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Study on Flexural Performance of Fiber Reinforced Concrete Beams Using Glass Fiber Reinforced Polymer Bars and Steel Rebars

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Abstract. Traditionally, reinforced concrete structures are constructed using steel rebars as reinforcement which is more susceptible to reinforcement corrosion in severe exposure conditions. This leads to many disadvantages, like deterioration of concrete, reduction in strength, and increase in maintenance costs, which leads to a decrease in the serviceability of critical infrastructure. Fiber Reinforced Polymer bars are often used as alternative materials for steel bars because they are anti-corrosive, exhibit an excellent strength-to-weight ratio and are easy to handle but the main disadvantage is its brittle nature. Hence, the combination of steel and FRP bars was effectively used to augment both flexural capacity and ductility. As the ductility performance of hybrid Reinforcement is lower than conventional reinforced beams, Polyvinyl Alcohol Fibers in volume fraction were added in this investigation.

The present investigation aims to determine the flexural capacity of reinforced concrete beams using Glass Fiber Reinforced Polymer (GFRP) bars and Steel bars. The optimum dosage of PVA fibers while evaluating compressive and split tensile strength is observed at 0.25% in volume fraction. Total six types of concrete beam specimens with and without PVA fibers were experimentally under four-point bending test tested such as beams reinforced with only steel bars, only GFRP bars, GFRP and steel bars. From the experimental results, it is observed that inclusion of PVA fibers in proposed beams with hybrid reinforcement enhanced the crack resistance by 80% and ultimate load capacity by 39% when compared with conventional beam.

Introduction

Reinforced concrete structures with steel rebars are susceptible to corrosion which leads to damage, and reduction in service also leads to high cost of maintenance. Numerous investigations have been carried out to avoid this problem, such as using steel reinforcement coated with epoxy. The presence of epoxy reduces the bond between concrete and steel and the cost shoots up by approximately 10%. An alternative material to steel rebars with the appropriate material characteristics is using Fiber Reinforced Polymer (FRP) rebars which possess high corrosion resistance. These bars possess high tensile strength and high durability. Hence, the concrete structures reinforced with FRP rebar show good performance during their service life. Many studies have been attempted to enhance the flexural capacity [1], and concrete beams using hybrid reinforcement demonstrate a significant improvement in capacity compared to conventional beams. [2] evaluated flexural performance of concrete beams with steel and GFRP bars, and determined that the ultimate moment capacity was 95% more than that of conventional RC beams.

The ultimate capacity in flexure of hybrid RC beams was up to 90% of conventional RC beams [3,4]. Placing FRP bars at the edges and Steel rebars in the middle shows better performance during service [5] and crack width using hybrid reinforcement with GFRP and steel is reduced 50% compared to concrete beams with FRP bars only [6]. In addition, under service conditions ductility can be increased by applying lower ratio of FRP to steel bars area (A_f/A_s). The introduction of PVA Fiber in fiber reinforced concrete beams improved ductility significantly [8] when compared with beams without

fiber and also concluded that PVA Fiber showed better results in flexural capacity when compared to Polypropylene fiber [9].
Some studies show an improvement in ductility by 30% when 0.5% PVA Fibers are used. Experimental investigations indicate that all the concrete grades introducing PVA Fiber exhibited good mechanical characteristics at 0.3% PVA fiber volume fraction [10,11]. The performance of RC beams using various hybrid reinforcement ratios are studied [12] and concluded that the stiffness of beams with hybrid Reinforcement is higher with a fixed amount of GFRP and varied amount of steel when compared to a fixed amount of steel reinforcement and increased quantity of GFRP.
The design of reinforcement for flexure using Hybrid reinforcement is proposed in [13] and identified that less amount of GFRP is necessary to prevent FRP bar rupture and also suggested two balanced reinforcement ratios to attain steel yielding and crushing of concrete Failure. [14] performed flexural performance of RC beams using BFRP bars, Steel and BFRP, only steel bars and suggested that concrete beams with hybrid reinforcement performance lie amidst of pure BFRP RC beams and RC beams with steel bars.
Flexural study of RC beams using Basalt FRP bars with microfibers improved [15] the flexural capacity and the crack widths less than 0.5mm at service load. [16] investigated that the flexural capacity of RC beams using GFRP bars and steel bars is 4 to 50 percent higher than Steel Reinforced Concrete beams. The ratio Af/As should lie between 1.0 to 2.5 to meet the requirements of ductility and flexural capacity [17].

Research Significance

In the literature so far, many researchers have focused on ultimate flexural capacity, cracking load, design guidelines, moment-curvature relationships, long-term flexural performance, and the effect of Reinforcement ratio. Equations have been presented in terms of ultimate moment, crack width, and failure modes to reach steel yielding (SY) and concrete crushing (CC). However, there are no studies that give a clear idea of improving both ductility and flexural capacity of RC beams using both GFRP and steel bars and compare with conventional beams made with only steel bars. In this paper, an attempt has been made to examine the PVA fibers influence on flexural and ductility performances on hybrid reinforced concrete beams.

Experimental Program

Material properties. In the present study, an ordinary Portland cement 53 grade and Class F Fly ash was used as a mineral admixture, locally available River sand, well-graded crushed granite of maximum size 20mm conforming to IS 383-2016. Concrete grade M30 was developed as per IS:10262-2019. Fiber details and mechanical characteristics of fiber reinforced concrete are tabulated below in Table 1 and 2. Three specimens for each test were carried out. It was observed that at 0.25% fiber volume fraction, compressive strength, split tensile strength and modulus of rupture were observed to be maximum. Therefore, the optimum fiber dosage arrived at 0.25%. In this study, a total of six reinforced concrete beams were experimentally investigated in which two RC beams using steel bars with PVA fibers at a dosage of 0%, 0.25%, two RC beams using GFRP bars and Steel bars with PVA fibers at a dosage of 0%, 0.25% and two RC beams using GFRP bars with PVA fibers at a dosage of 0%, 0.25% in volume fraction.

Methodology. For the preparation of reinforced concrete beams, Glass fiber reinforced polymer bars of 12mm diameter as per IS 18256: 2023 were adopted in this study which is made up of fiber glass saturated with Epoxy resin under pultrusion process at 65% volume fraction of fibers. The properties of rebars are mentioned in Table 3. The mix proportions are shown in Table 4.

Table 1. PVA Fibers Properties.

S.No	Test	Results
1	Fiber Type	Bunchy Mono Filaments
2	Density	1.29
3	Length	6mm
4	Tensile capacity [MPa]	1625
5	Elastic Modulus [GPa]	43

Table 2. Compressive Strength, Split Tensile Strength and Modulus of Rupture

Mix ID	Compressive Strength (MPa)	% Change	Tensile Strength (MPa)	% Change	MOR (MPa)	% Change
F 0.0	34.32	-	3.25	-	4.20	-
F 0.125	36.41	+6.09	3.98	+21.8	5.32	+26.7
F 0.25	37.29	+8.65	4.21	+29.54	5.72	+36.2
F 0.375	36.3	+5.76	4.13	+27.08	5.35	+27.4
F 0.5	35.5	+3.43%	3.84	+18.15	4.70	+11.9

Note: 1) F 0.0 represents Control Mix without fibers 2) F 0.125 represents mix with 0.125% PVA fibers 3) F 0.25 represents mix with 0.25% PVA fibers and similarly followed in all mixes.

Table 3. Mechanical Properties of Steel and GFRP bars

Rebar	Nominal dia (mm)	Weight(gms)	Density(g/cc)	f_y (MPa)	f_u (MPa)	MOE(GPa)
Steel	12	350	7.7	505	635	195
GFRP	12	90	2.0	-	865	45

Note: f_y and f_u represents yield strength and ultimate tensile strength; MOE -Modulus of Elasticity

Table 4. Mix Proportions of M30 Grade Concrete.

Grade	Cement[kg/m^3]	Fly Ash [Kg/m^3]	FA[Kg/m^3]	CA[Kg/m^3]	Water [Kg/m^3]
M30	306.7	76.68	702.3	1301.6	132

Note: FA and CA represent Fine Aggregate and Coarse Aggregate respectively

Casting of beams. A total of six reinforced concrete beams of M30 grade were prepared with length 2000mm, width 150mm, depth 200mm and effective cover at 25mm.Two 8mm diameter steel bars are provided as hanger bars in the compression zone. Steel stirrups are provided as shown in Fig.1 and Fig.2 to secure pure bending behaviour. RC beams with only steel bars and Hybrid reinforcement are designed as under reinforced section where effective reinforcement ratio is less than balanced reinforcement ratio whereas RC beams with only GFRP bars are having effective reinforcement ratio greater than balanced reinforcement [18]. The details are shown in the Table 5 and Table 6.

Table 5. Reinforcement Ratios of RC beams using GFRP and Steel bars.

Beam Type	Main Reinforcement		$\rho_{n,E}$ (%)	$\rho_{b,E}$ (%)	$\rho_{n,F}$ (%)	$\rho_{b,F}$ (%)
	Steel	GFRP				
Hybrid RC beam	2φ12	2φ12	1.09	1.93	1.83	0.695

Note: $\rho_{n,E}$ and $\rho_{b,E}$ represents nominal and balanced reinforcement ratio in terms of Elastic modulus; $\rho_{n,F}$ and $\rho_{b,F}$ represents nominal and balanced reinforcement ratio in terms of Tensile strength.

Table 6. Test Matrix Details

Beam Type	Main Reinforcement		f_{ck} (N/mm^2)	A_f (mm^2)	As (mm^2)	A_f/A_s	ρ_f (A_f/bd)	ρ_s (A_s/bd)
	Steel	GFRP						
F30 0PVA	-	4φ12	30	452.39	-	-	0.018	-
F30 0.25PVA	-	4φ12	30	452.39	-	-	0.018	-
H30 0PVA	2φ12	2φ12	30	226.19	226.19	1	0.009	0.009
H30 0.25PVA	2φ12	2φ12	30	226.19	226.19	1	0.009	0.009
S30 0PVA	4φ12	-	30	-	452.39	-	-	0.018
S30 0.25PVA	4φ12	-	30	-	452.39	-	-	0.018

Note: The first character "S30 or H30 or F30" represents M30 grade Concrete beams reinforced only with steel bars, both steel bars and GFRP bars, only FRP bars; the second character "0 or 0.25" represents RC beams with 0% and 0.25% PVA fibers in Volume fraction; third character PVA refers to PVA fiber content i.e., S30 0PVA represents RC beam with only steel bars and 0% PVA fibers. A_f and A_s represents Area of FRP and Area of Steel bars; ρ_f and ρ_f represents reinforcement ratio of FRP and steel bars; b and d refers width and depth of cross section.

Testing of beams. All the six reinforced concrete beams as shown in Fig. 3 are tested under four-point bending test. The beam is loaded monotonically by a hydraulic jack and the respective load is divided into two equal parts using a steel spreader beam to the test beam. Three linear variable differential transducers were positioned under the pure bending zone. The experimental work was tested using 100 Tonne capacity Universal Testing machine which is applied at a rate of 1.5mm per minute. The load was applied till the beam failed in flexure. Load at first crack and ultimate, failure modes were observed.

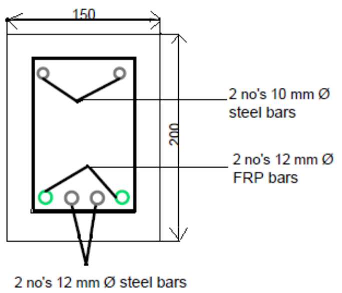

Fig. 1(a)

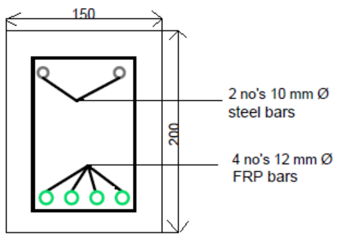

Fig. 1(b)

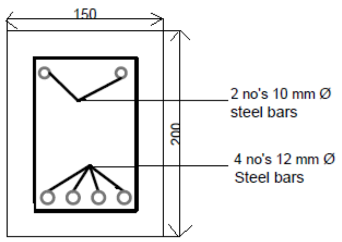

Fig. 1(c)

Fig.1. Cross-Section of RC beam

Fig. 1(a). Cross-section details of RC beam using GFRP and Steel bars; **Fig. 1(b)** Cross-section details of RC beam using GFRP bars; **Fig. 1(c)** Cross-section details of RC beam using only Steel bars

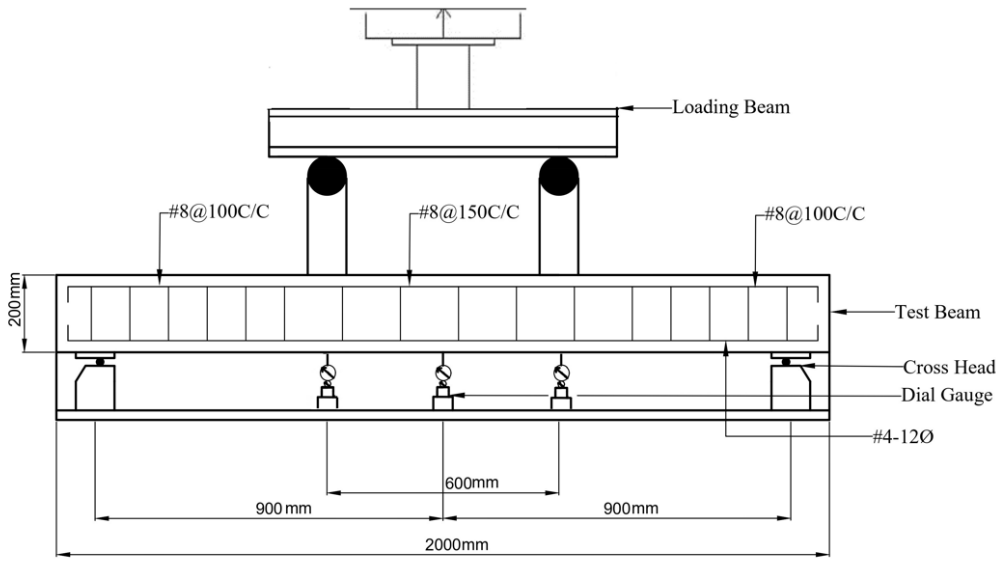

Fig. 2. Longitudinal Section of RC beam

Fig. 3. Beam test Setup

First Crack load and Ultimate Flexural capacity. From the study, it was observed that RC beams (S30 0PVA, H30 0PVA, F30 0PVA) without fibers undergone first crack at 0.1 to 0.2 Pu (ultimate load) whereas the RC beams (S30 0.25PVA, H30 0.25PVA, F30 0.25PVA) with fibers undergone first crack at 0.2 to 0.35Pu. This may be due to PVA fibers high tensile strength and high pull-out resistance which delay the appearance of the first crack [19]. This proves that cracking load is directly associated with concrete tensile strength. RC beams with only steel bars sustain a maximum load up to 105 KN, which is lower than the former beams. It is well known that all GFRP beam cracking loads are smaller followed by hybrid reinforcement and conventional beams. Among all other beams, RC beams with hybrid reinforced (GFRP & steel) at 0.25% dosage of PVA fibers exhibited the highest ductility and it was also observed that cracking load, ultimate load, and ultimate deflection are highest for hybrid reinforced (GFRP & steel) at 0.25% dosage of PVA Fibers when compared to the conventional beam. The ultimate flexural capacity of F30 0PVA is 32%, F30 0.25PVA is 58%, H30 0PVA is 15%, H30 0.25PVA is 38.78% enhanced when compared with conventional beam S30 0PVA.

Table 7. Cracking load, Ultimate Moment, Ductility and Failure modes.

Beam Type	Pcr (KN)	Pu (KN)	Mu (KN-m)	% Increase	μ ($\Delta u/\Delta y$)	Failure Mode
S30 0PVA	25	104.5	31.35	-	2.2	SY, CC
S30 0.25PVA	49	121.3	36.4	+16	4.9	SY, CC
H30 0PVA	22	120.6	36.19	+15.4	1.7	SY, CC, FR
H30 0.25PVA	45	145.0	43.51	+38.8	3.9	SY, CC, FR
F30 0PVA	19	138.0	41.41	+32.1	-	CC
F30 0.25PVA	30	165.6	49.69	+58.5	2.1	CC

Note: Failure Mode SY, CC means the respective beam failed by Steel Yielding followed by Concrete Crushing; failure Mode SY, CC, FR means the respective beam failed by Steel Yielding followed by Concrete Crushing and simultaneously FRP rupture; Failure mode CC means beam failed by Concrete Crushing.

Load- Displacement Response and Analysis of Various Failure Stages. To differentiate various stages of failure as shown in Fig. 4, the comparison of Load-Deflection curves for all tested beams with and without PVA Fibers. From the study, it was observed that all RC beams with only steel bars and Hybrid Reinforcement undergo three to four stages from the point of load application to failure of the beam ie., the pre-cracking stage before the first crack appears, the pre-yielding stage after the first crack and before yielding, post yielding stage till ultimate load and Failure stage. RC beams with only GFRP bars undergo linear failure after cracking load which shows brittle failure but the addition of PVA fibers shows pre-yielding and post-yielding stage. From the findings of the study, it was observed that in the first stage, all the RC beams behave linearly until the first crack appears. After the first stage, there is a stiffness reduction in members and an increase in deflection which can be reflected by the degradation of slope. In the second stage the behavior or stiffness of the member is linear which shows stability.

During yielding stage, the deflection of beam varies from 5mm to 15mm which is approximately 20 to 30% of the ultimate deflection. During the yielding stage, deflection increases and stiffness decreases even more. Similarly, beams reinforced only with steel or a combination of steel and hybrid reinforcement exhibit proportional behaviour in the third stage. However, beams collapse in the fourth stage when they reach the ultimate strain limits of either GFRP or concrete in the compression zone. Hybrid reinforced concrete beams fail through yielding of steel, crushing of concrete and GFRP rupture. Fig.4 shows that RC beams with only FRP bars went through two phases in contrast to RC beams with both steel and hybrid reinforcement.

There is comparable variation up to the first crack when comparing S30 0PVA and H30 0PVA. S30 0PVA has more stiffness than H30 0PVA after the first crack and before steel yielding [20]. However, once steel yields H30 0PVA acquires greater stiffness due to the GFRP bars significant involvement in load carrying capacity which is 18% higher than S30 0PVA. S30 0.25PVA and H30 0.25PVA exhibited comparable behaviour as indicated in Table 5, and they both increased their load carrying capacity by 19.5% when compared to S30 0PVA, the addition of PVA fibers improves ductility by 78% and load capacity by 39%. Out of six specimens evaluated, RC beams with GFRP bars had the highest load capacity whereas control beams having least which is limited to 105KN only. Therefore, hybrid reinforcement with fibers achieves a balance between load capacity and ductility

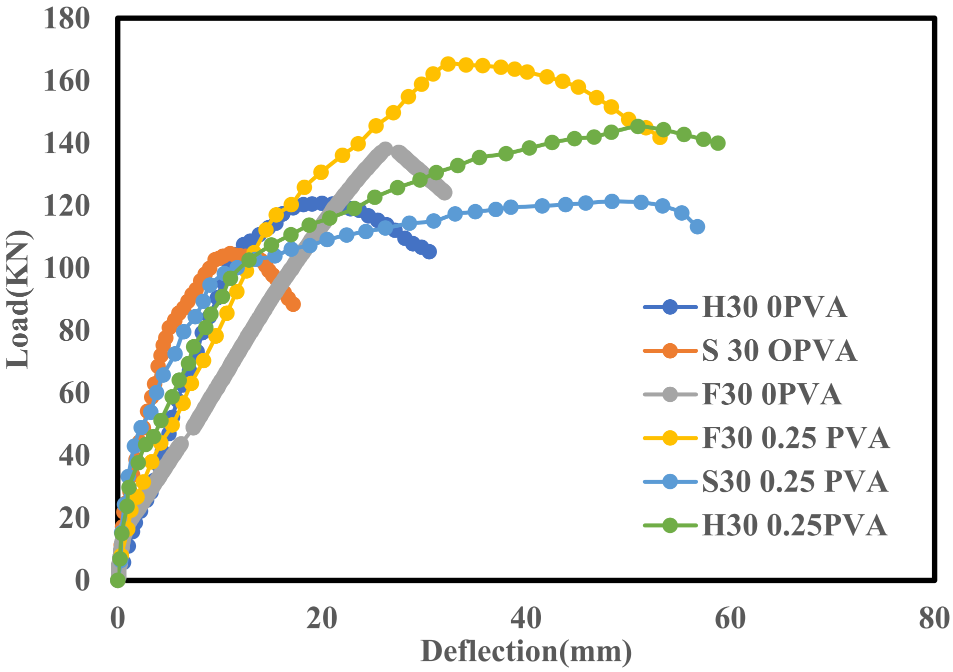

Fig. 4. Load-Displacement curves for all Test Specimens

Crack Propagation. All the tested beams started with a flexural crack at the mid span which is perpendicular to the longitudinal axis of the beams. The first crack was delayed in the conventional and Hybrid reinforced beams and with the increase in load, the number of cracks increased in the pure bending zone till further vertical cracks appeared and eventually flexure shear cracks appeared.

The first crack appeared earlier in pure FRP beams followed by Hybrid Reinforcement and conventional beams. Fig. 5 shows the crack propagation at service load (0.7Pu). Prior to steel yielding crack formation is similar to both Hybrid reinforced beams and Conventional beams. After Steel yielding there are more cracks in the Hybrid reinforced beam and its propagation is fast. The crack width for pure FRP RC beams is greater and that is expected because of its brittle nature and is less reflected in conventional beams and Hybrid Reinforced beams with PVA fibers.

It can be concluded that hybrid reinforced beam with PVA Fibers flexural capacity is 38.78% higher than control beams [21]. Ultimately, deflections are similar in both cases as the provision of PVA fibers enhanced cracking load, and ductility due to its bridging effect.

Fig. 5a. Crack Propagation of RC beam using only steel bars(S30 0PVA)

Fig. 5b. Crack Propagation of RC beam using Hybrid Reinforcement(H30 0PVA)

Fig. 5c. Crack Propagation of RC beam using only GFRP bars (F30 0PVA)

Fig. 5d. Crack Propagation of RC beam using Steel bars and PVA fibers (S30 0.25PVA)

Fig. 5e. Crack Propagation of RC beam using Hybrid Reinforcement and PVA fibers (H30 0.25PVA)

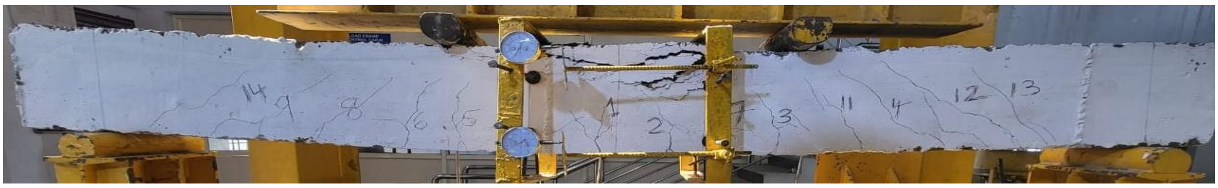

Fig. 5f. Crack Propagation of RC beam using GFRP bars and PVA fibers (F30 0.25PVA)

Fig. 5. Crack Propagation of Test Specimens at failure

Conclusions

The following are the conclusions drawn from the present investigation.

1. Concrete beams reinforced with GFRP bars alone exhibit higher flexural capacity compared to RC beams using hybrid reinforcement and control beam.
2. The flexural capacity of hybrid reinforced concrete beams with and without fibers is greater than that of conventional beams.
3. It was concluded that the proposed RC beam H30 0.25PVA enhanced both Flexural capacity and ductility compared to control beam.
4. The crack resistance of a conventional beam is greater when compared to F30 0PVA, H30 0PVA whereas the ultimate load capacity is less. That means crack resistance is greater in RC beams when steel bars are replaced whereas ultimate load capacity is greater when GFRP bars are replaced.
5. Pure GFRP reinforced concrete beams undergo typical failure mode by Concrete Crushing; RC beams made with only steel bars undergo failure by Steel Yielding followed by Concrete Crushing whereas all Hybrid Reinforced beams fail by SY, CC and eventually GFRP bar rupturing, which is the acceptable approach of failure.
6. The outcome of flexural behavioral studies of all test beams validated the effectiveness of Hybrid Reinforced beams in terms of Flexural capacity, Ductility, Crack resistance when compared to RC beams using only steel bars and only GFRP bars.

References

[1] Kim, S. & Kim, S. Flexural behavior of concrete beams with steel bar and FRP reinforcement. Journal of Asian Architecture and Building Engineering 18, (2019) 89–97.

[2] Lu, C. H., Li, H., Xu, K., Xuan, G. Y. & Abdullah, W. Experimental study of flexural behavior and serviceability of hybrid concrete beams reinforced by steel and G/BFRP bars. IOP Conf Ser Mater Sci Eng 770, (2020) 012007.

[3] Ge, W., Zhang, J., Cao, D. & Tu, Y. Flexural behaviors of hybrid concrete beams reinforced with BFRP bars and steel bars. Constr Build Mater 87, (2015) 28–37.

[4] Ruan, X., Lu, C., Xu, K., Xuan, G. & Ni, M. Flexural behavior and serviceability of concrete beams hybrid-reinforced with GFRP bars and steel bars. Compos Struct 235, (2020) 111772.

[5] Yinghao, L. & Yong, Y. Arrangement of hybrid rebars on flexural behavior of HSC beams. Compos B Eng 45, (2013) 22–31.

[6] Xingyu, G., Yiqing, D. & Jiwang, J. Flexural behavior investigation of steel-GFRP hybrid-reinforced concrete beams based on experimental and numerical methods. Eng Struct 206, (2020) 110117.

[7] Liu, S., Wang, X., Ali, Y. M. S., Su, C. & Wu, Z. Flexural behavior and design of under-reinforced concrete beams with BFRP and steel bars. Eng Struct 263, (2022) 114386.

[8] LOH, Z. P., MO, K. H., TAN, C. G. & YEO, S. H. Mechanical characteristics and flexural behaviour of fibre-reinforced cementitious composite containing PVA and basalt fibres. Sādhanā 44, (2019) 98.

[9] Shaaban, I. G., Said, M., Khan, S. U., Eissa, M. & Elrashidy, K. Experimental and theoretical behaviour of reinforced concrete beams containing hybrid fibres. Structures 32, (2021) 2143–2160.

[10] Noushini, A., Samali, B. & Vessalas, K. Flexural toughness and ductility characteristics of polyvinyl-alcohol fibre reinforced concrete (PVA-FRC). in Proceedings of the 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures (eds. J.G.M. Van Mier, G. Ruiz, C. Andrade, R.C. Yu & X.X. Zhang) (OPUS, 2013) 1110–1121.

[11] Said, M., Mustafa, T. S., Shanour, A. S. & Khalil, M. M. Experimental and analytical investigation of high performance concrete beams reinforced with hybrid bars and polyvinyl alcohol fibers. Constr Build Mater 259, (2020) 120395.

[12] Sagar, B. & Sivakumar, M. V. N. Compressive properties and analytical modelling for stress-strain curves of polyvinyl alcohol fiber reinforced concrete. Constr Build Mater 291, (2021) 123192.

[13] Xingyu, G., Yiqing, D. & Jiwang, J. Flexural behavior investigation of steel-GFRP hybrid-reinforced concrete beams based on experimental and numerical methods. Eng Struct 206, (2020) 110117.

[14] Nguyen, P. D., Dang, V. H. & Vu, N. A. Performance of Concrete Beams Reinforced with Various Ratios of Hybrid GFRP/Steel Bars. Civil Engineering Journal 6, (2020) 1652–1669.

[15] Ge, W., Zhang, J., Cao, D. & Tu, Y. Flexural behaviors of hybrid concrete beams reinforced with BFRP bars and steel bars. Constr Build Mater 87, (2015) 28–37.

[16] Zaki, M., Tobaa, A., Shehata, A., Mohamed, F., Khalef, R., Hagras, Y., Abou-Ali, R., Farag, M., Ghaly, A., Madi, M. and Sayed-Ahmed. Potential advantages of basalt FRP bars compared to carbon FRP bars & conventional steel. Australian Journal of Civil Engineering 19, (2021) 107–122.

[17] LOH, Z. P., MO, K. H., TAN, C. G. & YEO, S. H. Mechanical characteristics and flexural behaviour of fibre-reinforced cementitious composite containing PVA and basalt fibres. Sādhanā 44, (2019) 98.

[18] Hemalatha, K., & D. Ravi Prasad. Numerical analysis on reinforcement ratio of RC beams using FRP and steel rebars. E3S Web of Conferences. Vol. 391. EDP Sciences, 2023.18.

[19] Sijavandi, K., Sharbatdar, M. K. & Kheyroddin, A. Experimental evaluation of flexural behavior of High-Performance Fiber Reinforced Concrete Beams using GFRP and High Strength Steel Bars. Structures 33, (2021) 4256–4268.

[20] Wang, H. & Belarbi, A. Ductility characteristics of fiber-reinforced-concrete beams reinforced with FRP rebars. Constr Build Mater 25, (2011) 2391–2401.

[21] Qu, W., Zhang, X. & Huang, H. Flexural Behavior of Concrete Beams Reinforced with Hybrid (GFRP and Steel) Bars. Journal of Composites for Construction 13, (2009) 350–359.