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Performance of Geopolymer Concrete Reinforced with FRP Rebars - A Review

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Abstract

The advantages of FRP reinforcements have made the researchers to concentrate on the various studies of FRP reinforcements for repair and strength of RC structures in the recent past years. FRP rods have proven their excellence in the construction of structures which are exposed to corrosion. Similarly, Geopolymer (GPC) concrete outstands prominently with its distinct properties like improved strength, resistant to acid, fire flames, sulphate, lesser shrinkage and creep. This paper reviews the important and extensive studies conducted by the researchers to bring out the important aspects related with the flexural performance of FRP reinforcements in GPC.

Key-words: Geopolymer Concrete, Flexural Performance, FRP Reinforcements.

1. Introduction

Due to the rapid growth of construction industry, world is in great demand of finding an alternate material to OPC. To overcome this, Geo Polymer Concrete (GPC) which is also a type of concrete without cement but having remarkable potential has been introduced. The appropriateness and structural performance of GPC with FRP bars contribute a secure and meticulous opening of a new technology in construction and civil infrastructure. Davidovits (1988) introduced GPC as an alternative to the habitual cementitious binders, but with the additional benefits in order to reduce greenhouse emissions. Waste by products from industries such as, Ground granulated blast furnace slag (GGBS), Metakaolin, Fly ash have been used to manufacture GPC. Because of its stable reaction ingredients and microstructures, the handling of GPC is simplified. Speaking about FRP rebars, they are well known in the construction industry since past few decades for its higher reserved strength

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and distinct properties. In this study, some of the works rendered by the researchers on the properties and performance of GPC reinforced with FRP rebars have been reviewed.

2. Review on Properties of FRP Rebars

In recent years, FRP rebars has been projected as reinforcing material. FRP rebars consist reinforcing fibres to impart strength and matrix to clutch the fibres in the exact position, giving the composite material its structural integrity. Revolutionary research on fiber-reinforced polymer (FRP) composites has been started at the Swiss Federal Laboratories for Materials Testing and Research, or EMPA. Though the cost of FRP is very high nearly two to three times that of steel, the inherent properties of FRP such as corrosion restance, higher tensile strength and lower density, effortless handling by labours highlighted in the construction of special structures subjected to aggressive environments [1,2,4,15,17].

FRP rebars posses distinct characteristics like corrosion resistant, less density, higher reserved strength in the direction of fibres, Lower modulus of elascticity when compared to steel rebars. They are brittle in nature and show linear elastic response. The modes of failure depend on the type and volume fraction of fibres and resin. GFRP rebars have higher tensile strength, compressive strengths, durability, and electromagnetic permeability. Upto the failure point FRP rods show signs of a linear elastic behaviour. The type and volume percentage of fibres contribute lower elastic modulus to the rods. The FRP rods are distinct from steel rods, in lacking of yielding nature at the failure stage and exhibiting the rupture of rods. Some of the important Properties of GFRP rebars addressed by few researches are shown in Table 1

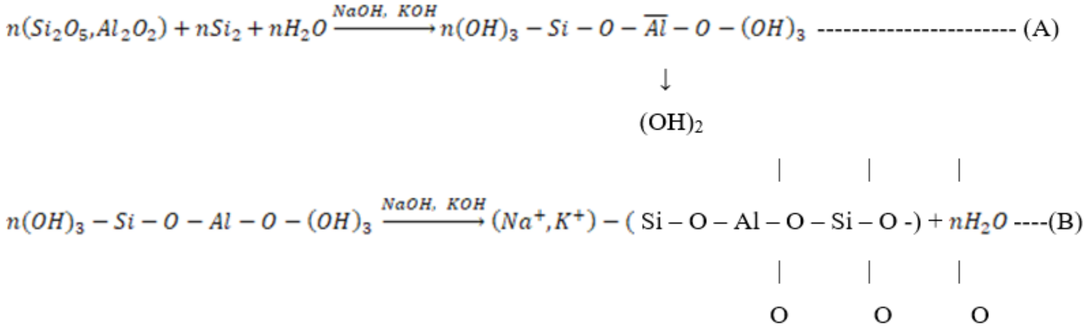
Table 1 - Properties of GFRP Rods

Properties /Reference	**Sivagamasundari & Kumaran (2007)**	CSA **(2012)**	**Ahmadi (2009)**	**ACI (2001)**
Density kg/mm^3	2560	2100	2500	2300
α (x 10^{-6}/°C)	9	6-10	--	6-10
Tensile strength (MPa)	690	1080	1700	1800
Longitudinal modulus (GPa)	68	39	73	69-90
Strain	0.01	0.5	---	0.45
Poisson’s ratio	0.22	0.28	----	0.3
Longitudinal Compressive strength (MPa)	415	620	---	840

3. Review on Properties of GPC

Geo Polymer Concrete (GPC) in construction is a challenging solution to decrease emission of CO_2 which seems to be a major problem in the production Ordinary Portland Cement (OPC). The main source materials to form GPC are fly ash and slag which are considered as industrial wastes instead of cement(3,5-14). The schematic formation of polycondensation material by alkali into poly (sialatesiloxo) [A] and the formation of geopolymers with the release of water[B] is shown in Fig.1 Water is just added to enhance the workability during manipulation just resembling the hydration process in OPC. Similar to OPC, the coarse and fine aggregates are mixed to these ingredients to produce GPC with the help of alkali-activated polymeric reaction of alumina-silicate source materials. The desirable strength can be achieved by proper mixing of ingredients to impart very apparent properties (17-19). Some of the research works that have been carried out on GPC were reviewed in this section.

Fig. 1 - Schematic Formation of GPC



$$n(Si_2O_5,Al_2O_2) + nSi_2 + nH_2O \xrightarrow{NaOH,\ KOH} n(OH)_3 - Si - O - \overline{Al} - O - (OH)_3 \text{ ----------------------- (A)}$$

$$\downarrow$$

$$(OH)_2$$

$$n(OH)_3 - Si - O - Al - O - (OH)_3 \xrightarrow{NaOH,\ KOH} (Na^+,K^+) - (\underset{\substack{|\\O}}{\overset{|}{Si}} - O - \underset{\substack{|\\O}}{\overset{|}{Al}} - O - \underset{\substack{|\\O}}{\overset{|}{Si}} - O -) + nH_2O \text{ ----(B)}$$

Lloyd, (2010) has listed the influencing factors on strength of GPC as temperature kept on curing, shape of aggregate, moisture content, procedure of preparation and grading of ingredients with some recent applications of geopolymer concrete. Antony Jeyasehar et al. (2013) have compared the mechanical properties of GPC such as compressive strength, split tensile strength and flexural strength with that of OPC. It has been observed that the strength of Geopolymer Concrete raised with enhance in Alkali –Activator Solution / fly ash ratio up to 0.5 and also, the strength of Geopolymer Concrete will be enhanced with increasing molarity of NaOH.

Zhijie Huang (2020) used the GPC subjected to ambient curing. The alkaline solution used was a mixture of 12 M sodium hydroxide (NaOH) and commercial D-grade sodium silicate

(Na2SiO3) solution. The mix proportions of M40 grade of GPC has been proposed as shown in Table 2.

Table 2 - Trial Mix Proportions of M40 GPC

Coarse agg	**Fine aggregate**	**Binder**		**Alkaline Solution**		**Alkaline solution / Binder ratio**
		Fly ash	**GGBS**	**Na2SiO3**	**NaOH**	
1196	644	360	40	173.7	59.4	0.6

Hemn Qader Ahmed (2020) used sodium silicate solution (Na2SiO3) and sodium hydroxide (NaOH) pellets with 98% limpidness. Low calcium fly ash type F, Coarse aggregate of size 9.52 mm and fine aggregates were used. To enhance the workability sulfonated naphthalene formaldehyde was used as superplasticiser. The variables considered for the GPC 13 trail mixes given in Table .3 were 1. molarity of sodium hydroxide (M), 2. alkaline-fly ash ratio and 3. water-binder ratio. The water–binder ratio was calculated as follows; the amount of water in sodium silicate solution, sodium hydroxide solution, and additional water was divided by the solid parts in sodium silicate solution, sodium hydroxide solution and fly ash.

Table 3 - Trial Mix Proportions and Results

Mix	**G(Kg/m^3)**	**S(Kg/m^3)**	**FA (Kg/m^3)**	**M**	**S/S**	**A/F**	**C (Kg/m^3)**	**EW (Kg/m^3)**	**SP % (Kg/m^3)**	**W/B ratio**	**W/C Ratio**	**Compressive Strength, f'$_c$ (Mpa)**
101	1230	660	400	12	2.5	0.45		0	3	0.2145		45.5
102	1230	660	400	12	2.5	0.45		32	2	0.3017		39.5
103	1230	660	400	12	2.5	0.45		14	2	0.2511		47.5
104	1230	660	400	12	2.5	0.45		48	2	0.3502		26.8
105	1230	660	400	16	2.5	0.45		36	2	0.3009		39.4
106	1230	660	400	8	2.5	0.45		27	2	0.3019		24.6
107	1230	660	400	8	2.5	0.45		43	2	0.3504		19.5
108	1230	660	400	8	2.5	0.4		50	2	0.3512		12.9
109	1230	660	400	8	2.5	0.35		57	2	0.3521		10.4
110	1230	660	400	12	2.5	0.45		38	2	0.3195		34.5
111	1230	660					400				0.3	52.2
112	1230	660					400				0.4	36.1
113	1230	660					400				0.5	25.7

G – Coarse Aggregate, S – Sand, FA- Flyash, M- Morality of Sodium Hydroxide, S/S – Sodium silicate- Sodium hydroxide Ratio, A/F- Alkaline Flyash Ratio, C- Cement, EW- Extra Water, SP- Super Plasticizer, W/B- Water Binder Ratio, W/C – Water cement Ratio

4. Review on Flexural Behaviour of FRP Rebars in GPC

Since the distinct brittle linear elastic behaviour of FRP rebars does not allow the existing guidelines of conventional flexural members in predicting its performance exactly, the experimental validations are required. The empirical equations involved in limit state design which is used in the conventional members are to be modified after the experimental examination. GPC reinforced with FRP bars provides an enhanced construction process with high robustness, and passable strength.

Maranan et al. (2015) investigated the flexural capability of GFRP reinforced GPC beams and concluded that the size of bar had no prominent effect on the flexural capacity of the beams. On increasing rebar ratio, the serviceability behaviour of beam increases (Maranan et al. 2015). Shear behaviour of GPC beams reinforced with GFRP rebars and stirrups have also been studied by Maranan et al. 2017 accomplishing that the GFRP stirrups enhances both the shear strength and deflection capacity of the beams by approximately 200%.

Hemn Qader Ahmed (2020) cast twelve beams out of which nine GFRP-RGPC and three GFRP-ROPC beams and tested under two-point loading test over an active span of 2000 mm. All beams have the same height 300 mm and width 160 mm. For all the beams a clear cover of 20 mm was used. Three different rebar ratios ($\rho f<\rho fb$, $\rho fb<\rho f< 1.4\ \rho fb$ and $\rho f> 1.4\ \rho fb$) in order to observe the different modes of failure, three different compressive strengths (20MPa,35 MPa and 50 MPa) and two types of concrete (OPC-Ordinary Portland Cement concrete and GPC-Geo polymer concrete) have been taken as variables. All beams were simply supported. GFRP rebars and steel rebars of 6 mm diameter were used for all beams as main longitudinal reinforcements. To prepare GPC low calcium flyash type F, aggregates satisfying ASTM C33,2003 were used. To enhance the workability, Sulfonated naphthalene formaldehyde was used as superplasticiser along with an optimum water binder ratio of 0.25. It was noted that the relative amount of rebar had a remarkable effect on both first cracking and ultimate loads.

It has been observed that both the deflection and initial cracking load were increased with the compressive strength. Four different types of failure were observed. Beams reinforced with $\rho f<\rho fb$ suffered tension failure of GFRP bars; beams reinforced with $\rho f<\rho fb$ failed due to tension failure of GFRP bars followed by a compressive failure of the top concrete part; beams reinforced with $\rho f>\rho fb$ subjected to debonding of GFRP from the concrete at the bottom of the beam. on increasing the compressive strength, the deflections of the beams was considerably reduced with less number of crack widths.

M. Ratnasrinivas et al. (2020) examined the flexural behavior of the beams with different molars of NaOH solution. Ambient curing has been carried out for the beams of size 1000 mm × 150 mm × 150 mm achieving M40 grade. It has been observed that GPC gives higher strength than OPC beams with a higher reserved load deflection performance. The flexural mode of failure has been occurred with the cracks generated from the tension zone to the compression zone.

5. Conclusions

From the literature, it has been observed that

1. GPC is termed as cement free concrete and the extensive researches confront it as a challenging replacement for OPC reducing Global Warming.
2. Various studies contribute the development of mix design in order to enhance the workability of GPC.
3. The flexural cracks are relatively less in GPC beams compared to RCC beams.
4. The flexural mode of failure occurs in the beams along with the cracks started from the tension zone to the compression zone.
5. The fineness of fly ash in GPC increases the compressive strength due to drop off porosity.
6. The load versus deflection behaviour of Geopolymer concrete structural elements are higher than the OPC structural elements.
7. On increasing the molarity, the load carrying capacity of GPC structural elements will increase.

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