Flexural Behaviour of RC Beam Strengthened with Hybrid of GFRP and Wiremesh

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Abstract, this paper presents selected results of experiment on flexural tests of RC beam strengthened with hybrid of GFRP and wire mesh. Beams have total length of 1700 mm, width and height of 150 mm and have compressive strength, f'_c of 26.43 MPa. Three beams consisted of one control beam without strengthening and other two beams strengthened with wire mesh and combined GFRP and wire mesh respectively. The beams were tested under four points bending. The results showed that the beam strengthened with hybrid of GFRP and wire mesh showed higher stiffness and load carrying capacity than other two beams.

Keyword: RC beam, Hybrid, GFRP, Wire mesh.

INTRODUCTION

The strengthening of reinforced concrete structure using Fiber Reinforced Polymer (FRP) has been implemented for more than two decades in construction industries (Zoghi, 2014). This advance material offers some benefits such as corrosion resistance, not conduct electricity, high tensile strength and available in market.

Previous study has been done to investigate the flexural behavior of RC beams strengthened with CFRP strip (Alami, 2006). Strengthening with 1 layer of CFRP Strip increased 41.13% compared with unstrengthening beam. However, 2 layer strengthening with CFRP strip was only increase 16.8 %. Both strengthening beams failed in local failure at the end of the laminate due to local stress. Concrete cover was broken and this category failure known as ripping-off. This indicated that thickness of strip laminate influenced failure of the beam. Another study of RC beams strengthened with GFRP wrap (Alami, 2010) showed the same failure where the beams failed at the end of laminated.

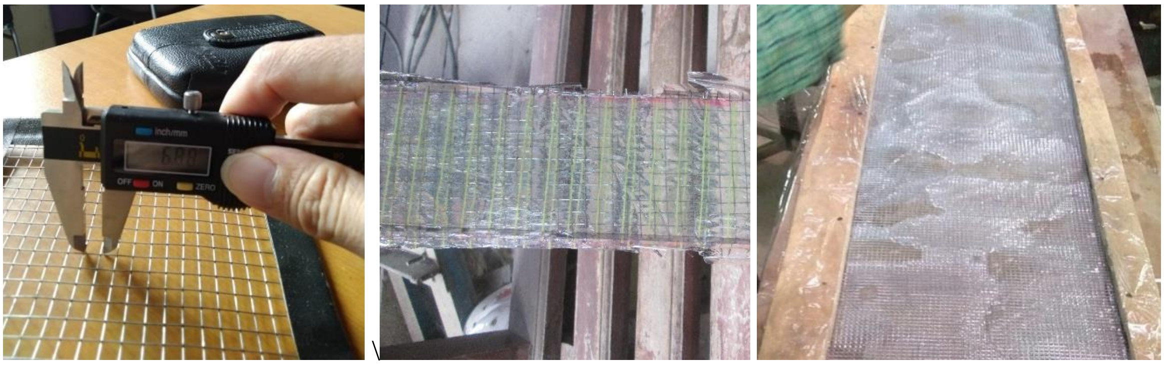
This study combined two material which were wire mesh and glass fiber sheet encapsulated in epoxy resin for strengthening system of RC beams. Wire mesh is material used as reinforcement in ferrocement and this material suitable used in strengthening of RC beam (Khan,et.al, 2013). By combining wire mesh and glass fiber sheet encapsulated in epoxy resin as single composite, it can increase flexural behavior of strengthening of RC beams.

RESEARCH METHODOLOGY

This study used experimental method and theoretical method to investigate the flexural behavior of RC beams strengthened with hybrid of wire mesh and Glass Fiber Reinforced Polymer (GFRP). Beams have span of 1.5 m, width of 150 mm and height of 150 mm. Theoretical method for analysis beam with external strengthening system was complied with ACI 440.2R-2008 standard (ACI 440, 2008) and for unstrengthening beam complied with ACI 318-2014 (ACI 318, 2014).

Material Properties

Beams was designed to use compressive strength, f'_c of 25 MPa and confirmed test was found 26.43 MPa. Beams was reinforced with mild steel round bar with diameter of 9 mm as flexural reinforcement and diameter of 6 mm as stirrups. It confirmed the yield strength of this reinforcement was 406 MPa. For strengthening system, it used wire mesh with diameter of 0.55 mm and 6.05 mm wide opening. Glass fiber sheet type SEH 51A combined with epoxy resin type S to make composite laminate with thickness of 1.3 mm for one layer. This composite material have ultimate tensile strength of 460 MPa, flexural elastic modulus of 20.5 GPa and ultimate strain of 1.76 %. Figure 1 shows material used for flexural strengthening system in RC beam.



(a) (b) (c)

Figure 1. Material used in experiment; (a) wire mesh; (b) laminate wire mesh; (c) composite laminate hybrid of GFRP and wire mesh

Loading Configuration

Figure 2 shows beam arrangement under four point bending with constant moment zone of 300 mm. For strengthening beams using composite wire mesh only and hybrid of GFRP and wire mesh, the composite laminate has wide as the same as concrete beam and its length up to 25 mm approaching both supports. Beam was strengthened with hybrid of 2 GFRP layers and 2 wire mesh layers has thickness of 5.20 mm and beam was strengthened with 2 wire mesh layers has thickness of 3.33 mm. Beams was loaded incrementally until it collapsed. Two dial gauges located at the bottom of beams at mid span to record deflection during load applied. Four strain gauges were attached to the top of beam, 14 mm below top, at steel round bar and at composite laminate to collect strains for this system. This strain data were evaluated to study the flexural behavior of these beams. Crack measurement was also used to record first crack on the beam and other cracks during the test.

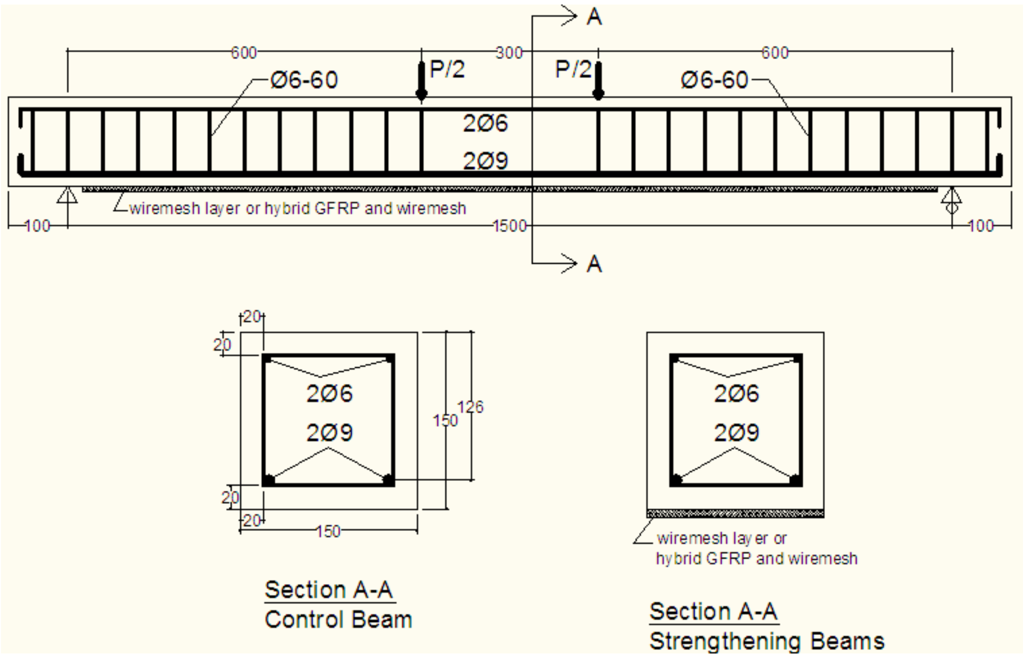


Figure 2. Simply supported beam under four point bending. Section A-A shows control beam section and beams with strengthening system.

RESULTS AND DISCUSSIONS

Figure 3 shows the relationship between applied load and mid-span deflection of three beams. It shows that beam with hybrid strengthening of 2 layers of wire mesh and 2 layers of GFRP (B3) has higher load carrying capacity, stiffness compared with control beam (B1) and beam strengthened with 2 layers of wire mesh (B2). However, the beam B1 shows higher ductility compared with other. It shows from maximum deflection where the beam B1 has highest deflection and ductility index. This ductility index is ratio between maximum deflection and deflection at beam yield. Table 1 showed that beam B3 has higher first crack load which was 1.86 Ton compared with B2 and B1 which were 1.71 Ton and 1.12 Ton respectively.

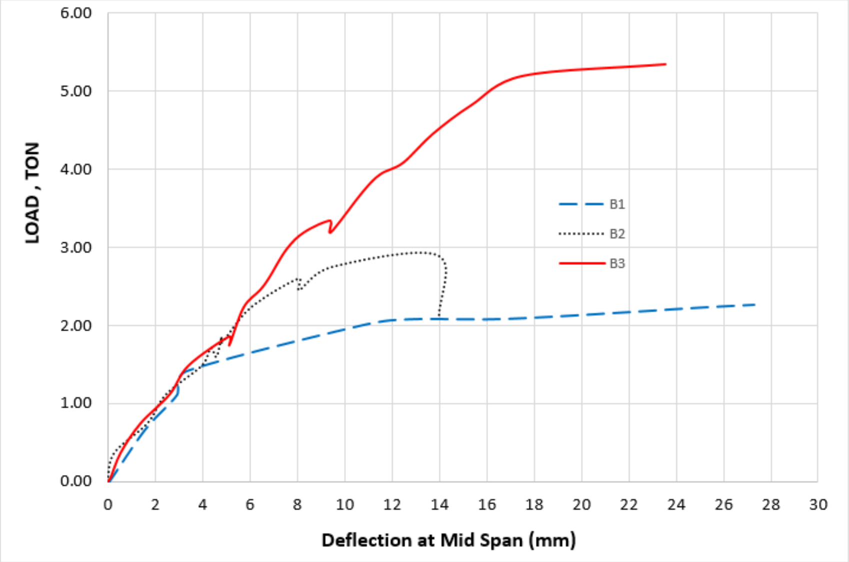


Figure 3. Relationship between load and mid-span deflection of three beams.

Beam B1, B2, and B3 have ductility index of 2.29, 1.51, and 1.34 respectively. In term of load carrying capacity, the beams B1, B2 and B3 have maximum load of 2.27 ton, 2.899 ton, and 5.352 ton respectively. Whereas, theoretically, the maximum load for beam B1, B2 and B3 were 1.92 Ton, 4.24 Ton and 9.38 Ton respectively. Beam B1 was 19.27% lower than experiment result. The beam with hybrid strengthening of 2 layers of wire mesh and 2 layers of GFRP (B3) increased the maximum load of 135.77% compared with unstrengthening beam (B1), whereas the beam with strengthening of two layers of wire mesh only increased 27.71% compared with beam B1.

Table 1. Comparison between experimental results and theoretical results for maximum load of beams and other parameter results.

BEAM	B1	B2	B3
Theory (Max Load)	1.92 Ton	4.240 Ton	9.380 Ton
Experiment (Max Load)	2.27 Ton	2.899 Ton	5.352 Ton
% Different	19.27 %	46.25 %	75.26 %
Ductility Index (experiment)	2.29	1.51	1.34
First crack (experiment)	1.12 Ton	1.71 Ton	1.86 Ton

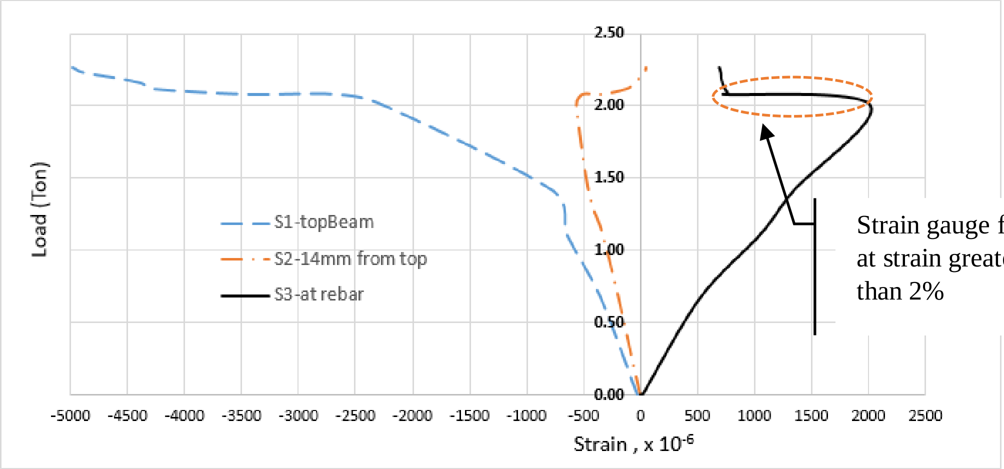


Figure 4. Relationship between load and strains on Beam B1.

Figure 4 shows the relationship between applied load and strains at several location on middle of beam B1. Control beam B1 failed at maximum load of 2.27 Ton where concrete compression strain has reach 0.005. At the time concrete rupture, the strain in reinforcement has yield (> f_y/E =0.02). However due to the maximum capacity of strain gauges which can cover only up to 2%, this increasing yielding strain cannot be seen in curve at Figure 4. This beam B1 failed in ductile manner.

Figure 5,6 and 7 shows cracks pattern of three beams, B1, B2 and B3. All cracks pattern showed that beams failed in flexural behaviour. First crack of all beams started inside constant moment zone. Beam B1 and B2 failed with single opening crack in the middle of the beam, where as beam B3 did not. Crack pattern of B3 was more spread extend along the beam with norrow opening crack.

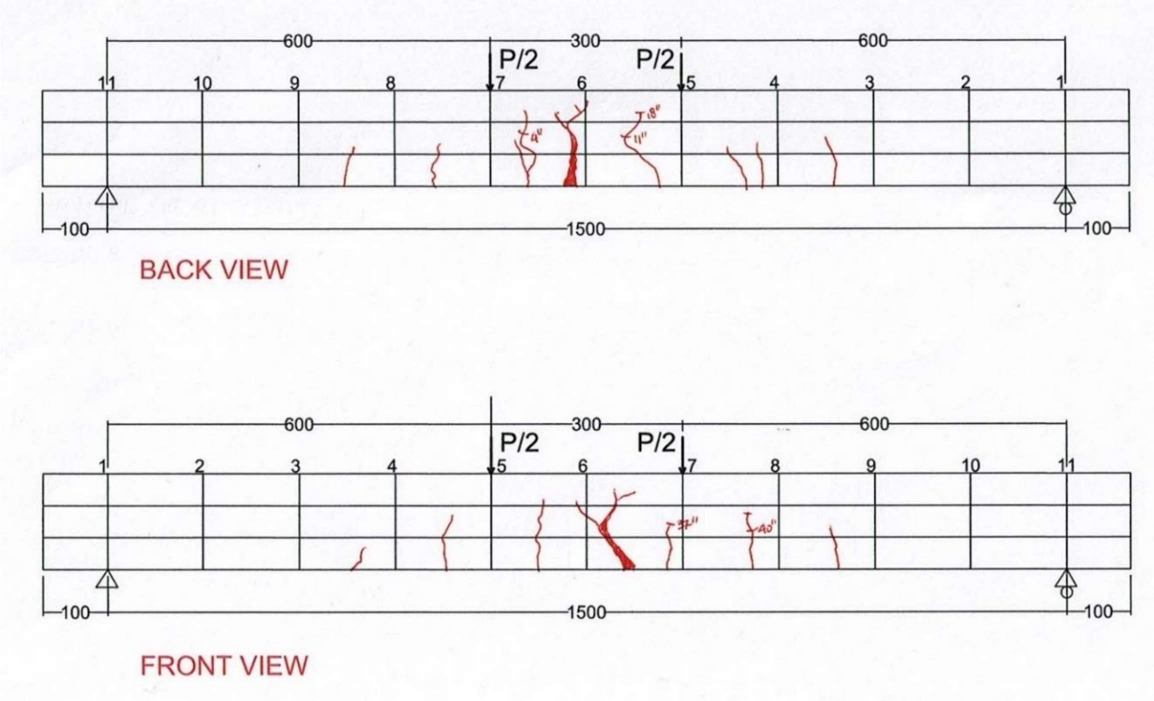


Figure 5. Crack pattern occurred at control beam (B1)

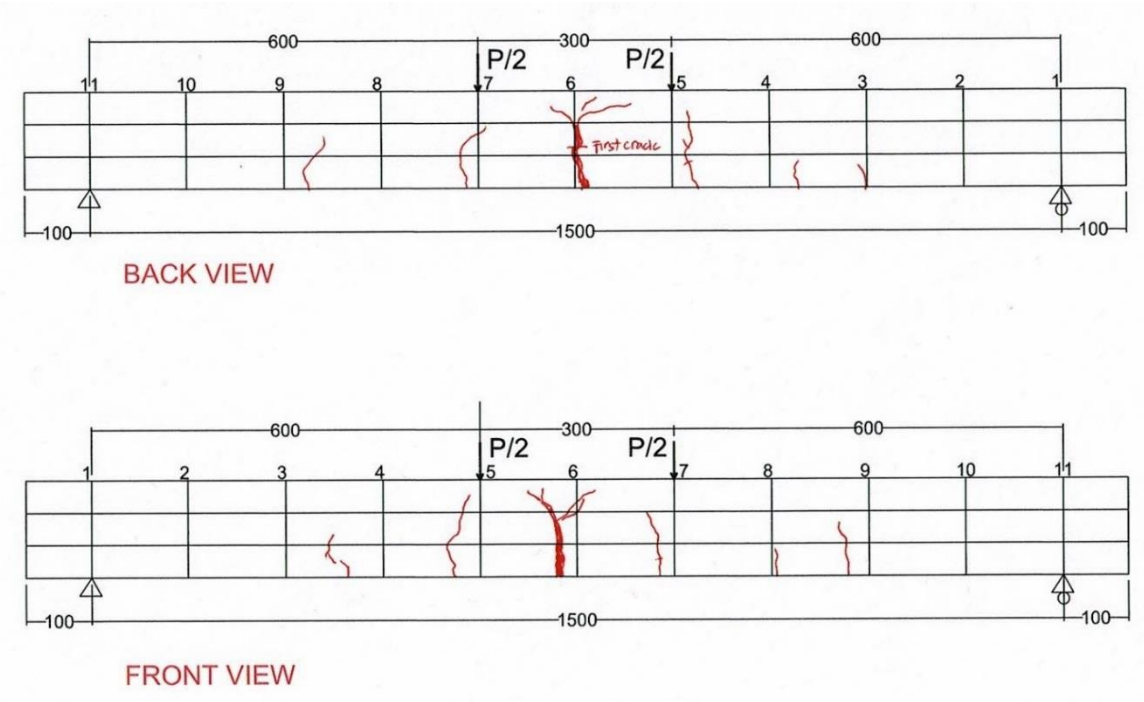


Figure 6. Crack pattern occurred at beam strengthened with 2 layer of wire mesh (B2)

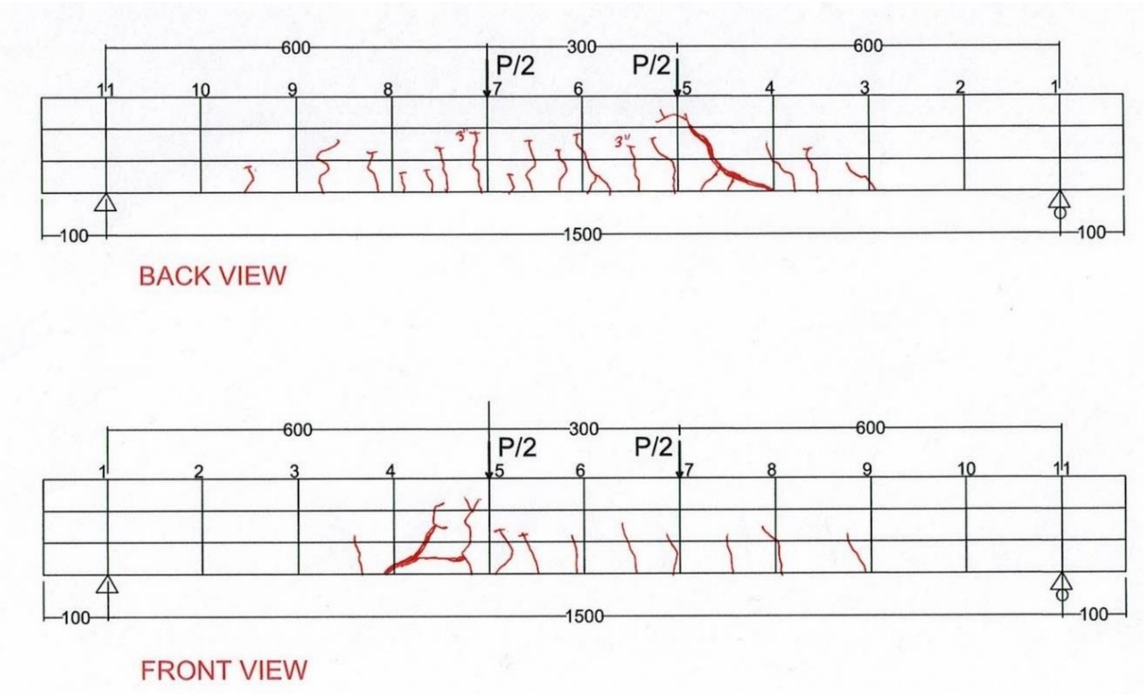


Figure 7. Crack pattern occurred at beam strengthened with 2 layer of wire mesh and 2 layer of GFRP (B3)

Figure 8 shows two different characteristic of strengthening beams failure. Beam B2 shows that laminate wire mesh snap due to wide opening concentrated cracks at mid-span of beam. Whereas beam B3 shows that beam start to de-bonding from crack which extend to beam support.

(a) (b)

Figure 8. (a) Strengthening beam (B2) failed due to laminate snap at mid-span bottom beam; (b) Beam B3 failed due to de-bonding at one end laminated.

CONCLUSIONS

It concluded that strengthening with hybrid of GFRP and wire mesh had significant improvement in increasing stiffness and maximum flexural load capacity of RC beam compared with unstrengthening beam and strengthening beam with only two layers of wire mesh. This hybrid system increased maximum load of 135.77% compared with unstrengthening beam and 84.62% compared with strengthening beam with two layers of wire mesh.

Strengthening beam with two layers of wire mesh failed at middle of the beam with fracture on wire mesh layer due to single wide opening concentrated crack. However, strengthening hybrid beam failed at different way which the beam failed due to de-bonding at the end plate of strengthening (25 mm from left-beam support).

In term of first crack load, strengthening beam with hybrid of GFRP and wire mesh has highest increasing first crack load compared with other two. First crack load of B3 and B2 increased 66% and 52.7% compared with unstrengthening beam B1.

Crack pattern of strengthening hybrid of GFRP and wire mesh (B3) looked better than other two beam, where cracks spread more extend along the beam. There is no single wider open crack occurred at this beam, whereas other two otherwise.

ACKNOWLEDGMENT

We would like to take this opportunity to thank to PT Fyfe Indonesia for providing us the material for research and to Faculty of Engineering, University of Lampung who providing grant for sharing contribution to support this research project as well.

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