Perpendicular Glue Line Dowel-Bearing Strength Properties of Mengkulang Glulam

Nor Jihan Abd Malek, Rohana Hassan, Adrian Loh Wai Yong and Haslin Idayu Amaruddin

Abstract Dowel-bearing strength also known as embedment strength is a significant parameter for the wood connection design. The wood connection design is still referring to the European Yield theory which predicts the load capacities of the connection under lateral load. Bolt has been extensively used for the wood connection due to ease of assembly and able to reassemble for variation of member size. Glulam is an engineered wood product which has good strength to weight ratio and is able to design to meet the required design strength. Existing data provided in the Malaysian Standard (MS 544: 2001) is only applicable for the solid timber, therefore it is insufficient. Research on determining the dowel-bearing strength of Malaysian tropical hardwood is ongoing; more information is required in order to enhance the application of the Glulam Malaysian tropical timber. This study determined the dowel-bearing strength of Glulam Malaysian tropical hardwood, Mengkulang also known as *Heritiera* spp. loaded perpendicularly to glue line using two different bolt diameter 16 and 20 mm. Dowel-bearing strength test is performed in accordance to the ASTM-D5764-97a using the half-hole test method. Dowel diameter is found to have influenced the dowel-bearing strength, where dowel-bearing strength increased 20.82 % when the dowel diameter increased from 16 to 20 mm. Both standard ASTM D 5764- and BS EN 383 are commonly used in determining the dowel-bearing strength. Comparison of dowel-bearing strength using the ASTM D5764-97a standard based on the 5 % offset load and BS EN 383 standard based on the maximum load is made and found to have higher value using the BS EN 383 standard, 12.27 % higher for specimens using 16 mm dowel diameter and 10.29 % higher for specimens using 20 mm dowel diameter.

Keywords Dowel-bearing strength · Wood connection design · Glulam · Mengkulang · Half-hole test

N.J.A. Malek (✉) · R. Hassan · A.L.W. Yong · H.I. Amaruddin
Faculty of Civil Engineering, Universiti Teknologi MARA, Bandar Pusat Jengka, Pahang, Malaysia
e-mail: norjihan.abdmalek@gmail.com

M. Yusoff et al. (eds.), *InCIEC 2015*, DOI 10.1007/978-981-10-0155-0_68

1 Introduction

Timber has been extensively used as construction material since the ancient time. Wood grows natural and unique, its structural properties is widely different as the wood strength is highly dependent on the environmental conditions [1]. Defects found in the wood can affect the strength of the wood. As timber has good strength to weight ratio and many benefits such as less carbon emission during the manufacturing process, enhancement has been done to it in order to promote the use of timber. Glued laminated timber (Glulam) is an engineered wood product which is made from numbers of timber lamina bonded together with an adhesive [2]. There are two type of glued laminated member, one is the horizontal Glulam in which the timber layer is glued horizontally while the other is vertical Glulam in which the timber layer is glued vertically [3]. Performances of the Glulam member can be improved by placing the greater strength timber layer in the regions of higher stress [4]. Developed countries such as America, Japan, and Europe have been widely using the Glulam timber in the construction of commercial building, sport complex, residential houses, and church. However, the extensive use of Glulam timber in Malaysia has is to be seen due to the lack of research and data provided regarding it. Mengkulang is one of the Malaysian tropical timber species which is often used in furniture, flooring, paneling, and glue-lamination [5].

The weakest part in the timber is the joint connecting the large structural system. Mechanical fastener such as nails, screws, dowel, and bolts are often used to enhance the performance of timber connection. Bolt is commonly used in the construction and to connect the Glulam timber member due to its ability to resist high lateral shear force [6]. European Yield Model (EYM) theory proposed by the Johansen in 1949 has been often used in prediction of the ultimate load capacities of the wood connection with fasteners. This theory has been extensively used and been revised over the years but still remains the basic concept same as Johansen proposed. Theory of connection design stated in the Eurocode 5 and National Design Specifications are based on the EYM.

Dowel-bearing strength is one of the important parameter for the design of wood connection. Wood connection performances rely upon the fastener bending strength and the dowel-bearing strength [7]. According to ASTM D 5764-97a, dowel-bearing strength is the yield load obtained from the load-displacement curve using the 5 % offset method of a dowel-bearing strength test over the dowel diameter and specimen thickness. There are two methods with which the full-hole test and half-hole test can be adopted in determining the dowel-bearing strength. Studies showed that the half-hole test provides uniform load along the dowel fastener length, and fastener does not bend during the loading process, where full-hole test method load is only acting at the both end of the dowel, bending might occur during the loading process [8]. ASTM D 5764-97a and BS EN 383 are two different standards of test which are commonly used to determine the dowel-bearing strength. ASTM D 5764-97a is usually based on the half-hole test method where BS EN 383 is based on the full-hole test method. Several researches have been done the using the half-hole test method such as research done by Wilkinson [9], Rammer [10, 11], Eratodi et al. [12], and Schmidt [13]. While the other researchers such as Hubner [14], Sawata and Yasumura [15], and Ivan [16] applied the full-hole test method in their study. The previous study done on the dowel-bearing strength for Malaysian tropical hardwood species is done and published by Jumaat et al. [17, 18], Awaludin et al. [19], and Hassan et al. [20, 21]. However, there is still lack of data emphasized on the effect of different dowel diameter loaded perpendicular tn the glue line of Mengkulang glulam. In order to enhance the current information and data on the dowel-bearing strength to promote the use of Malaysian tropical timber, more research and study are required. Therefore, the main objective of this study is to investigate the effect of two dowel diameters loaded perpendicularly to the glue lines of glulam made of Mengkulang species. The observation is also being made with two different code of practice which is the ASTM D 5764-97a and BS EN 383 in determination of the dowel-bearing strength. The effect of moisture content and density of the Mengkulang glulam species to the dowel-bearing strength is also being observed.

2 Materials and Method

Dowel-bearing strength was conducted on the Glulam Malaysian tropical hardwood Mengkulang (*Heritiera* spp.) species loaded perpendicularly to the glue line. Two different dowel diameter 16 and 20 mm of bolt (see Fig. 1) were used to determine the dowel-bearing strength of Glulam Mengkulang species with glue line embedded on the half-hole specimen (see Fig. 2). Specimens dimension and the test procedure is in accordance to the ASTM D 5764-97a, 2007. For specimens using 16 mm dowel diameter, the dimension is 64 mm × 64 mm × 38 mm, where specimens using 20 mm dowel diameter the dimension is 80 mm × 80 mm × 40 mm. Total sixty (60) specimens were tested, thirty (30) specimens using 16 mm dowel diameter, and thirty (30) specimens using 20 mm dowel diameter. The dowel-bearing strength test was tested with the universal testing machine (UTM) at

Fig. 1 Steel bolt 16 and 20 mm diameter

Fig. 2 Half-hole specimen

Fig. 3 Dowel-bearing strength test set up

a constant rate of 1 mm/m (0.02 mm/s) for each specimen. Figure 3 shows the dowel-bearing strength test set up on the UTM. Moisture content and density were determined using the dry-oven method according to ASTM D 4442 standard. Initial weight of specimens is first weighted and dried in the oven at 103 °C for 24 h and then dry weight of the specimens is recorded.

Load-deformation curve is plotted after the dowel-bearing strength test. According to ASTM D 5764-97a, 2007, 5 % offset method is used to determine the yield load from the load-deformation curve. Yield load were determined by drawing a straight line fit into the initial linear portion of load-deformation curve. Then, offset the line by 5 % dowel diameter. Load at which the offset line intersects with the load-deformation curve is selected as the yield load. Dowel-bearing strength using ASTM D 5764-97a is computed using the Eq. (1) which is based on the 5 %

offset load and dowel-bearing strength using BS EN 383 is computed using the Eq. (2) which is based on the maximum load.

$$F_y = \frac{F_5}{d \cdot t} \tag{1}$$

$$F_h = \frac{F_{\max}}{d \cdot t} \tag{2}$$

where F_5 is the 5 % offset load, $F_{\max}$ is the maximum load, d is the dowel diameter, and t is the thickness of specimen.

3 Results and Discussions

Figures 4 and 5 show the load-deformation curve of one of the specimens using 16 and 20 mm dowel diameter respectively.

Table 1 shows the mean dowel-bearing strength, standard deviation value, and coefficient of variance for the specimens using 16 and 20 mm dowel diameter. Table 2 shows the mean moisture content and density value of the specimens using 16 and 20 mm dowel diameter. Moisture content of specimens using 16 mm dowel diameter ranges from 9.52 to 12.03 % and moisture content of specimens using 20 mm dowel diameter ranges from 9.43 to 11.92 %. Density of the specimens using 16 mm dowel diameter ranges from 552.27 to 785.20 kg/m^3 and density of specimens using 20 mm dowel diameter ranges from 665.47 to 791.33 kg/m^3.

Figure 6 shows the mean dowel-bearing strength of specimens using 16 and 20 mm dowel diameter against the dowel diameter. It shows that the dowel-bearing strength is influenced by the dowel diameter. When the dowel diameter increases, dowel-bearing strength will also increases. This trend is found to be similar with the

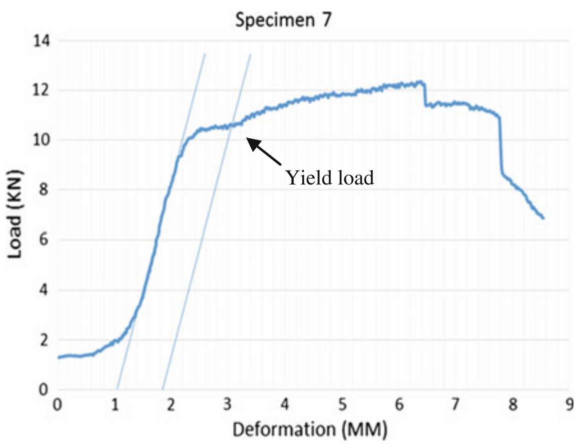

Fig. 4 Example of load-deformation curve for specimens using 16 mm dowel diameter

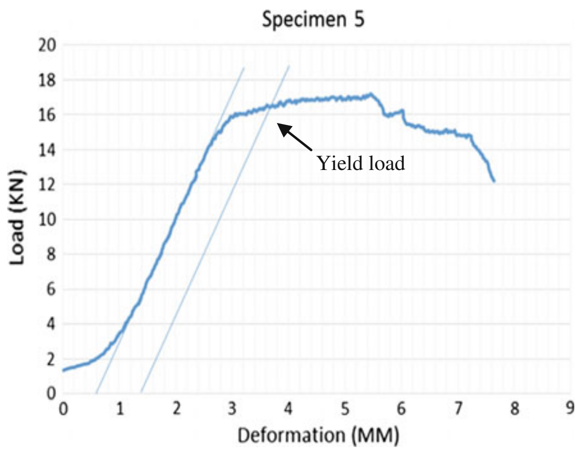

Fig. 5 Example of load-deformation curve for specimens using 20 mm dowel diameter

Table 1 Summary of the test results for specimens using 16 and 20 mm dowel diameter

Specimens (Nos)	Dowel diameter (mm)	Mean dowel-bearing strength, F_y (N/mm^2)	Standard deviation (SD)	Coefficient of variance (CV) (%)
30	16	17.77	1.12	6.30
30	20	21.47	1.79	8.34

Table 2 Mean moisture content and density value of specimens using 16 and 20 mm dowel diameter

Specimens (Nos)	Dowel diameter (mm)	Mean moisture content (%)	Mean density (kg/m^3)
30	16	10.82	648.52
30	20	10.86	722.56

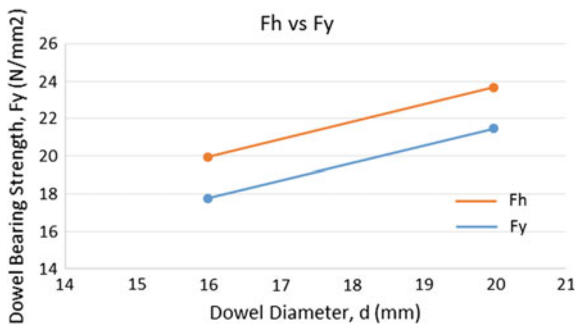

Fig. 6 Dowel-bearing strength versus dowel diameter

Fig. 7 Typical failure of the specimens using 16 mm dowel diameter

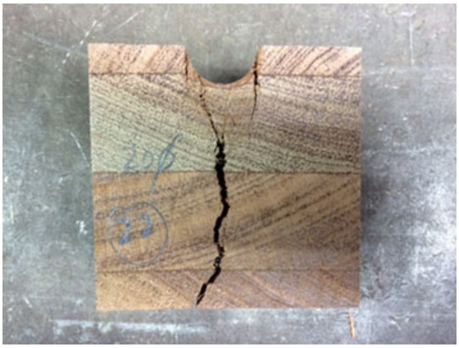

Fig. 8 Typical failure of the specimens using 20 mm dowel diameter

trend from the study by Jumaat et al. (2008) for Mengkulang solid timber species. Percentage differences of the dowel-bearing strength, F_y for Glulam Mengkulang with glue line species using 16 and 20 mm dowel diameter is 20.82 %.

Figures 7 and 8 shows the typical failure of the specimens using 16 and 20 mm dowel diameter. Both specimens are split perpendicular to the glue line. However, there are minor specimens observed in which the crack line is towards the glue line, this failure is due to lack of bonding of the adhesive between the timber layers on the specimens.

Table 3 shows the mean dowel-bearing strength, F_h is higher than the mean dowel-bearing strength, F_y. Percentage difference of mean dowel-bearing strength (F_y and F_h) for specimens using 16 mm dowel diameter is 12.27 %. Percentage

Table 3 Mean dowel-bearing strength (F_y and F_h) of specimens using 16 and 20 mm dowel diameter and percentage differences

Specimens (Nos)	Dowel diameter (mm)	Mean dowel-bearing strength, F_y (N/mm^2)	Mean dowel-bearing strength, F_h (N/mm^2)	Percentage differences (%)
30	16	17.77	19.95	12.27
30	20	21.47	23.68	10.29

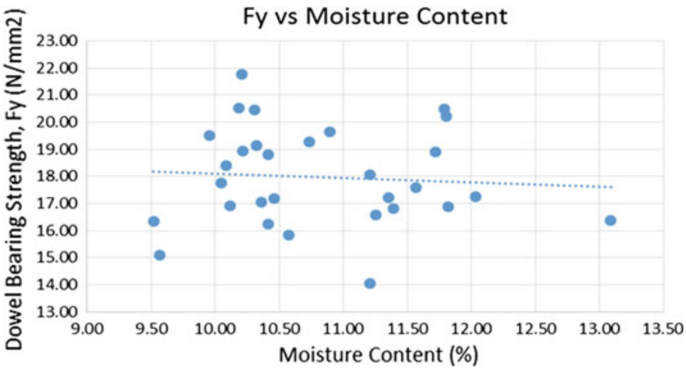

Fig. 9 Dowel-bearing strength versus moisture content (specimens using 16 mm dowel diameter)

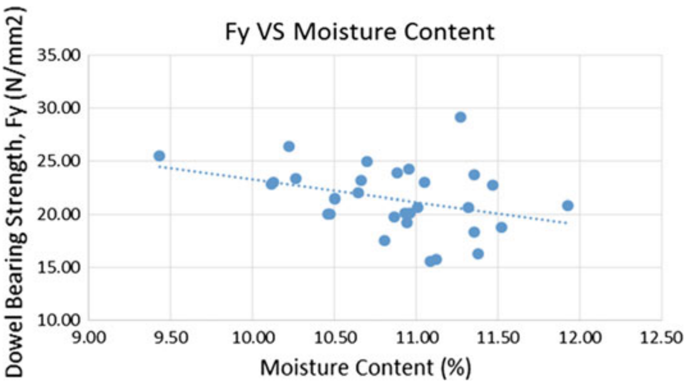

Fig. 10 Dowel-bearing strength versus moisture content (specimens using 20 mm dowel diameter)

difference of mean dowel-bearing strength (F_y and F_h) for specimens using 20 mm dowel diameter is 10.29 %.

Figures 9 and 10 show the relationship between moisture content and dowel-bearing strength of Glulam Mengkulang with glue line species. It is found that moisture content have a significant influence to the dowel-bearing strength. Dowel-bearing strength decreased when moisture content increased. These results agreed with the results from the study by Rammer in the year 2001. This is due to moisture content which causes the wood to shrink and expand, therefore degrading the strength of the wood.

Figures 11 and 12 show the relationship between density and dowel-bearing strength of Glulam Mengkulang with glue line species. It is found that density has a significant influence to the dowel-bearing strength. Dowel-bearing strength increased when density increased. This is because the wood fiber is more compacted in the wood specimens resulting in the value of mass over the higher

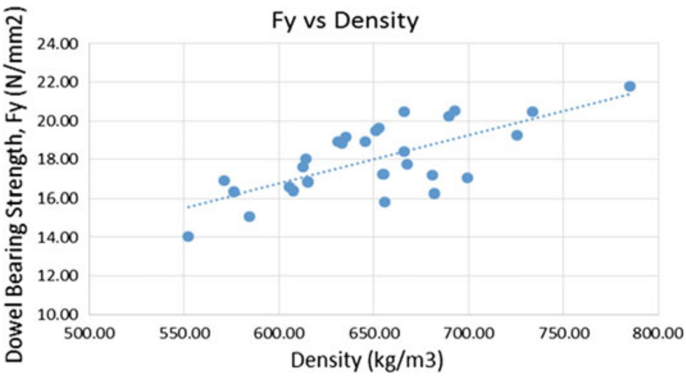

Fig. 11 Dowel-bearing strength versus density (specimens using 16 mm dowel diameter)

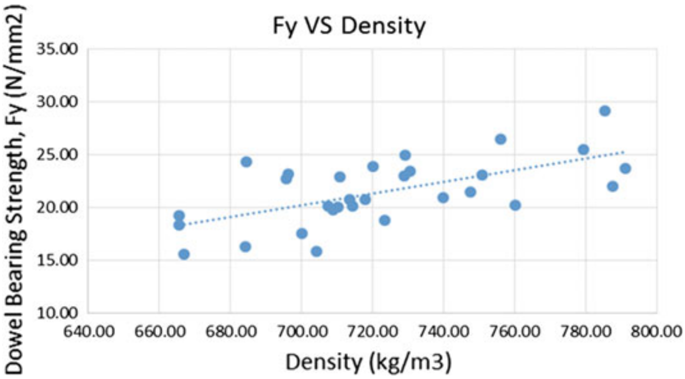

Fig. 12 Dowel-bearing strength versus density (specimens using 20 mm dowel diameter)

specimen volume. The results in terms of relation between dowel-bearing strength and density is similar with the results from Sawata and Yasumura (2002), Hubner (2008), and Ivan (2012).

4 Conclusion

Dowel-bearing strength of the Glulam Malaysian tropical timber, Mengkulang (*Heritiera* spp.) loaded perpendicularly to the glue line has been determined using 5 % diameter offset method according to ASTM 5764-97a, 2007. Dowel diameter is found to have influenced the dowel-bearing strength. When the dowel diameter increased from 16 to 20 mm dowel-bearing strength also increased. Percentage differences between the dowel-bearing strength using 16 and 20 mm dowel diameter is 20.82 %. Dowel-bearing strength obtained using BS EN 383 is found to have higher value than the value obtained from the ASTM D 5764-97a. Density and moisture content of the Glulam Mengkulang with glue line species is found to have significant influence on the dowel-bearing strength.

Acknowledgments This study is funded by Principal Investigator Support Initiative Grant (PSI) with the reference number 600-RMI/DANA 5/3/PSI(226/2013).

References

1. A. Aghayere, J. Vigil, Wood Properties, Species and Grades: Factors Affecting Wood Strength. Structural Wood Design: A Practice-Oriented Approach, John Wiley & Sons, Inc., Hoboken, New Jersey, pp.12–16 (2007).
2. T.H. Yang, S.Y. Wang, C.J. Lin, M.J. Tsai, Evaluation of the Mechanical Properties of Douglas-Fir and Japanese Cedar Lumber and its Structural Glulam by Nondestructive Techniques. Construction and Building Materials 22 487–493 (2008).
3. E.C. Ozelton, Glulam Beams. Timber Designers Manual Third Edition, Blackwell Science Ltd, Oxford, pp.123–152 (2006).
4. W.H.W. Mohammad, M.A. Razlan, Z. Ahmad, Bending Strength Properties of Glued Laminated Timber from Selected Malaysian Hardwood Timber', International Journal of Civil & Environmental Engineering IJCEE-IJENS, Vol: 11 No: 04 (2011).
5. T.M. Wong, S.C. Lim & R.C. Chung, A Dictionary of Malaysian Timbers, Forest Research Institute Malaysia, Malaysia, Kuala Lumpur (2002).
6. G. Coste, The Assessment and Applications of a New Connector Type for use in Timber Structural Systems', Degree of Doctor Thesis, Edinburgh Napier University (2010).
7. R. Hassan, S. Ismail, A.A. Siblamurisi, I.A.A. Bakar, C.M.M. Isa, Effectiveness of Glass Fibre Reinforced Plastic (GFRP) for Dowel-Type Timber Connections, University Teknologi MARA (2009).
8. Awaludin, Ali, Smittakorn, Watanachai, Hirai, Takuro, Hayashikawa, Toshiro, Bearing Properties of Shorea Obtusa beneath a Laterally Loaded Bolt, Journal of Wood Science, 53(3), 204-210 (2007).
9. T.L. Wilkinson., Dowel Bearing Strength Technology MARA. (2014), Res.Pap. FRL-RP-505 Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 9p. (1991).
10. D.R. Rammer, and S.G. Winistorfer, Effect of Moisture Content on Dowel -Bearing Strength, Wood and Fiber Science 33(1), pp.126-139 (1999).
11. D.R. Rammer, Effect of Moisture Content on Nail Bearing Strength, Res.Pap. FRL-RP-591. Madison, WI: US. Department of Agriculture, Forest Service, Forest Products Laboratory, 22p. (2001).
12. I.G.L.B. Eratodi, A. Triwiyono, A. Awaludin, T.A. Praytino, The Effect of Specific Gravity on Embedding Strength of Glued-Laminated Bamboo: Numerical Analysis and Experiment, Department of Civil and Environmental Engineering, Gadjah Mada University (2012).
13. R.J. Schmidt, Timer Pegs: Considerations for Mortise and Tenon Joint Design, Structure Magazine (2006).
14. U. Hubner, Embedding Strength of European Hardwoods, Graz University of Technology, Austria (2008).
15. K. Sawata, and M. Yasumura, Evaluation of Yield Strength of Bolted Timber Joints by Monte-Carlo Simulation (2002).
16. G. Ivan, Embedment Test on Wood for Dowel-Type Fasteners, Wood Research 57(4), 639-650 (2011).

17. Jumaat et al., The Determination of the Embedment Strength of Malaysian Wood, Department of Civil Engineering, University of Malaya (2006).
18. Jumaat et al., Development of Limit State Design Method for Malaysian Bolted Timber Joints, Department of Civil Engineering, University of Malaya (2008).
19. Awaludin et al., Bearing Properties of Shorea Obtusa beneath a Laterally Loaded Bolt, Journal of Wood Science,53(3),204-210 (2007).
20. Hassan et al., Effectiveness of Glass Fibre Reinforced Plastic (GFRP) for Dowel-Type Timber Connections, University Technology MARA (2009).
21. Hassan et al., Effects of Different Dowel Materialon Koompassia Malaccensis Bearing Strength, Faculty of Civil Engineering, University Technology MARA (2014).