Performance of composite local glass fibre sheets and epoxy on flexural strengthening of reinforced concrete beams

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Abstract. Application of fibre sheets to strengthening reinforced concrete members has been investigated extensively. This paper presents the results on the use of composite local materials such as woven roving glass fibre sheets and epoxy to flexural strengthening of reinforced concrete beams. As many as 24 specimens with variation on the number of fibre layers (one and two layers) and end anchorage techniques (fasteners, U-shape straps, steel bolts) have been tested. It is shown that the effectiveness of glass fibre can be attained only on the specimens with one-layer sheet indicated by the rupture of fibre composite before specimen failure. Strengthening using two layers, bonding failure and delamination of fibre occur before the fibre develops maximum strength. Applying end anchors on the cut-off point of the two layers of fibreglass improves performance of the composite materials in the range of 5.0% to 16.5%. In addition, the end anchors also prevent delamination of the fibre sheet to occur at the cut-off point.

1 Introduction

Application of carbon, aramid and glass fibre reinforced polymer (CFRP, AFRP and GFRP) with epoxy bonding agent to strengthen reinforced concrete beams have been studied extensively for decades [1,2,3,4]. A major problem of the method is debonding of FRP from the concrete surface. Some efforts have been done to overcome debonding problems such as roughening the concrete surface [5,6] and using CFRP spike anchors [7]. These techniques can significantly improve the performance of the FRP strengthened beams. However, CFRP material is too expensive for local domestic applications since those materials are imported. There are local products of woven roving fibres glass sheet (GFRP sheet) that are usually used to build boats and canoes with local epoxy resin (®Avian) that may be used to flexural strengthen reinforced concrete beams. These composite materials between GFRP sheet and epoxy have been tested in the laboratory as concrete confinement [8] and shear strengthening of beams [9]. It was shown that those composite materials enabled to improve the specimens' capacities. The applications of woven roving GFRP sheet and local epoxy to flexural strengthen beams have been tested by [10,11]. This paper presents some parts of the test results in order to evaluate the

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performance of local materials and three end anchorage techniques as alternative strengthening materials.

2 Experimental program

The experimental program was planned in two phases. The 1st phase (Phase I) studied the effect of the layer's number and the 2nd phase (Phase II) studied the effect of end anchors on flexural behaviour of the strengthened beams. Phase I and II were done in a different time therefore the concrete strength in each phase was different.

2.1 Material properties

The concrete was mixed using maximum aggregate diameter of 20 mm for both phases. The average concrete compressive strength in phase I was 31.99 MPa and in phase II was 21.13 MPa.

The properties of local GFRP woven roving and epoxy used in the study were laboratory tested. It was found that the ultimate tensile strength of GFRP (f_{fu}) and epoxy (f_{au}) were 123.33 MPa and 51.43 MPa, respectively, with modulus of elasticity of 5535.4 MPa and 20192.2 MPa.

Beam specimens were made using longitudinal and transversal reinforcement of diameter 10 mm and 6 mm, respectively. The yield strength of steel reinforcement was 389 MPa obtained from laboratory tension test.

2.2 Specimens

The size of beam specimens in both phases were identical, and namely were 100x150x1100 mm with 2ϕ10 mm for longitudinal reinforcement and ϕ6 mm for stirrups with spacing of 62.5mm and 45mm for phase I and II, respectively. The closer stirrups spacing were used in the specimens of phase I due to incline shear cracks that occurred in the specimens of phase I. Detail specimens for phase I and II can be seen in Figure 1 and 2, respectively.

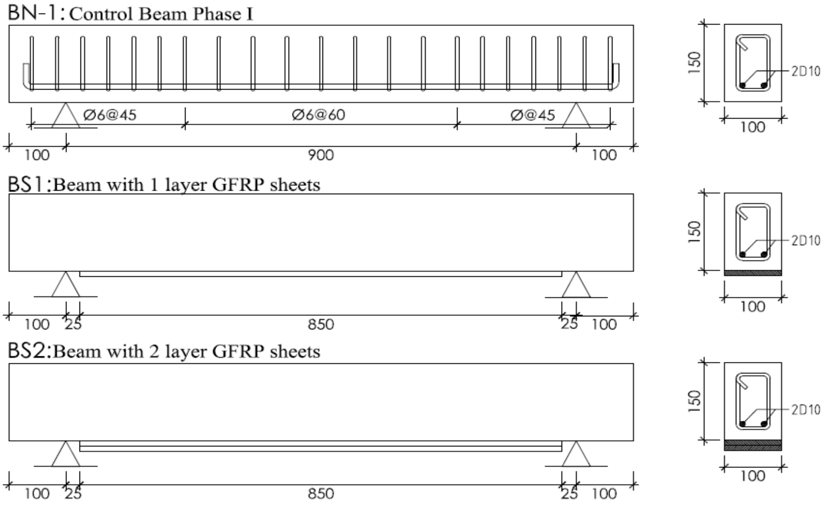


Fig. 1. Beam specimens in phase I.

Three specimens were made for each variation, therefore, 24 beam specimens were tested. All specimens were moist cured by covering all beam surfaces with wet burlaps and plastic sheets for seven days. After curing time, the specimens were stored in a safe place at room temperature until the time of testing.

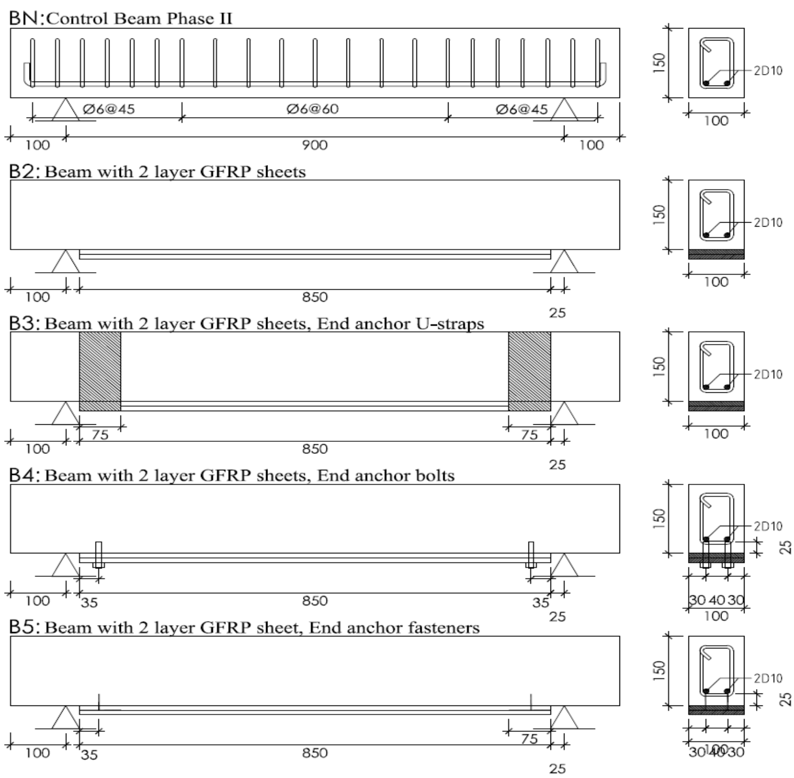
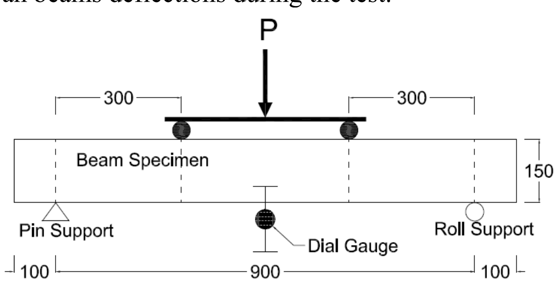


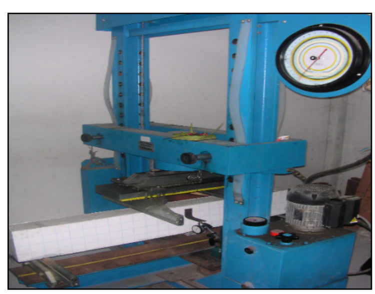
Fig. 2. Beam specimens in phase II.

2.3 Test setup and instrumentations

All specimens were tested after the concrete has aged for 28 days with four points loading setup as shown in Fig. 3. The beams were simply supported with load positions that were 300 mm from the supports. Two mechanical (or dial) gauges were used to measure mid-span beams deflections during the test.



(a) Schematic test setup



(b) Testing equipment

Fig. 3. Four points loading test setup (a) schematic test setup; (b) testing equipment.

3 Results and discussions

3.1 Mode of beam failure and capacities

All beam specimens failed in flexure whether it was preceded by GFRP rupture or GFRP debonding. Local material of GFRP and epoxy can be effective only for one layer indicated by the fibre rupture. Increasing GFRP layers results in GFRP debonding at the concrete interface as shown in specimens BS2 and B2 of phase I and II respectively. The application of end anchors in phase II can improve significantly the performances of GFRP sheet. End anchor of GFRP using bolts enabled the two layers of GFRP sheet to develop their capacity indicated by fibre rupture. End anchors using GFRP U-straps and fasteners failed and then followed by GFRP debonding at higher capacity than the control specimen. It was also observed that the end anchors enabled changes in the location of initial GFRP delamination from the cut off end to the middle span.

Table 1. Failure modes and load capacity of all specimens.

Specimen ID	Phase	Variations	Ultimate Loads (Pult) kN	Failure Modes
BN1	I	Control specimen Phase I	52,5	Flexure
BN2			54,0	Flexure
BN3			55,0	Flexure
BS11		One-layer GFRP	58,0	Flexure, GFRP Rupture
BS12			61,0	Flexure, GFRP Rupture
BS13			60,0	Flexure, GFRP Rupture
BS21		Two layers GFRP	62,5	Flexure, GFRP debonding
BS22			60,5	Flexure, GFRP debonding
BS23			60,0	Flexure, GFRP debonding
BN1	II	Control specimen Phase II (w/o GFRP sheet)	51.5	Flexure
BN2			50.0	Flexure
BN3			51.5	Flexure
B21		Two layers GFRP (w/o end anchors)	55.0	Flexure, GFRP debonding
B22			57.5	Flexure, GFRP debonding
B23			60.0	Flexure, GFRP debonding
B31		Two layers GFRP with end anchor of U-shape straps	60.0	Flexure, Anchorage rupture, GFRP debonding
B32			60.0	Flexure, anchorage rupture, GFRP debonding
B33			61.0	Flexure, GFRP rupture
B41		Two layers GFRP with end anchor of bolts	61.0	Flexure, GFRP rupture
B42			67.0	Flexure, GFRP rupture
B43			60.0	Flexure, GFRP rupture
B51		Two layers GFRP with end anchor of GFRP fasteners	63.0	Flexure, GFRP rupture
B52			69.0	Flexure, Anchorage rupture, GFRP debonding
B53			69.0	Flexure, Anchorage rupture, GFRP debonding

3.2 Beam deflections

Load-deformation behaviours of all specimens tested in phase I and II can be seen in Figures 4 and 5, respectively. It is shown that before the yielding of flexure reinforcement occurs, load-deflection curves of all specimens are similarly indicating that there is no significant improvement on beam stiffness in this stage. However, the local GFRP sheet bounded with local epoxy products to strengthen beams can improve the beam capacity. Once the GFRP failure occurs due to fibre rupture or debonding, all beams were back to the stage of yielding plateau to the capacity of control beam specimens. It occurred in all strengthened specimens both in phase I and II.

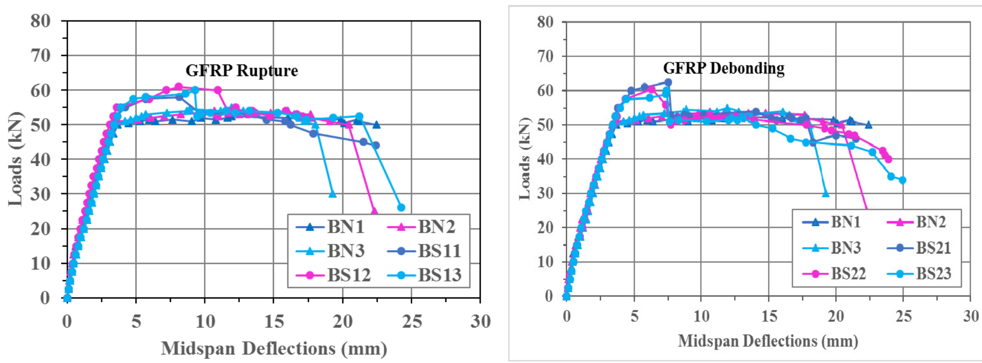


Fig. 4. Relationship between loads and midspan deflections of beams in Phase I.

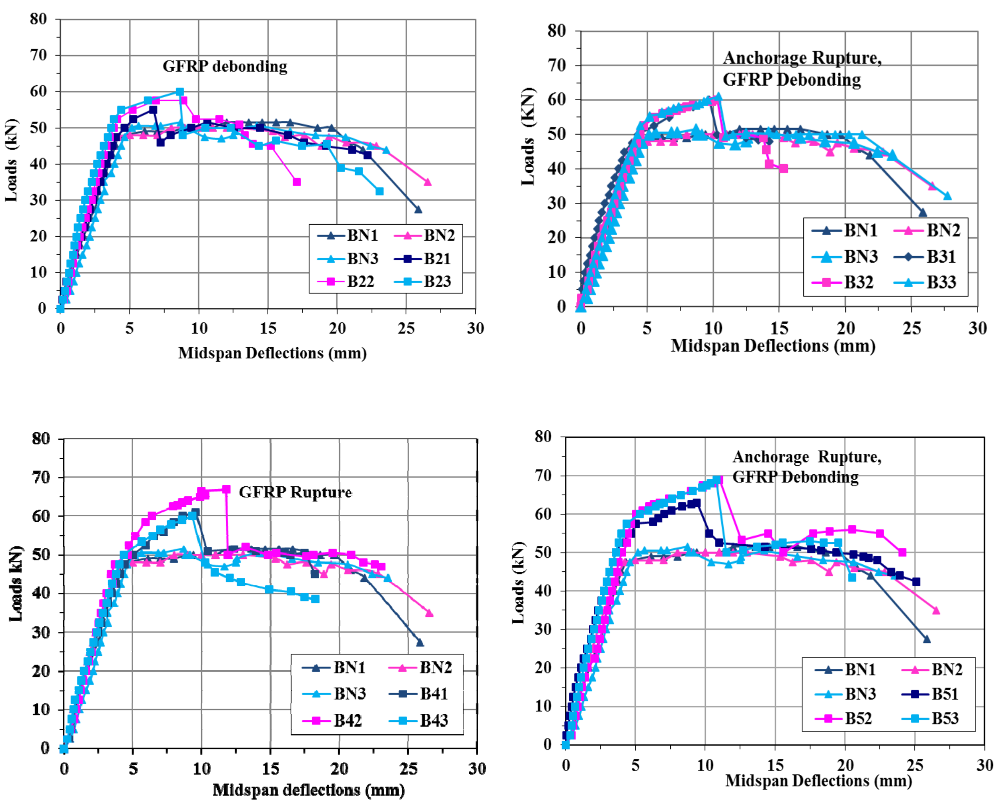


Fig. 5. Relationship between loads and midspan deflections of beams in Phase II.

3.3 Specimen capacities

The local material GFRP sheet and epoxy can improve the flexural capacity of the beams as can be seen from Table 2. From the specimen in phase I, the flexural capacity of the beams can be increased by 10.8% and 13.4% from that of the control beam, respectively, for one and two layers. It was also obtained that applying end anchors at both ends of the GFRP sheets can further increase the beam capacities as shown from the specimens in phase II. The specimens with end anchors of GFRP fastener gave the highest capacities although it failed during the test (in B52 and B53). However, it was a gradual failure in which the GFRP sheet was able to develop greater strength. Similar results on FRP anchor or spike to overcome FRP debonding problem were also reported by [7].

Table 2. Beam flexure capacities.

Beam ID	Phase	Loads (Pult) kN	M_{ult} (kNm)	$M_{ult,avg}$ (kNm)
BN1	I	52.5	7.88	8.08
BN2		54.0	8.10	
BN3		55.0	8.25	
BS11		58.0	8.70	8.95
BS12		61.0	9.15	
BS13		60.0	9.00	
BS21		62.5	9.38	9.15
BS22		60.5	9.08	
BS23		60.0	9.00	

Beam ID	Phase	Loads (Pult) kN	M_{ult} (kNm)	$M_{ult,avg}$ (kNm)
BN1	II	51.5	7.73	7.65
BN2		50.0	7.50	
BN3		51.5	7.73	
B21		55.0	8.25	8.63
B22		57.5	8.63	
B23		60.0	9.00	
B31		60.0	9.00	9.05
B32		60.0	9.00	
B33		61.0	9.15	
B41		61.0	9.15	9.45
B42		67.0	10.05	
B43		60.0	9.00	
B51		63.0	9.45	10.05
B52		69.0	10.35	
B53		69.0	10.35	

4 Conclusions

The following conclusions can be drawn on the performances of local GFRP and Epoxy materials based on test results and discussions:

1. For the beams without end anchors, the full strength of GFRP can only be achieved in one-layer GFRP specimens. Up to two-layers GFRP sheets, the debonding failure occurred at the interface between concrete and epoxy results in GFRP delamination.
2. The beam flexural capacity can be increased by 10.8% and 13.4% of the control beams for one and two layers of GFRP sheet, respectively.
3. In the presence of end anchors performance of GFRP improved. End anchors changes the initial GFRP delamination from cut off end to the middle beam span.
4. The flexural capacity increased by 31.4%, 18.3% and 22.9% of the 2^{nd} phase control beams, respectively for fastener, U-strap and bolts anchor's types.

References

1. C. K. Y. Leung, Cement & Conc. Composite. **28**, 742-748 (2006)
2. F. Ceroni, Const and Build. Mat. **24(9)**, 1547-1559 (2010)
3. N. Attari, S. Amziane, and M. Chemrouk, Const & Build. Mat. **37**, 746-757 (2012)

4. S. Tudjono, H. A. Lie, and B.S. Gan. Proc. Eng. **125**, 1070-1075 (2015)
5. S. Tudjono, H. A. Lie, A. Hidayat, and Purwanto, Proc. Eng. **171**, 1116-1122 (2017)
6. S. Tudjono, H. A. Lie, and B.S. Gan, Int. J. of Tech. **1**, 5-15 (2018)
7. R. Kalfat and R. Al-Mahaidi, Comp. Str. **155**, 89-98 (2016)
8. I. K. Sudarsana, A. A. Sutapa, J. Ilmiah T.Sipil, **11(1)**, 1-10 (2007)
9. P. Deskarta, J.Ilmiah T.Sipil, **13(2)**, 199-208 (2009)
10. I. M. A. Sudiasa, Final Project, PS.T.Sipil-Unud, (2003)
11. E. Artawa, Final Project, PS. T. Sipil-Unud, (2004)