www.cafetinnova.org

Indexed in
Scopus Compendex and Geobase Elsevier, Chemical Abstract Services-USA, Geo-Ref Information Services-USA, List B of Scientific Journals, Poland, Directory of Research Journals

ISSN 0974-5904, Volume 08, No. 02

International Journal of Earth Sciences and Engineering

April 2015, P.P.226-232

Rehabilitation of Reinforced Geopolymer Concrete Beam Using Glass Fibre Mat

K R YOGANATHAN[1] AND N MAHENDRAN[2]
[1]*Civil Engineering, KLN College of Information Technology, Pottapalayam, Sivagangai District, India*
[2]*PSNA College of Engineering & Technology Dindigul, India*
***Email:** kryogan1110@gmail.com, nm64@rediffmail.com*

Abstract: The aim of the paper is to evaluate the flexural strength of Geopolymer concrete beam with Glass Fibre Reinforced Polymer (GFRP) wrapping (tension side) and to compare 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 Glass fiber mat. A total of 18 beams were cast out of which 9 beams were conventional RCC beams (Scheme-I) and the remaining 9 beams were geopolymer concrete beams (Scheme-II) and were wrapped with the unidirectional Glass fiber mat in tension side (with one and two layers) by using epoxy resin and cured under atmospheric temperature. After 28 days, the both Scheme-I and Scheme-II beams were tested for flexural strength and results were compared with each other. 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. While most of the researchers have used oven curing to get enhanced strength of the specimens, an attempt has been made to cure the specimens at atmospheric temperature in this study. The results are not too competitive but they helped to draw the conclusion that the environment plays a major role in curing of geopolymer concrete elements. The success rate of curing the geopolymer concrete under atmospheric temperature is expected to use geopolymer concrete structures similar to conventional reinforced concrete structures prevailing in the field.

Keywords: *Flexural Strength, Geopolymer, Flyash, Glass fibre mat*

1. Introduction

The demand for cement increases with the demand for concrete as construction material. The production of cement has increased 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, red mud, 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 upto 118.90% for 3.5 mm thick GFRP plated beams [16].

2. Experimental Investigation

2.1. Materials

2.1.1. FlyAsh

It is the waste material obtained from Tuticorin Thermal Power Plant. 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.

2.1.2. 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.

2.1.3. 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.

2.1.4. 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.

2.1.5. Reinforcements

Two numbers of 8mm diameter HYSD bars at top and 2 numbers of 10mm diameter HYSD bars at bottom with 8mm diameter stirrups at 150 mm centre to centre spacing were used in all the specimens.

2.1.6. Glass fibre

Unidirectional Glass fibre was used in single and double layers.

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 (SO_3), % by mass	2.19
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

2.2. 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 shows the mix proportions of geopolymer concrete.

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

3. Strengthening schemes

Eighteen flexural beams (150 x 230 x 2100 mm) were cast out of which 3 beams (B1 to B3) are control beams i.e. without any wrapping (RCC), 3 beams (B4 to B6) with single layer of wrapping in tension side (RCGF1), 3 beams (B7 to B9) with two layers of wrapping in tension side (RCGF2), 3 geopolymer control beams (B10 to B12) i.e. without any wrapping (GPRC) , 3 geopolymer RC beams (B13 to B15) with single layer of wrapping (GPBF1), 3 geopolymer RC beams (B16 to B18) with two layers of wrapping (GPBF2). All the beams were kept under atmospheric curing for about 28 days and they were tested in universal testing machine with 40 tones capacity to observe the flexural behaviour. Before testing, the beams under wrapping schemes were wrapped with Glass fibre mat on their tension side using Epoxy Resin. The fibre is wrapped in the longitudinal direction of the beam since unidirectional Glass fibre is used. The fibre is wrapped to the beam specimen after thoroughly cleaning the surface of the tension side of the beam with portable vacuum cleaner to remove any dust. Prior, the surface was roughened with a wire brush so that the fibre mat sticks to the surface firmly. The fibre was wrapped thoroughly with the help of a roller, until the resin squeezes out. The schematic test setup of the beam is shown in figure 1and the section of the beam with the details of the reinforcement is shown in figure 5. The maximum flexure load taken by each beam is given in Tables 3 to 5 and the average flexural strength was arrived. From the tables, it is evident that the flexural strength of beam rehabilitated with Glass fibre mat wrapping improves when compared with the control RCC beam.

Further, there is an increase in flexural strength by 1.72% by the geopolymer reinforced concrete beam compared with control RCC beam as shown in table 4.

From table 3, it can be observed that the flexural strength of RCC beam with one layer of Glass fibre (RCGF1) increased by 4.95% when compared to conventional RC beam (RCC).

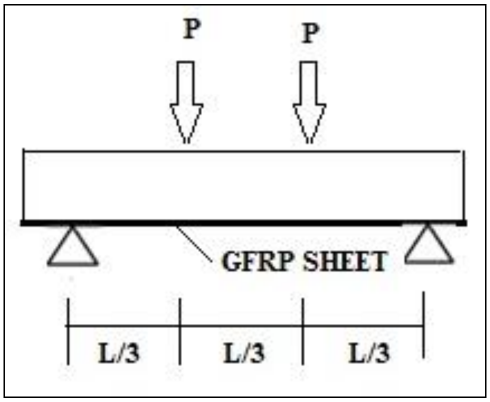

Figure 1 *Test setup*

Figure 2 *Experimental Setup - Beam with two points loading*

Figure 3*Crack propagation while loading*

Figure 4 *Beam with Glass fibre wrapped in tensile zone*

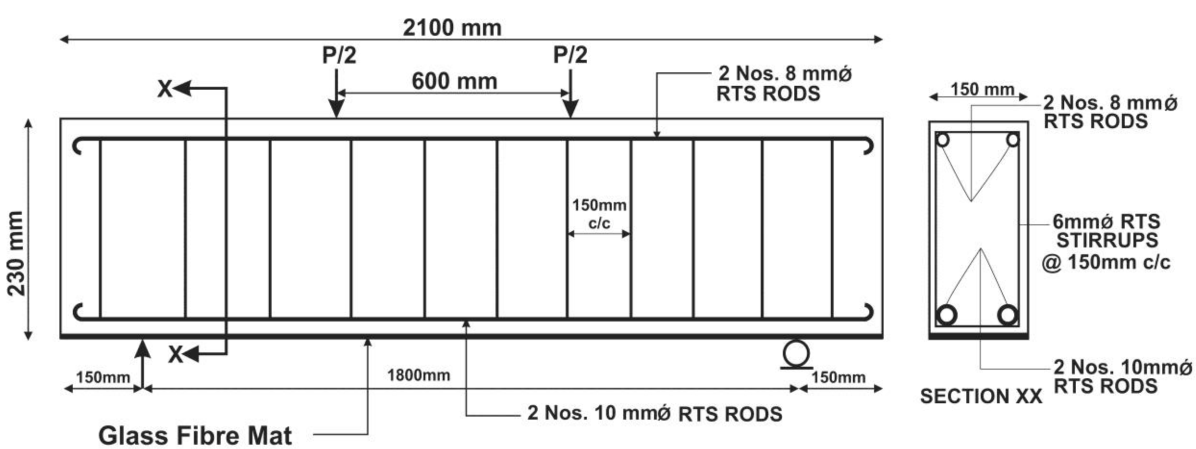

Figure 5 *Section of Beam showing details of Reinforcement*

***Table 3**: 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)	B1	61.80	14.02	13.94
	B2	61.95	14.05	
	B3	60.65	13.76	
Reinforced Cement Concrete Beam with Glass Fibre (RCGF1)	B4	64.20	14.56	14.63
	B5	64.65	14.67	
	B6	64.60	14.65	
Reinforced Cement Concrete Beam with Glass Fibre (RCGF2)	B7	69.10	15.67	15.91
	B8	70.90	16.08	
	B9	70.40	15.97	

Similarly, for RCC beam with two layers of Glass fibre mat (RCGF2), the flexural strength resulted in an increase of 14.13% when compared to conventional RC beam (RCC). Also, when comparing the flexural strength of wrapped beams, the beam with two layers of Glass fibre mat (RCGF2) show 8.75% more flexural strength than that beam with single layer of Glass fibre mat (RCGF1)

From table 4, it can be seen that GPRC beam without Glass fibre mat (GPRC) gives 1.72% more flexural strength compared to control RCC beam. Similarly, GPRC beam with one layer of Glass fibre mat (GPBF1) gives 6.20% more flexural strength than GPRC beam without GF mat (GPRC).

Also, GPRC beam with two layers of Glass fibre mat (GPBF2) gives 21.44% more flexural strength than the GPRC beam without Glass fibre mat (GPRC) and the beam with two layers of Glass fibre mat (GPBF2) shows 14.27% more flexural strength than GPRC beam with one layer of Glass Fibre mat (GPBF1). There is a considerable deviation in flexural strength for the geopolymer reinforced concrete beam when compared with control RC beam.

***Table 4:** 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)	B10	62.50	14.18	14.18
	B11	62.10	14.09	
	B12	62.90	14.27	
Geopolymer Plain Concrete Beam with Glass Fiber (GPBF1)	B13	67.15	15.23	15.07
	B14	66.80	15.15	
	B15	65.40	14.84	
Geopolymer Plain Concrete Beam with Glass Fiber (GPBF2)	B16	74.80	16.97	17.22
	B17	75.60	17.15	
	B18	77.35	17.55	

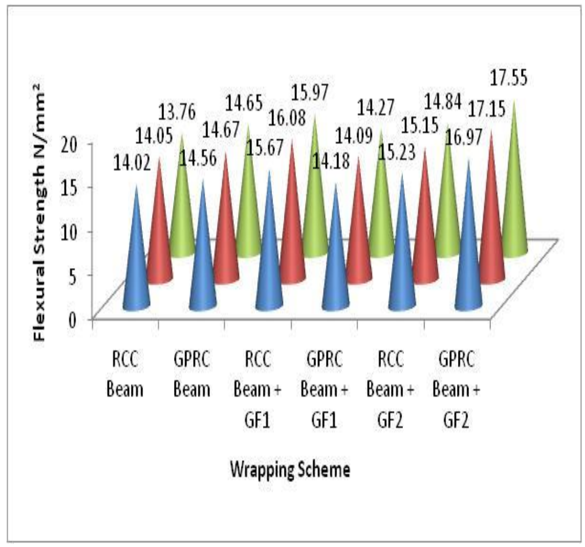

***Figure 6** Comparison of Flexural Strength of RCC and GPRC beams*

***Table 5:** Results and Observations*

RCC beam type	Geo-polymer beam type	AVERAGE FLEXURAL STRENGTH (N/mm^2)		Percentage deviation with control RC Beam
		RCC Beams	GPRC Beams	
RCC Beam	GPRC Beam	13.97	14.18	+1.50
RCC Beam +1 layer of GFRP	GPRC Beam +1 layer of GFRP	14.63	15.07	+3.01
RCC Beam +2 layer of GFRP	GPRC Beam +2 layer of GFRP	15.91	17.22	+8.23

The comparision of flexural strength of beams for various wrapping schemes are shown in figure 6 and figure 7 shows the same for average flexural strength.

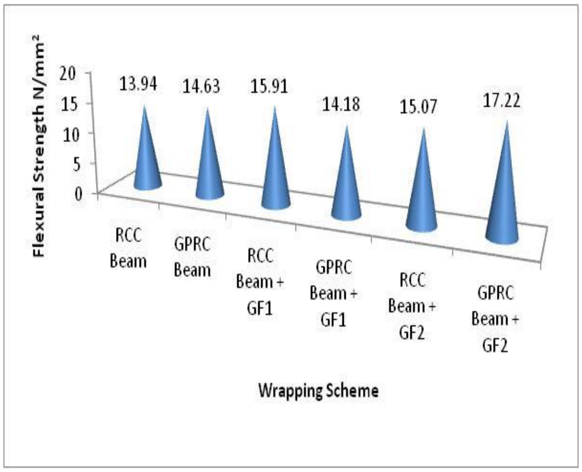

Figure 7 *Comparison of Average Flexural Strength of RCC and GPRC beams*

4. 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.

5. Conclusions

From the test results, the following conclusions can be made:

- The load deflection characteristics of the RCC & GPRC beams are observed similar.
- The flexural strength of GPRC beam is 1.50% more when compared to control RC beam.
- Deflection of GPRC beam under ultimate load is less when compared to control RC beam while it is retrofitted with Glass fibre mat.
- A very good performance is observed in bonding strength between steel and geo polymer concrete.
- GPRC beam with single layer GFRP (GPBF1) gives 3.01% more flexural strength when compared with RCC beam with single layer GFRP (RCGF1).
- GPRC beam with two layers of GFRP (GPBF2) gives 8.23% more flexural strength when compared with RCC beam with two layers GFRP (RCGF2) and crushing of concrete at top of the compression zone at mid-span of the beam is observed.

References

[1] B.V. Rangan, “Strength of Reinforced Concrete Slender Columns”, ACI Structural Journal, 87(1)32-38, 1990.

[2] M. Nakamura, H. Sakai, K. Yagi and T. Tanaka, “Experimental studies on the flexural reinforcing effect of carbon fibre sheet bonded to reinforced concrete beam”, Proceedings of the 1st International Conference on Composites in Infrastructure ICCI’96, Arizona, USA, pp.760-773.

[3] A.M. Malek, K. Patel, "Flexural strengthening of reinforced concrete flanged beams with composite laminates", Journal of Composites for Construction, Vol. 6, No. 2, May 2002, pp. 97-103

[4] A. Sharif, G.J. Al-Sulaimani, I.A. Basunbul, M.H. Baluch, and B.N. Ghaleb, "Strengthening of Initially Loaded Reinforced Concrete Beams using FRP Plates", ACI Structural Journal, Vol. 91, No. 2, 160 - 168, 1994.

[5] T.C. Triantafillou, “Shear strengthening of reinforced concrete beams using Epoxy bonded FRP composites”, ACI Structural Journal, 95(2), pp 107–15, 1998

[6] B.V. Rangan, “Low Calcium Flyash based Geopolymer Concrete”, Concrete Construction Engineering Handbook, CRC Press, New York, 2008.

[7] B. V. Rangan, “Engineering Properties of Geopolymer Concrete” in “Geopolymers: Structures, Processing, Properties, and Applications”, Woodhead Publishing Limited, London, 2009.

[8] S.E. Wallah, and B.V. Rangan, “Low Calcium Flyash based Geopolymer Concrete: Long term Properties”, Research Report GC2, Faculty of Engineering, Curtin University of Technology, Perth, 2006.

[9] M.D.J. Sumajouw, B.V. Rangan, “Low Calcium Flyash Based Geopolymer Concrete: Reinforced Beams and Columns”, Research Report GC3, Faculty of Engineering, Curtin University of Technology, Perth, 2006.

[10] ACI Committee 440-R96, “State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures”, American Concrete Institute.

[11] C .Antony Jeyasehar, S. Thirugnanasambandam, “An introduction to light weight concrete”, International Workshop on Geopolymer Cement and Concrete”, Cement and Concrete Association.

[12] A. Yusof, A. L. Saleh, "Flexural Strengthening of Timber Beams Using Glass Fibre Reinforced Polymer", Universigi Teknologi Malaysia, Skudai, Johor Bahru, Johor, Malaysia.

[13] Tara Sen, "Flexural Charecteristic Study of RCC Beams Retrofitted using Vinyl Ester Bonded GFRP and Epoxy Bonded GFRP", National Institute of Technology, Agartala, Tripura (West), India

[14] Gopal Rai and Yogesh Indolia, "Fiber Reinforced Polymer Composites, A Novel Way For Strengthening Structures", R & M International, SHM Consultant, Mumbai.

[15] Subhajit Mondal, J.N. Bandyapadhya , Chandra Pal Gautam "Strengthening and rehabilitation of reinforced concrete beams with opening", Indian Institute of Technology, Kharagpur, India

[16] N. Panirselvam, V. Nagaradjane, K. Chandramouli, "Strength Behaviour of Fibre Reinforced Polymer Strengthened Beam", VIT University, Vellore, India.