Flexural Behavior of Concrete Beams Reinforced with Hybridization Rebars

Barakat Shakir AL-Bahrany1a and Hayder H. Alkhudery2b

1Graduate student in Structural Engineering, Faculty of Engineering / Kufa University, Iraq
2Faculty of Engineering /Civil Dept / University of Kufa, Iraq

a Gmail: barban7918@gmail.com,
bemail: hayder.alkhudhri@uokufa.edu.iq

Abstract. Flexural behavior of concrete beams reinforced with hybridization steel rebar enclosed by CFRP sheet has been explored in this paper. Seven specimens have been casted and tested under two-point load, one served as a control beam which was reinforced by ordinary steel bars, and six beams were reinforced with hybrid steel bar/sheet CFRP. Two main parameters have been considered which were the length of the hybrid steel bar/sheet CFRP and layers of carbon sheet warping steel bar. The response has been investigated in terms of failure modes, ultimate load, first cracking load, maximum deflection, crack patterns, load-deflection curves. The experimental results indicated that hybrid steel bar/sheet CFRP techniques yielded the same behavior as the control beams and reduced the maximum deflection. Also, it is improved the load capacity by about (4.35% to 42.61%) in comparison with reference beam. Effective reduction of maximum deflection was indicated throughout behavior of all enhanced specimens while no change was recorded in first cracking load in comparison with control specimen. Hybridization length (1200 mm) which represent two-thirds of beam length gives an optimal length of strengthening for one and two layers in terms of ultimate load by 21.74% and 39.13% compared to control beam, respectively.

Keyword. Structural behavior; Flexural; Hybridization rebar; Reinforced concrete beam; CFRP

1. Introduction

Concrete is a brittle material and weak in tension but has high strength in compression. This has produced to a requirement for rebar in the tension parts of the structures. Traditionally, this had been done utilizing ordinary rebars. Over the final few periods, a study has been shown acceptable to obtain a resolution to the corrosion trouble in RC-beam. So, processes for instance the utilization of stainless-steel rebars, concrete additives, cathodic safeguard epoxy coatings, galvanization, etc., have been tested, but none of these processes has fully resolved the trouble of corrosion. The notable characters of fiber-reinforced polymer indicate that these materials may be the resolution to the corrosion trouble in steel. These characters contain fatigue strength, high strength-to-weight ratio and, high corrosion resistance. Composites of the hybrid have more developed complexes as related to standard composites of FRP. Hybrids may have more than one strengthening stage and one matrix stage or one strengthening stage with doubled matrix stages or doubled strengthening and doubled matrix stages. They have improved flexibility in comparison to other fiber strengthened complexes. Usually, it has a high- modulus fiber with a low- modulus fiber. The high-modulus fiber displays the load capacity properties and stiffness,
while the low-modulus fiber has the low-cost material and results in the composite more damage tolerant [1]. Aiello and Ombres, 2002 [2] explored the flexural performance of concrete beams reinforced with hybrid FRP rebar. It was found that the increase of stiffness was clearer for specimens which reinforcement were consisted of AFRP and steel rebar and reduced crack width and crack spacing values. Kamal, et al. 2008 [3] presented an investigation to study the strengthening of concrete beams by increasing the reinforcement region using GFRP rebars instead of conventional steel. Thirteen RC-beams had been tested. It was found that adding extra GFRP rebars enclosed in the stirrups enhanced the flexural capacity, while the stiffness was not increased because of the low modulus of GFRP rebars. Qu, et al. 2009 [4] investigated experimentally and analytically the behavior of RC-beams with hybrid steel and GFRP bars. Test results indicated that the usage of steel reinforcement in combination with GFRP reinforcement enhanced the flexural behavior of GFRP reinforced concrete specimens. Lau and Pam, 2010 [5] tested twelve beams up to failure, consisting of plain concrete beams, steel-reinforced concrete specimens, hybrid FRPRC specimens and pure FRPRC-specimens. It was concluded that the ductility of hybrid FRPRC specimens are more than pure FRPRC-specimens. While an increasing level of over reinforcement in the specimens was caused additional ductility in FRPRC-specimens. Yoon, et al. 2011 [6] studied experimentally and analytically the flexural capacity and deflection of high-strength RC beams. It was concluded that the stiffness and ductility improved and decreased the deflection when utilizing hybrid reinforcing with steel bars compared to FRP bars. Also, the use of hybrid bars reduced width of cracks and controlled the propagation of them. Hawileh, 2014 [7] presented analytical study by FEM to predict the load deflection response of RC beams carried out by Aiello and Ombres with a hybrid bar. The usage of diverse material kinds of FRP reinforcement gave different responses for the beams. Also, it was noticed that the response of the beam reinforced with hybrid bars preponderated as compared with remaining beams that purely reinforced with steel, AFRP and GFRP bars. El Refai et al., 2015 [8] presented an investigation to study the flexural behavior of hybrid-RC- beams. It was concluded that the usage of steel reinforcement in hybridization with GFRP reinforcement improved the behaviors of pure GFRP specimens regarding the ultimate load, cracking load, and stiffness. Maranan et al., 2018 [9] explored experimentally the behavior of geopolymer-concrete specimens reinforced with a hybrid of steel and GFRP bars. The hybrid specimens with GFRP bars at the lower and with steel bars at the upper showed increasing strength and stiffness at concrete crushing with respect to specimens with hybrid tensile reinforcement. Hayden H. et al., 2018 [10] introduced a theoretical model of analysis hybrid reinforced FRP and steel concrete member by using principle of strain compatibility and forces equilibrium, the moment-curvature relation, deflection, and ultimate moment strength, and a critical range of hybrid reinforcement (CFRP area/steel area) ratio were specified, that meets the ductility index and normalized ultimate strength index at the same level. Wenjie Ge et al., 2019 [11] studied the flexural behaviors of engineered cementitious composite (ECC) specimens having reinforcement of steel and FRP bars. It was found that the ductility of hybrid specimens was higher than that of RC specimens Wenjie Ge et al., 2020 [12] presented flexural behavioral investigation of RC beams reinforced with steel–FRP composite bar (SFCB). It was concluded that the hybrid and (SFCB) reinforced beams showed enhanced stiffness, larger bending capacity and reduced crack width compared with FRP reinforced beam.

2. Experiment scheme

2.1. Material Properties

An ordinary concrete mix has been utilized to produce every specimen of experimental work, with compressive strength $f_c$ (32 MPa). The material components are formed of cement type (V-sulfate resisting) corresponded to the Iraqi specifications (No.5/1984) [13]. The max. size of natural sand was 4.75 mm. While the max. size of coarse aggregate was 20 mm. Both fine and coarse aggregate are
checked to ensure the criterion of IQS (No.45/1984) [14]. Pure water is utilized for casting and treating. Three steel bars sizes are utilized; diameters (12 and 10) mm were utilized as the longitudinal rebars and shear reinforcement, respectively. Also, a diameter bar of 8 mm is used at compression zones. Table (1) displays steel rebars' accorded and properties with (ASTM A615-4) [15] specifications. To strengthen the bottom longitudinal reinforcement in beams, CFRP technique is used. The Sika Wrap ®-300C is a unidirectional woven carbon fiber fabric with mid-range strengths.

| Bar dia.(mm) | Φ 8  | Φ 10 | Φ 12 |
|-------------|------|------|------|
| Yield stress (MPa) | 500  | 575  | 593  |
| Ultimate strength (MPa) | 595  | 670  | 675  |

2.2. Specimens description

Seven RC beams are casted and tested under two-point load, one control specimen, and others are reinforced with hybrid steel bar/sheet CFRP composite bar. A standard specimen is (2000) mm total span, with center to center length (1800) mm and section depth (250) mm and (150) mm section width. Figure1 showed the method of hybridization. While Figure 2 displayed the reinforcement details, dimensions and loading. Moreover, the designations of the tested beams are presented in Table 2.

![Figure 1. The Method of Hybridization](image)
Table 2. The Specimen's Description

| Beams Symbol | Hybridization length(mm) | No. of layer |
|--------------|--------------------------|--------------|
| BC           | -                        | -            |
| B1           | 600                      | 1            |
| B2           | 1200                     | 1            |
| B3           | 1800                     | 1            |
| B4           | 600                      | 2            |
| B5           | 1200                     | 2            |
| B6           | 1800                     | 2            |

Figure 2. Plan of Reinforcement and Loading of The Beams

2.3. Instrument of Testing

Fig.2 shows calibrated electrohydraulic testing machine (PHILIPP HOLZMANN 2000 kN) in the structural test laboratory of the Engineering Faculty at the Kufa University was used to test the specimens.

Figure 3. The universal machine used in testing
3. Discussion the results

3.1. Pattern of cracks

Figure (4) displays the history for cracks propagation of testing specimens. It can be noticed that the first two cracks initiated at bottom face (i.e. tension zone) approximately within middle third of beam span (i.e. under the applied loads) as a flexural crack at a load value of 25 KN in all specimens including control beam. This is because of the CFRP sheet surrounded the steel bar is not effected at low loads. More flexural cracks were noticed on the shear span due to rise of the applied load and associated cracks become wider and more visible. The using of hybrid (steel bar/sheet CFRP) improved the beam strengthen and increased the load capacity by about (4.35 % to 42.61 %) in comparison of control beam. Also, it can be obviously seen that less density of cracks appeared at both sides of beams compared to control beam. This may be related to the increasing in hybridization length which enhanced the beam strength. In addition, almost of strengthening beams reinforced with hybrid steel (bar/sheet CFRP) were failed in the flexural pure failure mode which is the same failure mode of control specimen.

Table 3 shows results of testing specimens in terms of flexural crack load, load capacity, failure mode, and maximum deflection at failure level.

Table 3. Experimental Results

| Specimen | First Crack Load(kN) | Ultimate Load Pu (kN) | Increase% | max. Deflection (mm) | Failure Mode          |
|----------|----------------------|-----------------------|-----------|----------------------|-----------------------|
| BC       | 25                   | 115                   | -         | 17.50                | Flexural pure failure |
| B1       | 25                   | 120                   | 4.35      | 11.36                | Flexural pure failure |
| B2       | 25                   | 140                   | 21.74     | 15.12                | Flexural pure failure |
| B3       | 25                   | 135                   | 17.39     | 16.16                | Flexural pure failure |
| B4       | 25                   | 120                   | 4.35      | 11.24                | Flexural pure failure |
| B5       | 25                   | 160                   | 39.13     | 17.28                | Flexural pure failure |
| B6       | 25                   | 164                   | 42.61     | 17.48                | Flexural pure failure |
Figure 4. Patterns of Crack for Testing Beams

3.2. Load-deflection response

Figure 5 displays the load-deflection curves at middle span of the tested specimens strengthened with one-layer CFRP sheet compared to control beam. It is obvious that the specimens yielded according their behaviors until nearly at load 100 kN. The beams show an improvement in the ultimate load by about (4.35 to 24.35 %) with respect to control beam. Also, it can be indicated that the hybrid steel bar-sheet CFRP of two thirds span length (i.e. 1200mm) represents the effective hybrid length in terms of ultimate load capacity and beams ductility in comparison with other specimens. It seems the
strengthening length (Ls) of steel bar by CFRP sheet is not effective when exceeded two thirds of span beam as in comparison between B2 (Ls=1200mm) and B3 (Ls=1800mm).

Figure 6 presents the load-deflection curves for the beams strengthened with two-layer CFRP sheet compared to reference beam, the same behavior of one-layer CFRP sheet can be noticed through all load stages with enhancement of the ultimate load capacity of the beams by about (4.34 to 42.61%). Figure 7 shows comparison among B2, B5 and BC beams. The effects of number of strengthening layers were evident, that the load capacity of beam B5 is improved by 17.39% than beam B2.

Finally, it can be concluded that hybrid steel bar/sheet CFRP with length (1200 mm) which represents two thirds of beam span for one and two layers are more efficient than the other beams in increasing the beam stiffness. Because of such strengthening length achieved sufficient bond between the hybrid rebar and concrete and no more strengthening length of CFRP sheet needed.

**Figure 5.** Load-Mid Span Deflection for The Specimens with one layer

**Figure 6.** Load-Mid Span Deflection for The Specimens with two layers
Figure 7. Load-Mid Span Deflection for The Specimens BC, B2 and B5

4. Conclusions

The hybrid steel bar/sheet CFRP was improved flexural strength of reinforced concrete beam in term of ultimate load capacity and structural behavior of beam. The improvement in the ultimate failure load for beams was about (4.34 to 42.61%) compared to the control beam. Also, it was decreased number of cracks compared to the reference beam. The method of strengthening by using the hybrid steel bar/sheet CFRP with the length (1200 mm) with one and two layers conduct an improvement in the load capacity of beams by (21.74 and 39.13 %) for one and two layers compared to control beam, respectively. In addition, strengthening length of two thirds of beam span represents an optimal hybrid length to achieve sufficient bond between hybrid rebar and concrete and no more length needed.

5. References

[1]. Osman, M. A., Ismail, H. M., & Atya, H. A. (2016). Study of Flexure Behavior of Beams Reinforced with Different Hybrid Percent of Glass and Carbon Bars. *Current Journal of Applied Science and Technology*, 1-12.

[2]. Aiello, M. A., & Ombres, L. (2002). Structural performances of concrete beams with hybrid (fiber-reinforced polymer-steel) reinforcements. *Journal of Composites for Construction*, 6(2), 133-140.

[3]. Kamal, M. M., Safan, M. A., & Salama, R. A. (2008). EXPERIMENTS ON STRENGTHENED CONCRETE BEAMS WITH HYBRID STEEL-GRFP REBARS. *ERJ. Engineering Research Journal*, 31(2), 201-210.

[4]. Qu, W., Zhang, X., & Huang, H. (2009). Flexural behavior of concrete beams reinforced with hybrid (GFRP and steel) bars. *Journal of Composites for construction*, 13(5), 350-359.
[5]. Lau, D., & Pam, H. J. (2010). Experimental study of hybrid FRP reinforced concrete beams. *Engineering Structures*, 32(12), 3857-3865.

[6]. Yoon, Y. S., Yang, J. M., Min, K. H., & Shin, H. O. (2011). Flexural strength and deflection characteristics of high-strength concrete beams with hybrid FRP and steel bar reinforcement. In: 10th International symposium on fiber-reinforced polymer reinforcement for concrete structures 2011, FRPRC-10, in conjunction with the ACI Spring 2011 Convention, Farmington Hills, MI 48331, *United States, American Concrete Institute*, 1-22.

[7]. Hawileh, R. A. (2015). Finite element modeling of reinforced concrete beams with a hybrid combination of steel and aramid reinforcement. *Materials & Design (1980-2015)*, 65, 831-839.

[8]. El Refai, A., Abed, F., & Al-Rahmani, A. (2015). Structural performance and serviceability of concrete beams reinforced with hybrid (GFRP and steel) bars. *Construction and Building Materials*, 96, 518-529.

[9]. Maranan, G. B., Manalo, A. C., Benmokrane, B., Karunasena, W., Mendis, P., & Nguyen, T. Q. (2019). Flexural behavior of geopolymer-concrete beams longitudinally reinforced with GFRP and steel hybrid reinforcements. *Engineering Structures*, 182, 141-152.

[10]. Hayder H. Alkhudery, Oday M. Albuthbahak, and Haider A. A. Al-Katib (2018), “Investigation of Effective Hybrid FRP and Steel Reinforcement Ratio for Concrete Members”, *Journal of Engineering and Applied Sciences*, 13(13): 5150-5161.

[11]. Ge, W. J., Ashour, A. F., Yu, J., Gao, P., Cao, D. F., Cai, C., & Ji, X. (2019). Flexural behavior of ECC–concrete hybrid composite beams reinforced with FRP and steel bars. *Journal of Composites for Construction*, 23(1), 04018069.

[12]. Ge, W., Wang, Y., Ashour, A., Lu, W., & Cao, D. (2020). Flexural performance of concrete beams reinforced with steel–FRP composite bars. *Archives of Civil and Mechanical Engineering*, 20, 1-17.

[13]. Iraqi Specification No. 5 1984 Portland Cement (Baghdad).

[14]. Iraqi Specification No.45 1984 Natural Sources for Gravel that is used in Concrete and Construction (Baghdad).

[15]. ASTM A615/A615M-04 2004 Standard Specifications for Deformed and Plane Carbon-Steel Bars for Concrete Reinforcement (Annual Book of ASTM Standard).