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## Failure Mode Analysis of Reinforced Concrete Beams Using GFRP Sheet as Shear Strengthening

To cite this article: A A A Yusuf *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1134** 012001

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# Failure Mode Analysis of Reinforced Concrete Beams Using GFRP Sheet as Shear Strengthening

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**Abstract.** Corrosion is an electrochemical reaction that can cause deterioration to the reinforcing steel which has implications for the decrease in the flexural capacity of the beam. The use of corrosion resistant GFRP bar as a substitute for conventional reinforcement and GFRP sheets as a substitute for shear reinforcement without a concrete cover can increase the flexural capacity of RC beams. This study aims to analyze the flexural capacity and failure mode of reinforced concrete beams with GFRP bar and GFRP sheet, with variations in width of 50 mm (BFGS50) and 100 mm (BFGS100). Conventional RC beams (BK) and beams with GFRP bars as tensile reinforcement and conventional shear reinforcement (BFSB) were made as control beams. The beam is given a static-monotonic load until failure. The results showed that the flexural capacity of the BFGS50 and BFGS100 beams was higher than the control beam (BK and BFSB). From the failure mode analysis, the control beam experienced compression failure, while BFGS50 and BFGS100 experienced shear failure.

## 1. Introduction

Corrosion is an electrochemical process or reaction that is inherent and natural. This process can affect the structure of buildings, especially buildings located in coastal areas. In its mechanism, corrosion cannot be prevented or stopped but can be controlled by slowing down its speed [1]. Corrosion can reduce the number of reinforcement cross sections and can reduce the serviceability of the structure. In addition to reducing the cross-sectional area of the reinforcement, corrosion can also cause cracking and splitting of the concrete cover (spalling) [2]. Several methods have been applied to overcome the problem of corrosion on reinforcement such as the use of cathodic protection, epoxy coating, galvanization, and the use of corrosion-resistant reinforcement. Data published by Frost and Sullivan based on a survey from 2010 to 2011 showed that the use of corrosion-resistant reinforcement dominates the market to address corrosion in concrete reinforcement [3].

## 2. Experimental Program

The test beam is designed with a length of 3300 mm, a width of 150 mm, and a height of 250 mm. A span length of 3000 mm is the distance between two focal axes. The length of the shear spread is 1200 mm measured from the focus axle to the center of the load spreader [4].



2.1. BK and BFSB Beam

BK beams are conventional concrete beams that use 3D13 steel reinforcement as tensile reinforcement,  $\phi 8-100$  steel dash as Shear reinforcement accompanied by a concrete cover with a thickness of 30 mm. BFSB beam is a beam that uses GFRP bar 3D13 reinforcement as tensile reinforcement,  $\phi 8-100$  steel dash as Shear reinforcement also accompanied by a concrete cover with a thickness of 30 mm.

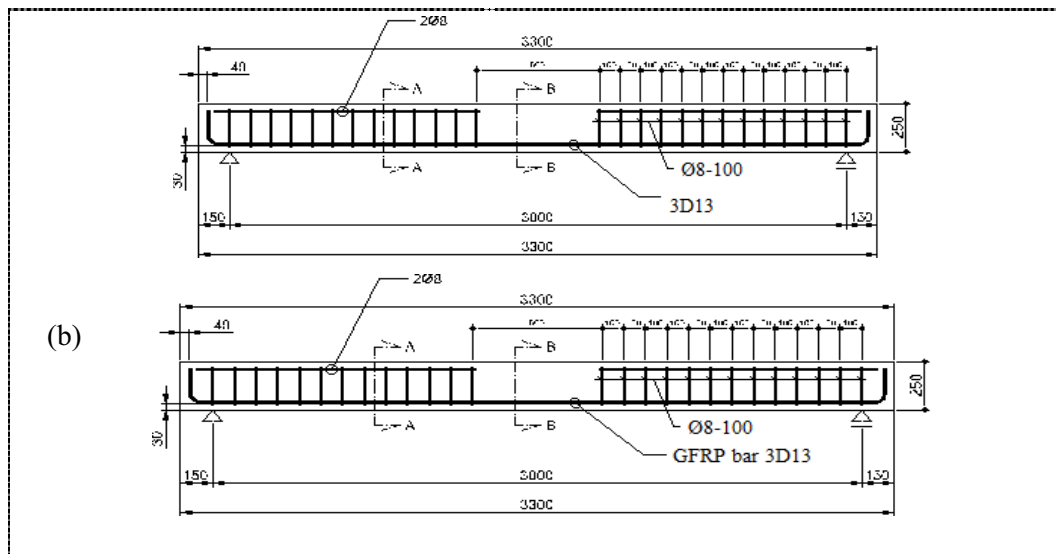


Figure 1. Control beam: (a); BK Beam (b); BFSB Beam

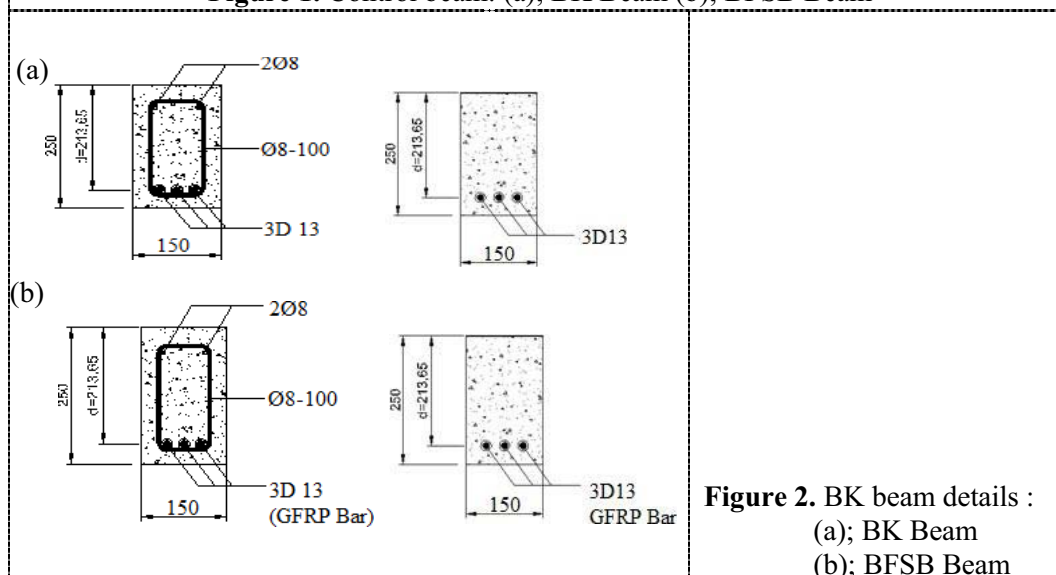
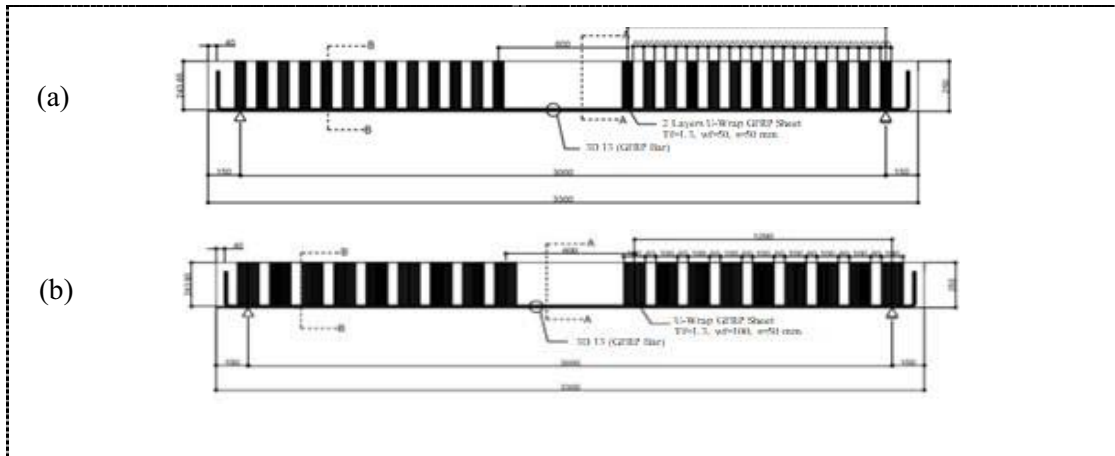


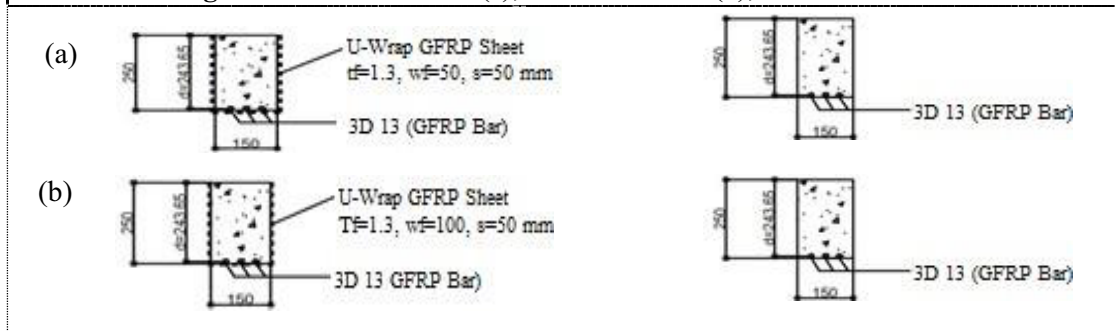
Figure 2. BK beam details :  
(a); BK Beam  
(b); BFSB Beam

2.2. BFGS50 and BFGS100 Beam

BFGS50 beam is a reinforced concrete beam that uses GFRP bar 3D13 reinforcement as pull reinforcement, GFRP sheet as Shear reinforcement U-Wrap GFRP sheet 1.3 mm thick, 50 mm wide 2 layers, installed at a distance of 50 mm and without concrete cover. BFGS100 beam is a reinforced concrete beam that uses GFRP bar 3D13 reinforcement as tensile reinforcement, GFRP sheet as Shear reinforcement U-Wrap GFRP sheet 1.3 mm thick, 100 mm wide and 50 mm spaced and without concrete cover.



**Figure 3.** Control beam : (a); BFGS50 Beam (b); BFGS100 Beam



**Figure 4.** BK beam details: (a); BFGS50 Beam (b); BFGS100 Beam

Reinforced concrete beams were tested with four loading points. The beam is supported by two simple supports (roll joints) with a bearing distance of 3000 mm. Two indirect load dividers with a distance of 600 mm from the steel profile.



**Figure 5.** GFRP Bar assembly



**Figure 6.** GFRP Bar installation



**Figure 7.** GFRP Sheet installation



**Figure 8.** Testing tools setting with static test equipment with two-point load

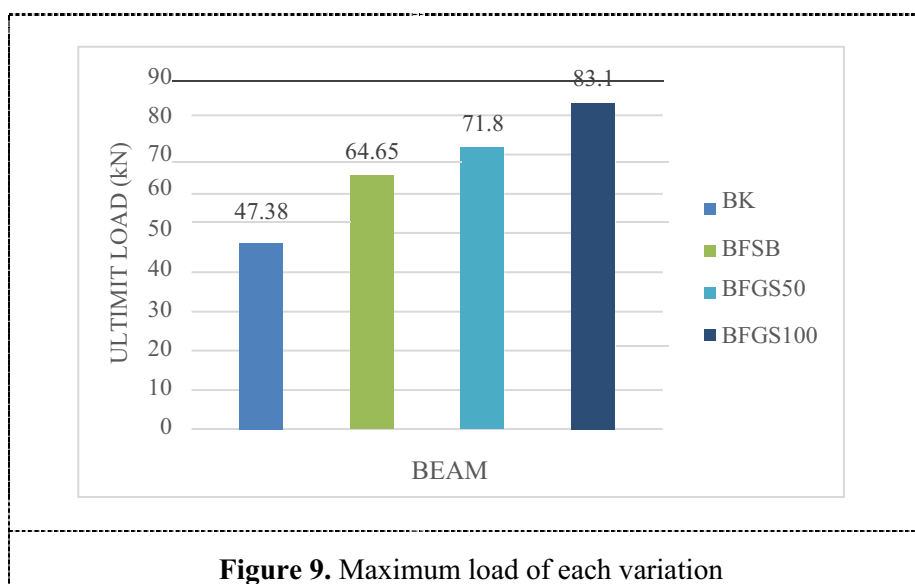
### 3. Result and Discussion

The mechanical characteristics of GFRP bar and GFRP sheet data were taken from the results of tests conducted by Fyfo.co.Ltd as the manufacturer of these materials. Table 1 shows a summary of the mechanical characteristics of GFRP bar reinforcement for diameter 13 and a summary of the mechanical characteristics of GFRP sheet in the form of a composite layer (GFRP sheet+epoxy).

**Table 1. Mechanical properties of GFRP bar and GFRP Sheet.**

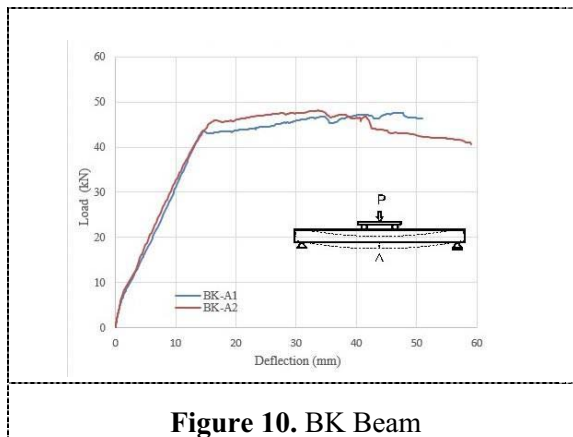
Mechanical properties	GFRP Bar	GFRP Sheet
Diameter	12.7 mm	-
Cross-sectional Area	129 mm <sup>2</sup>	-
Width	-	1.3 mm
Modulus of elasticity	44800 MPa	20900 MPa
Tensile Strength	708 MPa	460 MPa
Ultimate Tensile Strength	1.79 %	0.022 %

#### 3.1 Maximum load

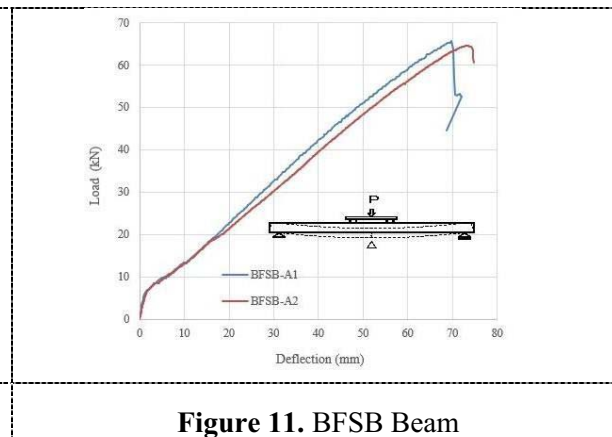


From Figure 9, it can be explained that the BFGS50 beam with GFRP bar and GFRP sheet without concrete cover has increased by 51.54% from the BK beam while the BFGS100 beam with GFRP bar and GFRP sheet as a shear strengthening has increased by 75.39%. This shows that the use of GFRP bars and GFRP sheets can increase the tensile strength of the beam.

### 3.2 Load and displacement relationship

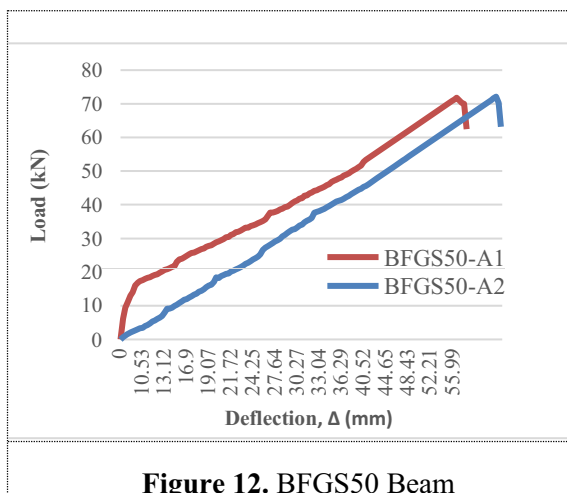


**Figure 10. BK Beam**

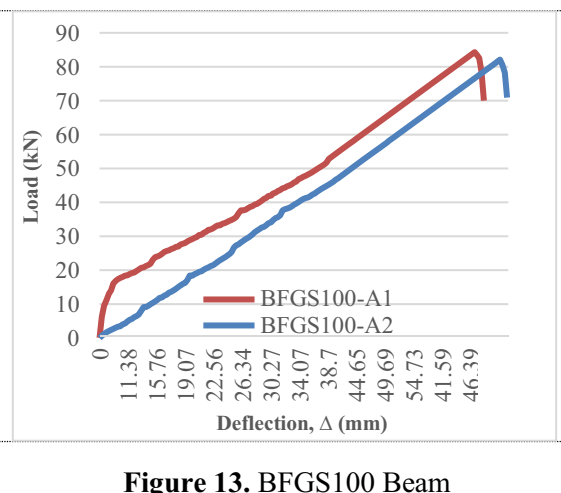


**Figure 11. BFSB Beam**

From figure 10 above, it explains that all samples of BK beams study three linear (tri-linear) curve patterns with flat peaks (plateaus). This curve pattern shows the deformation of the beam before cracking, after cracking and after yielding tensile reinforcement. The experimental ultimate load on all BK beams was greater than the design flexural load (flexure) but is still smaller than the design shear load. The ultimate load occurs after the beam undergoes the third phase where the tensile reinforcement has melted. All the BFSB beam samples in Figure 11 show a deformation pattern similar to the two linear (bi-linear) deformations without ductility as in the BK beam. The experimental ultimate load that occurs as shown is between the design flexural load and the design shear load.



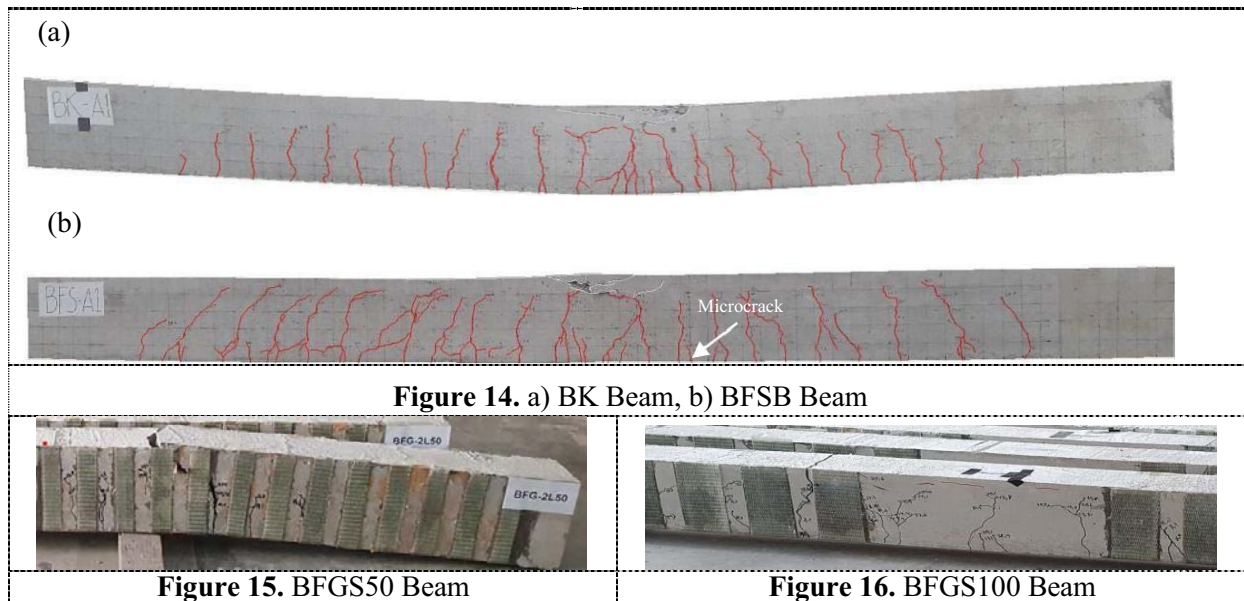
**Figure 12. BFGS50 Beam**



**Figure 13. BFGS100 Beam**

The pattern of the load-deflection relationship curve for the BFGS50 and BFGS100 beams as shown in Figures 12 and 13 is similar to that of the BFSB beam load-deflection relationship curve. Based on Figure 12 and Figure 13, it can be seen that the details of the load-deflection relationship in the initial and ultimate conditions of the BFGS50 and BFGS100 beams all show the same pattern as the BFSB beams. These results indicated that GFRP bar reinforced concrete beams without blankets using GFRP as shear reinforcement have the same load-deflection behavior as conventional GFRP bar reinforced concrete.

### 3.3 Crack patterns and failure modes



The development of cracks in the BK and BFSB beams shows the same crack pattern, namely the crack starts from the middle of the span and then spreads towards the support (Figure 14). The crack starts from the tension side of the beam and spreads to the compression side in the middle of the span. Failure Figures 15 and 16 show crack development in the BFGS50 and BFGS100 beams. The position of the reinforcement surface is parallel to the surface of the beam on the tension side. Cracks that appear at the beginning of loading are flexural cracks that occur in the constant moment region. The length of the crack in the constant moment region reaches half of the cross-sectional height. In the shear span region, cracks appear in the area that is not covered by the GFRP sheet.

### 4. Conclusions

- The flexural load capacity of BFGS50 and BFGS100 beams is higher than BK beams and BFSB beams. Although the use of GFRP bar reinforcement reduces the stiffness of the beam, the GFRP bar concrete beam without a concrete cover using GFRP sheet as shear reinforcement can increase the stiffness compared to conventional GFRP bar concrete beams.
- The failure mode that occurs in the BK and BFSB control beams with a concrete cover is experiencing compressive flexural failure. while the GFRP beams without concrete cover BFGS50 and BFGS100 experienced shear compression failure

### References

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