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Retrofitting Of Geopolymer Beam Using Carbon Fibre Mat

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ABSTRACT: The aim of the paper is to evaluate the flexural strength of Geopolymer concrete beam with Carbon Fibre Reinforced Polymer (CFRP) wrapping (tension side) and to validate with control beam. The material used for the preparation of geopolymer concrete beam are sodium hydroxide, sodium silicate, Class F flyash, fine aggregate, coarse aggregate, superplasticizer and carbon fiber mat. The geopolymer concrete flexural beams were casted and pasted with the carbon fiber in tension side by using 100% replacement of cement to achieve the required strength as equivalent to conventional concrete. The material used for the beam preparation of geopolymer concrete are carbon fiber, sodium hydroxide, sodium silicate, flyash, fine aggregate, coarse aggregate and super plasticizer. The geo polymer concrete flexural strength beams were cast and pasted with the carbon fibre in tension side by using epoxy resin and cured under atmospheric temperatures. After 28 days, the beams were tested for getting flexural strength of beams and results were compared with the conventional concrete beam. The report represents the comprehensive summary of extensive studies conducted on flyash based geopolymer concrete beam. Test data are used to identify the effects of salient factors that influence the properties of geopolymer concrete in the fresh and hardened states. The results show that the enhancement of strength depends on the environmental conditions of the location. This paper reports about curing that was done as atmospheric curing (sun drying), whereas some of the researchers have used oven curing to get enhanced strength. The results are not too competitive but they help to draw the conclusion that the environment plays a major role in rehabilitating structures. The success rate of curing the geopolymer concrete under atmospheric temperature will also lead to major usage for concrete structures.

KEYWORDS - Flexural Strength, Geopolymer, Flyash, Carbon fibre.

I. INTRODUCTION

As the demand for concrete as construction material increases, the demand for Portland cement also increases. It is estimated that the production of cement will increase from about 1.5 billion tons in 1995 to 2.5 billion tons in 2015. On the other hand, the climate change due to global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), into the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton Portland cement emits approximately one ton of CO_2 into the atmosphere . Several efforts are in progress to reduce the use of Portland cement in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement. In this respect, the geopolymer technology proposed by Davidovits shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries.

Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O Al-O bonds. An alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as flyash and rice husk ash to produce binders, because the chemical reaction that takes place in this case is a polymerization process. Water is released during the chemical reaction that occurs in the formation of geo polymers. The water emitted by the geopolymer matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of geopolymers. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process[1].

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in Silicon (Si) and Aluminum (Al). Natural materials such as flyash, silica fume, slag, rice-husk ash, redmud, etc., could be used as source materials. The choice of the source materials for making geo polymers depend on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble liquid used in geopolymerization which is a combination of sodium hydroxide (NaOH) and sodium silicate or potassium silicate[2]. Researchers all over the world are carrying out their research work by using the glass fibre[8] and geopolymer for retrofitting works. Beam retrofitted by vinyl ester bonded GFRP & epoxy bonded GFRP strip wrapping technique show less increase in strength in comparison to beams retrofitted by vinyl ester bonded GFRP & epoxy bonded GFRP full wrapping technique. It was also seen that the retrofitting cost of vinyl ester bonded GFRP is cheaper than the retrofitting cost epoxy bonded GFRP sheets[12]. Timber beam strengthened with GFRP rods had an increase in its ultimate load carrying capacity. The percentage of increase is between 20% - 30%. The strengthening of timber beams with GFRP enhanced the stiffness of the beam with a percentage of increase between 24% - 60%. No debonding or delamination occurred between GFRP rods and timber beams. It shows that the load carrying capacity is totally dependent on the strength of timber and GFRP. The failure mode was governed by the strength of timber beams since no rupture occurred to the GFRP rods. Further research on the use of Carbon Fibre Reinforced Polymer (CFRP) plate to strengthen the timber beams is recommended since the strength of CFRP is higher than GFRP and also easy to attach to timber beams without the need of the grooves. Although CFRP is another strengthening material, one must consider the cost because they are quite expensive[11]. The main concern with FRP composites is long-term durability because the materials do not have sufficient historical performance data in bridge applications. In bridge applications, resins are more desirable and practical as the binders for the fibre and adhesives for joints and connections that can adequately cure at ambient temperature and still offer comparable quality and characteristics. More research is needed to develop the most effective and durable resin formulations. More efficient manufacturing and effective production methods for large volume panels and higher modulus materials are needed to make it more cost effective for composites to compete in the civil infrastructure[14]. FRP can be used to strengthen and rehabilitate the beams with small opening only. FRP does not show the same efficiency for strengthened and rehabilitated beams. Beams with FRP wrapping shows debonding of FRP layer leading to diagonal failure. Further a large number of researches are required to understand the FRP strengthening technique for beam with large opening, rehabilitation of beam using FRP and also to understand their failure mechanism[15].The performance of GFRP plated RC beams increased with regard to strength and deformation capacity. The ultimate load for GFRP plated RC beams increased by a maximum of 42.84% for Singly Reinforced Woven Roving GFRP (SRWRGFRP) plated beam, by 71.40% for Singly Reinforced Unidirectional GFRP (SRUDGFRP) plated beam and by 85.70% for Singly Reinforced Chopped Strand Mat Woven Roving GFRP (SRCSMWRGFRP) plated beam, when compared to the reference beam. The type of GFRP influenced the performance of the GFRP plated beams. SRUDGFRP resulted in a better performance when compared to SRCSMGFRP. Deflection ductility values for beams showed increase up to 64.48% over the corresponding reference beams. Energy ductility values increased by up to 118.90% for 3.5 mm thick GFRP plated beams[16].

II. EXPERIMENTAL INVESTIGATION

A.Materials

a. FlyAsh:

It is the waste obtained from power plants. Workability, ease of pumping, improved finishing, reduced bleeding, reduced segregation, higher strength, decreased permeability, increased durability, reduced sulphate attack, reduced efflorescence, reduced shrinkage, reduced heat of hydration, reduced alkali silica reactivity, are the major properties of flyash.

Table 1: *Properties of flyash*

Sl.No.	Characteristics	Results
1	Silicon di oxide (as SiO_2) plus Aluminium Oxide (Al_2O_3) plus Iron Oxide (as Fe_2O_3), % by mass	85.94
2	Silica (as SiO_2), % by mass	60.21
3	Magnesium Oxide (as MgO), % by mass	1.99
4	Total Sulphur as Sulphur tri Oxide	2.19

	(SO_3), % by mass	
5	Available Alkali as Sodium Oxide (Na_2O), % by mass	0.39
6	Loss on Ignition, % of mass	2.05
7	Moisture Content, % of mass	0.28

b. Fine Aggregate: Fine aggregate used was clean dry river sand. The sand was sieved to remove all pebbles and impurities in the soil. The average specific gravity of the fine aggregate was found to be 2.68.

c. Coarse Aggregate: Hard granite broken stone was used as coarse aggregate. The size of aggregate used for the study varies from 7mm to 20mm. The aggregate crushing value and the aggregate impact value were found to be 22.7 and 19.48 respectively.

d. Alkaline Solution: Sodium hydroxide in pellets form and Sodium silicate in the gel form with 8 molarity solution is prepared and kept for 24 hours and used for making concrete.

e. Reinforcements: Four number of 10mm diameter HYSD bars with 8mm diameter stirrups at 100 mm centre to centre spacing were used in all the specimens.

f. Carbon fibre: Unidirectional carbon fibre was used in single and double layers.

B.Design of Geopolymer Concrete Mixtures

The mass of combined aggregates may be taken to be between 75% and 80% of the mass of geopolymer concrete. The perfomance criteria of a geopolymer concrete mixture depend on the application. For simplicity, the compressive strength of hardened concrete and the workability of fresh concrete are selected as the performance criteria. In order to meet these performance criteria, the wet- mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters. With regard to alkaline liquid-to-flyash ratio by mass, values in the range of 0.30 and 0.45 are recommended. Note that wet-mixing time of 4 minutes, and steamcuring at 60°C for 24 hrs after casting are proposed. Sodium silicate solution is cheaper than sodium hydroxide solids. Commercially with available sodium silicate solution A53 with SiO_2-Na_2O ratio by mass of approximately, i.e., Na_2O =14.7%, SiO_2=29.4%, and water=55.9% by mass, and sodium hydroxide solids (NaOH) with 97-98% purity are recommended. In other words, the coarse and fine aggregates in a geopolymer concrete mixture must neither be too dry to absorb water from the mixture nor too wet to add water to the mixture. In practical applications, aggregates may contain water over and above the Saturated Surface Dry (SSD) condition. Therfore, the extra water in the aggregates above the SSD condition must be included in the calculation of water-to-geopolymer solids ratio given.

Table 2: *Mix Proportion*

Material	Quantity
Sodium Hydroxide Solution	41 kg/m^3 (10.75 kg/m^3 of NaOH + 30.25 kg/m^3 of Water)
Sodium Silicate	102 kg/m^3 (44.98 $NaSiO_2$+57.02 kg/m^3 of Water)
Flyash (Class F)	408.8 kg/m^3
Fine Aggregate	554.4 kg/m^3
Coarse Aggregate	1293.6 kg/m^3
Water	87.25 kg/m^3
Water-Geopolymer ratio	0.177

III. RESULTS AND DISCUSSIONS

There are 36 numbers of flexural beams (150 x 150 x 700 mm) which were cast and kept under atmospheric curing for about 28 days. All the beams were tested in universal testing machine with 40tones capacity for finding the flexural strength. The maximum flexure load taken by each beam is given in Tables 3.1 to 3.4 and the average flexural strength were arrived. From the table, it is evident that the flexural strength of conventional beam retrofitted with carbon fibre wrapping improves the behavior of beam compared with the conventional RCC beam. Also, the flexural behaviour of carbon fibre wrapping for the PCC beam, RCC beam and CPRC beam is better, hence the carbon fibre wrapping can be utilized for retrofitting works.

Further the flexural strength of geopolymer plain concrete reaches 11.6% more than the conventional plain concrete beam strength as shown in table 7 whereas there is an increase in flexural strength by 32.06% for the geopolymer reinforced concrete beam compared with conventional reinforced cement concrete beam as shown in table 7.

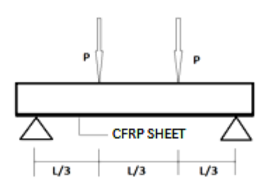

Figure 1. Test setup

Figure 2. Experimental Setup - Beam with two point loading

Figure 3. Crack propagation while loading

Figure 4. Beam with glass fibre wrapped in tensile zone

Table 3: *Flexural strength of PCC beams*

Beam	Beam ID	Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Plain Cement Concrete Beam (PCC)	B1	23.85	4.94	4.88
	B2	23.10	4.79	
	B3	23.65	4.90	
Plain Cement Concrete Beam with Carbon Fibre (PCC+CF1)	B4	43.62	9.04	8.94
	B5	42.75	8.86	
	B6	43.09	8.93	
Plain Cement Concrete Beam with Carbon Fibre (PCC+CF2)	B7	55.78	11.56	11.80
	B8	56.84	11.78	
	B9	58.14	12.05	

Plain Cement Concrete with one layer of glass fiber pasted on tensile fibre gives 1.83 times of more flexural strength when compare to PCC beam without Carbon Fiber mat. Plain Cement Concrete with two layer of Carbon Fiber pasted on tensile fibre of beam gives 2.42 times of more flexural strength. Plain Cement Concrete with two layers of carbon fibre mat gives 1.32 times of more strength than the PCC beam with one layer of carbon fibre mat.

Table 4**:** *Flexural strength of RCC beams*

Beam	Beam ID	Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Reinforced Cement Concrete Beam (RCC)	B10	91.40	18.94	19.62
	B11	95.70	19.83	
	B12	96.90	20.08	
Reinforced Cement Concrete Beam with Carbon Fibre (RCC+CF1)	B13	176.79	36.64	36.89
	B14	179.63	37.23	
	B15	177.70	36.83	
Reinforced Cement Concrete Beam with Carbon Fibre (RCC+CF2)	B16	242.79	50.32	50.68
	B17	237.92	49.31	
	B18	252.88	52.41	

Reinforced concrete beam shows 4 times the flexural strength than the plain cement concrete beam.

RCC beam with one layer of glass fiber mat gives 1.88 times of more flexural strength than RCC beam without carbon fibre mat. RCC beam with two layers of carbon fibre mat gives 2.58 times of more flexural strength when compared to the RCC beam without GF mat.

RCC beam with Carbon Fiber mat with two layers of Carbon Fibre mat shows 1.37 times of more flexural strength than RCC beam with one layer of Carbon Fibre mat.

Table 5: *Flexural strength of geopolymer beams*

Beam	Beam ID	Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Geopolymer Plain Concrete Beam (GPPC)	B19	25.20	5.22	5.45
	B20	26.40	5.47	
	B21	27.28	5.65	
Geopolymer Plain Concrete Beam with Carbon Fiber (GPPC+CF1)	B22	47.82	9.91	10.59
	B23	52.30	10.84	
	B24	53.27	11.04	
Geopolymer Plain Concrete Beam with Carbon Fiber (GPPC+CF2)	B25	77.25	16.01	16.50
	B26	78.74	16.32	
	B27	82.85	17.17	

GPPC beam shows 1.12 times of additional flexural strength than PCC beam.

GPPC beam with one layer of CF mat shows 1.94 times of more flexural strength than GPCC beam without Carbon fibre mat. GPPC beam with two layers of Carbon Fibre mat shows 3.03 times of additional flexural strength than GPPC without GF mat.

GPPC beam with two layers of Carbon Fibre mat shows 1.56 times of more flexural strength than GPPC beam with one layer of GF mat.

Table 6: *Flexural strength of geopolymner reinforced concrete beam*

Beam	Beam ID	Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Geopolymer Reinforced Concrete Beam (GPRC)	B28	124.07	25.71	25.91
	B29	125.81	26.07	
	B30	125.28	25.96	
Geopolymer Plain Concrete Beam with Carbon Fiber (GPRC+CF1)	B31	240.38	49.82	47.76
	B32	235.65	48.84	
	B33	245.24	44.61	
Geopolymer Plain Concrete Beam with Carbon Fiber (GPRC+CF2)	B34	333.84	69.19	69.41
	B35	332.54	68.92	
	B36	338.28	70.11	

GPRC beam without Carbon fibre mat gives 1.32 times of more flexural strength compared to RCC beam without Carbon fibre mat.

GPRC beam with one layer of carbon fibre mat gives 1.84 times of more flexural strength than GPRC beam without GF mat.

GPRC beam with two layers of carbon fibre mat gives 2.68 times of more flexural strength than GPRC beam without GF mat.

GPRC beam with two layers of carbon fibre mat shows 1.40 times of more flexural strength than GPRC beam with one layer of Carbon Fibre mat.

Further the flexural strength of geopolymer plain concrete reaches almost equivalent to the conventional plain concrete beam strength as shown in figure.1 whereas there is a large deviation for the geopolymer reinforced concrete flexural strength compared with conventional reinforced cement concrete shown in figure.2.

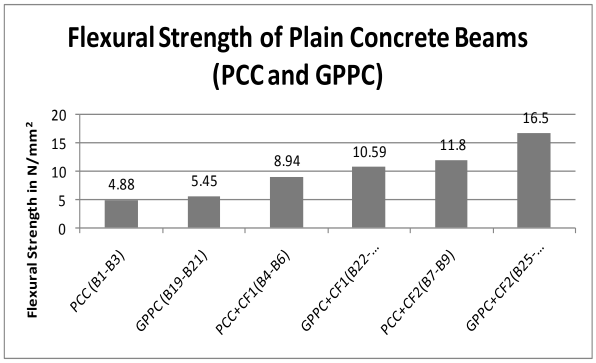

Figure 5. Flexural Strength of PCC and GPPC

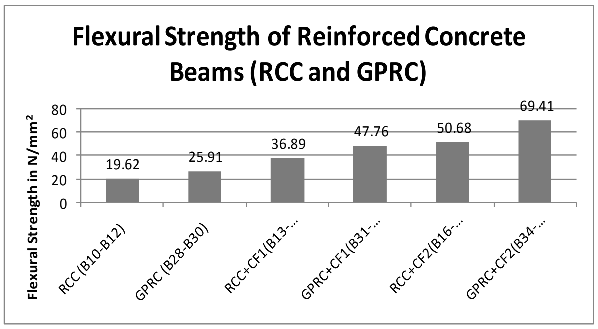

Figure 6. Flexural Strength of RCC and GPRC

Table 7: *Results and Observations*

Controlled concrete beam	Geo polymer concrete beam	Flexural strength (N/mm^2)		Percentage deviation with Control Beam
		Control Beam	Geopolymer Concrete Beam	
PCC	GPPC	4.88	5.45	+11.6%
PCC + 1 layer CFRP	GPPC + 1 layer CFRP	8.94	10.59	+18.46%
PCC + 2 layer CFRP	GPPC + 2 layer CFRP	11.80	16.50	+39.83%
RCC	GPRC	19.62	25.91	+32.06%
RCC + 1 layer CFRP	GPRC + 1 layer CFRP	36.89	47.76	+29.47%
RCC + 2 layer CFRP	GPRC + 2 layer CFRP	50.68	69.41	+36.96%

- CFRP wrapping in Geopolymer plain concrete beam shows 18% to 40% more than controlled plain concrete beam from fig.5
- CFRP wrapping in Geopolymer in reinforced concrete beams shows 30% to 37% more than the controlled RCC beams from fig.6
- Flexural strength of beam increases with respect to number of layers of CFRP wrapping.

Cost Analysis

Heat cured low calcium flyash based geopolymer concrete offers several economic benefits over Portland cement concrete. The price of one ton of flyash is only a small fraction of the price of one ton of Portland cement. Therefore, after allowing for the price of alkaline liquids needed to make the geopolymer concrete, the price of flyash based geopolymer concrete is estimated to be about 10 to 30 % cheaper than that of Portland cement concrete. Based on the investigation carried out, one ton low calcium flyash can be utilized to manufacture approximately 2.5 cubic meters of high quality flyash based geopolymer concrete, and hence earn monetary benefits through carbon trade. Furthermore, the very little drying shrinkage, the low creep, the excellent resistance to sulfate attack, and good acid resistance offered by the heat cured low calcium flyash based geopolymer concrete may yield additional economic benefits when it is utilized in infrastructure applications.

IV. CONCLUSIONS

By introducing reinforcement and pasting the glass fibre we can achieve improved flexural strength.

- The load deflection characteristics of the RCC & GPRC beams are observed as similar.
- The flexural strength of GPRC beam is 32.06% more when compared to control beam.
- Deflection of GPRC beam under ultimate load is less when compared to control beam while it is retrofitted with glass fibre.
- Bonding strength between steel and geo polymer concrete shows very good performance.
- The flexural strength of GPRC beam with single layer CFRP gives 29.47% more when compared with RCC beam with single layer CFRP.
- The flexural strength of GPRC beam with double layer CFRP gives 36.96% more when compared with RCC beam with double layer CFRP.
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