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AN EXPERIMENTAL STUDY TO ANALYSE THE EFFECT OF USING GLASS FIBRE REINFORCED POLYMER (GFRP) BARS AS MAIN REINFORCEMENT IN BEAMS AND COLUMNS

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Abstract - In this study, beams measuring 150 mm wide x 150 mm deep and 700 mm length were reinforced and casted with 10 mm diameter steel bars, Plain surfaced Glass Fibre reinforced Polymer (GFRP) bars and ribbed surfaced GFRP bars. Out of the nine Beams, three were casted with plain surfaced GFRP bars, three with ribbed surfaced GFRP bars as per American Concrete Institute (ACI- 440) and the remaining three with steel bars as per detailing obtained by IS 456: 2000 – plain and reinforced concrete code of practice. Similar approach was conducted in case of columns. All the beams and columns were provided with 8 mm diameter steel stirrups. The beams and columns were tested after 28 days of curing period. The beams were tested for flexural strength and deflection under two point loading test from flexural testing machine while columns were tested for compressive strength under compression testing machine of capacity 3000 kN. The performance of beam and column specimen was analysed with reference to the important parameters like reinforcement material type (GFRP and Steel) and concrete compressive strength. It was comprehensively noted that ribbed GFRP bars in columns showed better performance than steel bars reinforced columns considering the appearance of initial cracks. In beams, although the load carrying capacity of steel bars reinforced beams was high but ribbed bars reinforced beams showed promising response in deflection.

Keywords - Glass Fibre Reinforced Polymer bars, Steel bars, Beams, Columns, Flexural strength, Compressive Strength, Deflections.

1. INTRODUCTION

Reinforced structures near water bodies are specially suspected to cracks due to presence of salt like chlorides in large water masses. The steel reinforcement in it gets soaked up to approximately three times to its original size and thus the propagation of cracks in the concrete starts, leading to the rusting of steel bars. The durability of reinforced concrete members gets altered due to such exposure conditions and thus reducing the life expectancy of the structure. Extensive research in the field of fibre reinforced polymer bars helped to overcome the drawbacks of steel. Hence, it is now been often been replaced with Fibre Reinforced Polymer (FRP) bars. Lightweight, corrosion durability in aggressive environment, high tensile strength are the properties of Glass Fibre Reinforced Polymer (GFRP) bars which makes it a better alternative of steel. Bonding of Glass fibre rod with concrete has always been a serious area of research. Glass Fibre reinforced Polymer (GFRP) bars have large applications in reinforced structures. The flexural behaviour of beams reinforced with Glass Fibre Reinforced Polymer (GFRP) bars have been tested and analysed under various studies [1,6,8,12,13,17,18,21,25,26,28,29]. These studies were based on reinforcement types, reinforcement ratio, and concrete strength (f_{ck}) parameters. Maher A Adam et.al [8] focused on investigation the flexural behaviour of concrete beams reinforced with locally produced glass fiber reinforced polymer (GFRP) bars. According to the experimental results, the reinforcement ratio and elastic modulus of GFRP bars may be the most significant variables for calculating the deflection. Mohamed Said et.al.[13] presented that the shear behaviour of concrete beams reinforced with glass fiber reinforced polymer (GFRP) bars. Specimens with GFRP vertical stirrups had a higher reserve capacity after formation of the first inclined crack when compared to specimen without shear reinforcements. On increasing the grade of concrete the shear capacity increased and strain was found to be better than proposed in code. Wen- rui yang et.al. [12] mentioned that the damage evolution process for concrete structures can be used to directly predict their entire performance histories. Data on the cracking loads, ultimate loads, crack propagation behaviours, fractal analysis and load–deflection curves of GFRP-reinforced concrete beams and steel-reinforced concrete beams was reported to characterize the damage to such beams observed at the failure stage. Kinga Brozda et.al. [17] showed that the beam reinforced GFRP bars indicates the lowest nominal moment capacities. The reason is similar values of modulus of elasticity.

The major advantage of using Glass fibre reinforced Polymer (GFRP) bars is that they provide greater deflection limits. H.A.Abdalla [1] measured deflections of fifteen simply supported Fibre Reinforced Polymer (FRP) concrete beams and slabs to evaluate the deflections and strains of concrete members reinforced with Fibre Reinforced Polymer (FRP) rods which were found to be larger than those reinforced with steel rods. Amr El-Nemr et.al.[29] in their paper reported on the flexural behaviour of concrete beams reinforced with different types of Glass Fibre Reinforced Polymer (GFRP) bars. Axial-reinforcement stiffness governed the flexural behaviour of Fibre Reinforced Polymer Reinforced Concrete members; the higher the reinforcement, the better the flexural performance. The flexural strength of reinforced concrete structure with Fibre reinforced polymer bars is of great concern. Since, the brittle nature of fibre makes it more prone to failure.

The performance of columns was also investigated under numerous studies[7,9,10,11,15,16,20,27,30] Ehab M.Lofty [16] described the influences of the main reinforcement ratio, the main reinforcement type, the transverse reinforcement ratio, and characteristic strength of concrete on the ultimate loads, ultimate strain and initial cracking loads of columns. Woraphot Prachasaree et.al.[10] used Glass fiber reinforced polymer (GFRP) to assess the performance and structural behavior of reinforce concrete columns under compression loading. Specimens were prepared with varied longitudinal reinforcement, concrete cover, and lateral reinforcement. The outcome of the experiment was that the amount of GFRP longitudinal and lateral reinforcement slightly affected the column strengths. Kittipoom Rodsin [9] showed that the use of GFRP could increase column shear capacity and also confine the concrete in the plastic hinge region. Viktor Gribniak et.al. [27] investigated cracking and deformation behaviour of concrete ties reinforced with multiple GFRP bars
In this research work the bond behaviour between Glass fibre bars and concrete has been dealt by using two different surfaced GFRP bars.. It has been observed that the bond of glass fibre bars and concrete varies with the type of surface. Dong -Uk Choi et.al. [5] did splice tests to assess the bond strength of GFRP bars in unconfined concrete. The bond strengths of specimens with GFRP bars were found to be lower than those with conventional steel rebar. Wai How Soong et.al.[4] dictated the bonding relation between glass fiber reinforced polymer (GFRP) bar and concrete by pull out tests.

2. OBJECTIVE

The main aim of the present work is to compare the behaviour of plain surfaced, Ribbed Surfaced Glass Fibre Reinforced Polymer (GFRP) bars with that of steel bars in beams and columns. This study gives a clear understanding for the optimum use of Glass Fibre Reinforced Polymer (GFRP) bars in place of Steel.

3. MATERIALS

Cement

The cement which was used in the present study was Ambuja Portland Pozzolana Cement (PPC). It is a silica based locally available cement. The properties of Cement are confirming to IS 1489(Part 1)1991 specifications. The properties are shown in Table No.3.1

Table3.1 Physical properties of Cement

S. No.	Property	Results
1.	Specific Gravity	3.15
2.	Time of setting	Initial = 0 hours,54 minutes Final = 6 hours, 10 minutes
3.	Consistency	32.5%
4.	Fineness	2.25%

Fine Aggregate

Fine aggregates used in the study were locally available and it conformed to IS 383:1970 Specifications. The properties are shown in Table No.3.2

Table 3.2 Physical properties of Fine Aggregate

S. No.	Property	Result
1	Specific Gravity	2.64
2	Fineness Modulus	3.09
3	Zone	Zone –II

Coarse Aggregate

Coarse aggregate of nominal size 12 mm, obtained from local quarry confirming to IS 383:1970 specifications were used. The properties of coarse aggregates are shown in Table No. 3.3.

Table 3.3 Properties of Coarse Aggregate

S.No	Property	Result
1	Specific Gravity	2.70
2	Water Absorption	1.01% (for 12mm)
3	Fineness modulus	6.53

Steel Bars

High grade deformed steel bars (Fe 500) of nominal diameter 10 mm were used as main reinforcement in this work, mild steel bars of 8 mm diameter was used as stirrups. The relevant mechanical properties of reinforcement steel bars are tabulated in table 3.4.

Table 3.4 Properties of Steel Bars

S.No.	Parameter	IS-1786:2008	Gallent TMT bars Fe500
1	Yield Stress(N/mm^2)	500	520
2	Ultimate Tensile	545	600
3	Strength (N/mm^2) Elongation (%)	12	18

Glass Fibre Reinforced Polymer (GFRP) Bars

Glass Fibre reinforced Polymer (GFRP) bars are made up of fibre held in a matrix of resin binder. Strength in bars and transmission of load is provided by fibre while load retransmission and harsh environmental impact effect is controlled by matrix binder. The various types of resin that are in use are vinyl ester, epoxy, and polyster. In this research work epoxy based glass fibre reinforced polymer bars were used. Table 3.5 shows the general, physical and mechanical characteristics of used bars as per provided by the supplier.

Table 3.5 General, Physical and Mechanical properties of Glass fibre reinforced polymer (GFRP) bar

S. NO.	CHARACTERISTIC	STANDARD	UNIT	SPECIFIED VALUES
1	MATERIAL			ECR
2	GRADE			EPOXY
3	COLOUR			NATURAL
PHYSICAL PROPERTIES				
1	SPECIFIC GRAVITY	ASTM D 792 – 2008		2.0 ± 0.1
2	GLASS CONTENT (BY WEIGHT)	ISO 1172:1996		80% (MIN.)
3	DIE PENETRATION	IEC - 61109-2008	Minutes	> 15
4	WATER ABSORPTION	ASTM D 570 – 81	%	0.1 MAXIMUM
MECHANICAL PROPERTIES				
1	TENSILE STRENGTH	ASTM D 638 – 1991	mPA	1000 (10200 Kgf./ cm^2)
2	FLEXUREL STRENGTH	ASTM D 790 – 1992	mPA	600 (6100 Kgf./ Cm^2)
3	COMPRESSIVE STRENGTH	ASTM D 695 – 1991	mPA	500 (5100 Kgf./ Cm^2)
4	IMPACT STRENGTH (IZOD)	ASTM D 256 – 2006	Kj / Mtr^2	400 MIN.
5	HARDNESS	ASTM D 2583 – 1986	Barcol Nos.	65 MIN.
6	STRESS CORROSION (1mol / 1HNO3 at 80% SML)	REC Cl No.2	Hours	96

Water:

The water used for casting and curing of concrete test specimens was free of acids, organic matter, suspended solids and impurities which when present can adversely affect the strength of concrete.

4. CONCRETE MIX DESIGN

As per IS 10262- 2009, concrete mix cubes were casted at the same time from the batch of beams and columns in order to determine the compressive strength of concrete. Table 4.1shows the mix design proportion used in concreting.

Table 4.1 Mix proportion and Quantity of material

Grade (M25)	**Cement (Kg/m^3)**	**Fine Aggregates (Kg/m^3)**	**Coarse Aggregate (Kg/m^3)**	**Water**
Quantity	472.727	894.897	818.1648	208
Proportion	1	1.89	1.73	0.44

Design of Beam reinforced with steel bars and Glass fibre reinforced Polymer (GFRP) Bars (Using IS 456:2000)

The available dimension of beam is 150 x 150 mm with length being 700 mm. The grade of concrete is M25 and grade of steel is Fe 500. The beams were reinforced with 4# 10 mm main bar while 8 mm diameter stirrups spaced at 70mm at ends and 120 mm at the centre to centre.

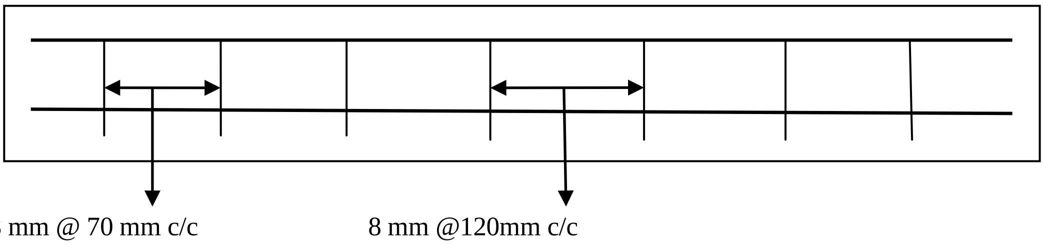

Figure 1 Details of reinforcement of Steel and Glass fibre bars reinforced Beams

9 beams samples (3 steel reinforced , 3 plain Glass fibre Reinforced Polymer and 3 ribbed Glass Reinforced Polymer (GFRP) bars reinforced) of size 150 x 150 mm and length 700mm were casted. Following steps were followed before testing of beams.

1. Reinforcement cage as per detailing provided on previous page was used.
2. The mix of concrete was made using the procured cement, fine aggregate, coarse aggregates and water.
3. The concrete was poured in the mould and was well compacted.
4. The concrete was left to harden for 24 hours and then the mould was removed. The concrete beams were then placed in the curing tank available at concrete technology lab.
5. Flexural test was conducted on beams after 28 days of curing. On removing the beams from curing tank, the beams were allowed to dry. Further markings were made in order to perform two point load test.

Figure 2 Marking and flexural testing of beams

Design and detailing of steel and Glass Fibre bars reinforced columns

9 column specimens having dimensions 150 x 150 mm and 700 mm height were casted with following details of reinforcement in the Table 4.2.The columns specimens were casted and cured in tank for 28 days.

Table 4.2 Details Of Tested Columns Specimens

Column No.	**Reinforcement material**	**Reinforcement**	**Stirrups**	**Notes**
C1, C2, C3	Steel bars	4#10mm	8mm @120mm c/c	1.Steel reinforcement 2.Steel Stirrup
C1, C2, C3	Plain Glass Fibre Reinforced Polymer (GFRP) bars	4#10mm	8mm @120mm c/c	1.Plain Glass fibre reinforced polymer(GFRP) bar reinforcement 2.Steel Stirrup
C1, C2, C3	Ribbed Glass Fibre reinforced Polymer (GFRP) bars	4#10mm	8mm @120mm c/c	1.Ribbed Glass fibre reinforced polymer(GFRP) bar reinforcement 2.Steel Stirrup

5. RESULTS AND DISCUSSIONS

5.1 The main parameter included in this research work is to compare the ultimate load carrying capacity of columns reinforced with Glass Fibre Reinforced Polymer (GFRP) bars with that of steel bars. The results obtained are tabulated in table 5.1.

Figure 3 Cracking in Column after compression test

Table 5.1 Results of tested columns

Reinforcement Type	Column no.	Initial cracking load (P_{cr}) (KN)		Ultimate Load (P_u (KN)	
			A vg		Avg.
Steel reinforced columns	C1	585	625.66	998	1016.96
	C2	672		1043.3	
	C3	620		1009.6	
Plain surfaced Glass Fibre bars Reinforced columns	C1	534	511.33	808	763.6
	C2	512		776	
	C3	488		707	
Ribbed surfaced Glass Fibre Reinforced columns	C1	610	662	940	959.66
	C2	690		974	
	C3	686		965	

From the table it is very clear that steel columns performed better than plain and ribbed surfaced GFRP bars reinforced columns, although third columns in both the cases of Plain and Ribbed surface performed much better which initiates a talk of GFRP bars as good replacement of Steel in harsh environmental conditions.

5.2. The beams reinforced with steel and glass fibre reinforced polymer (GFRP) bars were tested under flexural testing machine. The flexural strength, moment of resistance and the deflection of the beam was calculated and as obtained in the test are presented in Table no.5.2.

The flexural strength formula $f_b = P\ l/\ (bd^2)$ was used for two point loading test to calculate the experimental value obtained from Flexural testing machine. The bending formula M/I = f/y was used to evaluate the moment of resistance in the beam.

Figure 4 Crack Pattern in Steel and GFRP bars reinforced Beams

Table 5.2 Flexural Tests Results

Property/Parameter	Sample No.	Steel reinforced Beams		Plain Glass Fibre Bars Reinforced Beams		Ribbed Glass Fibre Bars Reinforced Beams	
		Test	Avg.	Test	Avg.		Avg.
Load (N)	B1	411.08	404.99	388.54	350.94	399.05	383.66
	B2	401.09		342.21		382.01	
	B3	402.8		322.09		369.92	
Moment of resistance ($\times 10^6$ N-mm)	B1	11.65	12.43	11.55	11.35	11.61	11.54
	B2	11.60		11.30		11.58	
	B3	11.62		11.22		11.45	
Flexural strength (N/mm^2)	B1	3.67	3.67	3.65	3.41	3.66	3.55
	B2	3.66		3.31		3.55	
	B3	3.61		3.28		3.46	
Deflection (mm)	B1	0.033	0.0316	0.038	0.0356	0.039	0.0366
	B2	0.032		0.034		0.037	
	B3	0.030		0.035		0.034	

The beams with ribbed GFRP bars showed better performance than beams with plain reinforced GFRP. The deflection in both the cases of Glass fibre bars reinforced Beams showed promising hand as compared to that of Steel beams. The flexural strength and bending moment of steel bars reinforced beams although proved to be higher than GFRP bars reinforced Beams. This showed that if the GFRP bars reinforced beams are over reinforced then they will comply will that of steel reinforced beams.

6. CONCLUSIONS

6.1. From the results found from the experimental study following conclusions can be drawn.

6.1.1 The experimental results from three Steel reinforced concrete columns, three plain surfaced Glass Fibre and three ribbed surfaced fibre bar reinforced columns demonstrates the influence of the reinforcement material on the performance of RC members.

6.1.2 Tested column with steel reinforcement was found to have more ductility than column with Glass Fibre Reinforced Polymer (GFRP) reinforcement of either case.

6.1.3 The initial cracking load of ribbed GFRP bars reinforced concrete columns has greatest value, which testifies its better tensile strength and bonding in concrete.

6.1.4 The initial cracking of columns reinforced with GFRP is 5.8% more than that of steel reinforced columns.

6.1.5 Difference between ultimate load carrying capacity of Ribbed GFRP bars and Steel bars reinforced column is not too high. Hence, better transverse reinforcement, better grade of concrete and high grade of Steel bar stirrups might help in getting desired result.

6.1.6 The problem of bonding in case of Plain surfaced GFRP bars reinforced in columns leads to its' earlier failure. Hence plain surface GFRP bars in RC members should be checked experimentally before adapting it in proper uses. Thus, for columns ribbed GFRP bars can be one of the better replacements of steel with better transverse reinforcement.

6.2. The Glass Fibre Reinforced Polymer (GFRP) holds a promising hand in improving the durability of the concrete. GFRP bars are used in the strengthening of RC members and have a huge application in the bridges construction. From the above experiment it is evident that-

6.2.1 The good tensile strength of the Glass Fibre Reinforced Polymer (GFRP) bars is minimised due to brittle failure. This problem can be decreased by using better material matrix through the material hybridization technique.

6.2.2 The cracking failure mode in steel and GFRP case is found to be in tension zone of beam, which would have failed in compression zone.

6.2.3 The Deflection of GFRP bars reinforced beams is more than that of the Steel bars Reinforced beam. This shows that GFRP bars reinforced beams can show larger deflection before actual failure.

6.2.4 Beams with ribbed surface performed better than plain surfaced glass fibre bar reinforced beam. Thus, it is rectified that the bond strength among concrete and Glass fibre rod is a major aspect for consideration.

SCOPE OF FUTURE WORK

1. Different Grades of Columns reinforced with various types of GFRP bars may be casted and compared with that of steel bars reinforced columns. A relationship need to be established for using appropriate grade of concrete with GFRP bars in columns.

2. Beams functionality may be enhanced with better transverse reinforcement and matrix implantation in Bars. Fibres which enhance the concrete properties may be adapted or geo polymer concrete may be collaborated with GFRP bars in better understanding of beams' performance.

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