PAPER • OPEN ACCESS

Reinforced Concrete Beams Strengthened with Externally Bonded Hybrid FRP Sheets

To cite this article: J S Limbongan *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1117** 012003

Reinforced Concrete Beams Strengthened with Externally Bonded Hybrid FRP Sheets

J S Limbongan[1], **R Djamaluddin**[1], **R Irmawaty**[1] **and Jasman**[1]

[1] Civil Engineering Department, Engineering Faculty, Hasanuddin University, Makassar, Indonesia

joeylimbongan@gmail.com

Abstract. Fiber Reinforced Polymer (FRP) is commonly used in structural repair and strengthening due to its high tensile strength, non-corrosive and lightweight. On the other side FRP is relatively brittle compared to steel. This study used hybrid FRP consisting of GFRP and CFRP, by combining two type of FRP with different characteristic it is to be expected that the more brittle FRP will fail first followed by the more elastic one, therefore creating a sequential failure. However CFRP have a higher tensile strength in comparison to GFRP, therefore it's necessary to reduce its tensile strength by reducing its volume. This study is divided into two topics, hybrid FRP tensile strength test and beam flexural test. For the hybrid FRP tensile strength test, a total of three variation of hybrid FRP will be compared (GC30, GC40, and GC50). The variation that shown a sequential failure behaviour, will then be applied to a reinforced concrete beam and tested under monotonic point load device. The test result shown that sequential failure occur on GC30 and GC40. However GC40 had a higher ultimate load at 24.86 kN. For the beam flexural test, there will be two variation, i.e. control beam (CB) and beam strengthened with hybrid FRP (BGC). When compared, BGC had a 40.0% increase in yield strength and 55.43% increase for ultimate load.

Keywords: Reinforced Concrete Beam, Strengthening, Hybrid FRP

1. Introduction

Damage to reinforced concrete structures may occur due to the age of the structure, changes in loading or natural disasters. Most damaged structures will be dismantled immediately without considering the possibility of repair or retrofitting. Nowadays, the development of science and technology is growing rapidly, including developments in the field of civil engineering. One method of structural improvement that is currently being developed is to use a fiber layer reinforced with a polymer matrix or commonly known as Fiber Reinforced Polymer (FRP). Utilization of FRP material in building structures is useful for increasing the ability and restoring the strength of reinforced concrete structures. The use of an externally bonded FRP system is an effective reinforcement to strengthen damaged structural elements. Repair using FRP is also a more economical alternative when compared to building reconstruction.

In its application, FRP sheet is a material that is resistant to corrosion, has a relatively high tensile strength and good workability despite its light weight. But on the other hand FRP has brittle properties so that if a structure fails, the structure will fail suddenly. So it is necessary to create a solution that can be a factor of safety.

One solution that can be done is to combine two layer of FRP which have different characters, namely, Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP). GFRP has more elastic properties than CFRP. By combining the two it is hoped that if the load carried is excessive, the more brittle CFRP will fail first so that sudden collapse can be prevented.

The next problem is that CFRP has a better tensile strength than GFRP, so adjustments need to be made to reduce the tensile strength of CFRP. The method used is to reduce the width of CFRP. With this reduction, it is expected that CFRP will fail before GFRP.

2. Literature Review

Mufti Amir Sultan [1] in their research on the flexural capacity and ductility of reinforced concrete beam strengthened with GFRP-S. The beams tested with a static loading system with two-point load. The experimental results show that the installation of GFRP-S on the beam can increase the flexibility and ductility of the beam, respectively 37.96% and 25%.

Saddam Husein [2] present in their writings the analysis of flexural capacity and failure patterns of concrete beams without a blanket using GFRP bar reinforcement material. The research design is an experimental laboratory with a recapitulation of 6 samples consisting of 2 concrete blocks using steel reinforcement with concrete covers, 2 concrete blocks using GFRP bars with concrete covers, 2 concrete blocks using GFRP bars without concrete covers. The results of this study indicate that the flexural capacity of the beam with GFRP bar reinforcement is greater than that of the steel reinforcing beam and is able to increase the flexural capacity of the beam to withstand the load by 39.76%.

Koosha Khorramian [3] conducted a study using longitudinal CFRP strips to increase the flexural stiffness of columns for strengthening slender columns and eccentrically loaded columns where additional flexural stiffness is required for buckling control. The test results show that the use of a longitudinal CFRP unlaminated sheath is more effective than the proposed hybrid system for reinforcement of small-scale concrete columns subjected to axial loads.

Szmigiera et al. [4] explored the combination of Basalt Fiber Reinforced Polymer (BFRP) with CFRP with the aim of obtaining Hybrid Fiber Reinforced Polymer (HFRP) with better mechanical properties than BFRP and more economical than CFRP. The variations of the test objects used are, (C:B): 1:1, 1:2, 1:3, 1:4, and 1:9. Based on the test, the results of the 1:3 combination showed an increase in the modulus of elasticity by 68% and tensile strength by 15.8% when compared to BFRP.

3. Experimental Programme

3.1. Test Specimen

This study is divided into two topics, hybrid FRP tensile strength test and beam flexural test. In the hybrid FRP tensile strength test, GFRP is used as a base to determine the width of the CFRP. Trough out this test the width of GFRP is 40 mm. While for CFRP it is varied to 30% (GC30), 40% (GC40), and 50% (GC50) of GFRP width, which is equal to 16 mm, 18 mm, and 20 mm. Sample measurement based on ASTM D3039 [5] as shown in Figure 1.

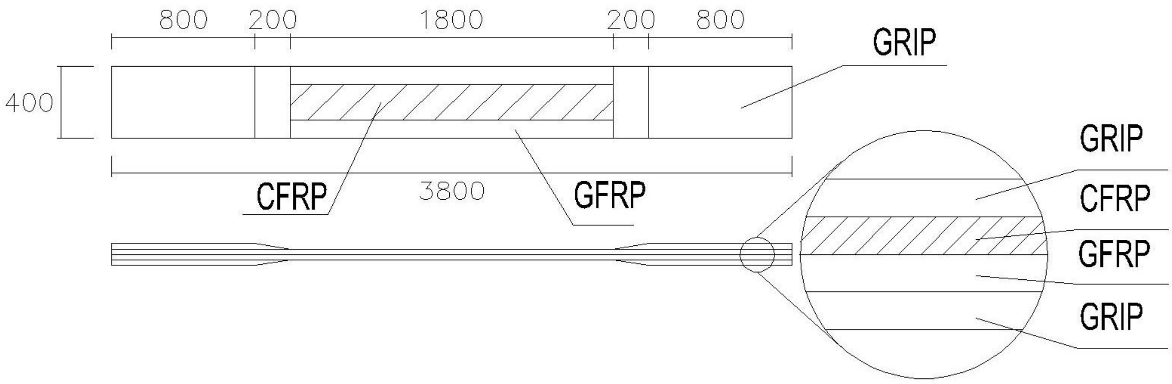

Figure 1. Hybrid FRP sample design

For the beam flexural test, there will be two variation, i.e. control beam (CB) and beam strengthened with hybrid FRP (BGC). The detail of the beam dimensions are 150x200x3000 mm. Sample beams are reinforced with steel reinforcement 3 D13 for the tension area, 2 Ø8 for the compression area, and Ø8-80 for shear reinforcement. For more details can be seen in Figure 2.

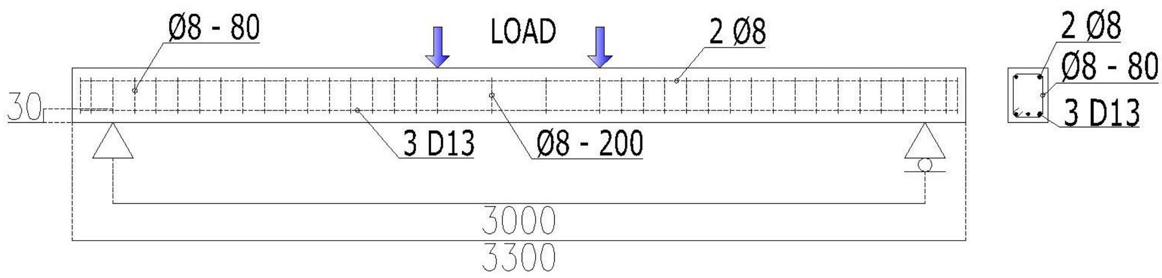

Figure 2. Test Beam Details

3.2. Material Properties

3.2.1. FRP composite

Mechanical properties of FRP composite used are as shown in Table 1.

Table 1. Mechanical Properties of FRP Composite. [6,7]

Properties	CFRP	GFRP	Epoxy
Tensile strength (MPa)	986	575	72.4
Modulus of Elasticity (GPa)	95.8	26.1	1.45
Thickness (mm)	1.0	1.3	
Elongation (%)	1.0	2.2	5

[a] Manufacturer’s data

3.2.2. Concrete and Steel

Based on the compression test on 6 concrete cylinder samples, the average compression strength of concrete used in this experiment is 20 MPa. For tensile, shear, and compression reinforcements, yield strength of the rebar used is 315 MPa.

3.3. Beams Strengthening and Instrumentation

After curing process for 28 days, the test beam will be strengthened with hybrid FRP and allowed to dry for 3 days. Installation of hybrid FRP is done by applying a layer of epoxy resin to the concrete surface. In a separate place, GFRP is smeared with epoxy resin and then affixed to the surface of the concrete that has been applied with resin. The same steps are carried out for CFRP, then applied to GFRP. Detailed measurement can be seen in Figure 3 and finished strengthened beam in Figure 4.

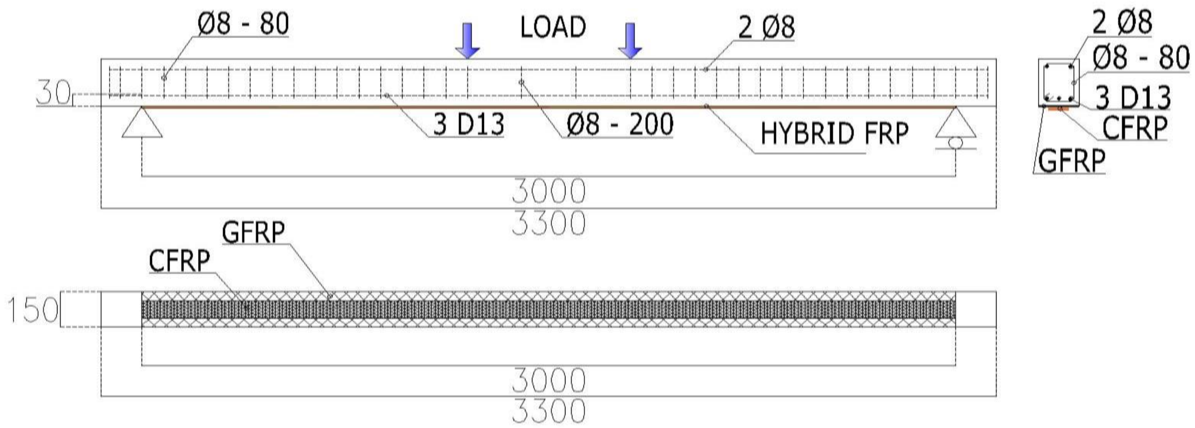

Figure 3. Hybrid FRP strengthened beam design

Figure 4. Hybrid FRP strengthened beam

All beams are subjected to static monotonic point load using displacement control with increments of 0.05mm/s. Two-point load each applied 300 mm from mid-span. Deflection was measured using an LVDT below the mid-span and two more under the point load. Details can be seen in Figure 5.

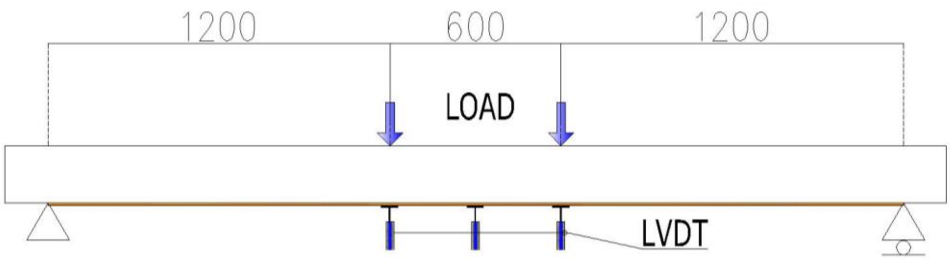

Figure 5. Test beam setting

4. Result and Discussion

4.1. Behavior of Hybrid FRP

The code for every variation used in this test is as mentioned in 3.1. Based on the test result, GC50 has the highest ultimate load at 27.83 kN, followed by GC40 with 24.86 kN, and the last GC30 with 21.91 kN. While it is the opposite in strain, with GC50 being the lowest at 0.00452197, GC40 with 0.00627847, and GC30 with 0.00656938. However for GC50 while having the highest ultimate load doesn't show the sequential failure behavior, both GFRP and CFRP fail at the same time. For GC30 and GC40, CFRP fails first before GFRP creating the sequential failure behavior. This behavior can be observed in Figure 6, where GC30 and GC40 had a decrease in load nearing its ultimate load. It is caused by the CFRP already failing beforehand, leaving GFRP to carry the load.

Therefore GC40 will be used for beam strengthening due to it is higher in ultimate load than GC30 while still showing the sequential behavior.

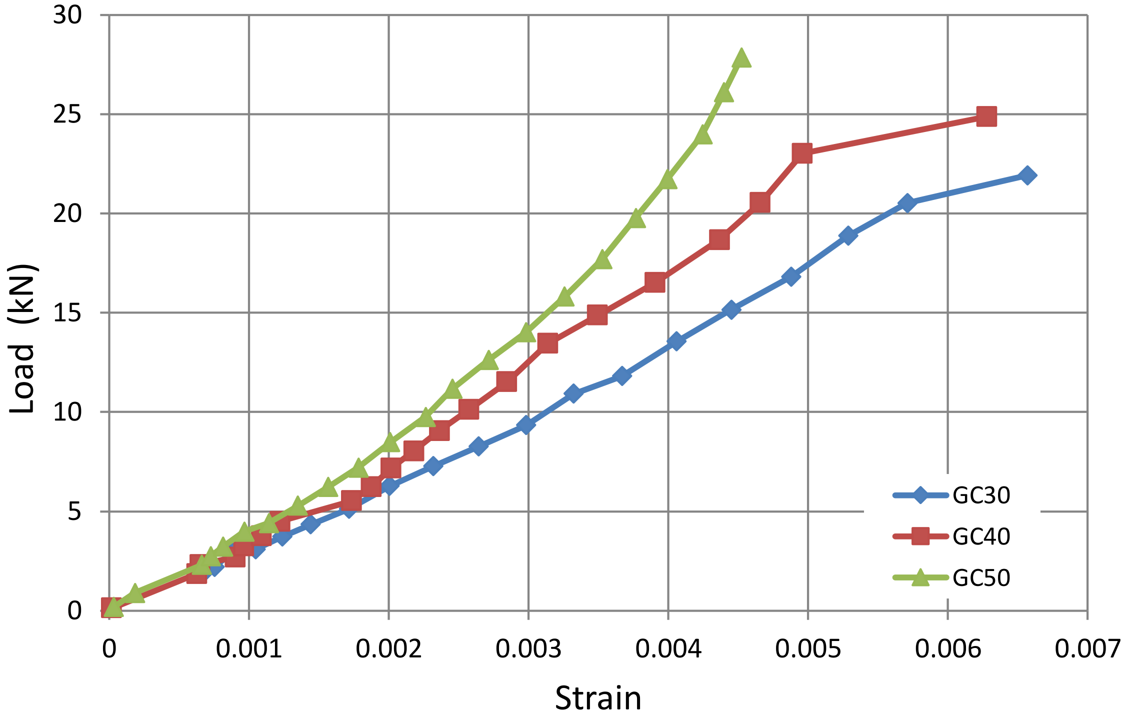

Figure 6. Hybrid FRP Tensile Strength Test Result

4.2. Beam Flexural Test

The control beam (CB) is observed to have a yield load of 25.32 kN and an ultimate load of 29.14 kN. The steel elastic phase ended at a displacement of 16.40 mm. The hybrid FRP strengthened beam (BGC) had a yield load of 35.45 kN and an ultimate load of 43.60 kN. When compared, the test beam had a 40.0% increase in yield strength and a 55.43% ultimate load increase. Beam behavior could be observed in Figure 7. The load on the specimen BGC drops from 42.51 to 34.98 kN due to delamination caused by a lack of bonding strength between the hybrid FRP and the beam surface when the displacement of the BGC at 38.7 mm leaving the rebar to carry the load. The test stopped soon after.

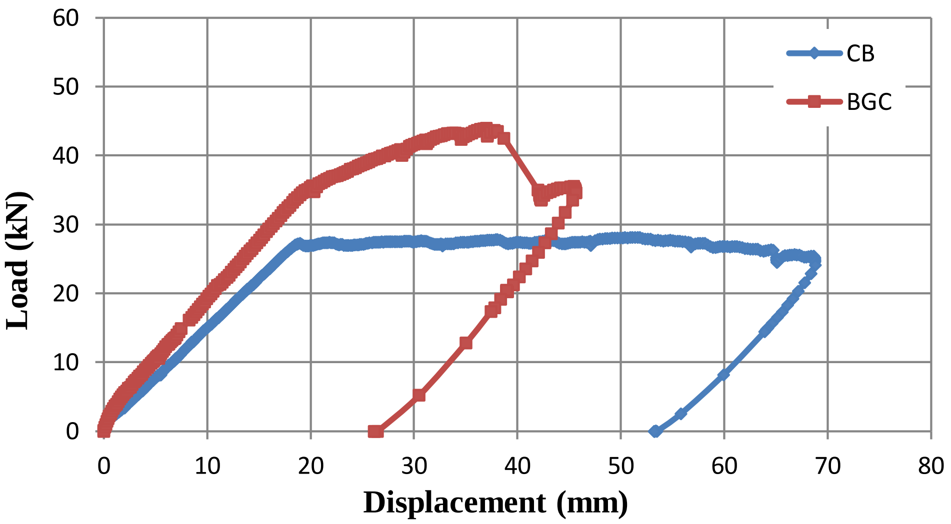

Figure 7. Beams Flexural Test Result

4.2.1. Failure mode

Though the BGC shows an increase in capacity compared to CB, the sequential failure behavior of the Hybrid FRP didn't occur due to delamination caused by a lack of bonding strength between the hybrid FRP and the beam surface. Delamination started from a crack under the point load.

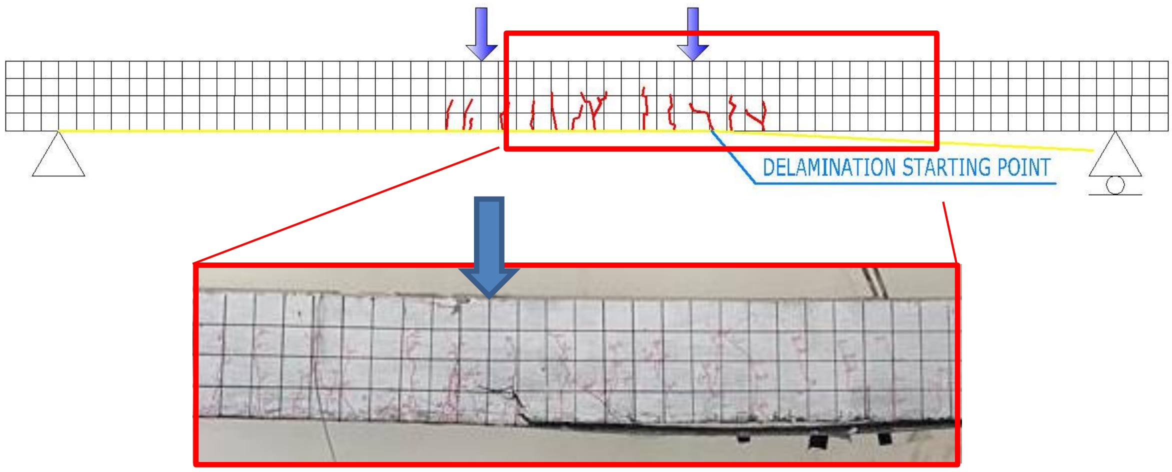

Figure 8. BGC post flexural test

Through observation in Figure 8, the delamination is located directly below the point load to the end of the beam.

5. Conclusion

From this experiment, it can be concluded as below:

- From 3 variation of hybrid FRP, only GC30 and GC40 shown the sequential failure behaviour, where GC40 had a higher load capacity compared to GC30
- By strengthening a beam using hybrid FRP (GFRP 100%, CFRP 40%), the yield strength increased by 40.0% and ultimate strength by 55.43%
- Failure mode of BGC (hybrid FRP strengthened beam) is delamination, caused by a lack of bonding strength between the hybrid FRP and the beam surface

References

[1] Sultan, M. A. (2020). Ductility and Flexural Capacity of GFRP-S Strengthened Reinforced Concrete
[2] Husein, S. (2020). Failure Mode Analysis of Concrete Beams using GFRP Rebar without Concrete Cover
[3] Khorramian K. (2021). Hybrid System of Longitudinal CFRP Laminates and GFRP Wraps for Strengthening of Existing Circular Concrete Columns
[4] Szmigiera E. D. (2019). Mechanical Properties of Hybrid FRP Bars and Nano-Hybrid FRP Bars.
[5] ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials 2017.
[6] Fyfe. Co. LLC (2012), Characteristic CFRP (Carbon Fiber Reinforced Polymer)
[7] Fyfe. Co. LLC (2012), Characteristic GFRP (Glass Fiber Reinforced Polymer) type SHE-51A