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Flexural Behavior of Glulam-Concrete Composite Beams Reinforced Using CFRP Sheets

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ABSTRACT
Glulam-concrete composite beams can be a solution for bridge construction with the principle of flexible beams, where the stress must be designed with the upper fibers to withstand the pressure and the lower fibers to withstand the tension. In this case the compressed area is held by the concrete slab, the tensile area is held by wood and the flexural area is reinforced using CFRP (Carbon Fiber Reinforced Polymer) sheets. The experimental study aims to analyze the increase in the value of strength, stiffness and ductility of composite beams by using the number of CFRP sheets as reinforcement in the flexural area of the composite beam. The number of test objects was 4 composite beams consisting of 1 control beam without CFRP reinforcement (BN) and 3 test beams using the total reinforcement of 1 CFRP sheets (BFRP-1), 2 CFRP sheets (BFRP-2) and 3 sheets CFRP (BFRP-3). Flexural testing is carried out with three points of loading using the displacement control method. The test results show that the composite beam BFRP-1, BFRP-2 and BFRP-3 can increase the strength value respectively 3.07%; 9.84%; 1.68%, ductility 72.96%; 38.97%; While the BFRP-1 and BFRP-2 composite beams by 21.28% were able to increase the stiffness by 9.45% and 4.70%, but the BFRP-3 test beam using 3 sheets of CFRP sheets experienced a decrease in stiffness by 16.00%. Composite beams that are reinforced using 1 sheet and 2 sheets of CFRP in the flexural area show better / effective strength, stiffness and ductility than using 3 CFRP sheets.

Keywords: *Composite beams, CFRP sheets, flexural, glulam beams*

1. INTRODUCTION

Composite structure is a form of structure that can consist of two or more different materials that work together to withstand the working load. Composite structure is able to provide good structural performance and is more effective in increasing loading capacity, stiffness and ductility. The availability of wood is closely related to the forest potential in an area. Like Indonesia, which has quite an area of tropical forests, of course it will be very supportive of the construction process of composite bridges made of wood. The advantages of wood are that it is light and easy to work with but has limited dimensions, technology to support wood as a bridge construction, namely lamination where the outside will receive a greater load than the inner wood so that the outer wood must have greater strength than the inner wood [1]. Based on the direction of the laminate arrangement against loading, laminated beams are divided into horizontal and vertical laminated beams. This concept adopts the principle of the strength of bamboo from the inside to the greater part of the skin. [2]. Composite material is a combination of two or more different materials that behave as a unit when supporting external forces or loads. Composite materials take advantage of the physical and mechanical properties of each forming material to form a new, better material, and have different characteristics compared to the characteristics of the forming material [3]. In terms of structure, wood is quite good at resisting tensile, compressive and bending forces. The compressive stress can be resisted by the concrete layer and the tensile stress by the wood. Difficulty producing sufficient strength and stiffness for long span logs. The use of CFRP (Carbon Fiber Reinforced Polymer) sheets in the bending part of laminated wood beams can increase the maximum load 18.6% to 56.0%, stiffness 11.1% to 19.5%, and the ultimate tensile strain increases 14.6 to 24 , 8% [4]. Strengthening using FRP types CFRP and GFRP on laminated rubber wood blocks on the stress side experienced an increase in flexural stiffness 36.91% to 40% by using GFRP (Glass Fiber Reinforced Polymer) while using CFRP could increase the flexural stiffness 45.86% to 50.62% [5]. The addition of CFRP plates with an area percentage of 0.15% and 0.42% was able to increase the ultimate load by 31.8% to 44.5%, the maximum load from 27.1% to 80% and stiffness from 32.6 to 87.6 %. There is no debonding or delamination between CFRP plates and wood beams, where the load bearing capacity depends on the strength of the wood and CFRP [6]. The number of sheets, length and width of the FRP bond greatly determine the increase in strength, stiffness and ductility of laminated beams [7]. Glulam-reinforced concrete composite structures in Indonesia have not been developed much, especially in relation to their application for bridge beam components. The presence of wood as part of the composite section is expected to reduce the volume of concrete. The experimental study aims to analyze the effect of the number of CFRP sheets on the load (P), stiffness (K), deflection (δ) and ductility (μ) in the glulam-concrete composite beam structure.

2. RESEARCH METHOD

The dimensions of the glulam-concrete composite beam specimen with glulam dimensions 100 mm x 180 mm and reinforced concrete slab dimensions 75 mm x 300 mm with a composite beam span length of 2.480 mm. Composite beams use camphor wood concrete with a quality of f'c 22 MPa and reinforcing steel with quality BJ37. The number of test beams 3 consists of 1 test beam without CFRP reinforcement as a control beam (BN), 1 test beam reinforced with one CFRP sheet (BFRP-1), 1 test beam reinforced with two CFRP sheets (BFRP-2) and 1 test beam CFRP triple sheet reinforcing beam (BFRP-3) (Table 1). Flexural testing of composite beams with three points of loading which are placed on a simple pedestal. (Figure 3) The loading was carried out using the displacement control method until the test beam collapsed. The results of the bending test will get a graph of the relationship between load and deflection

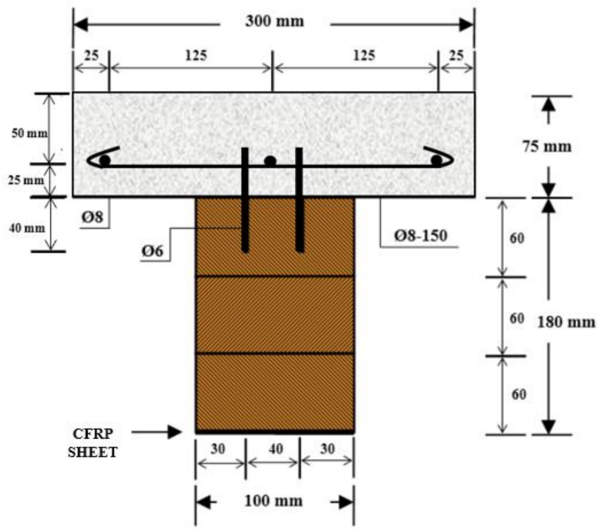

Figure 1 Cross section of the composite test beam.

The process of making glulam beam consists of: lamination manufacturing, drying and sorting, surface bonding, pressing and finishing and manufacturing of laminate. The wood that will be used for the manufacture of lamina is cut to a predetermined size. Then the adhesive process is carried out using PVAc (Polyvinyl Acetate) glue where the adhesive process used in the manufacture of laminated blocks must meet the requirements for use in dry conditions (water content <16%). The laminate needs to be dried properly to minimize dimensional changes and improve properties structurally. The lamina are then arranged into a defined shape. After the adhesive has reached the proper open assembly time, pressure is applied. In several studies, pressing was carried out using cold pressing with a pressure level of 2 MPa with a varying duration of pressuring between 24 hours. After the laminated block has been removed from the pressing system, the wide surface is ground to remove the adhesive escaping between adjacent laminates and to flatten the sides of the lamina. Thus, the finished laminate block is slightly smaller than the nominal size of the laminate. (Figure 2)

Figure 2 Glulam beam making process.

Figure 3 Setting up the composite beam test

Table 1. Code and number of test beam

Code	Type of Test Beams	Number
BN	Control Beam	1 Beam
BFRP-1	Reinforcement of 1 CFRP Sheet	1 Beam
BFRP-2	Reinforcement of 2 CFRP Sheet	1 Beam
BFRP-3	Reinforcement of 3 CFRP Sheet	1 Beam

3. ANALYSIS METHOD

3.1. Strength

Strength is the ability of a structure or structural component to withstand loads, moments and internal forces. The strength assessment will be carried out from the results of the composite beam test against the maximum load value (Pmax) obtained.

3.2. Stiffness

The stiffness of the glulam-concrete composite beam with the addition of 1 (one), 2 (two) and 3 (three) sheets of CFRP was analyzed based on the load value and proportional limit deflection using Equation 1.

$$K = \frac{Pp}{\delta p} \qquad (1)$$

Information:

K : stiffness (kN/mm)

P_{prop} : proportional load (kN)

δ_{prop} : proportional deflection (mm)

Analysis of the stiffness of the test beam based on the proportional limit load is P_{prop} = 0.4 Pmax with proportional deflection δ_{Prop} = δ 0.4 Pmax is formulated based on the Commonwealth Scientific and Industrial Research Organization (CSIRO) standard [8] (Figure 4)

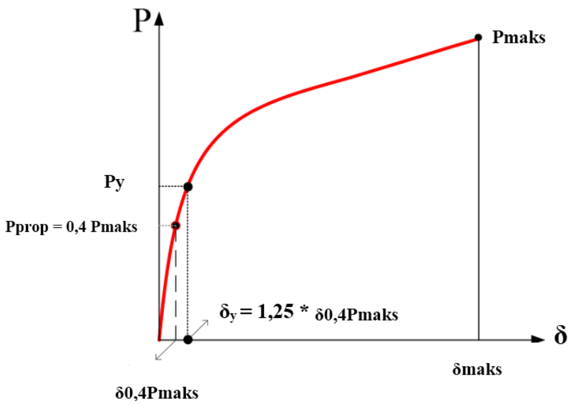

Figure 4 Determining Pprop and Py in the load-deflection relationship of the CSIRO method.

3.3. Ductility

The ductility value of the glulam-concrete composite beam with the addition of 1 (one), 2 (two) and 3 (three) sheets of CFRP is calculated based on the Commonwealth Scientific and Industrial Research Organization (CSIRO) standard. Ductility is the ratio value of δu / δy where δy and δy are the deflection at the ultimate load and the deflection at the yield limit load, respectively. The deflection value at the ultimate load δu was determined based on the ultimate PU load = 0.8 Pmax and the yield limit deflection value δy = 1.25 * δ0.4Pmax as can be seen in Figure 3, while the ductility value (μ) was calculated using Equation 2.

$$\mu = \frac{\delta u}{\delta y} \qquad (2)$$

Information:

μ : ductility value

δu : ultimate deflection (mm)

δy : deflection at yield load (mm)

4. RESULT AND DISCUSSION

4.1. Test Result

The results of glulam-concrete composite beam testing without and using the CFRP sheet are presented in the form of a load-deflection relationship graph (Figure 5).

4.2. Discussion of test result

The discussion of the test results was carried out on the strength, stiffness, ductility and failure mode that occurred in the test beam.

4.2.1. Strength of composite test beam

The strength of the glulam-concrete composite test beam is generated from the graph of the load and deflection relationship to get the maximum load and deflection value for each beam. The results of the strength analysis are shown in Table 2.

Table 2. Composite test beam strength

Code	P_{maks} (kN)	δ_{maks} (mm)
BN	81.32	83.70
BFRP-1	82.82	116.65
BFRP-2	89,32	95,22
BFRP-3	82.69	89.76

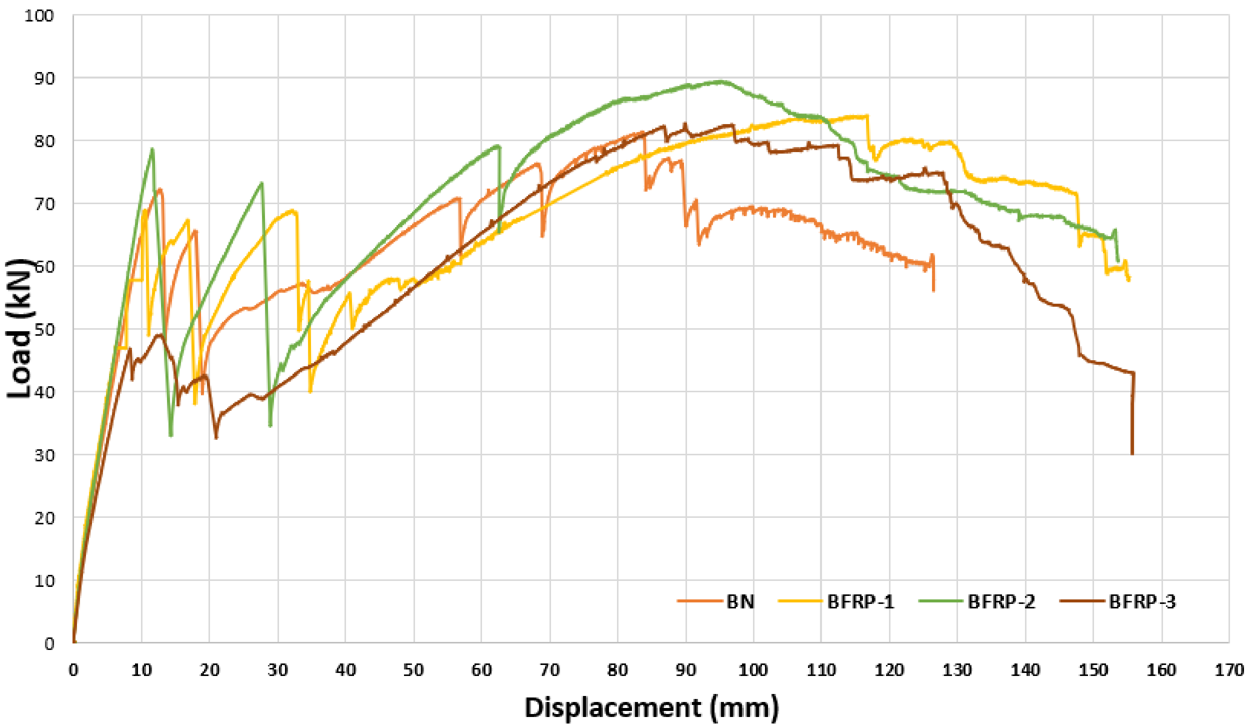

Figure 5 Graph of the load-deflection relationship of the composite test beam BN; BFRP-1; BFRP-2 and BFRP-3

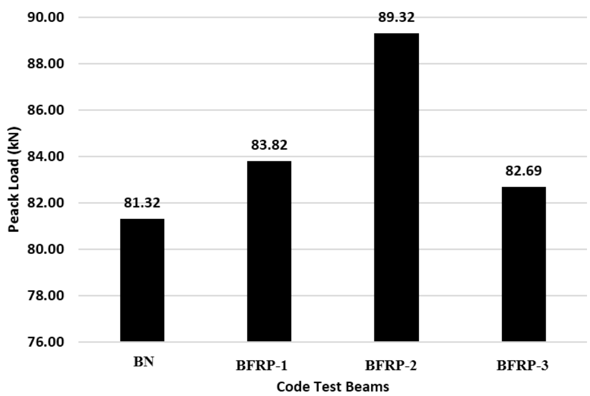

Figure 6 Barchart strength of composite test beam BN, BFRP-1, BFRP-2 and BFRP-3

As shown in Table 2 and Figure 6, the use of one CFRP sheet (BFRP-1) in the flexural area of the composite beam can increase the strength by 3.07% whereas using two CFRP sheets (BFRP-2) increases the strength of 9.84% but three CFRP sheet can only increase the strength value of 1.68% compared to composite beams without using a CFRP (BN) sheet. Thus the addition of CFRP sheets from two sheets (BFRP-2) to three sheets (BFRP-3) is not able to increase the strength value of 89.32 kN (100%) to 82.69 kN (92.57%). The percentage increase in load due to the addition of the CFRP sheet, that CFRP can reduce deformation because it can be seen from the maximum load size of normal unreinforced beams (BN) is smaller than the beam using reinforcement (BFRP).

4.2.2. Stiffness of composite test beam

The results of the stiffness analysis are shown in Table 3 as follows

Table 3. Stiffness of composite test beam

Code	P_{maks} (kN)	δ_{maks} (mm)	P_{prop} (kN)	δ_{prop} (mm)	K_{prop} (kN/mm)
BN	81.32	83.70	32.53	4.33	7.51
BFRP-1	82.82	116.65	33.63	4.08	8.22
BFRP-2	89,32	95,22	35,81	4,55	7,87
BFRP-3	82.69	89.76	33.08	5.23	6.32

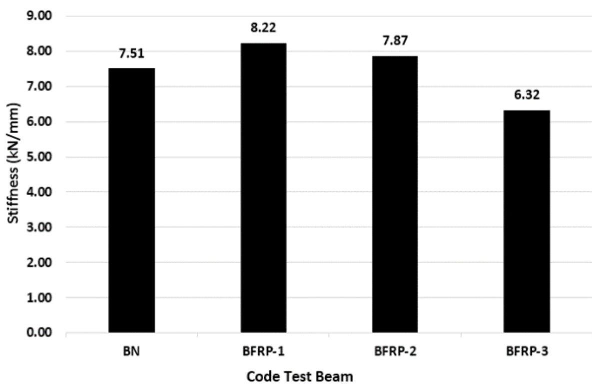

Figure 7 Barchart stiffness test beam composite BN, BFRP-1, BFRP-2 and BFRP-3.

As shown in Table 3 and Figure 7, the use of one CFRP sheet (BFRP-1) in the flexural area of the composite beam can increase the stiffness value by 9.45% whereas using two CFRP sheets (BFRP-2) only increases the stiffness 4.70% but using three sheets of CFRP (BFRP-3) was unable to increase the stiffness which resulted in a stiffness of 6.32 kN / mm (84.15%) compared to a beam without CFRP sheet reinforcement (BN), where with the addition of 3 sheets of Carbon Fiber Reinforced Polymer (CFRP) in the bending area, resulting in damage to the shear area, so that the stiffness is reduced due to the occurrence of shear (slip) at the beginning of loading so that the structural performance does not increase linearly with the number of CFRP sheets. The strength and stiffness of the composite structure are strongly influenced by the ability to withstand the slip where the greater the load intensity, the lower the stiffness value of the structure. Thus the addition of 1 sheet (BFRP-1) to 2 sheets (BFRP-2) and 3 sheets (BFRP-3) was unable to increase the stiffness value from 8.22 kN / mm (100%) to 7.87 kN / mm (95.74%) and 6.32 kN / mm (76.88%).

4.2.3. Ductility of composite test beam

The results of the ductility analysis are shown in Table 4 as follows.

Table 4. Ductility of composite test beam

Code	δ_u (mm)	$\delta 0.4\ P_{maks}$ (mm)	$\delta_Y = 1{,}25{*}\delta 0{,}4P_{maks}$ (mm)	μ (δ_U / δ_Y)
BC	90.21	4.33	5.41	16.67
BFRP-1	147.65	4.08	5.12	28.83
BFRP-2	131,84	4,55	5,69	23,16
BFRP-3	132.39	5.23	6.55	20.21

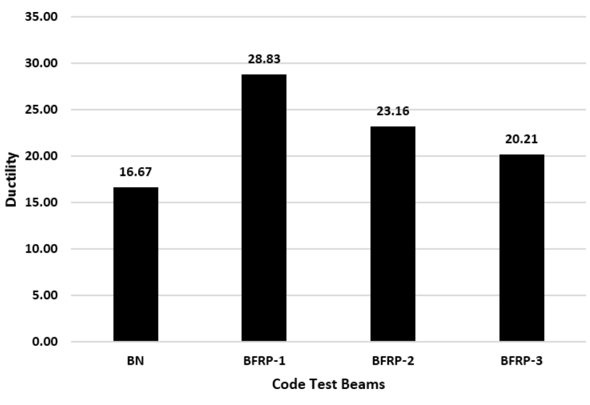

Figure 8 Barchart of composite ductility test beam BN, BFRP-1, BFRP-2 and BFRP-3.

As shown in Table 4 and Figure 8, using 1 sheet of CFRP (BFRP-1) in the flexural area of the composite beam can increase the ductility value of 72.96%. Meanwhile, using two CFRP sheets (BFRP-2) was only able to increase the ductility value of 38.97%. However, the use of three CFRP sheets (BFRP-3) was only able to increase the ductility value of 21.28% compared to without using CFRP (BN) sheets. Thus the addition of CFRP sheets from 1 sheet (BFRP-1) to 2 sheets (BFRP-2) and 3 sheets (BFRP-2) was unable to increase the ductility value from 28.83 to 23.16 and 20.21. The analysis showed that all glulam concrete composite test beams without using (BN) and using CFRP sheets (BFRP-1, BFRP-2 and BFRP-3) had ductility values greater than 4, so they were categorized as very ductile [9].

4.2.4. Failure mode of composite test beam

Generally, composite beam damage occurs in the flexural area. This is in accordance with the test plan, namely in an area of one third of the span, in the middle of the length of the test beam. Failures that occur in composite beams are grouped into 2 types, namely in concrete slabs and laminated wood beams.

4.2.4.1. Concrete slabs

When the glulam-concrete composite beam is subjected to flexural, it collapses suddenly after the tension of the fibers in the wood occurs. There was crushing and small cracks in the concrete wing at the bottom. This results in the concrete reaching the maximum stress before the wood breaks, so that the tensile strength of the concrete is exceeded, then a sudden collapse with crushed concrete (crushing) occurs in the tensile part of the concrete. Meanwhile, from eye observation, there was no visible damage to the shear link, no visible slip, or significant separation (uplift) between wood and concrete. This shows that the shear connector is strong / sufficiently functional in forming a composite action as shown in Figure 9 below.

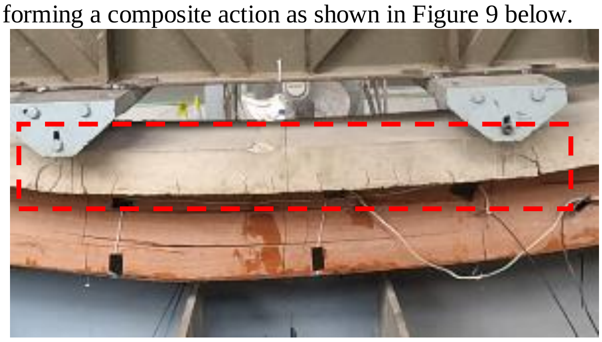

Figure 9 Failure mode of concrete slab

4.2.4.2. Glulam Beam

All composite beams (BN; BFRP-1 BFRP-2 and BRP-3) fail due to flexural, which is then accompanied by shear failure. From the observations when testing the flexural strength of shear failure on the laminated beam, the damage occurred in the bonding between the laminates. The pattern of damage occurs starting with cracks in the loading area, then at the next loading, horizontal cracks occur (initial cracks) in the lamina sheet, which then occurs shear failure in the adhesive plane starting from the edge of the span to the middle of the span. As a result of the composite beam being loaded, stress and strain arise throughout the composite beam. The flexural moment that occurs causes the lower part of the beam to experience a tensile force and the top of the block to experience a compressive force. Due to the opposing compressive and tensile forces on the adhesive line, some parts of the surface of the adhesive plane experiences internal stress so that it slips between the laminate when the blocks are loaded. This is more due to imperfections in the bonding process where the gluing process in the manufacture of laminated blocks affects the quality of the resulting laminated blocks, as shown in Figure 10.

Figure 10 Damage along the adhesive plane of the glulam

The shear damage of laminated wood is caused by horizontal sliding in the adhesive plane between the laminates, causing the strength of the laminated wood beams not to exceed the strength of the wood base material used. Thus the strength and stiffness of laminated wood blocks are not optimal in carrying the maximum load.

4. CONCLUSION

Based on the results of testing and analysis, it can be concluded

1. The test results showed that the composite beam using 1 sheet (BFRP-1) and 2 sheets (BFRP-2) CFRP was able to increase the strength, respectively 3.07% and 9.84% while the addition of 3 sheets of CFRP (BFRP-3) only increased 1.68% strength compared to composite beam without using CFRP (BN).
2. Using 1 sheet of CFRP (BFRP-1) was able to increase the stiffness of 9.45% but using 2 sheets of CFRP (BFRP-2) was only able to increase the stiffness 4.70% whereas using 3 sheets of CFRP (BFRP-2) was not able to increase the stiffness, even the stiffness value decreased by 16.00% compared to the composite beam without using CFRP (BN).
3. By using 1 sheet of CFRP (BFRP-1) can increase the ductility value of 72.96% but by using 2 sheets (BFRP-2) and 3 sheets (BFRP-3) CFRP each can only increase the ductility in a row 38.97 % and 21.28% compared to composite beams without using CFRP (BN).
4. Composite beams that are reinforced using 1 sheet and 2 sheets of CFRP in the flexural area show better / effective strength, stiffness and ductility than using 3 CFRP sheets.
5. Failure modes that occur in all composite beams (BFRP-1 BFRP-2 and BFRP-3) fail due to flexural, then move to adhesive plane shear failure.

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