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Experimental Study on the Flexural Behaviour of a Novel Concrete Filled Hybrid Beams Reinforced with GFRP and Steel Bars

Ferhat Aydın*

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Abstract

This study presents the flexural performances of hybrid beams where glass fibre reinforced plastic (GFRP) box profile, concrete, steel or GFRP bars were used together. By conducting flexural tests on beams of varying properties produced for this purpose, the minimum reinforcement effects in GFRP profile-concrete beams were experimentally presented. Beam series of two sizes, as 74–74–500 mm small beams and 100–100–1,500 mm large beams, and varying combinations were produced. In addition, some properties of GFRP box profiles were improved. Following the tests conducted on small beams, the number of large beam samples was reduced and while steel bars were used in some beams, GFRP bars were used in others. The hybrid beams were compared with reinforced concrete beams have the same dimensions in large beams. On the basis of the results obtained from the tests it was determined that the flexural performances of steel reinforced hybrid beams increased at a higher level. Flexural strength of the improved hybrid beams increased by about two times compared to the classical reinforced concrete beams. Fracture toughness of the hybrid beams improved 53%.

Keywords: *hybrid beams, bar, GFRP, concrete, steel, flexural performance*

1. Introduction

Building materials of higher levels of effectiveness can be designed by using different materials in different combinations. Through the design of new composite or hybrid materials, materials that have superior properties than their component materials can be produced. In the recent years fibre reinforced plastic (FRP) composites became the popular materials with their high tensile strength, light weight, durability and corrosion resistance. Having been initially used in aeronautical and space equipments, today these materials are used also in the building sector as both load bearing and secondary building elements (Ayman, 2004).

The use of FRP composites in the building sector increases day by day. Particularly the excellent performance obtained by FRP composites in the aeronautical and space industries for a period of more than 50 years, enabled them to be reliably included in the construction industry (Ayman, 2004). The use of FRP composites in buildings has been realized in a period of more than two decades (Zhang *et al*., 2015; Hollaway and Teng, 2008). The initial uses of FRP composites in the construction industry included wrapping columns for seismic improvement and strengthening bar and beam elements in construction infrastructure (Karbhari, 2004). In addition, hybrid designs where FRP composites are used in combination with traditional building materials and systems completely made of composite profiles have a wide area of implementation including strengthening of walls, beams, boards and composite deck bridges (Karbharı, 2004). FRPs have a wide field of application as being alternatives of traditional construction materials such as concrete, steel and wood materials in construction infrastructure (Hota *et al*., 2007). Strengthening and improvement works carried out by using laminated FRP on the underside of beams and by completely covering columns with FRP fabrics are the most common uses of such composite materials in combination with concrete (Xie and Ozbakkaloglu, 2015; Jian and Ozbakkaloglu, 2015; Koksal *et al.,* 2009). In buildings mostly carbon fibre reinforced plastic (CRFP) or GFRP layers, fabrics or FRP composites produced as profiles are used. FRP profiles are generally used as fabrics or laminated layers in repairing and strengthening buildings, as profiles in small structures, bridges and towers, as reinforcement materials in concrete or in hybrid designs together with traditional construction materials.

Nowadays hybrid material designs that integrate FRP materials with traditional building materials attract high levels of attention. There have been many studies carried out in the recent years on hybrid FRP columns filled with concrete, or made of empty FRP pipes (Ozbakkaloglu, 2015; Xie and Ozbakkaloglu, 2016; Becque *et al*., 2003; Yu *et al*., 2006). Furthermore, the behaviours of hybrid beam under the influence of various loads were also studied by some researchers (Wenjie *et al*., 2015; Kara *et al*., 2015; Ahmed

*Associate Professor, Dept. of Civil Engineering, Sakarya University of Applied Sciences, 54187 Sakarya, Turkey (Corresponding Author, E-mail: ferhata@sakarya.edu.tr)

and Radhouane, 2015; Aydın and Sarıbıyık, 2013; Mohamed and Masmoudi, 2010; Belzer *et al*., 2013). This inclination of scientific studies clearly shows that in the new future the use of FRP composites in new buildings will mostly focus on the use of hybrid structures. Several studies conducted on this topic have manifested that the use of FRP composites together with traditional materials such as concrete will be one of the solutions to negate some inconveniencies and disadvantages of using building materials solely made of FRP (Schaumann, 2008; Aydın and Sarıbıyık, 2013; Hong *et al*., 2002).

Concerning the use of FRPs with different fibres as reinforcement, intense researches on improving reinforcement surface properties, durability properties and the usage in beams continue (Zhu *et al.*, 2018; Aydin, 2018; Yang *et al.*, 2018; Najafabadi *et al.,* 2018). The use of FRPs as reinforcement started in the USA in 1990s, particularly against corrosive effects on bridges, and they were considered as a general solution for corrosion on bridge beams and grids. Canadian civil engineers carried out many projects concerning the use of FRP in the bridges connecting highways in Canada. For instance, in Headingley Bridge CFRP and GFRP were used together with reinforcements. On the other hand, in Joffre Bridge that was commissioned in 1997, GFRP reinforcements were used in combination with CFRP beams (Benmokrane *et al.*, 1996).

The works conducted on hybrid beams produced by filling concrete into FRP box profiles have been usually used as circular section, FRP profile concrete in combination with column and pile foundation. FRP reinforcements on the other hand are used in classic reinforced concrete beams or ground concretes. Among FRP materials, mostly GFRP are used due to their cost-efficient quality. Usually produced as profiles, GFRP come into prominence with their high tensile strength, light weight and corrosion resistance. The hybrid uses of particularly box GFRP profiles in combination with principal building materials such as concrete offers many further advantages to the users. Contrary to other studies, in the present study GFRP or steel reinforcements were used in the tensile region as well as concrete in GFRP box section profiles. Beams produced with varying combinations were subjected to flexural tests and their flexural performances were examined. By means of the GFRP profiles used as forms, these hybrid beams offer the advantages of protecting the concrete and the reinforcements in it at a better level, better curing of concrete, low thermal conduction, increased strength and rigidity, impermeability and light weight.

In this hybrid beam system, GFRP box profiles protect both steel bars and the concrete against water, humidity and chemicals, and prevent deformations caused by detrimental effects. Therefore, they can be considered as a solution to the durability and corrosion problems mostly seen in shore structures or structures under the effect of seawater. In the production of these hybrid beams, no other form that would shape the concrete is needed. GFRP box profiles shape the concrete as permanent forms. Thus, essential purpose of this study was to determine how the flexural behaviour would be affected by hybrid materials and could the newly designed hybrid beams with bar be used and what advantages they would bring. The test used smaller beams to determine their flexural performance and then used those numbers could be interpreted to see the affect it would have on regular sized beams.

2. Experimental Program

2.1 Method

Within the scope of the experimental studies, 5 small and 5 large beams of each sample type were produced (total 50 beams). According to the results of the tests conducted on small beams, the types of samples were reduced and tests on the large beams were carried out accordingly. Thus, the number of samples was reduced and the performance of the beams was analysed by producing beams that had more realistic dimensions. In the section tests, the concrete ratio was tested according to GFRP profile ratio in applicable dimensions. Table 1 presents the types of beams containing different types of reinforcement with improved concrete adherence, increased fibre content in comparison to standard hybrid beam.

Small beams were produced by placing fresh concrete and reinforcements into GFRP box profiles of 74 × 74 × 500 mm dimensions and 4 mm wall thickness (Fig. 1). Standard hybrid beams produced by filling GFRP box profile with concrete were designated "HB". In this study, HB beams were the reference beams that are formed by filling concrete into a GFRP box profile. While the beams produced by using two GFRP bars of 8 mm diameter at the tensile region of the standard hybrid beams were designated "GHB", those produced by using steel bars of the same diameter were designated "SHB". While the beams produced by increasing the lateral felt rate of GFRP box profiles

Table 1. Beams Types

Type	Small Beams	Symbol	Large Beams
1	Hybrid Beams (Reference beams)	HB	Hybrid Beams (Reference beams)
2	Reinforced Hybrid Beams with GFRP bar	GHB	-
3	Reinforced Hybrid Beams with Steel bar	SHB	Reinforced Hybrid Beams with Steel bar
4	Reinforced Extra Felt Hybrid Beams with Steel bar	SFHB	-
5	Reinforced Sandy Hybrid Beams with Steel bar	SSHB	-
6	Reinforced + Sandy + Extra Felt Hybrid Beams with Steel bar	SSFHB	Reinforced + Sandy + Extra Felt Hybrid Beams with Steel bar
7	-	RCB	Classical Reinforced Concrete Beams

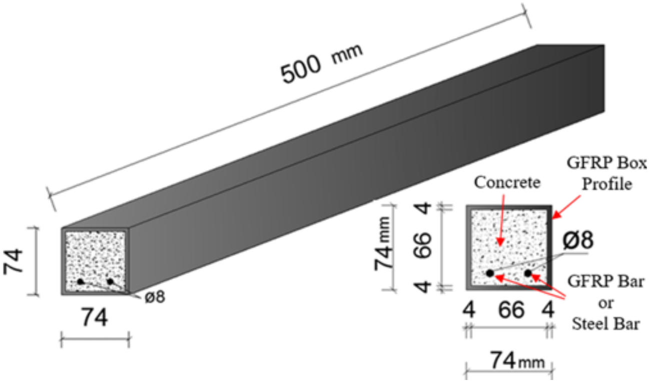

Fig. 1. Small Hybrid Beams Dimensions

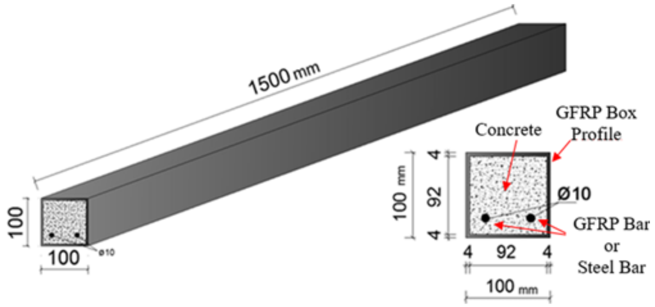

Fig. 2. Large Hybrid Beams Dimensions

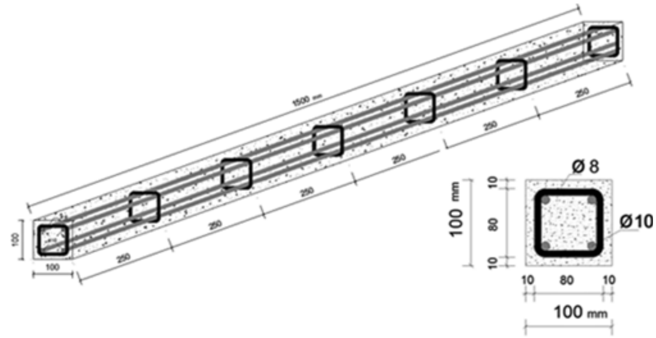

Fig. 3. Reinforced Concrete Beams Dimensions

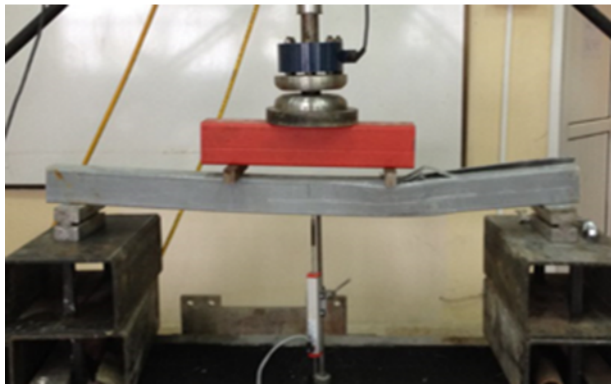

Fig. 4. Flexural Test of Hybrid Beam

by 50% were designated "SFHB", the hybrid beams created by using steel bar and adhering 0 – 2 mm diameter sand particles onto the inner surface of GFRP profile for the purpose of improving concrete and GFRP box profile adherence were designated "SSHB". In consequence of the improvements made on the hybrid materials, the flexural performance of the samples also improved. Finally, the steel reinforced hybrid beams the felt rate of which were increased and sand was used in their profile inner surfaces were designated "SSFHB".

After reducing the number of samples on the basis of the test results obtained from small beams, testing of large beams started. Hybrid beams were produced by using GFRP profiles of 100 × 100 × 1,500 mm dimensions and 4 mm wall thickness (Fig. 2). The sample types that gave the best results in small beam tests were produced and tested. For these tests, 5 beams of four different beam types (standard hybrid, steel-reinforced hybrid, steel reinforced + sandy + extra felt hybrid and classic reinforced concrete beam) were produced. Steel reinforced beams were produced by using two steel bars of 10 mm diameter at the tensile region. Also classical reinforced concrete beams of the same dimensions were designated "RCB" in large beams (Fig. 3). The diameter of bar depended on the section diameter of the small and large beams. The diameters of steel and GFRP bars contained the same test group in the same.

Using a flexural test apparatus that has a capacity of 100 kN-capacity load cell, 8-channel data logger, potentiometers four-point flexural tests were carried out at 1,350 mm bracket interval, distance between the loading points is 450 mm, loading speed is 2 kN/minute (load control). Fig. 4 presents the flexural tests and breakages of hybrid beams. In consequence of flexural tests, load-deflection graphs were generated and flexural strengths were calculated.

2.2 Material Properties

The physical and mechanical properties of GFRP box profiles which are the main components of the hybrid beams were determined (ASTM, 2007; TS EN, 2007; TS EN, 2010) through experimental studies that are given in Table 2.

Ribbed GFRP and steel bars used in hybrid beams (Fig. 5) and the tensile graphs of GFRP and steel bars are presented in Fig. 6. Table 3 on the other hand presents the physical and mechanical properties of the bars. The material properties given represent average values for a large number of tested samples.

GFRP box profiles, plastic consistency concrete and steel or GFRP bars were used in the production of the hybrid beams. In

Table 2. Physical and Mechanical Properties of GFRP Profiles

Characteristics	
Unit weight (g/cm^3)	1,74
Specific gravity	1,82
Modulus of Elasticity (GPa)	30
Tensile Strength (MPa)	560
Poisson Ratio	0,34
Longitudinal Fiber Rate (%)	42
Felt fiber Ratio (%)	9

some profiles granulated sand was adhered onto the inner surface in order to improve the adherence between concrete and the profile (Fig. 7). Concrete mixture used in the hybrid beams is presented in Table 4. Water/cement ratio is about 0.51 and maximum aggregate diameter is 12 mm. The average strength of concrete cured for 28 days is 28 MPa.

Fig. 5. FRP and Steel Bars

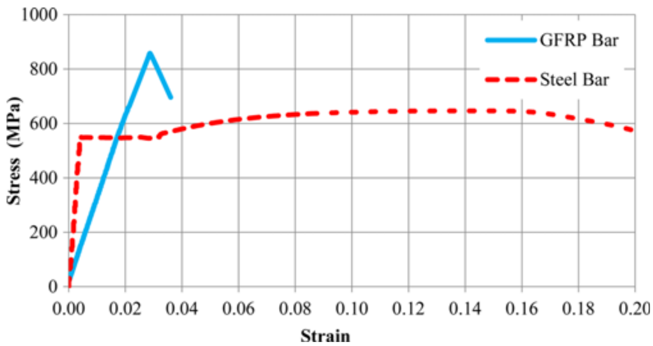

Fig. 6. Stress-Strain Curves for GFRP and Steel Bar

Table 3. GFRP and Steel Bar Properties

Characteristics	GFRP Bar	Steel
Unit weight (g/cm^3)	2,01	7,89
Specific gravity	2,10	7,95
Modulus of Elasticity (GPa)	48	190
Tensile Strength (MPa)	870	585
Yield Strength (MPa)	-	460
Fiber Rate (%)	65	-
Resin Ratio (%)	35	-

3. Test Results and Discussion

3.1 Small Beam Tests

As a result of the hybrid beam tests, load-deflection curves were obtained and each curve represents each beam type that has been selected and used. The graphs representing all beam types are compared in Fig. 8.

Examining the load-deflection curves of the standard hybrid beams (HB) shows that all samples acted linearly up to a flexural load of 20 kN and broke within the profile. After the disruption of the linear behaviour, GFRP profile breaks at different areas. In hybrid beams tearing does not take place completely and the flexural load continuous decrease. GFRP reinforced beams (GHB) on the other hand were observed to act linearly up to a load of 25 kN and exhibit local breaks in the profile after the disruption of linearity. It was observed that steel-reinforced hybrid beams (SHB) act linearly until an approximate load of 30 kN, that the first breakage takes place after a deflection of 6.6 mm in all samples and that local breaks occurs after an average of 17%

Table 4. Mix Proportion of Concrete (1 m^3)

Materials	kg/m^3
Coarse aggregate	1,042
Sand	890
Portland cement	331
Water	170

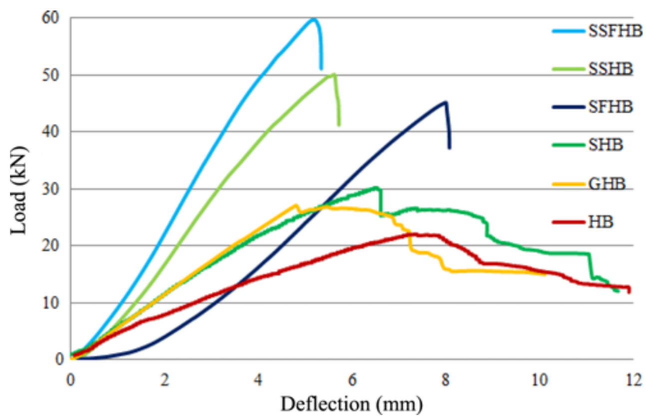

Fig. 8. Comparison of Flexural Curves for Small Hybrid Beams

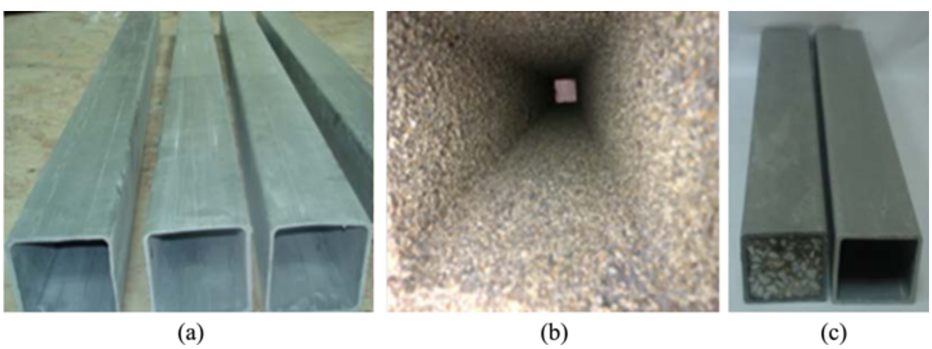

Fig. 7. Inner Surface of Hybrid Beams: (a) GFRP Profile, (b) Inner Surface of the Profile, (c) Hybrid Beam

Table 5. Flexural Strength and Fracture Toughness of Hybrid Beams

Type	Symbol	Flexural Strength (MPa)	Standard Deviation (MPa)	Fracture Toughness (kN-mm)	Standard Deviation (kN-mm)
1	HB	30,5	3.8	81,92	10.2
2	GHB	40,2	4.2	84,32	9.7
3	SHB	42,4	3.6	98,17	8.9
4	SFHB	64,4	7.1	145,21	13.4
5	SSHB	72,6	7.3	140,55	11.6
6	SSFHB	86,8	6.7	155,53	15.3

load loss. It was determined that steel-reinforced hybrid beams with extra felt (SFHB) act linearly and break until 40 kN. On the other hand, steel-reinforced sandy hybrid beams (SSHB) exhibited a similar behaviour and linearly behaved the load until approximately 50 kN. Steel reinforced sandy hybrid beams with extra felt (SSFHB) on the other hand were determined to remain linear until 60 kN. It was observed that complete tearing did not take place in any of the hybrid beam types, but local breakages occurred in all of them. While Table 5 presents the average flexural strength and fracture toughness results of all experiments, Fig. 9 presents the comparison of the beams in terms of flexural strength. The flexural strength of beams was calculated using maximum load. The fracture toughness was found by calculating the area of the load displacement curve.

Average flexural strength of HB beams were calculated to be 30,5 MPa. As for the average flexural strength of GHB and SHB beams, they were calculated to be 40,2 MPa and 42,4 MPa, respectively. Flexural strength of GHB beams increased 32% in comparison to HB beams, while that of SHB beams increased by 39%. Flexural strength of SFHB and SSHB beams were determined to be 64,4 MPa and 72,6 MPa, respectively. While SFHB beams' strength was determined to be 111% higher than that of HB beams, SHB beams' strength was 52% higher than the strength of HB beams. Flexural strength of SSHB beams increased 138% in comparison to HB beams and 71% in comparison to SHB beams. Flexural strength of SSFHB beams, where all improvements were used together, was determined to be 86,8 MPa.

It was determined that SSFHB beams had 2.85 times higher flexural strength than HB beams. Flexural strength of SSFHB beams was determined to be 105% higher than SHB beams, 35% higher than SFHB beams and approximately 2% higher than SSHB beams. Fracture toughness of GHB beams increased 3% in comparison to HB beams, while that of SHB beams increased by 20%. While SFHB beams' toughness were determined to be 77% higher than that of HB beams, SSHB beams' toughness were 72% and SSFHB beams' toughness was 80% higher than the toughness of HB beams. It was further determined that in these types of hybrid beams using sand is 15% more effective than providing extra felt in terms of flexural strength. On the other hand, the use of steel reinforcement was determined to be 8% more effective than using GFRP reinforcement.

It is observed that GFRP reinforced GHB beams' rigidity increased significantly as well as their strength in comparison to HB beams. The level of rigidity is the same between SHB and GHB beams, however SHB beams have a higher level of flexural strength. It was determined that while the flexural strength of the steel reinforced SFHB beams with extra felt increased significantly, material rigidity decreased. It is believed that the concrete and profile adherence is inadequate particularly under low flexural loads. With the increase of adherence, it was observed that both the strength and rigidity of SSHB beams increased under flexural load in comparison to the other samples. Finally, the rigidity and flexural strength of the steel reinforced, sandy SSFHB beams with extra felt reached the maximum values respectively. In addition, compared to the results of previous studies (Aydın and Sarıbıyık, 2013), the use of steel bar in hybrid beams increases the flexural strengths considerably.

3.2 Large Beam Tests

On the basis of the results obtained from small beam tests, the types of samples were reduced to HB, SHB and SSFHB, and beams of these types were produced at 100 × 100 × 1,500 mm dimensions for further testing. Reinforced concrete beams of the same dimensions were added in large beams. Fig. 10 presents the comparison of the graphics representing the beams of different

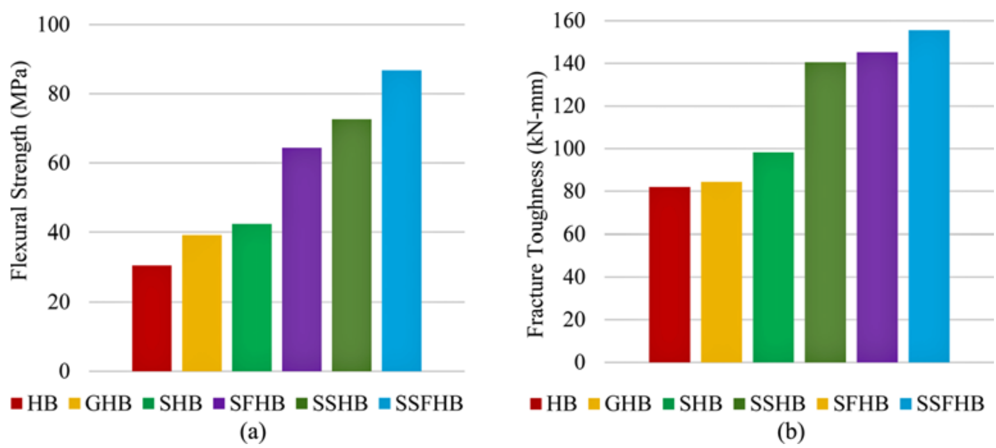

Fig. 9. Comparison of Flexural Strength and Fracture Toughness for Small Hybrid Beams: (a) Flexural Strength, (b) Fracture Toughness

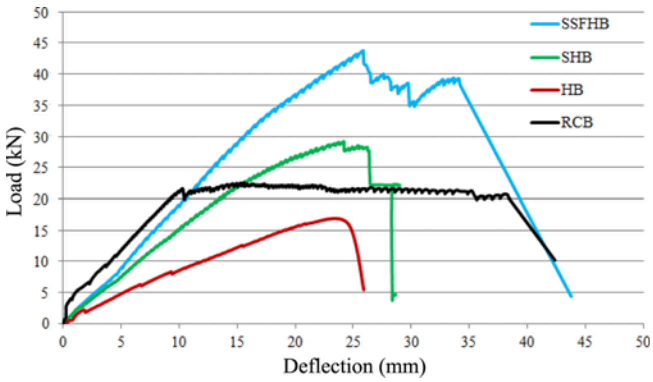

Fig. 10. Comparison of Flexural Curves for Large Beams

properties. Table 6 shows the average flexural strength and fracture toughness results representing 5 beams as per group obtained in the tests performed.

Examining the graphs of HB beams shows that all samples act linearly up to a load of 15 kN. It was observed that breakages occur on the concrete within the profile and that the concrete and GFRP profile do not wholly act together. It was determined that the SHB beams that feature steel bars of 10 mm diameter at tensile region bear a flexural load over 30 kN and that the breakages continue locally. It was determined that SSFHB beams have the highest strength. Total tearing did not take place in any of the beams. The flexural load increased linearly up to 20 kN and then the steel bars have reached yield stress in reinforced concrete beams. The total longitudinal steel bar cross-sectional area is 314,16 mm^2 in reinforced concrete beams. GFRP cross-sectional area is 1,536 mm^2 and the total longitudinal steel bar cross-sectional area is 314.16 mm^2 in hybrid beams.

It was observed that the flexural load of linearly acting HB beams increased approximately to 16 kN. Flexural loads of SHB and SSFHB beams on the other hand were determined to be 33 kN and 42 kN, respectively. While the flexural strength values were improved significantly, also the rigidity levels of the beams substantially increased. It was determined that using steel reinforcements in tensile region and applying sand on the inner surface of GFRP for improving concrete adherence significantly improved rigidity as well as strength.

The average flexural strength values of large HB, SHB, SSFHB and RCB beams were calculated to be 22,2 MPa, 44,7 MPa, 56,4 MPa and 28,5 MPa, respectively. Comparison of the flexural strength and fracture toughness are shown in Fig. 11.

Flexural strength of SHB beams that feature two steel bars of 10 mm diameter in the tensile region within the GFRP profile has increased 2 times in comparison of the strength of SHB beams. With the implementation of sand and extra felt, the flexural strength of SSFHB beams were determined to be 2.5 times higher than that of HB and 26% higher than that of SHB beams. Fracture toughness of SSFHB beams increased 5.5 times in comparison to HB beams, while that of SHB beams increased by 137%. While SSFHB beams' toughness were determined to be 53% higher than that of RCB beams in large beams. When the fracture patterns of hybrid beams were examined, it was observed that they were generally parallel to the fibres (Fig. 12). The fracture of all GFRP profiles occurred in parallel to the longitudinal fibres. Because the ratio of lateral fibres is 9% and the ratio of longitudinal fibres is 42% in GFRP profiles. Thus beams are failed from the lateral axis in all test.

Table 6. Flexural Strength and Fracture Toughness of Large Beams

Type		Flexural Strength (MPa)	Standard Deviation (MPa)	Fracture Toughness (kN-mm)	Standard Deviation (kN-mm)
1	Standard Hybrid	22,2	4,7	201,33	16.9
3	Steel- Reinforced Hybrid	44,7	5.2	465,27	26.1
6	Steel Reinforced + Sandy + Extra Felt Hybrid	56,4	6.6	1104,52	65.3
7	Reinforced Concrete Beams	28.5	5.4	723,55	32.1

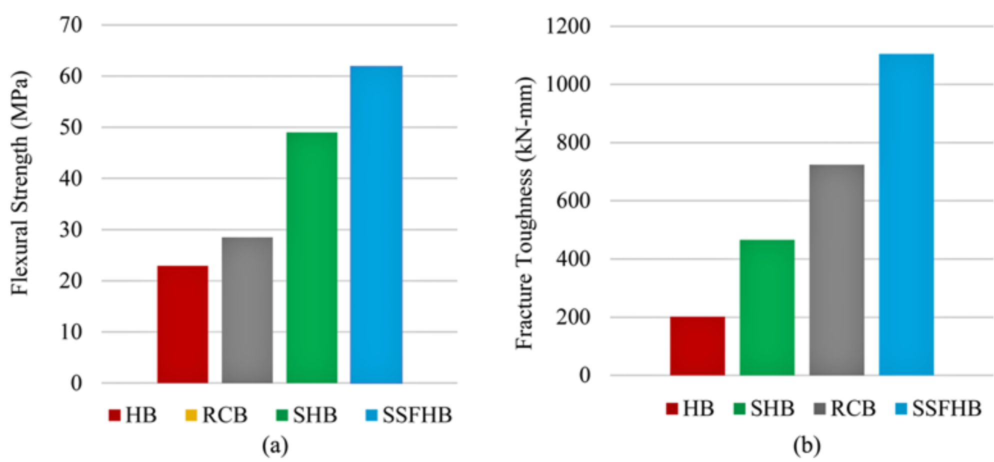

Fig. 11. Comparison of Flexural Strength and Fracture Toughness for Large Beams: (a) Flexural Strength, (b) Fracture Toughness

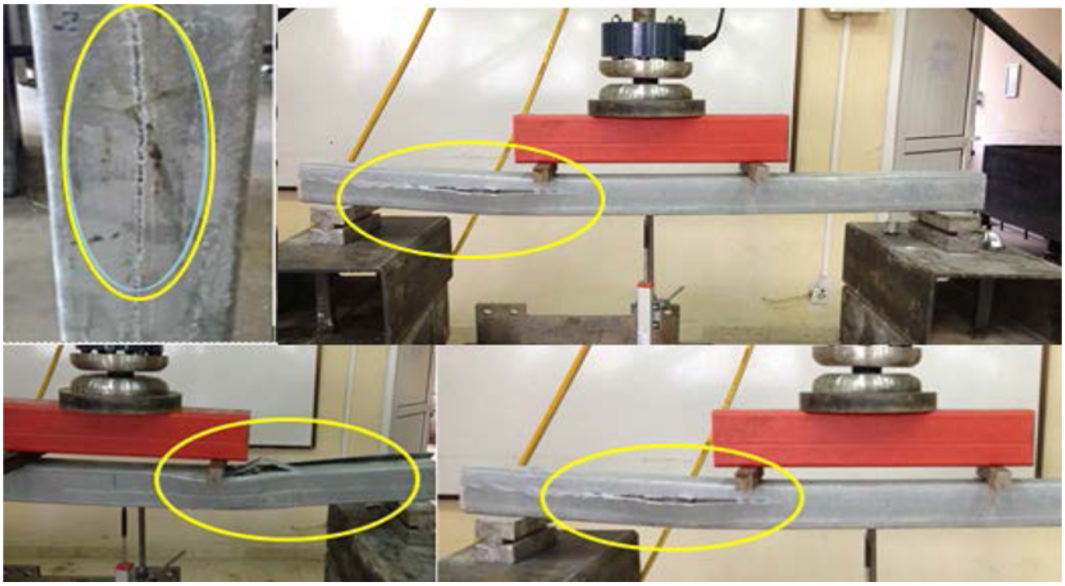

Fig. 12. Failure Mode of the Tested Beams

4. Conclusions

This paper was presented the results of an experimental study on the behaviour of the influence of steel or GFRP bars on the flexural behaviour of hybrid beams. Based on the discussions and results presented in this study, the following conclusions can be drawn:

1. In consequence of the experimental studies it was determined that in hybrid beams of 74 × 74 × 500 mm dimensions, the flexural strengths of GFRP reinforced beams and steel reinforced beams increased by 32% and 39%, respectively in comparison to standard beams. Steel reinforcements provided 8% more contribution to flexural strength. Increasing fibre rate provided a strength increase of 52% in comparison to steel reinforced beams. Applying sand on the profile surface resulted in an increase of 71%. Using both sand and extra fibres on the other hand provided 35% higher strength than the strength of the samples with only extra fibres and 20% higher strength than the strength of samples where only sand was used.
2. Using steel bars in the profile increased the strength of hybrid beams two times in large beams. With the implementation of sand and lateral fibres in combination with steel reinforcements, the strength increased by 26% in comparison to the beams where only steel bars were used.
3. In all the beams have been increases in fracture toughness. Fracture toughness of SSFHB beams increased 3.2 times in large beams and 1.9 times in small beams in comparison to HB beams. SSFHB beams' toughness were determined to be 53% higher than that of RCB beams in large beams.
4. In large beams, flexural strength increased in proportion with the increasing section and length. Thus, the effect of steel bars on the strength value was revealed more with the increase of the section.
5. In consequence of the conducted tests it was determined that the use of steel reinforcements in hybrid beams and the use of sand in the profile inner surfaces in order to enhance concrete adherence significantly improved beam flexural behaviour and strength.
6. Therefore, in utilization of hybrid beams, the reinforcements placed into GFRP box profile at minimum level increases the flexural strength, ductility and rigidity of the beams. With the improvements made by the hybrid beams, it is clear that great gains would be acquired. This new material design can be used safely in applications under the effect of water, humidity and corrosion. These novel hybrid beams can be developed to have more strength in small dimensions.

Acknowledgements

Not Applicable

ORCID

Ferhat Aydin https://orcid.org/0000-0001-9472-8366

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