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COMPRESSION STRENGTH OF COMPOSITE GLULAM TIMBER REINFORCED BETWEEN FIRST AND SECOND, THIRD AND FOURTH LAMINA

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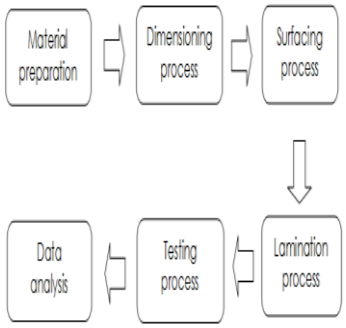
Graphical abstract



Abstract

The use of GFRP sheet as reinforcement in Mengkulang glulam timber is considered to be particularly promising, since the durability of Mengkulang glulam is improved and the application is easier and faster due to lightweight properties of GFRP. Fiber reinforced polymers incorporated with glulam provide significant gains in strength and stiffness, as well as modify the rupture mode of these structural elements. In this study, compression test was carried out on two types of specimen, reinforced and unreinforced Mengkulang glulam block. Size of Mengkulang glulam block is 120 mm x 120 mm x 120 mm. For reinforced glulam block, GFRP sheet was placed between the first and second layer, third and fourth layer of lamina. The compression load was applied perpendicularly to the timber grain. Compression test is carried out using Universal Testing Machine (UTM 1000kN). Consequently it has been noted that by layering GFRP sheet between lamina could increase the compression strength of glulam to resist load. Significant differences between unreinforced and reinforced specimens are 12.6 percent. The highest average compressive strength of reinforced and unreinforced glulam is 11154.05 kN/m^2 and 9808.75 kN/m^2 respectively.

Keywords: Mengkulang, compression strength, glass fiber reinforced polymer, glulam, composite timber

1.0 INTRODUCTION

Generally, wood is not considered as main items of construction. The usage of concrete and steel seems to dominate the construction market, hence minimizing woods usage to limited area. However in the recent years, sustainability and environmentally friendly concept seems to have taken over the world, holding timber into the limelight. Timber serves well as a sustainable material since it can be harvested thus renewed. Timber has several advantages as opposed to other material such as flexibility and lightweight.

Timber has less strength when compared to reinforced concrete or steel. Therefore, many countries introduced new timber innovation, which is glued laminated timber namely 'glulam'. Glulam caters all disadvantages of solid wood such as longevity, strength and ability to make long and complex shapes [1]. However failure due to compression is concentrated in the middle of the glulam specimen according to Hoffmeyer *et al*., [2] as shown in Figure 1 as a result of loads applied perpendicular to grain. From the study conducted by Hoffmeyer *et al*., [2], it shows that the crack of glulam blocks with load being applied perpendicular to grain is originated from the centre of the glulam block.

In order to enhance timber strength, several attempts had been made to incorporate fibre reinforced polymer into timbers. Glass fibre reinforced polymer had been tested suitable to increase strength in timber as reinforcement in forms of rods and plates [3]. Even though steel is considered as good strengthening material but steel has limitations for example steel has high rate of corrosion compared to FRP which has low rate of corrosion if in contact with water. In addition, FRP is more flexible compared to steel plates since FRP itself is in sheet.

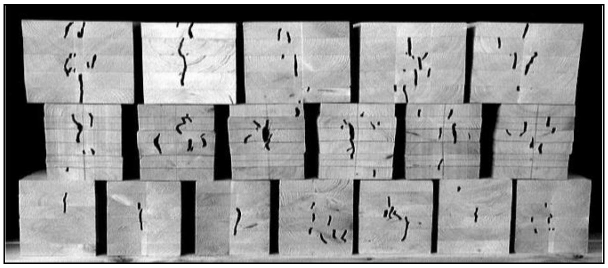


Figure 1 The image of glulam block after tested for compression (Hoffmeyer *et al*., 2000)

1.1 Glued Laminated Timber

Glulam or laminated woods refers to products of gluing two or more layers of different sizes of wood with their grain parallel. Glulam may consist of layers that differ in sizes, shapes and species but combined together to form a single beam [4]. Glulam is end product resulting from layering several laminas by bonding with epoxy resin perfectly [5]. According to Sulistywaty *et al*., [6], technically any strength group is suitable to be used as glulam lamina. Based on MS 758:2001, thickness of lamina cannot be exceeding 50mm.

Instead of using same type of species of timber, according to Moody and Hernandez, [8], as reported by Mohamad *et al.,* [5], mixed species of timber combinations are commonly used in the Northern United States instead of using the same species. Hence it shows that glulam has potential to be calibrated to achieve the desirable level of strength, by mixing the species. However, in this study, glulam that is intended to be laminated comes from the same species. The timber that used in this study is classified as a Mengkulang. Mengkulang is not durable when in contact with the ground or when used in exposed condition. Mechanical properties of some Mengkulang species have been evaluated by MS 544:Part 1: 2001 and summary of the result is given in Table 1.

Table 1 Mengkulang specification [9]

Malaysian name	**Scientific name**
Mengkulang	**Heritiera spp.**
Strength group	5
Colour	Red-brown to dark red-brown
Compressive strength	1.62 N/mm2
Perpendicular to grain	
Parallel to grain	8.9 N/mm2
Shear strength	
Parallel to grain	1.45 N/mm2
Modulus of Elasticity	
Mean	10600 N/mm2
Minimum	6500 N/mm2

1.2 Fiber Reinforced Polymer

Common engineering practice in concrete reinforcement is using reinforcement bar made from steel. However in recent years, fibre reinforced material seems to be taking over the market. Even though steel is consider as good strengthening material but steel has limitation for example steel has high rate of corrosion compare to FRP which has low rate of corrosion if intact with water. In addition, FRP is more flexible compare with steel plate since FRP itself is in sheet. Nevertheless steel can be pre bent to a limited radius, and limited length.

Fibre reinforced material (FRP) could be further classified as glass, carbon and aramid polymer. However, glass fibres are the most used polymer in the FRP production. Glass fibre consist of sand, kaolin, limestone and colemanite blended together [10]. Strength of fibre can be up to 6000N/mm2 based on research has been done after 1920s. Advancement in fibre reinforced polymer manufacturing especially of cold setting resin system can produce large amount of FRP makes FRP become more popular in 1940s. In 1948 GFRP was used chemical in pipe line. GFRP was used as tendon in reinforced concrete structure in 1950 [11].In United State and Europe the usage of FRP is famous to strengthen old bridge.

Studies had been made by Hashim *et al*., [12] in journal titled 'The Future of External Application of Fibre Reinforced Polymer in Tropical Climate Region'. From the journal, the author stated that FRP used as extra reinforcement in reinforced concrete (RC) had caused the RC beam to gain higher stiffness level compared to unexposed beam even though being placed under tropical climate. Hence it denies the claims that FRP could not withstand tropical climate.

Few years ago strengthening timber using material such as FRP and steel had become the solution to increase strength of timber and stiffness of timber [13]. The materials that is used as reinforcement for timber is manufactured in thin plates or bar rod before being embedded in timber. Thin plates are being glued on the outer laminas where the bars were embedded in the pre cut slots in between the laminas. Fibre reinforced polymer is not strictly can be used as reinforcement only. Research by Chen, [14] stated that fibreglass addition to timber joints leads to higher performance and provide a good security factor to the timber joints.

FRP is considered better than any other reinforcement. Kliger *et al., [15]* also stated in his report that timber beam reinforced with CFRP have a higher stiffness than beam reinforced with steel plates for short term bending. Kliger *et al., [15]* also concluded that it is possible to increase the stiffness of the timber beam by 100 percent and strength up to 90 percent compared with unreinforced timber beam. Usage of CFRP also could reduce the dimension of the glulam by 25 percent or lengthen the span of glulam by 20 percent while still achieving the same deflection.

One of the examples of thin plates FRP is GFRP thin plates glued at timber lap joint connections as shown in studies done by Saribiyik *et al., [16]*. GFRP bar elements functions as connection pieces system in longitudinal lap joint. The lap joint is tested for bending and then the result was tested against common longitudinal lap joint. Lap joint strengthened with GFRP shows a higher connection capacity than its counterpart. The bending strength increases almost 300 percent when the timber connection is reinforced with GFRP. Apart from being strengthened internally, FRP also had been used as composite external reinforcement of timber beam. Karmazinova [17] stated that CFRP externally bonded on the tensile part of the beam for strengthening the member against ultimate and serviceability limit state shows that the after being reinforced externally, the beam posses higher resistance against ultimate and serviceability limit state.

Fiorelli *et al*., [18] had published a report on Pinus Caribea timber beams externally bonded using FRP sheets on tension area. FRP used were CFRP and GFRP thus yields the result that shows increment of 15 percent to 30 percent flexural stiffness.

1.3 Compression Strength of Timber

Timber has several mechanical properties or strength properties that are useful to be exploited when designing timber structures. Strength of timber refers to ability of the timber to resist external forces or load. The effect of applying external load will induce internal forces within the body that will resist changes in size and alteration in shape. This strength is called stresses and is denoted by unit Pascal. The change in size or shape is known as deformation or strains. Compression perpendicular to grain is determined using these formula:

$$f_{t,90} = \frac{F_{t,90\,max}}{Bl}$$

where $F_{t,90\,max}$ is obtained using this figure from BS EN 408-2010.

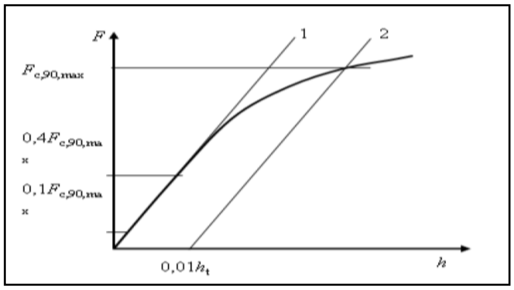


Figure 2 Load-deformation diagram for compression [19]

Figure 2 shows a load-deformation diagram for compression. Based on the test results, load versus deformation diagram is plotted to as shown in Figure 2. Then the value of 0,1 *Fc,90,max* and *0,4 Fc,90,max* is calculated. The point where these two values intersect the load/deformation curve is determined. A straight line labelled as 1 is drawn connecting both point of intersection as shown in Figure 2. Line 2 is drawn parallel to line 1 having its origin at load F = 0 and at a distance from it equivalent to a deformation of *0,01 ht* as shown in Figure 2. *Fc,90,max* is where line 2 intersect with the load-deformation curve. If the value of *Fc,90,max* as determined is within 5 % of *Fc,90,max*, then that value may be used to determine the compressive strength. Otherwise, repeat the procedure until a value of *Fc,90,max* within that tolerance is obtained [19].

The compression strength of horizontally laminated timber depends on the position of various grades of lamination. High grade of lamination may be placed in the outer portion of the member where their high strength may be effectively used and lower grade of laminations in the inner portion, where their low strength will not greatly affect the overall strength of member. Compression strength perpendicular to grain often appears as local loading in joints where difference in height of specimen showed no significance difference in the compression strength.

2.0 EXPERIMENTAL

The procedure starts with material preparation of GFRP, Mengkulang timber and adhesive. As for type of timber and glulam preparation, Malaysian Standard MS 758: 2001 is used. The testing equipment was Universal Testing Machine (UTM) 1000kN. Experimental work was conducted based on British Standard EN 408 : 2010. The flow chart of experimental work is shown in Figure 3.

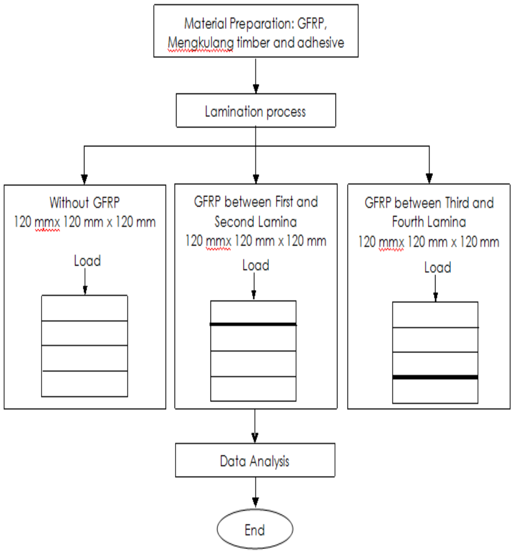


Figure 3 Flow chart of experimental work

2.1 Glulam Fabrication

Fabrication of glulam based on MS 758:2010 stated that thickness of lamina cannot be exceeding 50mm. The range permitted is to be between 20 mm to 50 mm. Thus, in this study, the thickness of glulam chosen is 30 mm per lamina. According to BS EN: 408-2010, for compression test, specimen need to be have minimum width, b, and 100mm. As for this study, the width of glulam constructed is 120 mm, which adhere to the minimum 100 mm width specification.

Other than that, in glulam fabrication, glulam use unique joint that enables large spans of glulam to be constructed. Finger joints are used because by cutting a series of depressed finger at the end of one timber they are readily interlocked for assembly with only initial axial pressure being supplied. As for this study, finger joint will not be constructed as stated in MS 758:2001, finger joints specification is referred to AS/NZ: 1491 where glulam exceeds 2.5 metres need to be jointed with a finger joint.

While taking into account all the specifications above, the glulam to be constructed in this study is of depth 30 mm per lamina with each sample having four laminas. Total depth of each sample is 120 mm width × 120 mm length × 120 mm depth.

Surfacing of lumber using sand paper was carried out to produce a smooth surface of timber block for the lamination process. This process to ensure the lamination become sturdier as there will be no gap in between the lamina. After the surfacing, lamina was clamped together to form a single unit of glue laminated timber block. The GRFP is placed and glued between the desired layers using the epoxy resin. The reinforcement was positioned at the centre of the glulam. This is due to the fact that normal glulam block, when axially loaded, will crack starting from the middle of the block [2]. After gluing, the laminates sandwiched with GFRP mesh was being piled together in the correct order and pressure of 0.77N/mm2 is applied. Each block was left for 24 hours or overnight to ensure the glue is totally cured. This is very sufficient since the requirement of glue setting is only 3 hours. After block was left for 24 hours or overnight to ensure the glue is totally cured, the pressure was released and the block were left for at least 24 hours in the workshop before being tested for compression using Universal Testing Machine (UTM 1000). During testing, the loading rate of 1mm/s was imposed on the specimen. Load versus displacement graph was generated automatically using software UTS10 (Materials Strength Test).

Three types of glulam block were used in the experiment, one as a control without lamination of GFRP, another type is by placing GFRP between the first and second lamina, and the other type is laminate with GFRP at the layer between third lamina with last lamina as shown in Figure 4.

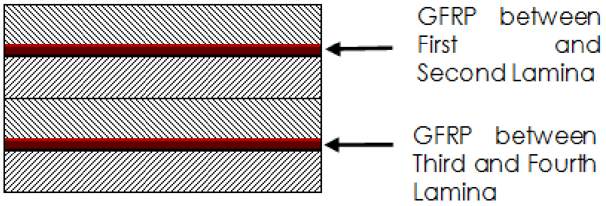


Figure 4 Position of GFRP sheet between the lamina in glulam block

Figure 5 Testing specimen using Universal Testing Machine (UTM 1000)

3.0 RESULTS AND DISCUSSION

The results were obtained from the compression test conducted using Universal Testing Machine (UTM) 1000kN. There were three group of samples. First, control samples without reinforcement of GFRP. Second, samples reinforced with GFRP between first and second lamina. Third, samples reinforced with GFRP between third and fourth lamina. The results obtained from the UTM 1000kN software were then analysed using the formulae as shown in Figure 5.

3.1 Control Sample Unreinforced with GFRP

The maximum compression load that the unreinforced sample could hold to was in average 141.25 kN while the compression strength that the sample could hold was 9808.75 kN/m2.

Figure 6 shows the load versus deformation graph for all control samples which were unreinforced with GFRP. From this figure, the patterns for deformation for all five control samples were almost similar, thus conforming that all glulam blocks deform at the same pattern. As the load increases, the deformation also gradually increases. Then at a certain point the deformation become slightly increasing before coming to an almost plateau state. This condition occurred because the timber block had reached the maximum compressive load it can achieve at that particular point. Despite the almost planar line condition, it can be said that the specimen had already failed based on observation. This condition occur due to the nature of timber where it can absorb load because of its natural individual fibers act as many hollow columns firmly bound together. Failure under compression occurs when the fibers, by crushing into little bodies and sliding over each other, cease to act as a firm volume. From the figure shown the maximum compressive load that the timber could hold is calculated to be 137.5 kN where its compressive strength after considering its surface area was 9375kN/m^2.

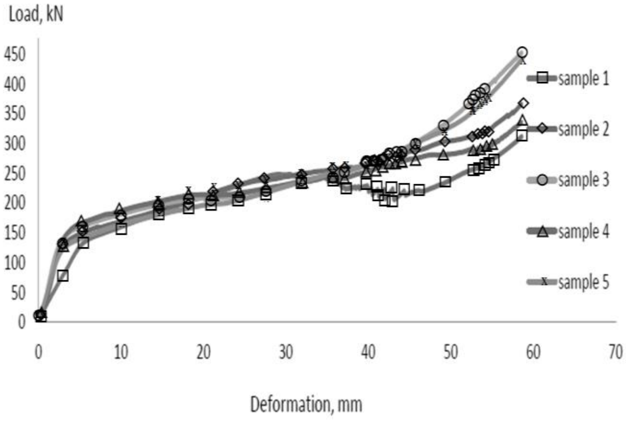


Figure 6 Load versus deformation graph pattern of all of the control samples unreinforced with GFRP

3.2 Sample Reinforced with GFRP between First and Second Lamina

The maximum compression load that the sample reinforced with GFRP could hold to in average was 149.87kN while the compression strength that the sample could hold was 10407.64 kN/m^2.

Figure 7 shows the load versus deformation graph for all samples which were reinforced with GFRP. The figure also shows that the reinforced glulam block experienced compression at the linear increment graph, where after it reached its maximum point, the block is said to had failed.

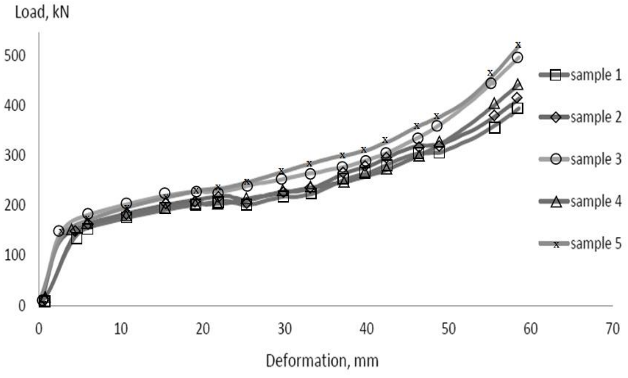


Figure 7 Load versus deformation graph pattern of all of the control samples reinforced with GFRP

3.3 Sample Reinforced with GFRP between Third and Fourth Lamina

The maximum compression load that the sample reinforced with GFRP could hold to in average was 160.63 kN while the compression strength that the sample could hold was 11154.05 kN/m^2.

Figure 8 shows the load versus deformation graph for all samples which were reinforced with GFRP. From the figure, the patterns for deformation for all five control samples were almost similar, thus conforming that all reinforced glulam blocks deform at the same pattern. The figure also shows that the reinforced glulam block experienced compression at the linear increment graph, where after it reached its maximum point, the block is said to have fail.

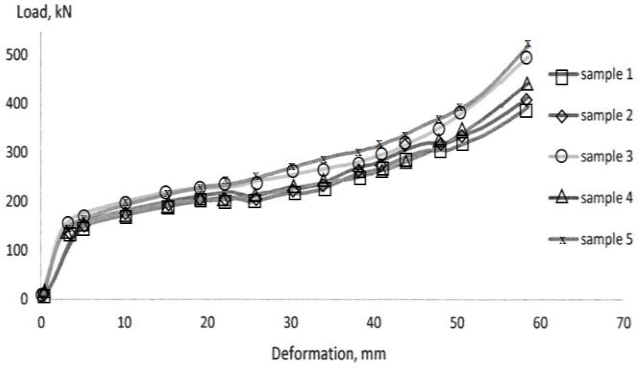


Figure 8 Load versus deformation graph pattern of all of the control samples reinforced with GFRP

3.4 Comparison between Control Sample and Samples Reinforced with GFRP

Figure 9 presents the comparison between control sample and samples reinforced with GFRP. While comparing these two graph, the gradual line before the specimen reached its maximum compressive load is steeper compared to the control specimen. It shows that adding GFRP in between the glulam layers could increase the timber resistance to load up till a point where it reaches its maximum compression load capacity. When GFRP was reinforced between the third and fourth lamina, the maximum compressive load was 162.5 kN where as its compressive strength after considering its surface area was 11285 kN/m^2.

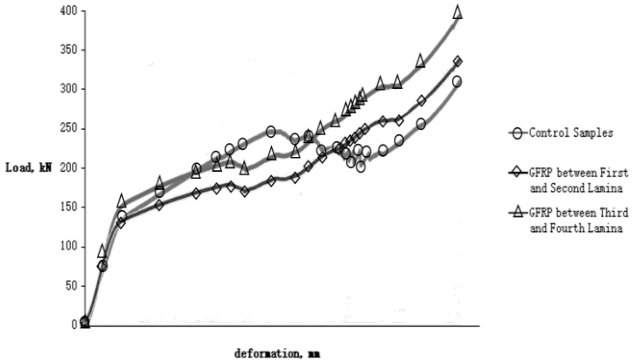


Figure 9 Comparison in load versus deformation graph pattern of control samples and samples reinforced with GFRP

After all values of compressive strength were calculated, the average compressive strength for each type of specimen was then determined and presented in Table 2. The percentage difference was represented in the bar chart in Figure 10. The glulam block reinforced with GFRP between first and second lamina had shown significant increment in compression strength than control sample, which are 5.75 percent. The glulam block reinforced with GFRP between its last layers experienced increment of 12.06 percent in strength compared to control sample. This is due to the ability of GFRP that reinforced the timber fibres from collapsing. The difference of compression strength when GFRP located in first layer and third layer was approximately 6.31 percent. Hence, the compression strength was found to be higher with the present of GFRP.

Table 2 Maximum compression load and compression strength of samples reinforced with GFRP

Sample	Maximum Compression Load (kN)	Compression Strength, $f_{c,90}$ (kN/m²)
Control sample	141.25	9808.75
Sample with GFRP between first and second lamina	149.87	10407.64
Sample with GFRP between third and fourth lamina	160.63	11154.05

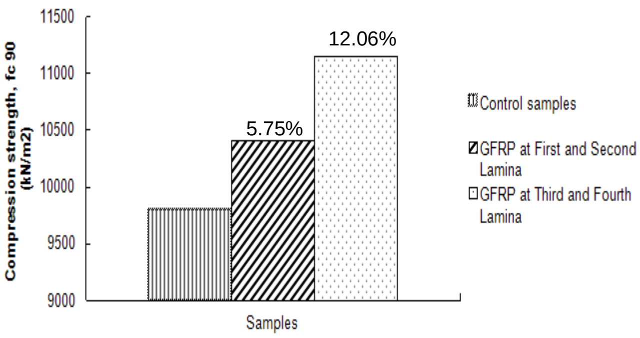


Figure 10 Comparison of compression strength between control samples and samples reinforced with GFRP

3.5 Failure Pattern

Based on the Figure 11 (a), the failure of the timber block reinforced with GFRP was on the sides, while the centre of the block layered with GFRP was kept intact. It shows that by reinforcing the glulam with GFRP, the fibres of the timber could hold on to a much higher compression strength before collapsing. This findings was in line with the research done by Saribiyik et al., [16]. The failure of the glulam block with GFRP was then compared with the failure of ordinary glulam block as shown in Figure 11 (b). From the picture taken after the glulam block had experiencing maximum compression load, it shows that the block start to break under compression starting from the edge then the creeps start to form towards the centre. Without any reinforcement, the timber fibres start collapsing and cannot perform as a unit.

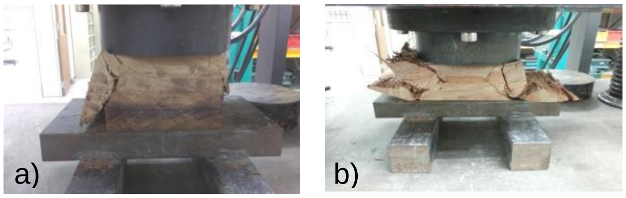


Figure 11 a) failure pattern for sample reinforced with GFRP; b)failure pattern for sample unreinforced with GFRP

4.0 CONCLUSION

From the analysis of data, the conclusions were drawn. The average compressive strength of glulam reinforced with GFRP was 11154.05 kN/m2 while unreinforced glulam was 9808.75 kN/m2. From the results shown, there is evidence that there is a significant increment of the glulam compression strength when GFRP was incorporated in glulam block. When the GFRP positioned between the first and second layers, the strength increase about 5.75 percent. Meanwhile, the increment of strength was recorded at 12.6 percent when GFRP was placed between the third and fourth layers. Therefore, GFRP sheet is recommended to be placed in the third and fourth layer since this position can significantly increase the strength of glulam block. The GFRP that was introduced caused the layers of the lamina holds by the GFRP to be kept intact under compression load. The ordinary glulam block started to break starting from the centre in between the laminas.

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