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PULL OUT STRENGTH FOR DIFFERENT SIZE OF DOWEL AND GRAIN DIRECTION OF GLULAM

Tengku Anita Raja Hussin[a*], Mohamad Iswandi Jinne[b], Rohana Hassan[b]

[a]Infrastructure University Kuala Lumpur (IUKL), Kajang, Selangor, Malaysia
[b]Universiti Teknologi Mara (UiTM), Shah Alam, Selangor, Malaysia

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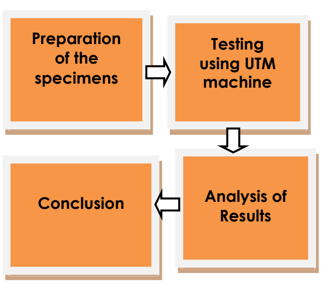
*Corresponding author
anita@iukl.edu.my,

Graphical abstract



Abstract

This paper presents an experimental program for testing glued-in dowel glulam timber joints. Hundred thirty glulam specimens, each with a single glued-in rebar parallel to the grain and perpendicular to grain with different size of dowels 12mm, 16mm and 20mm were tested to evaluate the effects of anchorage length and different dowel diameter for parallel and perpendicular to the grain on pull-out strength and bond behaviour of glued-in rebar timber joints. The test results showed that the maximum load for specimen with dowel glued-in parallel to the grain given the higher maximum load than dowel glued-in perpendicular to the grain direction. Failure modes were characterized by pull out failure in the mode of adhesive-dowel, yet one sample failed in timber-adhesive mode. This might happened because the surface of the timber was burned by drilling machine during the drilling process. The pull-out was tested with different thickness grain direction with different dowel size with a rate of 2mm/min and the failure modes were observed after the testing of pull-out test. PRF is the adhesive used for the strengthening purposes. Resistance to the withdrawal of dowels glued-in perpendicularly was 44.2% to 53.5 % lower than that obtained for dowels glued-in parallel to the grain direction. The result shows that the dowel glued-in parallel to the grain given the higher maximum load than dowel glued-in perpendicular to the grain direction.

Keywords: Glulam, parallel, perpendicular, dowel, joint

1.0 INTRODUCTION

Timber Industry is one of the common contributions for economic growth in Malaysia. This industry is a major supply of quality timber product to the world market. However, in Malaysia timber member focuses on a simple structure where small load applied. If compared with steel or concrete, timber is also found to have less strength. In Malaysia, the bigger size for beam is hard to find so the factory or existing timber can only be built with the equivalent load carrying and strength with a larger beam [1]. The timber structures should have a good joint to produce a strong spanning. There are two the most appropriate method of joining pieces of timber, firstly requirement for the strength and also the quality of joining [2]. Batchelar and Mcintosh [3] reported that the connections consume up to 70% of the design effort if not carefully be visually unattractive. Efficient connection systems are very important in modern timber engineering. Proper connection details are important for the structural performance and serviceability of any timber structure. Connections must be designed to transfer design loads to and from a structural glulam member, without causing localized stress concentrations beyond the capacity of either the connector or the timber member. One of the famous connections for glulam timber is bonded-in. Bonded-in dowels can be used to prevent cracks in the apex zone of curved beams and in end-notched beams reported by Barber D.J [4].

Many factors need to consider for pull-out loads such as the adhesive type, steel rod type, geometry of embedment and timber species [4]. An important method for the repair and upgrading of historically important timber structures which exist throughout Europe has been provided [5]. Mechanical joints needs to be taken into account to allow a certain initial displacement between the parts that are connected [6].

The main aim of this study is to determine the shear strength of different size of dowel diameter glued-in and different grain direction of glulam for Mengkulang species.

2.0 EXPERIMENTAL

The timber species used in this research is Mengkulang with grade of SG5. The preparation of glulam is done initially and the whole glulam is segmented out according to the dimension required to conduct the experiment. The dowel tested in this study is S 275 as classified in Eurocode 5 [7].

The scope of work for this study is to focus on pull-out strength of different dowel size diameter and different grain direction of glulam. For this purpose, the totals of thirty (30) specimens were used where fifteen (15) specimens were tested for each perpendicular and parallel to the grain of glulam block. Dowel with diameter of 12 mm were glued-in the block size 100 mm breadth x 100 mm length x 100 mm depth. Dowel with diameter of 16 mm were glued-in the block size 115 mm breadth x 115 mm length x 115 mm depth and Dowel with diameter of 20 mm were glued-in the block 130 mm breadth x 130 mm length x 170 mm depth. The Table 1 below shows the summary of the material preparation for this research.

Table 1 Summary in preparation of materials

Grain Direction	Adhesive	Types of Fastener	Dowel Diameter (mm)	No. of Sample	Lab Testing
Perpendi-cular	PRF	Dowel	12	5	Pull-out Test
			16	5	
			20	5	
Parallel	PRF	Dowel	12	5	Pull-out Test
			16	5	
			20	5	

The schematic diagram and the correlation between the interface reaction and the specimen of the pull-out test specimen as shown in Figure 1 and Figure 2 respectively.

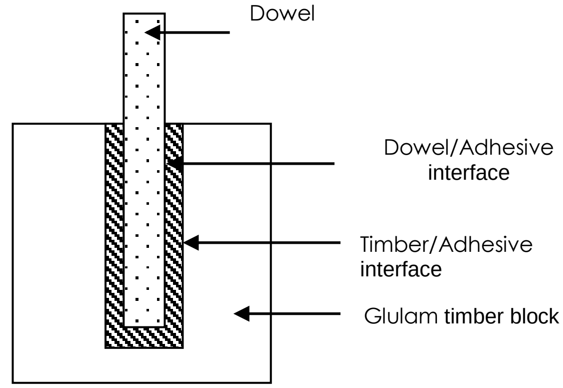


Figure 2 Correlation between the point of interface reaction and the specimen

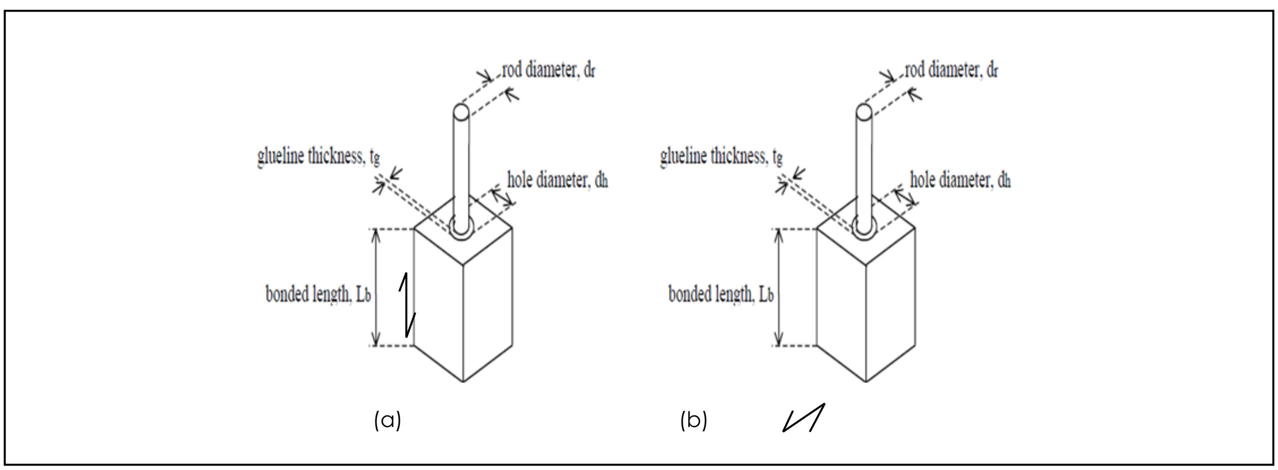


Figure 1 Schematic diagram of the pull-out test specimen (a) Parallel to the grain (b) Perpendicular to the grain

3.0 RESULTS AND DISCUSSION

The effect of the parameter was investigated in this research. The variable was the glueline. The relationship between the strength of the bonding and the variable were examined. Various failures modes are also recorded. Average shear stress at the timber/adhesive interface of the samples for a given bonded length is also illustrated.

3.1 Modes of Failure

Figuring out modes of failure is a very important, because in order to make improvement on the structure, the weakest link of the structure has to be identified. It is known that the pull-out test will make the timber, adhesives and the dowel to have shear stress on its surface. Thus, it is the matter of identifying the location of the failure that is crucial.

There are two major failure mechanisms associated with bonded-in rod connections loaded perpendicular to the grain are first is longitudinal timber shear around the hole with non-uniform thickness and second is longitudinal timber splitting [8]. However, Z. Ling *et al*. [9] had found that the pull-out strength of glued-in single rebar in glulam was significantly affected by the anchorage length. N.Gattesco *et al*. [10] reported there were four types of failure observed.

Figure 3 presents the actual situation prevailing after the failure; dowels are continued to pull-up until it ripped from hole of specimens. Observation was made where no adhesive attached to the dowel to hold the bond between dowel and adhesive. This shows the type of failure modes occur was dowel-adhesive interface failure.

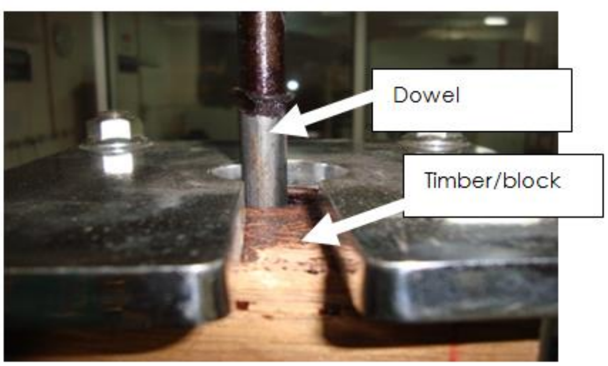


Figure 3 The pull-out test specimen

3.2 Pull-out Test For 12mm Diameter Dowel Subjected to the Grain Direction

Figure 4 shows typical load displacement graphs for tensile strength of 12mm dowel glued-in parallel to the grain direction. The graph shows that displacement increases with load until the point of the specimen failed. Generally for each specimen, the graph shows decrease in load at few point before the point of actual failure occurred. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 2. For 12mm dowel glued-in parallel to the grain direction, average maximum load recorded was 4.57 kN. From the patterns of the load-displacement graph in Figure 4 reveal that the joint are in the brittle failure mode. These caused initial lack of fit between the adhesive and the surface of dowel. This is seem to be in agreement with study conducted by D. Otero Chans *et al*. [11] shows higher value of pull-out capacity in parallel to the grain direction than in perpendicular direction.

Table 2 Pull-out strength for 12mm dowel glued-in parallel to the grain.

Parallel				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	S1	Nil	Nil	Nil
2	S2	4.45	1.61	Dowel-Adhesive failure
3	S3	2.28	0.90	Dowel-Adhesive failure
4	S4	6.86	1.82	Dowel-Adhesive failure
5	S5	4.68	1.81	Dowel-Adhesive failure
Average		**4.57**	**1.54**	
SD		**1.62**		
COV (%)		**35.4 %**		

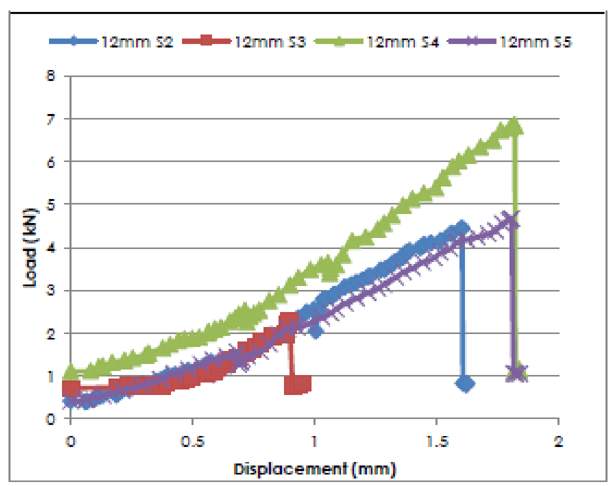


Figure 4 Load VS displacement graph for 12mm dowel glued-in parallel to the grain direction

In order to know whether the data are close to the average (mean) maximum load or the distribution is spread out over a broad range, standard deviation of the specimens had to be calculated. The formula for calculating standard deviation (sd) are as follows:

$$sd = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \mu)^2} \quad (1)$$

From Equation 1, the standard deviation for specimens 12mm dowel glued-in parallel to the grain direction calculated is 1.62. The range of maximum load will be from 2.95 kN to 6.19 kN.

Figure 5 shows typical load displacement graphs for tensile strength of 12mm dowel glued-in perpendicular to the grain direction. The graph shows that displacement increases with load until the point of the specimen failed. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 3. For 12mm dowel glued-in perpendicular to the grain direction, average maximum load recorded was 2.55 kN. From the result determined in this study show that pull-out strength for 12mm diameter dowel glued-in parallel to the grain direction had higher load to reach the actual failure.

Table 3 Pull-out strength for 12mm dowel glued-in perpendicular to the grain

Perpendicular				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	SP1	1.76	0.99	Dowel-Adhesive failure
2	SP2	2.78	0.62	Dowel-Adhesive failure
3	SP3	2.17	0.83	Dowel-Adhesive failure
4	SP4	2.73	0.80	Dowel-Adhesive failure
5	SP5	3.31	2.26	Dowel-Adhesive failure
	Average	**2.55**	**1.1**	
	SD	**0.54**		
	COV (%)	**21.1%**		

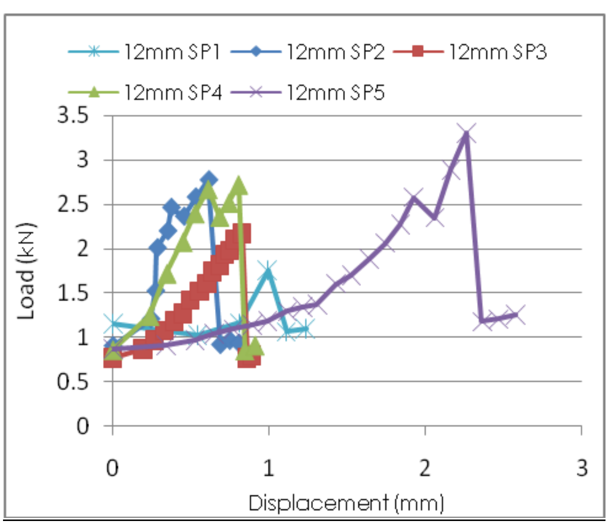


Figure 5 Load VS displacement graph for 12mm dowel glued-in perpendicular to the grain direction

The standard deviation for specimens 12mm dowel glued-in perpendicular to the grain direction calculated is 0.54. The range of maximum load will be from 2.01 kN to 3.09 kN. Thus, specimen 1 to be found below the range and specimen 5 is found to be higher than the range of maximum load.

The cause of different of maximum load value between specimen 1 and specimen 5 is difficult to identify since all the specimen are in the same condition before the pull-out test conducted.

3.3 Pull-out Test for 16mm Diameter Dowel Subjected to the Grain Direction

Figure 6 shows typical load displacement graphs for tensile strength of 16mm dowel glued-in parallel to the grain direction. The graph shows that displacement increases with load until the point of the specimen failed. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 4. For 16mm dowel glued-in parallel to the grain direction, average maximum load recorded was 5.63kN.

Table 4 Pull-out strength for 16mm dowel glued-in parallel to the grain

Parallel				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	S1	5.62	2.22	Dowel-Adhesive failure
2	S2	Nil	Nil	Nil
3	S3	5.46	2.17	Dowel-Adhesive failure
4	S4	6.16	2.12	Dowel-Adhesive failure
5	S5	5.27	1.38	Dowel-Adhesive failure
	Average	**5.63**	**1.97**	
	SD	**0.33**		
	COV (%)	**5.9%**		

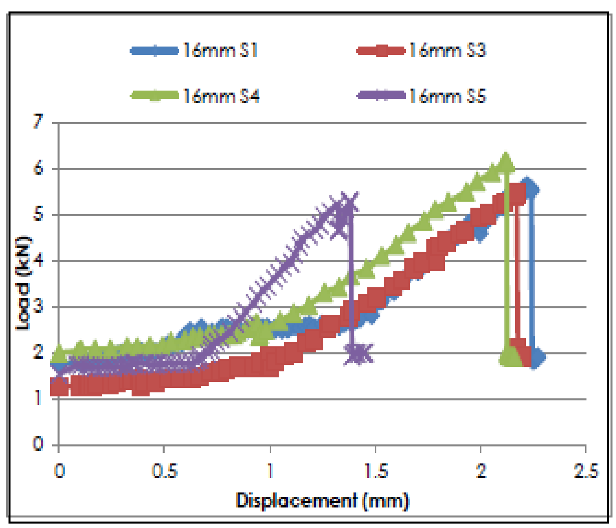


Figure 6 Load VS displacement graph for 16mm dowel glued-in parallel to the grain direction

The standard deviation for specimens 16mm dowel glued-in parallel to the grain direction calculated is 0.33. The range of maximum load will be from 5.30 kN to 5.96 kN. Thus, specimen 5 to be found below the range and specimen 4 is found to be higher than the range of maximum load. The cause of different of maximum load value between specimen 5 and specimen 4 is difficult to identify since all the specimen are in the same condition before the pull-out test conducted.

Table 5 Pull-out strength for 16mm dowel glued-in Perpendicular to the grain

Perpendicular				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	SP1	2.51	2.96	Dowel-Adhesive failure
2	SP2	3.12	1.15	Dowel-Adhesive failure
3	SP3	3.32	1.33	Dowel-Adhesive failure
4	SP4	4.17	2.47	Dowel-Adhesive failure
5	SP5	Nil	Nil	Nil
	Average	**3.28**	**1.98**	
	SD	**0.59**		
	COV (%)	**18%**		

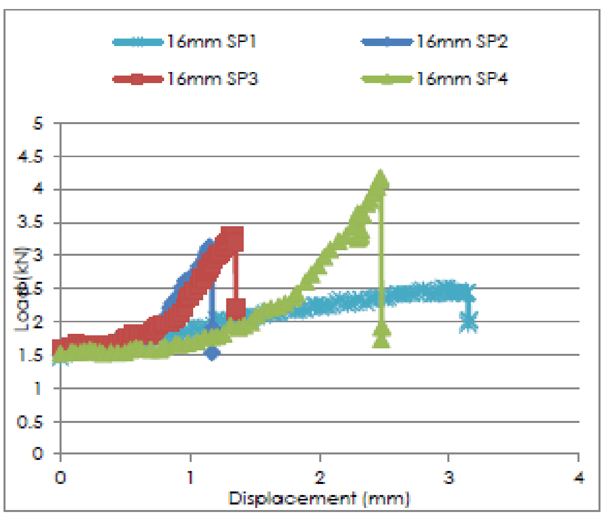


Figure 7 Load VS displacement graph for 16mm dowel glued-in perpendicular to the grain direction

Figure 7 shows typical load displacement graphs for tensile strength of 12mm dowel glued-in parallel to the grain direction. The graph shows that displacement increases with load until the point of the specimen failed. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 5. For 16mm dowel glued-in perpendicular to the grain direction, average maximum load recorded was 3.28 kN.

From the result determined in this study show that pull-out strength for 16mm diameter dowel glued-in parallel to the grain direction had higher load to reach the actual failure.

The standard deviation for specimens 16mm dowel glued-in perpendicular to the grain direction calculated is 0.59. The range of maximum load will be from 2.69 kN to 3.87 kN

3.4 Pull-out Test for 20mm Diameter Dowel Subjected to the Grain Direction

Figure 8 shows below typical load displacement graphs for tensile strength of 12mm dowel glued-in parallel to the grain direction. The graph shows that displacement increases with load until the point of the specimen failed. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 6. For 20mm dowel glued-in parallel to the grain direction, average maximum load recorded was 10.25kN.

Table 6 Pull-out strength for 16mm dowel glued-in Perpendicular to the grain

Parallel				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	S1	10.46	2.16	Dowel-Adhesive failure
2	S2	13.40	2.57	Dowel-Adhesive failure
3	S3	8.67	1.93	Dowel-Adhesive failure
4	S4	10.16	2.21	Dowel-Adhesive failure
5	S5	8.58	2.42	Dowel-Adhesive failure
	Average	**10.25**	**2.26**	
	SD	**1.75**		
	COV (%)	**17.1%**		

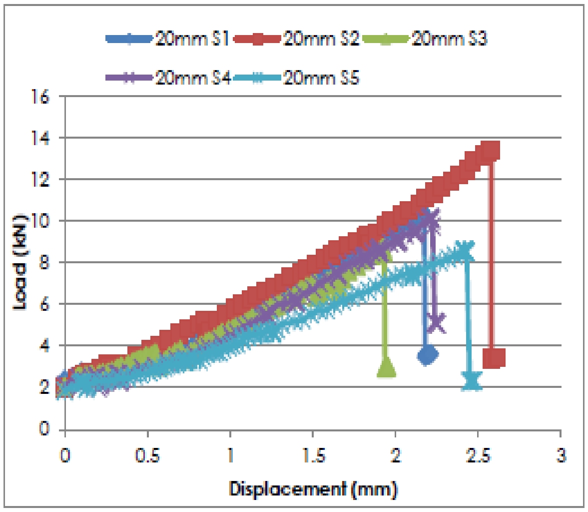


Figure 8 Load VS displacement graph for 20mm dowel glued-in parallel to the grain direction

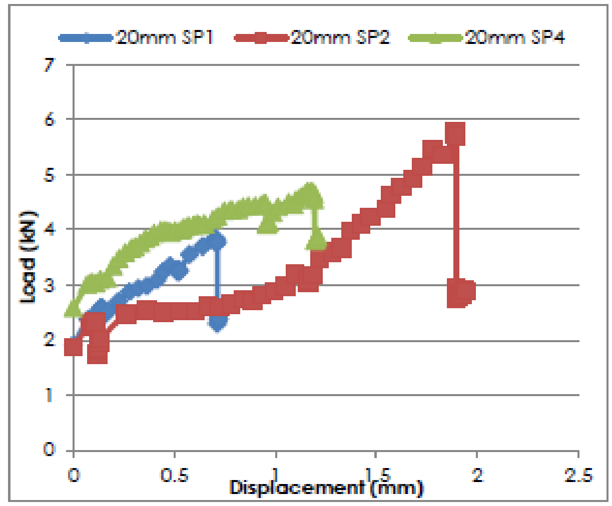


Figure 9 Load VS displacement graph for 20mm dowel glued-in perpendicular to the grain direction

The standard deviation for specimens 20mm dowel glued-in parallel to the grain direction calculated is 1.75. The range of maximum load will be from 8.50 kN to 12.0kN.

Table 7 Pull-out strength for 20m m dowel glued-in Perpendicular to the grain

Perpendicular				
No.	**Specimen**	**Max Load (kN)**	**Displ (mm)**	**Failure Mode**
1	SP1	3.84	0.70	Dowel-Adhesive failure
2	SP2	5.77	1.89	Dowel-Adhesive failure
3	SP3	Nil	Nil	Nil
4	SP4	4.70	1.16	Dowel-Adhesive failure
5	SP5	Nil	Nil	Nil
Average		**4.77**	**1.25**	
SD		**0.79**		
COV (%)		**16.6%**		

The graph in Figure 9 shows that displacement increases with load until the point of the specimen failed. The actual failure occurred at the highest point where the load reached its maximum value as described in Table 7. For 20mm dowel glued-in perpendicular to the grain direction, average maximum load recorded was 4.77 kN. From the result determined in this study show that pull-out strength for 20mm diameter dowel glued-in parallel to the grain direction had higher load to reach the actual failure.

The standard deviation for specimens 20mm dowel glued-in perpendicular to the grain direction calculated is 0.79. The range of maximum load will be from 3.98 kN to 5.56 kN.

4.0 CONCLUSION

In conclusion, it is found that there are significant affect by the bonded length. Taking 90 mm bonded length as the baseline, dowel glued-in parallel to the grain shows increase of 23.2% in maximum load with increased of 16.7% in bonded length and maximum load increased by 124.3% with increased of 77.8% in bonded length. For dowel glued-in perpendicular to the grain direction, maximum load will increased by 28.6% with increased of 16.7% in bonded length and 87.1% increase in maximum load with increased of 77.8% in bonded length. Resistance to the withdrawal of dowels glued-in perpendicularly was 44.2% to 53.5 % lower than that obtained for dowels glued-in parallel to the grain direction.

Therefore, the result shows that the dowel glued-in parallel to the grain given the higher maximum load than dowel glued-in perpendicular to the grain direction.

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