at 0.03% fibers is also higher than that of plain GPC though there is a reduction compared to 0.02% fiber GPC (table 3).

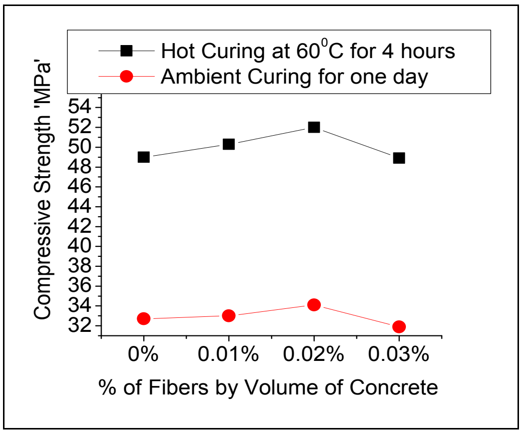

Fig10. *Variation of compressive strength with % of fibers*

Plate 4 *: Balling Effect at 0.03% of fibers by volume of concrete*

Plate 5:*Failed Glass Fibered GPC Cube*

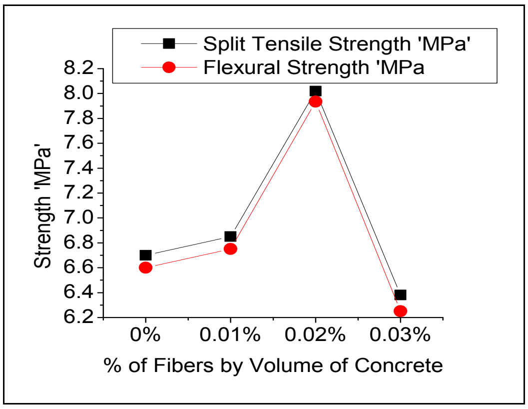

Fig11.*Variation of split-tensile strength & flexural strength values with % of fibers*

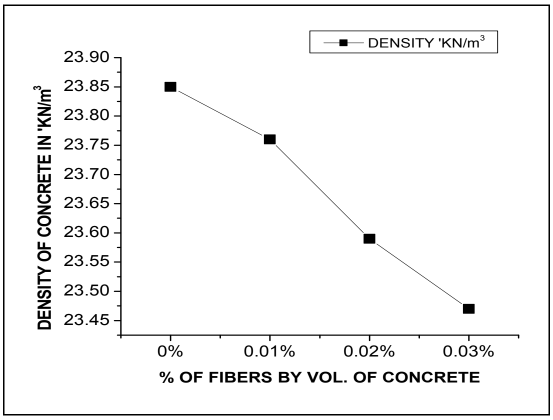

Fig12. *Variation of Density of concrete with % of fibers*

Plate 6*: Failure of fiber reinforced GPC Cylinder with 0.03% fibers in compression*

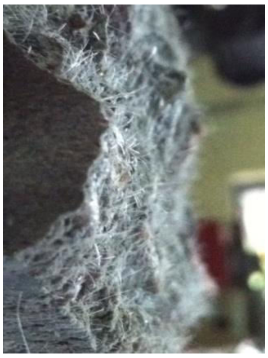

Plate 7*: Distribution of Glass Fibers in failed fiber reinforced GPC Prism*

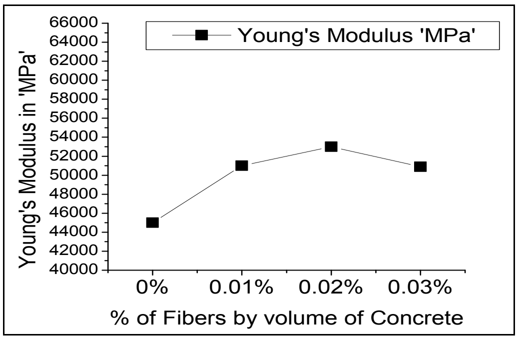

Fig13*. Variation of Young's Modulus values with % of fibers*

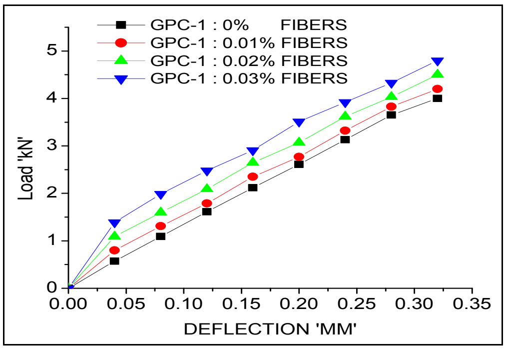

Fig14*. Load vs Deflection curves for GPC Prisms with different % of fibers*

The optimum percentage of (A.R) glass fibers, was found to be 0.02% by volume of concrete (mix GPC-2), at which compressive strength, split-tensile strength, flexural strength and young's modulus of the fly ash based fiber reinforced geopolymer concrete were maximum.

5.2.2.5 Load vs Deflection Behaviour: The deflections of GPC prisms, tested under static two-point loading, were reduced as the fiber content increased, indicating improved flexural stiffness (Fig.14). This phenomenon is true for all percentages of fiber contents used in this investigation. The initial paths of load deflection curves are almost straight line for plain as well as fiber reinforced GPC prisms. However, the curves slowly turned bilinear as the fiber content increased.

6. Conclusions

1. The strength of geo-polymer concrete increased with increase in Sodium Silicate to Sodium Hydroxide (S/H) ratio, curing time and temperature, and molarity (M) of NaOH solution.
2. The strength decreased with increase in Alkaline liquid to Fly ash (A/F) ratio and super-plasticizer dosage beyond 2% of fly ash by mass.
3. The optimum percentage of alkaline resistant (A.R) glass fibers was 0.02% by volume of concrete (GPC-2) at which compressive strength was increased marginally while the split-tensile strength, flexural strength and modulus of elasticity increased reasonably by 19.7%, 20.2% and 17.8% respectively.

4. Fibers improved crack resistance and deformability, and avoided brittle failure of the geo-polymer concrete.
5. Geo-Polymer concrete can gain strength rapidly when compared to OPC concrete. However, It was observed that minimum one day rest period is required for concrete specimens to get set before curing is started, during monsoon season.
6. The optimum strength was noted as the strength corresponding to hot air curing for 4 hours at 60^0C as the increase in strength was not appreciable beyond 60^0C temperature and 4 hours curing time.
7. Compressive strengths of 49 MPa for plain GPC and 52 MPa for GPC-2 at 0.02% of fibers were achieved when cured in hot air oven at 60^0C temperature for 4 hours.
8. Ambient cured specimens for one day achieved a compressive strength of 32.7 MPa for plain GPC and 34.1 MPa for glass fibered GPC satisfying the design strength criterion.

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