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Structural Performance of Concrete Beams with Hybrid Reinforcement in Flexure

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ABSTRACT

In substitution of steel bars, fiber reinforced polymer bars have been utilised in reinforced concrete flexural members owing to their excellent corrosion resistance and strong tensile strength. This paper attempts to study the performance of concrete beams reinforced with a hybrid combination of steel and various fiber reinforced polymer bars. A three-dimensional finite element modeling of beam specimens of 1800x180x300mm was done in ANSYS Workbench (2021R2) and was subjected to a four-point bending test until it failed. An investigation was conducted to analyse the performance of the different types of fiber reinforced polymer bars and steel bars provided in the tension zone using multiple layers. The ultimate moment capacity was about 1.65 times higher for the carbon fiber reinforced polymer bars hybrid combination compared to the steel reinforced beam. Moreover, the reinforced concrete beams reinforced with carbon fiber reinforced polymer bars performed better than other fiber reinforced polymers such as Glass, Basalt, and Aramid fiber reinforced polymer bars. As a result, hybrid reinforcement will be more cost effective. The generated finite element models account for the nonlinear behaviour of the constituent materials between the reinforcing bars and concrete surfaces and can be used to predict the moment capacity and ultimate deflection of reinforced concrete beam using fiber reinforced polymer and steel bars.

Keywords – Corrosion, Fiber reinforced polymer bar, Finite element analysis, Flexure, Hybrid reinforcement

1. INTRODUCTION

One of the main reasons for the deteriorated performance of concrete structures is the corrosion of steel reinforcement in concrete [1]. Fiber reinforced polymer (FRP) reinforcement, which has the advantages of high strength and lightweight as well as high corrosion resistance, is the most promising material to replace conventional steel in concrete structures [4]. The modulus of elasticity of FRP bars is much lower than that of steel bars, which results in greater deflection and wider cracks in FRP reinforced concrete beams [3]. Thus, an alternate solution of hybrid reinforcement with FRP and steel bars can be provided to enhance the performance in terms of deformability and ductility of concrete beams reinforced with FRP bars. Different types of FRPs like Aramid, Basalt, Carbon and Glass fiber reinforced polymers are used in this work [13].

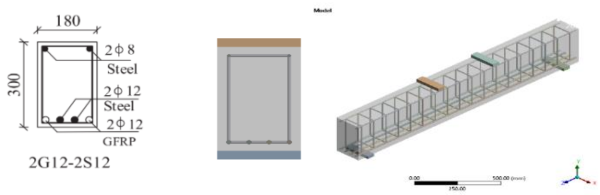
In this paper, an attempt has been made to compare the flexural behaviors of hybrid beams with various FRP with conventional RC beams.

2. MODEL VALIDATION

The material properties and model dimensions for the validation were taken from the paper titled “Flexural behavior and serviceability of concrete beams hybrid-reinforced with GFRP bars and steel bars” authored by Xiangjie Ruan et al (2020) [10]. They had experimentally tested beams reinforced with GFRP and steel. The specimen with the most favorable results was chosen as the model to be validated. All analyses were done on ANSYS R1 (2021) Workbench platform [2].

2.1 Description of the Validated model

The GFRP and Steel combination with 4 bars of 2-12 mm diameter of bars each were used [10]. The beam dimensions were 1800×180×300 mm. The ANSYS modelled sample is shown in Fig. 1 where G & S are steel reinforcement & GFRP reinforcement respectively.



(a) (b)

Figure 1 (a) Experimental result taken from the journal (b) modelled by Ansys R1 2021

Material properties used are shown in Table 1 2G12-2S12 model combination of GFRP and steel material.

All beams were subjected to four-point flexural testing [12], as shown in Fig. 2.

Table 1. Material Properties of GFRP

Material properties	
Elastic Modulus	$0.4 X 10^5$ MPa
Yield Stress	868 MPa
Ultimate Stress	2000MPa

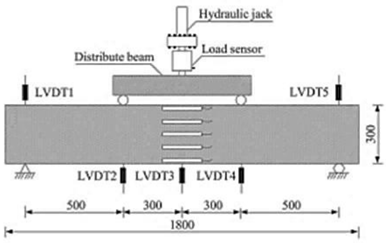


Figure 2. Loading Protocol adopted for Validation

The ultimate moment carrying capacity of 2G12-2S12 obtained from literature was 57.50kNm and that obtained from the validation model was 55.41kNm with an ultimate deflection of 11.25mm. The percentage error was found to be 4.72% (less than 5%), and hence could be validated.

3. ANALYTICAL PROGRAM

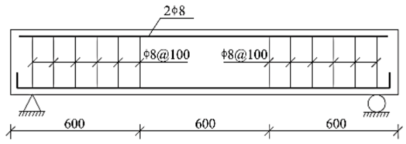
The material properties and dimensions of the hybrid beam were taken from X. Ruan, et al., 2020 [10]. The beam span of 1800 mm and 180×300 mm was modelled. The material properties of the FRPs are given in Table 2 [14]. Various FRP bars were provided as tensile reinforcement and were analysed for ultimate moment and deflection.

Table 2. Mechanical properties of FRP used

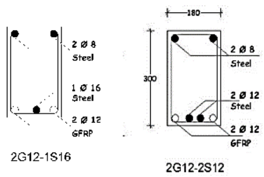
	Glass FRP	Aramid FRP	Carbon FRP	Basalt FRP
Modulus of Elasticity (MPa)	$0.4x10^5$	$0.51x10^5$	$2.05x10^5$	$0.79x10^5$
Yield Strength (MPa)	868	1172	1745	2070
Passion ratio	0.28	0.28	0.28	0.28

Flexural performance analyses were conducted on several specimens to determine the hybrid combination that exhibits satisfactory moment deflection behaviour on the chosen singly reinforced beam [9]. A total of 10 such specimens were analysed and a suitable model was determined. The hybrid beam adopted had a single layer reinforcement with reinforcement ratio A_f/A_s as 1 and 1.12. The type and material property of the steel and different combination of FRP bars are given in Table 3.1 [13].

The dimension of the hybrid with steel and FRPs are shown in Fig 3.1. The beam configurations were provided in various FRPs and steel in similar model.



(a)



(b)

Figure 3. Hybrid beam with the combinations (a)1S16-2G12 with A_f/A_s =1.12 (b) 2S12-SG12 with A_f/A_s =1

4. RESULTS AND DISCUSSION

Four types of fiber reinforced polymers AFRP, CFRP, BFRP, and GFRP were combined with steel as a hybrid reinforced in different proportions. The results obtained are tabulated in Table 4.1. The table depicts the percentage increase in the moment of each configuration over the hybrid beam. Fig 4.1 shows the failure mode of concrete and steel. A hybrid beam combination of FRP and steel doesn’t record any considerable increase over full steel provided in terms of both ultimate moment (M_u) and deflection ($\mathbf{\Delta_u}$). Therefore, the analysis was aimed to achieve characteristic values for hybrid beam which are similar to fully steel reinforced beams, i.e., a configuration with an ultimate moment in the range of 68.45 kNm with an acceptable deflection value.

4.1 Study on number of bars

Number of bars has more influence in hybrid beams. Deflection obtained on each beams is shown in Fig. 4.2.

On analysing the results obtained, as depicted in Table 4.1 and Fig. 4.2, it could be inferred that CFRP as hybrid model M2 with 2S12-2C12 acquires the most satisfactory result in terms of both deflection and ultimate moment. The specimen M7 having a reinforcement ratio of 1.12% exhibits a lesser value of deflection than the M5 specimen and hence M5 was not preferred. Also on studying the results, it could be observed that with further increase in the number of layers and size of the bars, a subsequent increase in an ultimate moment carrying capacity is shown. This could be attributed to the increase in stiffness, as a result of variation in reinforcement ratio.

(a) (b)

(c) (d)

Figure 4 Failure mode in (a)concrete for M2 specimen (b)concrete for M7(c) reinforcement for M2 specimen (d)reinforcement for M7 specimen

Table 3. Comparison of results of all the combinations

Designation	Specimen	Δ_{ini}	Δ_u	Mu (Th)	Mu	A_f/A_s	%Moment Increase
M1	**2S12-2A12**	1.52	9.647	53.55	57.45	1	8.01
M2	**2S12-2C12**	1.50	9.136	68.45	68.45	1	2.261
M3	**2S12-2G12**	1.56	9.43	57.50	57.50	1	4.297
M4	**2S12-2B12**	1.57	11.74	62.254	67.75	1	11.35
M5	**4S12**	2.25	14.18	46.71	46.635	-	-
M6	**1S16-2A12**	1.65	12.56	48.45	49.45	1.12	2.05
M7	**1S16-2C12**	1.54	9.45	51.75	53.45	1.12	3.56
M8	**1S16-2G12**	1.68	11.25	47.58	48.45	1.12	1.788
M9	**1S16-2B12**	1.98	12.48	50.45	51.65	1.12	2.467

The results are graphically depicted in Fig. 5 and Fig. 6. The graphs clearly show that configuration 2S12-2C12 has a better set of characteristics in terms of ultimate moment and deflection. This model has increased its ultimate moment capacity by about 1.65 times than the 4S12. It could again be observed that a subsequent increase in moment capacity is seen with provided CFRP bars.

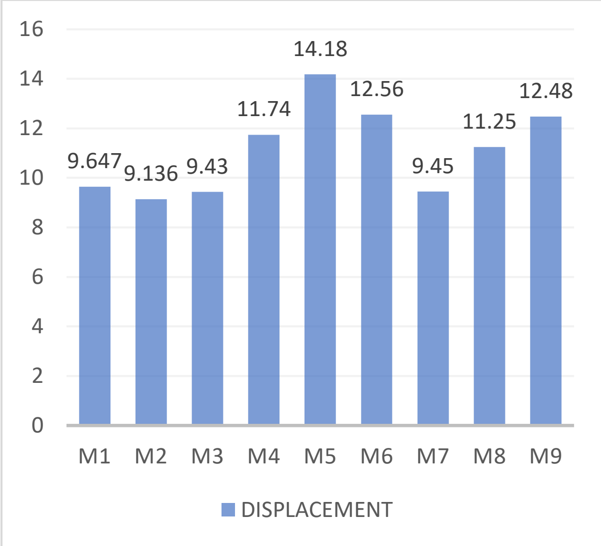


Figure 5. Comparison of Ultimate Deflection

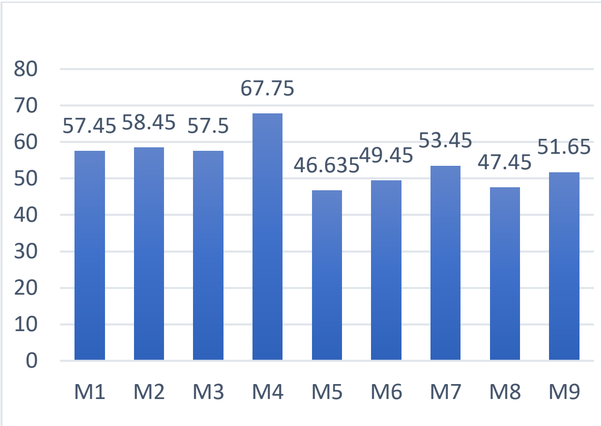


Figure 6. Comparison of Ultimate Moment Capacities

5. CONCLUSIONS

The following were the conclusions drawn from the study,

- The ultimate moment of CFRP and BFRP hybrid beams shows better results when compared with conventional beams, and an increase in the ultimate moment of approximately 36.99% and 36.53% respectively.

- The hybrid beam combination with steel bars and CFRP bars at the tension zone was found to be the optimum model with satisfactory moment and deflection curve. Also, the hybrid beam with this combination induces mid-span crack due to the weak debonding of CFRP and concrete. When the load was increased, a combination of flexure and shear crack was noticed in the mid-span and moving towards the support.

- The ultimate moment capacity was enhanced about 1.65 times in the CFRP hybrid combination when compared with the conventional steel reinforced beam

- Hybrid CFRP and BFRP have constantly increased moment carrying capacity as compared to conventional reinforcement. Hence it can be concluded that hybrid reinforcement will be more economical.

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