Journal of Engineering and Science Research 5 (2): 06-10, 2021
e-ISSN: 2289-7127

DOI: 10.26666/rmp.jesr.2021.2.2

Performance of Pine and Kempas Glulam under Single Shear Load Test

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Abstract: Tropical countries around the world whether in Africa or Asia are heavily contribute to timber harvesting. Malaysia is one of these countries having a large number of timber species inclusive of different properties covering hardwoods and softwoods. Kempas species is one of Malaysian timber that is categorized in Malaysian standard classified in Strength Group 2 (SG2), which have good strength and durability. Whilst, Pine species categorized under softwood and easily available in countries like Australia, Spain and Scotland. This study concerns on the performance of single shear connections between these two selected species in the form of glued laminated timber (Glulam). Connection is an important issue, which should be well studied in order to establish a timber structure since it has a huge impact on the connection sys-tem. Single shear test was conducted on Kempas and Pine species jointed with steel bolts with 12mm and 14mm diameters. The result shows that carrying load carrying capacity of single shear connection for Kempas species is higher than Pine species for 12mm and 14mm diameters with 7.65% and 27.07% respectively. It is shown that load carrying capacity increases with increment of embedment strength value. The deformation increased with increment of bolt size and significantly affected the embedment strength and the load carrying capacity. The modes of failure for the samples were observed based on BS EN 1995-1-1:2004 standard accordingly. It was found that all samples failed under failure mode I having brittle in one of the members.

Keywords— *Connection; single shear; load carrying capacity; embedment strength; modes of failure*

1. Introduction

Timber structures are used throughout mankind lifespan due to the flexibility of timber to form a specific shape. However timbers are homogenous material thus having a different strength, density, physical and mechanical properties are common. Different performances of structural timber are also depending on the type of connection such as bolts, dowel, screw, nails and others. The different performance in timber connection is also huge between the solid and engineered wood. Glulam is much stronger than solid timber because the glue between the pieces of timber gives more rein-forcement to the timber and makes it tougher against separating of cells. The final product of glulam has lesser defects than solid timber (Angst-Nicollier, 2012) [1]. Connection is one of the critical parts in wood-based products. It can help the structure to build up its strength performance (Rosdi et al., 2015) [2]. Moss (1996) [3] mentioned that Trayer (1932) [4] tested hundreds of test and recommended numbers of theory or recommendation for a configuration of a bolted connection design. Trayer found up reasonable results for the bolt spacing, end distance, edge distance and size of the diameter and the results become the basis for connection design in the United States for many years (Moss, 1996) [3].

Mechanical connection is used nowadays due to the high load applied. This method is transferring the load from one piece to another of which make it able to resist more load such as bolts, nails, screws and nuts. If the structure is too huge, shear plates or split rings can be used (Kuilen and Vries, 2008) [5]. Timber joints are known to be less effective than steel joints due to the low embedding strength and the low strength of wood in shear perpendicular to grain (Branco et al., 2006) [6]. The nail shaped deformed in the timber-concrete application should be two times higher than timber-timber (Aicher et al., 2003) [7]. Timber joints are

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available in single or double shear connections. The double shear joint is the guided method in analyzing other traditional and modern joints design (Hassan et al., 2014) [8].

Most tropical countries are using tropical timber species either hardwood or softwood. Similar selection of species is found for the productions of glulam. Glulam is produces in large dimension and long span up to 40m in length and height of the section up to two meters and also have a good strength to weight ratio. It has been used in transportation infrastructures like bridges and roof of warehouses (Sena-Cruz et al., 2012) [9]. Santos et al., 2009 [10] found the comparison between ultimate strength, initial joint slip modulus and ductility with Eurocode 5:2008 [11] values. The result double-shear single dowel wood connection experimented under monotonic quasi-static loading. The three dimensional finite element wood connection models were created using experimental data. Lukaszewska et al., 2008 [12] performed direct shear test on glulam block segment attached with prefabricated concrete slab. Shear test procedures can be improved by single cube apparatus method (Hassel et al., 2009) [13].

European Yield Model (EYM) states a number of failure mechanism of the bolted connection structure involving entirely plastic yielding of the wood member only or the bolt only or both of them the bolt and the wood member (Smith et al, 1988) [14]. However, EYM have been adopted by most of countries and its application procedure of the failure mechanism is used in their national codes for the wood connection with dowel fasteners such as Eurocode5 and (NDS) national design specification. In the study done by (Quenneville et al, 2001) [15] stated that in the thicker bolted connection row the load was not equally of uniformly distributed and the failure was brittle but still some individual bolts experience ductility but the majority was brittle. EYM which explains the 5% offset yield, it describes the basis of lateral strength of a single fastener. The offset of 5% is defined as the point that the load-displacement curve is intersected with a line parallel to the linear zone as shown in Fig.1. Therefore the yielding strength of the specimen is predicted based on elastic and plastic of both materials which are the wood sample and the diameter or dowel (AFPA, 1997) [16].

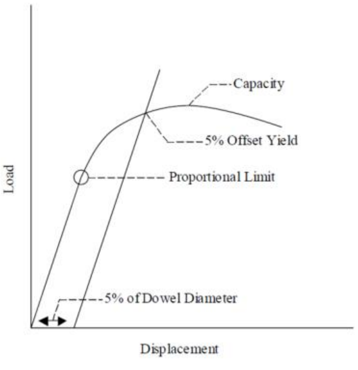


Fig. 1. The two holes on each specimen (a) block dimension, (b) minimum end and edge distance.

Branco et al., 2009 [17] compared between the slip modulus and load carrying capacity values with analysis specified in Eurocode 5:2008 [11]. The single shear test is being applied to determine the single shear strength for a specific type of connection. This resulted in a limited single shear strength data for Pine and Kempas species. There are lacking of data for the bolted timber connection with steel bolts having diameter size of 12mm and 14mm using single shear test (Malek et al., 2016) [18]. There are restricted comparison data available on discussing the connections performance between Pine and Kempas. Thus, this research is aimed to determine and compare the load carrying capacity for Pine and Kempas species for two different sizes of diameters, which are 12mm and 14mm. The single shear characteristics are as shown in Fig. 2.

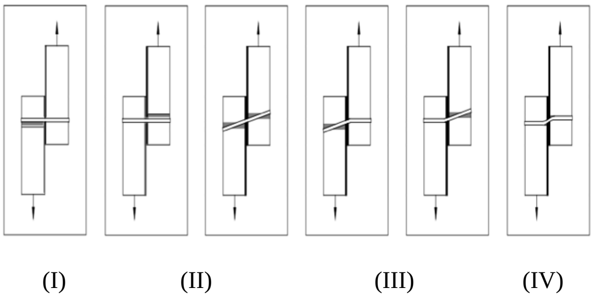


Fig. 2. Possible failure mechanism for bolts in single shear joint (Larsen, 1973 [19] and McLain & Thangjitham, 1983 [20])

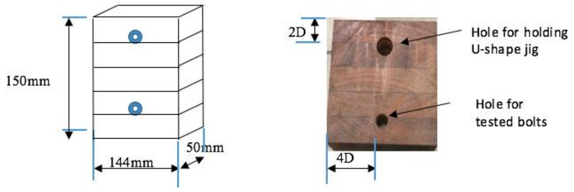
Where;
Yield Mode I: wood crushing at one of the member either in the main or side member.
Yield Mode II: wood crushing at both members without bending of the fastener.
Yield Mode III: crushing of one of the members with bending of the fastener.
Yield Mode IV: bending of the fastener without crushing of wood members.

2. Methodology

A. Sample Preparation

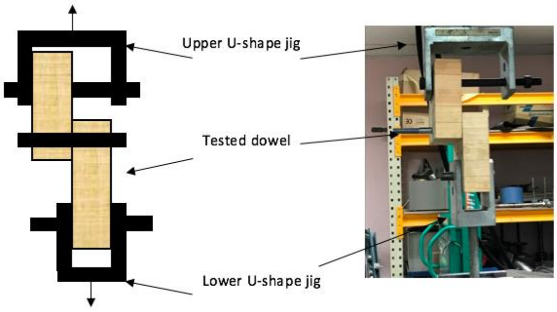
The test was conducted on the Pine and Kempas species with 150mm x 144mm dimension and a thickness of 50mm for side and main members. The drilled holes of 12mm and 14mm diameters for the bolts to hold the connection between the two members is as shown in Fig. 3. Each sample was drilled with minimum end distance, 2D and edge distance, 4D as stipulated in Malaysian Standard (MS544: Part5: 2001) [21]. The specimens were hold to the heavy-duty Universal Testing Machine (UTM) using steel jigs that designed in a form of U-shapes (Fig. 4). Holes for the U-shape jig that holds the samples at the upper and bottom positions, each was predrilled 4mm bigger than the tested dowel diameter.

The clearance of bolt hole is very crucial since the tight hole may lead to failure of the sample before achieving its desired load capacity. However the clearance between the bolt and the drilled hole should be suitable enough. Common clearance normally between 1mm to 3mm depends on the bolt sizes. In this experiment, 1mm clearance was adopted.



(a) (b)

Fig. 3. The two holes on each specimen (a) block dimension, (b) minimum end and edge distance.



(a) (b)

Fig. 4. Single shear test set-up (a) sketch up (b) actual

B. Universal Testing Machine

The Universal Testing Machine (UTM) has a hydraulic controller device, which allows the machine to move up and down and open or close for the gripping. UTM was connected to computer devices which allow user to choose a specific type of test to be run and input the data of the samples that required and choose the rate that have been stated in the code for the specific experiment. For this experiment the speed rate was referred to ASTM D143:1994 [22] which is 0.254mm/min.

3. Result & Discussion

The complied results are the maximum load carrying capacity for Pine and Kempas species bolted by 12mm and 14mm bolt diameters under single shear load test. The mean maximum load for Pine species 12mm bolt diameter was 3.764kN, the standard deviation was 0.075 and the CoV was 0.02. The 14mm bolt diameter was 3.619kN, standard deviation 0.029 and CoV was 0.008. Nevertheless, for Kempas species 12mm bolt diameter was 4.965kN, standard deviation was 0.414 and CoV was 0.083. The 14mm bolt diameter was 4.115kN, standard deviation was 0.184 and CoV was 0.045 respectively.

Fig. 5. Percentage difference for Pine between of 12mm and 14mm bolt diameter

Fig. 5 shows the percentage difference for load carrying capacity of Pine species for 12mm and 14mm bolt diameters. The load carrying capacity of 12mm and 14mm diameter obtained was 3.8kN and 3.62kN respectively. The percentage difference between the two sizes was 4.7%, though the dimension of the tested samples were the same which was 150x144x50mm the load carrying capacity have different values and the sample with smaller diameter obtain high load carrying capacity. It shows that the smaller diameter connections performed better than the bigger diameter for the same samples sizes. Glulam members with bigger bolt diameter tend to crush wider than the smaller samples.

(a) (b)

Fig. 6. Typical failure modes of glulam sample due to single shear test for Pine (a) 12 mm diameter and (b) 14 mm diameter

Fig.6 shows the typical crushing of glulam samples after the test. The 12mm diameter seems to have less deformation or crushing. This wood crushing failure only occurs at one of the member either in the main or side member. Thus it shows that the failure modes failed under Yield Mode I. The bolt connections were found without bending of the fasteners. Its shows the limitation for the similar sizes of tested members is only suitable for 12mm diameter rather than 14mm diameter.

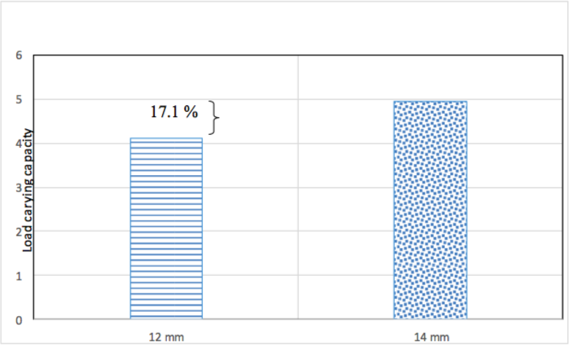


Fig. 7. Percentage difference for Kempas between of 12mm and 14mm bolt diameter

Fig. 7 shows the percentage difference of load carrying capacity for Kempas species. The load carrying capacity Kempas bolted with 12mm and 14mm diameter was 4.115kN and 4.964kN respectively. The strength carried out with 14 mm diameter was found 17.1% higher the the 12mm diameter. This behavior shows that the capacity of Pine is contradicts compared to Kempas. It clarifies that 14 mm diameter shall be used to design a glulam connection made of Kempas species rather than Glulam made of Pine species.

(a) (b)

Fig. 8. Typical failure modes due to single shear test for Kempas (a) 12mm diameter and (b) 14mm diameter.

Fig. 8 shows the typical failure modes of glulam samples made of Kempas species. The typical failure is in the forms of small horizontal cracks or crushing failure. Similar patterns of failure was found to Pine since the wood crushing failure only occurs at one of the member either in the main or side member. Thus it shows that the failure modes of Kempas performed falls in the same group of Pine. The bolt connections were found without bending of the fasteners. From the experimental test, it clarifies that the glulam connection made of Kempas deformed or crushed higher for bigger bolt diameter. However, the load carrying capacity increased significantly when the larger diameter was used. In contradiction to Kempas connections, the behaviour of Pine connections shows that the diameter of bolt increased once the shear strength decreased.

The shear strength is effected by the applying load and the size of the diameter of the fastener such as bolt, nail or dowel. Deformation is also effecting the applying load and if the deformation is high the applying load will be decreased and the sample will fail earlier. Therefore from these results is clear that the shear strength decrease with the increment of the area of the bolt.

Deformation increased with increment of bolt size, that what is stated in the theoretical studies and what was obtained in Kempas species, the bolt size of 12mm has average deformation of 5.513mm while bolt size of 14mm has average deformation of 5.85mm , however in case of Pine species this theory was not reflected and the results were 10.8mm for bolt size of 14mm and 11.565mm for bolt size of 12mm and similar to the load carrying capacity the 12mm diameters resist load more than 14mm bolt diameter which are 3.62kN and 3.8kN respectively , and these results are acceptable because the maximum load applied in 12mm was higher than the applied load on the 14mm diameter so as a result the deformation will be higher and this is what was calculated.

Timber can be effected by weather condition whether as wet or dry condition, moisture content, temperature at the storage place and defects. The failure modes in this experiment was all similar to each other and belong to failure mode (I) which was identified in literature review as the crushing of one of the members without bending of the bolt and all of the failure occurred on the upper specimen only Kempas sample B the failure was on the lower sample but still under same category of mood of failure.

The results shown that the deformation and load carrying capacity increased with increment of bolt size. This was happened for Kempas species when the bolt size was increased from 12mm to 14mm the maximum tensile load applied increased from 4.115kN to 4.965kN respectively. However in Pine species the results shows that when the area of the bolt increased the shear strength decreased, diameter of 12mm and 14mm resist tensile load of 3.8kN and 3.62kN respectively.

The clearance of bolt hole is very essential aspect when the sample is tested on tension or compression, because if the hole is too tight to the bolt it may lead to failure of the sample before achieving its desired load capacity therefore the maximum shear strength will not be obtained, however the clearance of the bolt must have desired space and not be very loose otherwise the load will not be distributed equally and the joint will not have an effective load resistance therefore tension and compression results will not provide the users of an accurate results, however for clearance usually 1mm to 2mm is used and in this experiment 1mm clearance was adopted.

The effect of end distance and edge distance are very important, but in this experiment the end distance and edge distance are constant depending on the size of the diameter of the bolt which was 2D and this is the minimum end distance for dry timber stated in the Malaysian standard MS544:Part5 and the edge distance was the width of the sample divided by two since we have only one single bolt. The increment of end distance will increase the carrying load capacity because more area will be compressed around the bolt which is the most failure part in timber connection thus the specimen will carry more load due to the large distance from the centre of the bolt to the edge of the specimen.

Member thickness is an important affect when carrying load capacity needs to be increased, the increment of the thickness will reduce the stress on the specimen and will allow for more load to be carried, however the size and dimension of the timber specimen not easily can be chosen the care must be taken and dimension must be based on the codes of practices like the Malaysian standard or Eurocode or other code of practices. In this experiment that used equal thickness for all samples and members, usually there is side member and main member so the increment of thickness of one of them will may also contribute in increasing the carrying load capacity.

In this experiment the bolts are made of steel having diameter size of 12mm and 14mm, its known that the modules of elasticity pf steel is higher than timber and this could be the reason of non-failure behaviour of the bolt and only timber members have failed, so when the bigger diameter has used then the bolt may be affected. The result could shows differently if the fastener was made out of other material such as timber dowels. Normally, steel bolts are more expensive than timber dowels therefore timber dowels are concerned to be more economical.

The pattern of bolt failure for both species connections were found. Therefore, this results shows that Glulam made of Kempas species shall carry a stronger load carrying capacity than Pine species when it is subjected to shear load test.

4. Conclusion

The maximum tensile load can be applied and the load carrying capacity for the Kempas and Pine species bolted with 12mm diameter were determined, for Kempas species was 4.551kN with deformation of 5.513mm and carrying load capacity of 4.551kN and for Pine species was 3.764kN with deformation of 11.565mm, while in the case of 14mm diameter Pine species obtained carrying load capacity of 3.62kN with applied load of 3.62kN and deformation of 10.8mm. In Pine species the diameter of 12mm obtain carrying load capacity more than 14mm diameter with difference of 4.7%. Whereas, in Kempas species diameter of 14mm obtained higher carrying load value than 12mm with difference of 17%. In both cases Kempas species were stronger than Pine species with difference of 7.5% in 12mm bolt diameter and 27% in 14mm bolt diameter. Eventually, it was found that Glulam connections made of both species failed under Yield Mode I, which is brittle of one of the members and without bending of the fasteners.

Acknowledgment

The authors gratefully acknowledge the help of Universiti Teknologi MARA, Shah Alam and SEGi University that contributed in this research.

References

[1] V. Angst-Nicollier, “Moisture Induced Stresses in Glulam: Effect of Cross Section Geometry and Screw Reinforcement,” 2012.

[2] N. Rosdi, R. Hassan, M.H. Yasin, “A Review of Connections for Glulam Timber,” In: Hassan R., Yusoff M., Alisibramulisi A., Mohd Amin N., Ismail Z. (eds) InCIEC 2014, pp. 1163-1173, Springer, Singapore, 2015.

[3] P.J. Moss, “Research into row modification factors for multiple-bolted timber joints,” In Proceedings of the International Wood Engineering Conference, vol. 4, pp. 197-204, 1996.

[4] G.W. Trayer, “The bearing strength of wood under bolts,” US Dept of Agriculture, vol. 326, 1932.

[5] J.W.G. Van de Kuilen, and P.A. De Vries, “Timber joints with high strength steel dowels,” In 10th World Conference on Timber Engineering, paper vol. 401, 2008.

[6] J.M. Branco, M. Piazza, P.J. Cruz, and H. Varum, “Strengthening methodologies of portuguese traditional timber connections,” 2006.

[7] S. Aicher, “Structural adhesive joints including glued-in bolts,” Timber engineering, pp. 333-363, 2003.

[8] R. Hassan, A. Ibrahim, Z. Ahmad, and M.N. Shakimon, “Factor of safety for dowelled-double shear kempas and kapur connections,” In InCIEC 2013, pp. 61-73, 2014 Springer, Singapore.

[9] J. Sena-Cruz, J. Branco, M. Jorge, J.A. Barros, C. Silva, and V.M. Cunha, “Bond behavior between glulam and GFRP’s by pullout tests,” Composites Part B: Engineering, vol. 43(3), pp.1045-1055, 2012.

[10] C.L. Santos, A.M. De Jesus, J.J. Morais, and J.L. Lousada, “Quasi-static mechanical behaviour of a double-shear single dowel wood connection” Construction and Building Materials, vol. 23(1), pp. 171-182, 2009.

[11] Eurocode 5. (2008). Design of Timber Structures (BS EN 1995-1-1- 2004+A1:2008).

[12] E. Lukaszewska, H. Johnsson, and M. Fragiacomo, “Performance of connections for prefabricated timber-concrete composite floors,” Materials and structures, vol. 41(9), pp. 1533-1550, 2008.

[13] B.I. Hassel, P. Berard, C.S. Modén, and L.A. Berglund, “The single cube apparatus for shear testing–Full-field strain data and finite element analysis of wood in transverse shear,” Composites Science and technology, vol. 69(7-8), pp. 877-882, 2009.

[14] I. Smith, L.R.J. Whale, C. Anderson, B.O. Hilson and P.D. Rodd, “Design properties of laterally loaded nailed or bolted joints,” Can. J. Civil. Eng., 15(4), pp. 633-643, 1988.

[15] J.H.P. Quenneville, M. Mohammad, “Design method for bolted connections loaded perpendicular-to-grain,” Canadian Journal of Civil Engineering, vol. 28 (6), pp. 949-959, 2001.

[16] AFPA, “National design specification for wood construction,” NDS-1997, American Forest and Paper Assoc., Washington, D.C. (1997).

[17] J.M. Branco, P.J. Cruz, and M. Piazza, “Experimental analysis of laterally loaded nailed timber-to-concrete connections,” Construction and Building Materials, vol. 23(1), pp. 400-410, 2009.

[18] N.J.A. Malek, R. Hassan, E. Mohamed, and M.N.S. Ali, “Double shear test behaviour of balau species for different end distance,” Jurnal Teknologi, vol. 78(5-4), pp. 89-93, 2016.

[19] H.J. Larsen, “The yield of bolted and nailed joints,” Proc., Div. V Conf., Int. Union of Forestry Res. Org., pp. 646-654, 1973.

[20] T.E. McLain, A.M. Thangjitham, "Bolted Wood-Joint Yield Model" Journal of Structural Engineering, vol. 109 n.8, pp. 1820-1835, 1983.

[21] Malaysian Standard, “Code of Practice for Structural Use of Timber. Part 5, Timber Joints, Malaysia,” MS544, 2001.

[22] ASTM D143, “Standard Methods of testing small clear specimens of timber,” American Society for Testing and Materials, Philadelphia, PA, USA, 1994.