Journal of Tropical Forest Science 30(1): 67–74 (2018)
https://doi.org/10.26525/jtfs2018.30.1.6774

PULL-OUT STRENGTH OF STEEL RODS BONDED INTO MENGKULANG (*TARRIETIA JAVANICA*) GLULAM AT FIVE DIFFERENT ANGLES TO THE GRAIN

Mohamad WNN*, Suliman NH, Kamarudin MK, Mohd-Amin N & Hassan R

Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

**wan_nasuha92@yahoo.com*

Submitted February 2017; accepted August 2017

The design of a glued-in rod into timber, with respect to the grain, is critical as the capacity of the joint is highly dependent on the grain orientation. Since there has been no research carried out on mengkulang (*Tarrietia javanica*) glulam experimental pull-out strength at different angles to the grain, this study is important to provide fundamental information for steel rod connection. A total of 25 pull-out strength tests were conducted on glued-in threaded steel rods bonded into glulam made of mengkulang at 0° (parallel), 45°, 60°, 75° and 90° (perpendicular) to the grain, using epoxy adhesive. The rod was subjected to constant cross-head displacement of 2 mm min^{-1}. The pull-out strength was found to be negatively correlated with the angle of the grain, with failure load decreasing from 97 to 62 kN as grain angle increased from 0° to 90°. Displacement (until failure) was greatest (10 mm) when the load was applied perpendicular (90°) to the grain and smallest (6.8 mm) at 45°. The highest percentage difference in strength (44.12%) was between 0° and 90° angles to the grain, thus the former was twice as strong as the latter connection. Significant increase in percentage of strength (11.2%) was observed as grain angle decreased from 90° to 0°. Shear breakage along the adhesive and timber interface was the dominant mode of failure recorded for all the samples tested.

Keywords: Pull-out test, glued-in rod, grain direction, glulam timber connection

INTRODUCTION

The full-scale manufacture of glulam structures requires efficient connection systems. Selecting and detailing the connection is a critical aspect because the strength of the whole structure depends on its parameters (Sjödin, 2008). Timber jointing is a significant area of research in engineering studies, with many aspects that need to be investigated. The performance of a joint is influenced by factors such as bonded length, type of glue, dowels pattern, grain orientation and timber species (Ahmad et al. 1993). Modern timber engineering requires a good connection system, and this need has spurred recent research on the use of glued-in rods (GiR) in glulam structures. The GiR are used in heavy and huge timber construction which requires large load capacity of joint, coinciding with glulam (Gustafsson & Serrano 2000, Tanaka et al. 2012, Dorn et al. 2013). In addition, glued-in rod was purposely invented to strengthen the timber structure, especially to increase shear strength perpendicular to the grain (Harvey 2003, Za'ba et al. 2013, Steiger et al. 2015). The GiR are considered a hybrid joint with combination of three different materials, i.e. rod, adhesive and timber, where the rod is bonded into the timber using an adhesive (Figure 1).

In addition to benefits such as architectural strength and economical production, GiR connections offer high strength and stiffness, lower weight, good fire resistance and better aesthetic value (Ling et al. 2014). Besides, GiR connections do not result in many large holes in the timber, which may reduce the structural performance of the timber. Considerable research has been done on designing connections with GiR configuration parallel and perpendicular to the grain (Steiger et al. 2006, Widmann et al. 2007, Rossignon & Espior 2008, Hunger et al. 2016, Hussin et al. 2016). However research on joint strength related to load-to-angle grain is limited. It is important to determine the weight-bearing capacity that can be sustained by a joint when loads are applied at different angles to the grain, and the average percentage difference of the capacity, to precisely know which structures

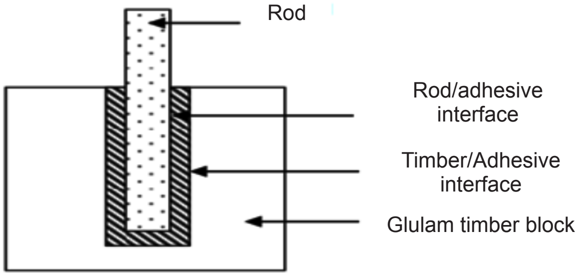

Figure 1 Schematic diagram of a glued-in rod (GiR)

and designs are applicable for strength. Results from previous studies vary significantly since there is no general consensus in selecting the materials and methods. In addition, the insertion of GiR at different angles to glulam grain is a concern as it affects joint strength and failure as timber strength and type varies and bonding properties at different grain angle is unknown (Zhu Hong et al. 2017). Essentially, every intersection of structure has a joint to connect from one to another, in order to lengthen or to form a curve/arch beam (Harvey 2003). Intersections are important structural elements that must be able to distribute loads effectively from one to another (Sjödin 2008). The grain direction in glulam structures varies as the structures are formed in many shapes and sizes depending on its purpose.

Thus, it is necessary to consider the grain direction of glulam in designing structures with GiR connections, e.g., column to beam, frame corner and trusses system. Therefore, the objective of this study was to determine the pull-out strength of GiR inserted into mengkulang (*Tarrietia javanica*) glulam blocks at five different angles to the grain, that is from 0° to 90°. It is expected that the proposed angles will affect the pull-out strength of the glulam connection.

MATERIALS AND METHODS

Glulam

The glulam timber species used was mengkulang (*T. javanica*), grade SG5 (MS 544: Part 2 2001). Mengkulang is a hardwood of medium weight with a density of 590–760 kg m^{-3}, dried to moisture content of 15%, and available in the Malaysian timber industries. According to the standard, a timber is characterised by its strength group, grade and species, sizes and surface condition, service classes or moisture content, durability, preservation and preservatives of timber and special requirements. Glulam is manufactured in accordance with the standard MS 758. 2001.

Adhesive

The adhesive used was a low viscosity crack injection epoxy. This adhesive can flow and penetrate spaces, hardens without shrinkage, can be used with most substrates, results in a high strength mechanical bond with good early strength, has high chemical resistance and does not break or become brittle. The adhesive is an epoxy resin with two components, component A (clear colour) and component B (pale yellow colour), which is three parts resin to one part hardener by volume or weight, as recommended by the manufacturer. The curing period is about 10 days, yielding a relatively high strength bond.

Threaded rod

High quality S275 steel threaded rods with a diameter of 16 mm were used. The threads on these rods offer mechanical interlocking between rod and adhesive, superior to common rebar and eliminates shear failure along the adhesive and rod interface (Steiger et al. 2015). Threaded rods create an effective bonding of rod to timber due to its surface feature that provides more grips. Connection with threaded rods embedded at an angle to the grain is an alternative connection for the dowel-type fasteners or glued-in rods (Stamatopoulos 2016).

Sample preparation

Twenty five samples of pull-out glulam timber blocks were prepared, each measuring 140 mm x 140 mm x 140 mm (width x length x depth). The study focused on single dowel-type connection. Testing of single rods allows a simplified analysis and isolation of parameters showing their influence on the mechanical performance of the joint (Rossignon & Espion 2008, Tlustochowicz et al. 2011). Oversized holes of 20 mm diameter were drilled into the glulam blocks at 0°, 45°, 60°, 75° and 90° angles to the grain (Figure 2). Five samples were prepared for each drill angle, for testing. The adhesive was injected to fill a third of the depth of the drilled hole. The rod was then inserted under continuous pressure, with a counter-thread turning motion, until it contacted the bottom of the hole. This method of insertion ensures good wetting and expels trapped air that may affect the strength of the joint. An O-ring was placed over the hole as a guide, ensuring that the rod was inserted precisely in the middle of the hole, resulting in an adhesive layer of 2 mm thickness. The best epoxy-bonded joints was found to be a minimum bond line of 2 mm thickness (Harvey et al. 2003). The bonded length of the rod was 130 mm (Figure 3), which was eight times the diameter of the rod, L_{bmin} = max (0.4 dr^2, 8 dr). Increasing the bonded length of the rod will increase the pull-out failure load of the joint, due to the increased surface area of rod and timber in contact with the adhesive (Harvey 2003). Thus, the recommendation minimum bonded length should follow the Eurocode 5, L_{bmin} = 8dr. The samples were then cured for ten days before testing.

Experimental method

The pull-out rod sample was installed on a digital-servo hydraulic universal testing machine, with a load capacity of 1000 kN. The end of the rod was clamped with a gripping jig and a rig plate was placed above the glulam block to support the sample (Figure 4 and 5). The pull-out sample was secured in such a way as to prevent movement in any direction. The rod was pulled upward at a constant cross-head displacement of 2 mm min^{-1} up to failure, with a duration of approximately 6 minutes (EN 2689 1991). The load applied was increased until the connection failed, and the failure load (kN) for each test was recorded and evaluated.

RESULTS AND DISCUSSION

The strength of GiR connection was negatively correlated with the increase in grain angle and

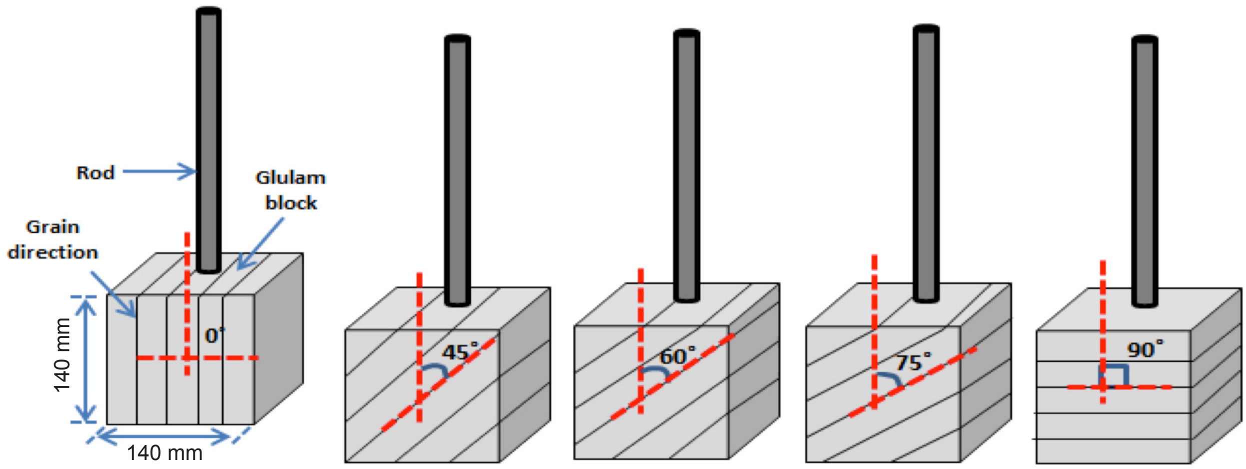

Figure 2 Schematic diagram of glulam blocks with rods inserted at different angles to the grain

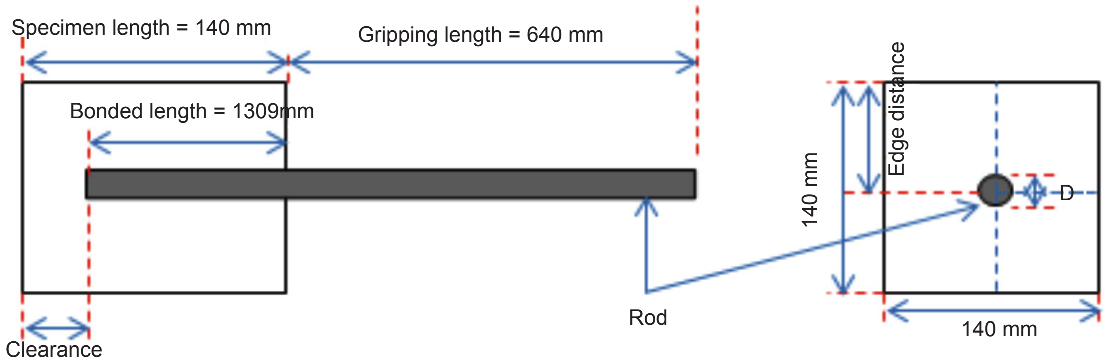

Figure 3 Dimensions of the pull-out test sample

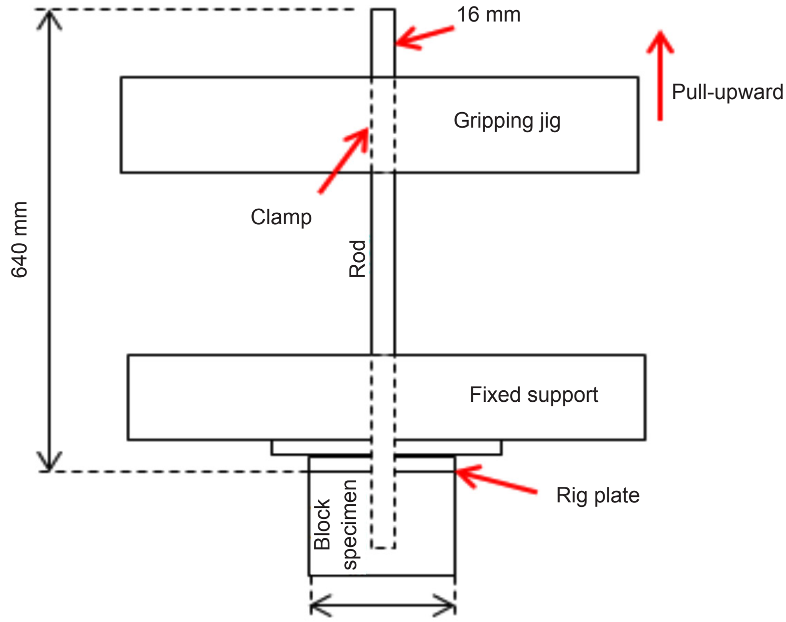

Figure 4 Schematic diagram of the pull-out test set up

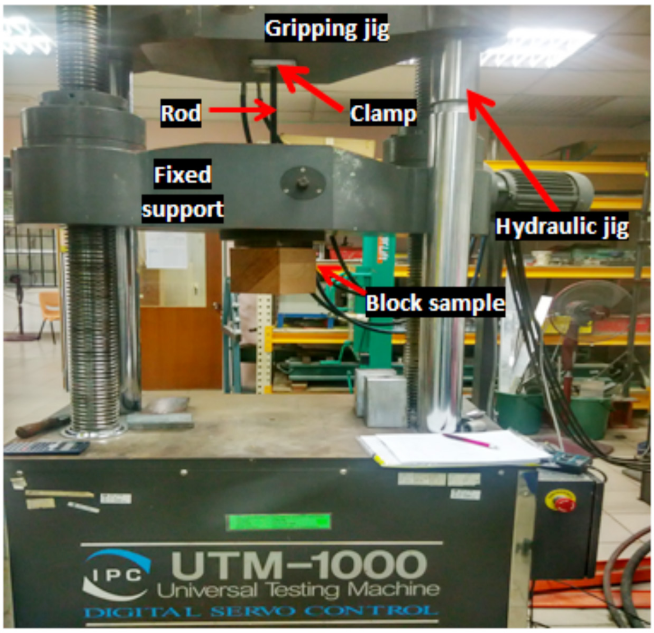

Figure 5 Set up for the pull-out test

larger shear interface along the joint, with failure load decreasing from 97 to 62 kN as grain angle increased from 0° to 90° (Table 1). The small standard deviation values indicated that the strength for all samples was fairly uniform, while small range in coefficients of variation indicated uniformity of the data. The load-carrying capacity of GiR in glulam timber was thus dependent on the grain direction of the glulam. Rods inserted into glulam parallel (0°) to the grain were stronger and had more shear resistance, compared to rods inserted horizontal (90°) to the grain. However, the difference in load-carrying capacity from one angle to the other was not significant.

At all angles tested, displacement increased steadily with loading, until the elasticity of the structure was exceeded, failure load was reached, and the joint ruptured (Figure 6). Displacement (until failure) was greatest (10 mm) when the load was applied perpendicular

Table 1 Mean values of failure load for rods glued-in at different angles to the glulam grain

	Grain direction				
	0°	45°	60°	75°	90°
Mean (kN)	97.08	77.68	73.73	67.70	61.99
Standard	11.49	11.98	23.50	32.72	13.49
Coefficient of variation	0.12	0.15	0.32	0.48	0.22

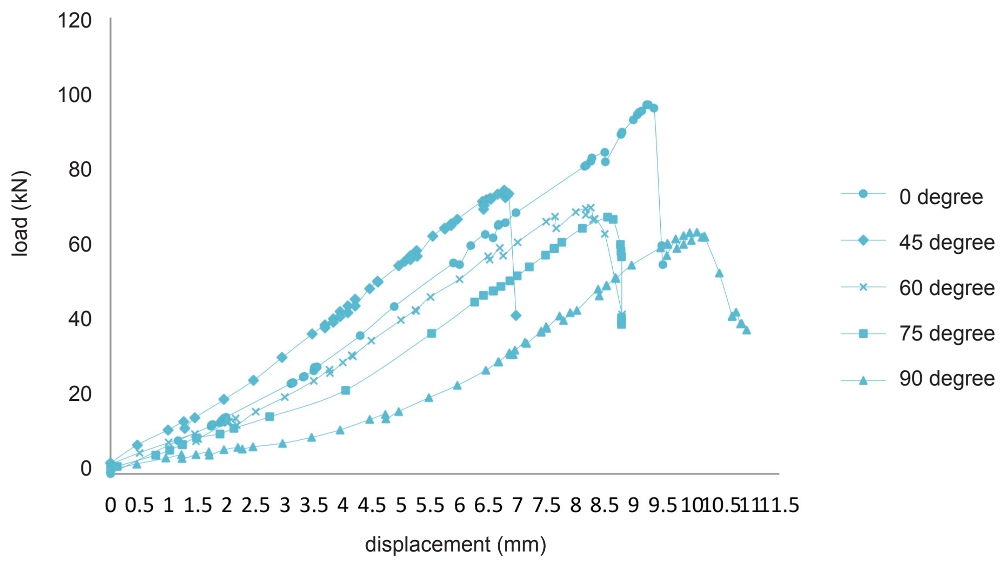

Figure 6 Load versus deformation for different grain direction

(90°) to the grain and smallest (6.8 mm) at 45°. Rods glued-in parallel to the grain had greater strength, compared to rods glued-in at other angles to the grain, as reported by similar studies on hybrid joints (Bengtsson & Johansson 2001, Tlustochowicz et al. 2011, Hussin et al. 2016). Hussin et al. (2016) found that glulam joints with dowels glued-in parallel (0°) to the grain bore twice the maximum load, then joints with dowels glued-in perpendicular (90°) to the grain. Harvey (2003) reported that the average failure load (kN) for rods parallel to grain is higher (40%), than rods perpendicular to grain. On the other hand, Widmann et al. (2007) reported that rods bonded perpendicular to the grain were 20–50% stronger than those bonded parallel to the grain. In addition, elasticity of the adhesion was evidently influenced by the grain direction, as shown in the present study, concurring with previous findings that the effective modulus of elasticity of adhesion was related to the load-to-grain direction. Compared to the parallel dowel adhesion, the perpendicular dowel adhesion had lower shear strength because the adhesive faced more layers and intersections along the bond line (Figure 7). The highest percentage difference in strength was between 0° and 90° angles to the grain (44.12%), showing that the former was twice as strong as the latter connection, and the strength difference of the load-to-grain direction for both angles was not more than 50%. Other insertion angles also showed varying percentage differences that were not very large (Figure 8).

The load-displacement curve for a glulam sample with GiR inserted at 0° to the grain was examined to explain the behaviour of the sample during testing (Figure 9). The curve showed brittle type behaviour due to sudden failure of the connection after reaching its elastic limit. It was noticed that a small breaking point existed during the elastic zone. Part l was linear due to the elastic behaviour of the materials and joint, which was the highest load, directly proportional to displacement. Part ll showed non-linearity with the materials reacting and breakage occurring as the load increased. Part lll showed a straight downward line as the joint failed totally. There was no increment in the load although there were movements in the joint, as the whole structure could no longer sustain any loads.

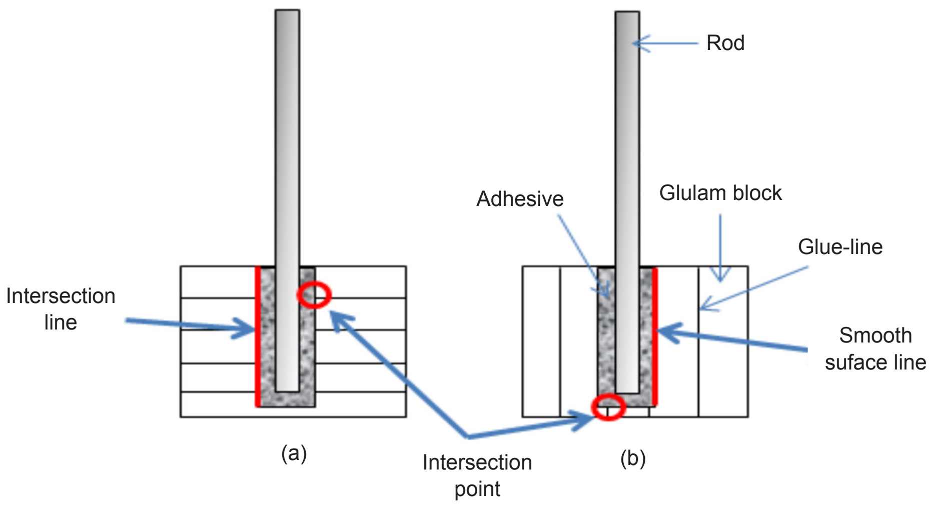

Figure 7 Schematic diagram of hybrid joint with GiR inserted (a) perpendicular and (b) parallel to the glulam grain

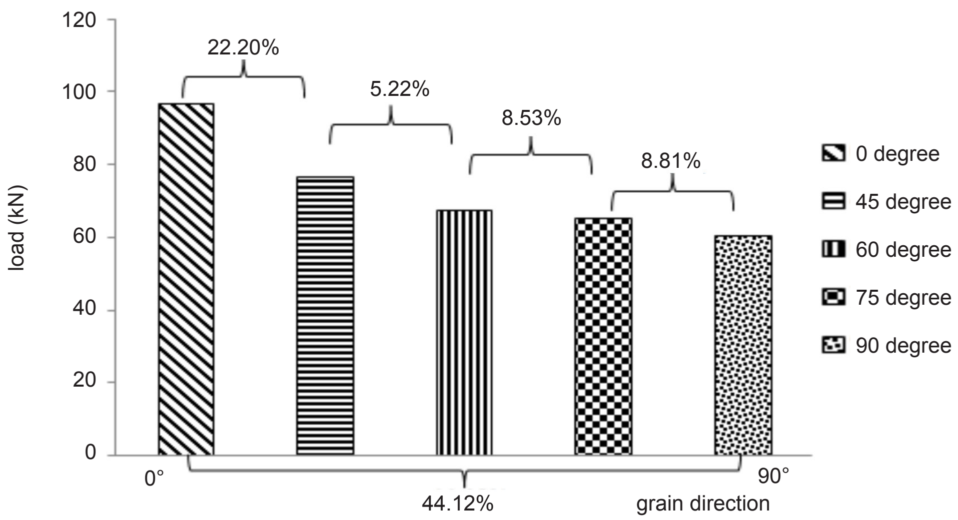

Figure 8 Differences in strength of GiR inserted at varying angles to the glulam grain

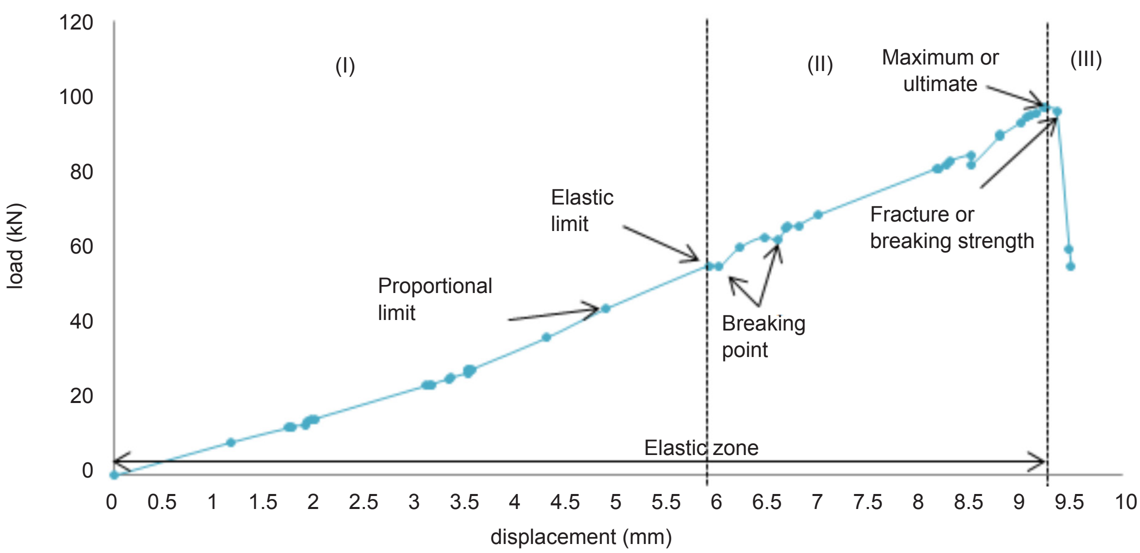

Figure 9 Typical load-displacement curve of the rod glued in at 0° to the glulam grain; (I) = linear, (II) = non-linearity , (III) = straight downward line

Failure modes

Identifying the modes of failure is a crucial step in improving a structure. Generally, failure modes are found in the connection (Ahmad et al. 2010). Brittle failure modes should be overcome by designers as these may pose a safety hazard and occur suddenly, without warning (Tlustochowicz et al. 2011). However, in the present study, shear failure along the adhesive and timber interface (brittle) was the dominant cause of failure, (Figure 10). The rod and adhesive had pulled away from the glulam block along pre-drilled holes. There was no shearing between adhesive and rod, as the adhesive was still intact around the threaded rod. This indicated that the bond-ability between the adhesive and steel rod is highest, whereas failure occurred on adhesive to timber interface due to the timber surface being burned during drilling process (Ahmad et al. 2010). The modes of failure were chosen based on frequency observed on each grain direction. Almost all grain directions showed a similar pattern of failure mode, despite having different values of loads and displacements.

CONCLUSIONS

The pull-out strength characteristics and behaviour of glued-in rod joint system with different grain directions were investigated and concluded that the strength of glued-in rod was proportionally dependent on grain direction. Comparing grain directions showed that grain direction at 0° permitted a stronger bond compared to others. The maximum strength value achieved by 0° was 97.08 kN and the lowest strength of 61.99 kN by 90° grain directions. Whereas the percentage difference for 0°, recorded as highest, and 90°, recorded as lowest, was 44.12%, nearly 50% difference. The overall average percentage difference of strength between these angles was about 11.2%. The modes of failure for all the grain directions had demonstrated a similar pattern, with shear failure occurring along the adhesive and timber interface.

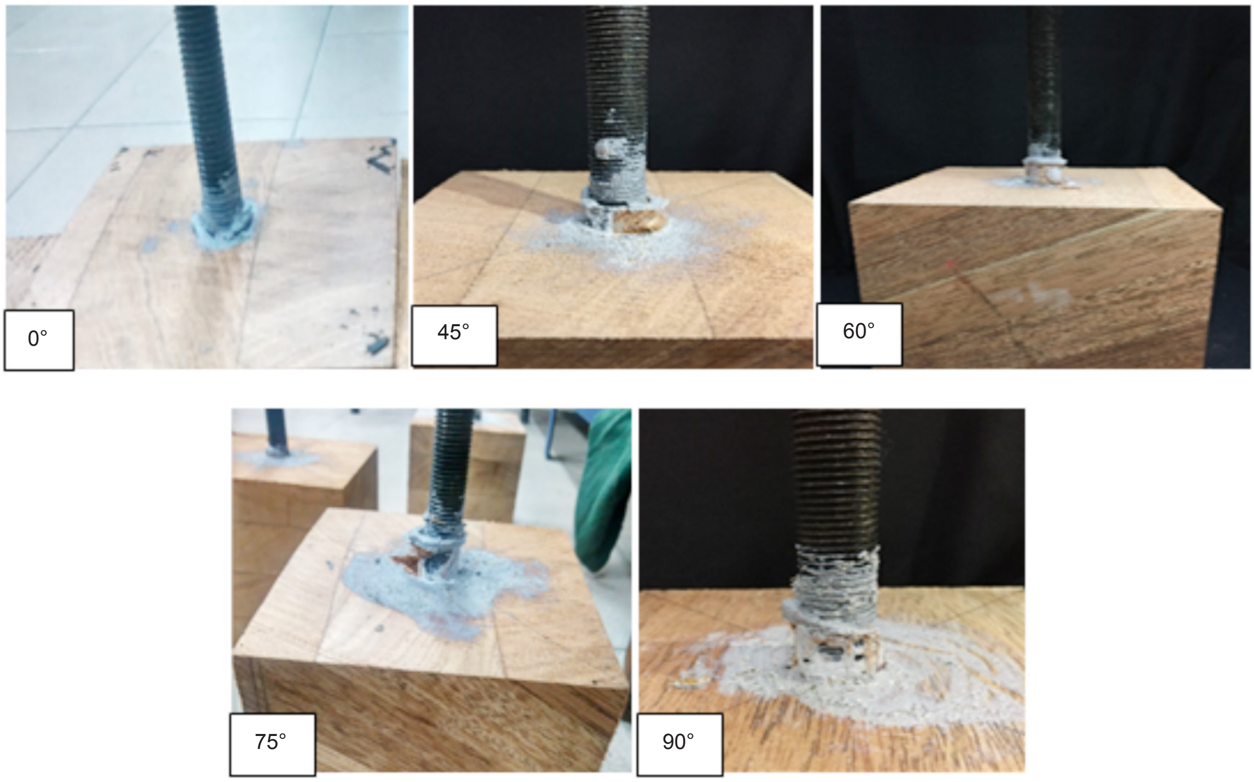

Figure 10 Typical adhesive and timber interface failure of rods glued into glulam blocks at varying angles to the grain

ACKNOWLEDGMENTS

The study was financially supported by IRMI, Universiti Teknologi MARA, through the Lestari Grant (600-IRMI/MYRA 5/3/LESTARI (0115/2016).

REFERENCES

Ahmad S, Haji-Amin A, Ali R & Mad-Tahir H. 1993. Withdrawal and bending strengths of dowels from three Malaysian timbers. *Journal of Tropical Forest Science* 6: 74–80.

Ahmad Z, Ansell MP & Smedley D. 2010. Epoxy adhesives modified with nano-and micro-particles for in-situ timber bonding: effect of microstructure on bond integrity. *International Journal of Mechanical and materials engineering* 5: 59–67.

Bengtsson C & Johansson CJ. 2001. *GIROD – Glued-in Rods for Timber Structures. Report 2002: 26*. Swedish National Testing and Research Institute, Venezia.

Dorn M, De Borst K & Eberhardsteiner J. 2013. Experiments on dowel-type timber connections. *Engineering Structures* 47: 67–80.

EN 26891. 1991. *Timber Structures: Joints Made with Mechanical Fasteners. General Principles for the Determination of Strength and Deformation Characteristics*. European Committee for Standardization (CEN), Brussels.

Gustafsson PJ & Serrano E. 2000. Predicting the pull-out strength of glued-in rods. Pp 7–4 in Barrett JD (ed) *Proceedings of the Sixth World Conference on Timber Engineering*. 31 July–3 August 2000, Whistler.

Harvey K. 2003. Improved timber connections using bonded-in GFRP rods. PhD thesis. University of Bath, Bath.

Hunger F, Stepinac M, Rajčić V & Van de Kuilen JWG. 2016. Pull-compression tests on glued-in metric thread rods parallel to grain in glulam and laminated veneer lumber of different timber species. *European Journal of Wood and Wood Products* 74: 379–391.

Hussin TA, Jinne MI & Hassan R. 2016. Pull-out Strength for different size of dowel and grain direction of glulam. *Jurnal Teknologi* 78: 5–4.

Ling Z, Yang H, Liu W, Lu W, Zhou D & Wang L. 2014. Pull-out strength and bond behaviour of axially loaded rebar glued-in glulam. *Construction and Building Materials* 65: 440–449.

MS 544: Part 2. 2001. *Code of Practice for Structural Use of Timber*. Department of Standards Malaysia, Cyberjaya.

MS 758. 2001. *Glued Laminated Timber: Performance Requirements and Minimum Production Requirements*. Department of Standards Malaysia, Cyberjaya.

Rossignon A & Espion B. 2008. Experimental assessment of the pull-out strength of single rods bonded in glulam parallel to the grain. *Holz Als Roh- Und Werkstoff* 66: 419–432.

Sjödin J. 2008. *Strength and Moisture Aspects of Steel Timber Dowel Joints in Glulam Structures: An Experimental and Numerical Study*. Växjö University Press, Växjö.

Stamatopoulos H. 2016. Withdrawal properties of threaded rods embedded in glued-laminated timber elements. PhD thesis. University of Science and Technology, Trondheim.

Steiger R, Gehri E & Widmann R. 2006. Pull-out strength of axially loaded steel rods in glulam parallel to the grain. *Material Structure* 40: 69–78.

Steiger R, Serrano E, Stepinac M, Rajčić V, O'Neill C, McPolin D & Widmann R. 2015. Strengthening of timber structures with glued-in rods. *Construction and Building Materials* 97: 90–105.

Tanaka K, Kawano K, Noguchi Y, Mori T & Inoue M. 2012. Proposal of calculation method for pull-out strength of glued-in rod connector embedded in perpendicular to the grain in glulam. Paper presented at the World Conference on Timber Engineering, Auckland.

Tlustochowicz G, Serrano E & Steiger R. 2011. State-of-the-art review on timber connections with glued-in steel rods. *Materials and Structure* 44: 997–1020.

Widmann R, Steiger R & Gheri E. 2007. Pull-out strength of axially loaded steel rods bonded in glulam perpendicular to the grain. *Materials and Structures* 40: 827–838.

Za'ba N, Ibrahim A & Ahmad Z. 2012. Bond strength of glued-in rods in Malaysian tropical timber as influenced by adhesive. *ASEAN Journal on Science and Technology for Development* 29: 1.

Zhu H, Faghani P & Tannert T. 2017. Experimental investigations on timber joints with single glued-in FRP rods. *Construction and Building Materials* 140: 167–172.