Experimental study on the effectiveness of finger joint with variations in wood species toward bending strength of glulam beams

B Anshari1*, A Rofaida2, F Mahmud2, Pathurahman2 and R Rahmalia3

1 Master Program of Civil Engineering, Faculty of Engineering, Mataram University, Jl Majapahit 62 Mataram, NTB, Indonesia.
2 Department of Civil Engineering, Faculty of Engineering, Mataram University, Jl Majapahit 62 Mataram, NTB, Indonesia
3 Graduate Student, Department of Civil Engineering, Faculty of Engineering, Mataram University, Jl Majapahit 62 Mataram, NTB, Indonesia

*E-mail: buan.anshari@unram.ac.id

Abstract. Recently, the utilization of timber as building materials was very promising for now and future. As renewable resources they have high mechanical properties, lightweight, environmentally friendly and economic. One of the most durable engineered wood products is glued-laminated timber which commonly called Glulam. Glulam is a material made of several layers of wood glued together with waterproof adhesive at specific pressure and temperature. The benefit of Glulam is enable to produce the structural member with longer span compared with solid wood. In order to obtain the structural Glulam with longer span, it required the finger joint connection on lamina layer. This study aims at to find out the effectiveness finger joint with variation in wood species towards flexural properties of Glulam beam. Experimental study have been done by using local wood Sengon and Rajumas as laminae and Biomatex as adhesive, at 0.6 MPa of clamp pressure. The variation of finger joint slope was tested are 1:8; 1:12; and 1:16. The result show that the glulam Sengon and Rajumas beam with slope finger joint of 1 over 12 produce the highest average bending strength of 299 kg/cm² and 318 kg/cm² respectively. The flexural strength of glulam Rajumas was 20% higher compared with glulam Sengon.

1. Introduction
The need for wood as raw material for needs is increasing, especially for building materials. However, the availability of large timber is difficult to obtain. This is due to the speed between harvesting and replanting unbalanced trees. With the decreasing amount of wood available, people are turning to fast-growing and small-diameter community timber. This has an impact on the quality of wood obtained because the relatively young age of wood contains many defects such as wood eyes, fiber sloping, deformed shapes, and so on. One effort to improve the quality of community timber obtained in order to meet the requirements of building construction materials is to utilize laminate technology. The advantage of using lamination technology is being able to produce wood products with larger dimensions, more uniform wood structure, easy to design according to the desired shape, and can be made from weak-strength wood.
A reliable lamination technology to meet construction needs is laminated wood (glulam). Glulam is a piece of wooden boards or relatively small pieces of wood arranged and glued with glue in the direction of parallel fibers. Laminating these wooden boards will cause the dimensions of wood and specific gravity to be larger.

The relatively short availability of solid wood (less than 5 m) is a problem to get glulam with a long size. Therefore a connection is needed that is suitable for laminated wood. According to a previous study, the connection that is commonly applied to laminated wood is a scarf joint and finger joint.

Glulam is a material glued from selected pieces of wood (lamina) at a certain temperature and pressure in a straight or curved form where the direction of the fiber is parallel to the longitudinal axis of the stem (Moody and Hernandez, 1997). To get the length and dimensions according to the needs of the laminated beams, it is necessary to connect the ends of the beams or connect to certain places of the wood layer (lumber). The connection that is commonly used is the connection of the scarf joint and finger joint. One of the advantages of finger joints compared to scarf joints is shorter joint length and less wood loss (Moody and Hernandez, 1997).

Anshari and Agustiar (2006) studied about bending behaviour of glulam beam with finger joint. The efficiency of finger joints in wood reaches a minimum of 80% of the tensile strength of solid wood and its optimum finger slope is 1:12 or more sharp (Hernandez, et al., 1997). Variation in the slope of finger joints to flexural strength of Bajur laminated timber by obtaining flexural strength 313, 3 kg / cm² on finger slope 1:16 (Thamrin, 2015). The finger joints commonly used in fabrication for the length of L (length) are 15 mm to 20 mm (Castro and Paganini, 1997). Whereas in North America finger joints for structural components that are commonly used with finger length (length) are between 22 mm and 29 mm (Gong, 2009).

To find out the effectiveness of finger joints on laminated wood beam structures, it is necessary to do a further study of finger joints with variations in several types of local wood with a different density level of local wood species in West Nusa Tenggara.

2. Research methods
The manufacturing of specimens and testing is carried out in the Structure and Materials Laboratory of the Faculty of Engineering, University of Mataram and the Materials Science Laboratory of the Faculty of Engineering, University of Mataram. The materials to be used in this study are Rajumas and Sengon Wood, Biomatex brand as adhesives. Some tools for making specimens and test equipment used in this study are:

a. Planner is used to smooth and flatten the surface of the specimen to be glued.
b. Hammer and knife, used for finger joint alignment.
c. Universal Testing Machine, used for testing tensile strength that is connected to a computer.
d. Advantest 9 capacity of 300 kN is used for shear strength testing, strong adhesion and testing of flexural modulus that is connected to a computer for load readings with brands of controls.
e. Hydraulic Jack, used for testing the bending of laminated beams with the Enerpac brand and with a capacity of 259 kN.
f. The dial gauge(LVDT) is used to measure deflection of 0.01 mm.
g. Hydraulic Pump, used to adjust the height to the maximum load that can be held by the test object.

2.1. Manufacturing of specimen
There are two type of specimen which already made, namely specimen for preliminary test and glulam beam with finger joint for flexural test.
2.1.1. Specimen for preliminary test

The preliminary test consists of physical properties (specific gravity and moisture content test) and mechanic properties (tensile strength, compressive strength, shear strength, bonding strength of adhesive and elastic moduli test). The size of specimen based on National Indonesia Standard (SNI).

2.2. Specimen for bending strength of glulam beam

This test is carried out based on SNI 03-3972-1995 using wooden blocks with a size of 5cm × 6cm × 165 cm as in Figure 1. The location of finger joint spread at specific place along the span of the beam. The specimen is made into three variations of finger joints; one specimen consists of three samples of test specimens. The recapitulation of flexural testing specimen can be seen in Table 1. There are 18 beam specimens in total with three variations of finger joint slope.

![Figure 1. Glulam beam specimen with finger joints](image)

Table 1. Recapitulation of flexural beam specimen with three variations of finger joint

| Glulam beams with slope variation | Size (cm) | Amount of specimen |
|----------------------------------|-----------|--------------------|
|                                  |           | Rajumas | Sengon |
| Slope 1 : 8                      | 5 × 6 × 165 | 3       | 3      |
| Slope 1 : 12                     | 5 × 6 × 165 | 3       | 3      |
| Slope 1 : 16                     | 5 × 6 × 165 | 3       | 3      |
| Total beams specimen             |           | 18      |        |

3. Results and Discussion

Based on the testing series from section 2, the results are as follows

3.1 Physical properties of woods

The physical properties of Sengon and Rajumas wood can be seen in Table 2. The results show that the moisture content of the wood used qualifies as laminated wood material which requires less than or equal water content to 16%. The value of density can be categorized as medium density wood.

Table 2. The results of moisture content and specific gravity tests

| Wood species | Moisture Content (%) | Specific gravity |
|--------------|----------------------|------------------|
| Sengon       | 15,08                | 0,34             |
| Rajumas      | 15,42                | 0,81             |

3.2 Mechanical properties of woods

The result of mechanical properties test can be seen in the Table 3 to determine the grade level of wood which have been used in this study.
Table 3 The results of moisture content and specific gravity tests

| Wood specimen | Bending strength (Fb) Mpa | Tensile strength (Ft) Mpa | Compressive strength (Fc) Mpa | Shear strength (Fv) Mpa | Bonding Strength (Fs) Mpa |
|---------------|---------------------------|--------------------------|-------------------------------|------------------------|--------------------------|
| Sengon        | 32.49                     | 29.63                    | 28.00                         | 5.22                   | 6.45                     |
| Rajumas       | 45.51                     | 34.86                    | 32.67                         | 9.80                   | 3.70                     |

In Table 3 it can be seen that the average flexural strength of Sengon wood is 32.49 MPa and is included in E15 wood quality based on the standard RSNI T-02-2003. Suryawan and Poerwodiharjo (2007), obtained a flexural strength of 30.30 MPa and entered into E14 wood grade. While Rajumas wood has an average flexural strength of 45.51MPa and is included in E19 wood grade based on the standard RSNI T-02-2003. Table 3 also reveal that the compressive strength parallel to Sengon wood fiber is 28 MPa. Based on the same code, with the value of the compressive strength Sengon wood is included in the E10 wood quality. The average compressive strength of Rajumas wood is 32.67 MPa which can be categorized as E15 wood grade. In terms of the average shear strength of Sengon wood at 7.61 MPa. The research conducted by Suryawan and Poerwodiharjo (2007), obtained the results of testing the shear strength parallel to Sengon wood fiber of 5.37 MPa. While Rajumas wood has an average shear strength value of 9.80 MPa. Rofaida et al (2013) conducted a shear strength tests parallel to Rajumas wood fiber and obtained results of 5.72 MPa. The difference in the shear strength obtained can be caused by differences in the basic nature of the origin of wood which affects the value of shear strength which is not always the same.

3.3 Flexural test of glulam beam

3.3.1 Flexural test of glulam beam Sengon

The result of flexural test of glulam Sengon beam can be summarized in Table 4. Table 4 shows the average flexural strength of 29.86 MPa. The value of the flexural strength of the S12 beam is the highest because it has a greater number of fingers than the S8 laminated beam, its surface is more adhesive, has a smaller risk of fracture in the joints of the joints compared to S16 beam. The average flexural strength of S16 beam is 29.58 MPa. S16 beam is a beam that has the most number of fingers, but the yield of flexural strength is lower than that of S12 beam. This can be caused by the increasing number of fingers, the thickness of the finger joint is getting smaller and the risk of fracture becomes greater. In addition, because the greater the slope ratio of the finger connection, the angle between the fingers is getting smaller, so that the effect on adhesive on contact surface is not optimal.

Table 4. The result of flexural test of glulam Sengon

| Sengon Beam | Load (P) (kg) | δ (Deflection) (mm) | Bending Strength (MPa) |
|-------------|---------------|---------------------|------------------------|
| S8          | 291.67        | 18.62               | 24.31                  |
| S12         | 358.33        | 24.67               | 29.86                  |
| S16         | 355           | 25.63               | 29.56                  |
Typical relationship between load and deflection for glulam Sengon can be seen in Figure 2. It can be seen that Beam S12₁ test material occurred failure at the maximum loading of 300 kg with proportional boundary points at 180 kg loading with 8.75 mm deflection, S12₂ specimen experienced first collapse at loading 315 kg then final collapse at 375 kg loading with deflection 22.84 mm with a proportional limit at 200 kg loading with a deflection of 10 mm. While the S12₃ specimen occurred the first crack at 385 kg loading and final failure at 400 kg loading with 29.24 mm deflection with proportional boundary point at 210 kg loading with deflection of 10.62 mm. This failure pattern resulted in Sengon laminated wood beams occurred at joint and cracking.

Figure 2. Relationship between Load and Deflection Glulam Sengon with finger joint slope 1:12

3.3.2 Flexural test of glulam beam Rajumas

The result of flexural test of glulam Rajumas beam can be summarized in Table 5. Table 5 showing the results of flexural testing for the R8 beam are laminated beams from Rajumas wood with a finger slope of 1: 8. From the results of the R8 beam testing, the average flexural strength was 27.78 MPa. The value of the flexural strength of the R8 beam is the lowest value because it has a smaller number of fingers so that the area of gluing in the finger joint is a little. Based on Table 4.8 the average B12 beam flexural strength is 31.81 MPa. The value of R12 beam flexural strength is the highest value because it has a greater number of fingers so that the adhesive surface becomes stronger. The results of flexural testing for R16 beams are laminated beams from Sengon with a slope of 1:16. From the results of the R16 beam testing the average flexural strength of 29.86 MPa was obtained. R16 beam is a beam that has the most number of fingers, but the result is lower flexural strength compared to R12 beam. This can be caused by the increasing number of fingers, the thickness of the finger joint is getting smaller and the risk of fracture becomes greater. In addition, because the greater the slope ratio of the finger connection, the angle between the fingers is getting smaller, so that the effect on adhesive resurfacing is not optimal.
Table 5. The result of flexural test of glulam Rajumas

| Rajumas Beam | Load (P) (kg) | δ (Deflection) (mm) | Bending Strength (MPa) |
|--------------|---------------|---------------------|------------------------|
| R8           | 333.33        | 25.04               | 27.78                  |
| R12          | 381.67        | 23.26               | 31.81                  |
| R16          | 361           | 26.81               | 29.86                  |

Typical relationship between load and deflection for glulam Rajumas can be seen in Figure 3. Figure 3 also shows that the R12₁ specimen failed first at 300 kg loading and then collapsed at 360 kg loading with proportional boundary points at a load of 180 kg with a deflection of 5 mm. The R12₂ specimen collapsed at 400 kg loading with a proportional boundary point at 200 kg loading with a deflection of 8.75 mm, while the R12₃ specimen collapsed at a load of 385 kg with a proportional proportion of 190 kg with 7.5 mm deflection. The collapse resulted in cracking of the R12 laminated beam.

![Figure 3. Relationship between Load and Deflection Glulam Rajumas with FG slope 1:1](image)

4. Conclusion

Based on the three variations of slope of the finger joints used, it was found that the highest average flexural strength occur at Glulam Rajumas beam at the slope of the 1:12 finger joint was 31.8 MPa. While the largest mean bending strength value of Sengon laminate beam is at the slope of 1:12 finger joint with flexural bending strength of 29.9 MPa.
References

[1] Anshari B and Agustiar 2006 Prilaku Lentur Balok Kayu Laminasi (Glulam Beam) dengan Finger Joint, Fakultas Teknik, Universitas Mataram

[2] Castro G and Paganini F, 1997, Parameters Affecting End Finger Joint Performance In Polar Wood International Conference of IUFRO S 5.02 Timber Engineering, Denmark

[3] Hernandez R, Davalos, DF., Sonti, SS., Kim,C. Moody, RC., 1997, Strength and Stiffness of Reinforced Yellow-Poplar Glued-Laminated Beams, United States Department of Agriculture

[4] Moody C R, and Hernandez R, 1997, Engineered wood products-A guide for specifiers,designers and users, Chapter 1, 1-39, Glued-Laminated Timber,

[5] Rofaida A, Anshari B and Sugiartha W, 2013 Investigasi Mutu Kayu Lokal Berbasis Standar Nasional Indonesia (SNI). Universitas Mataram

[6] National Indonesian Standard (SNI), 2003, RSNI-T-02-2003 Tata cara perencanaan konstruksi kayu di Indonesia (Design Manual for Timber Structure in Indonesia), National Standard Board, Jakarta.

[7] Suryawan, Lorentius H and Poerwodihardjo F E 2007 Sifat-sifat fisika dan mekanika kayu Keruing-Sengon, Teodolita Vol.8 p.39-44

[8] Thamrin H 2015 Pengaruh Variasi Kemiringan Sambungan Jari (Finger Joint) terhadap kuat lentur balok kayu laminasi, Tugas Akhir Fakultas Teknik Universitas Mataram, Mataram.

[9] Gong, M., Delahunty, S., Chui, Y. H., 2009, Development of A Material-Efficient Finger Joint Profile for Structural Finger Joined Lumber, University of New Brunswick, Canada