The Determination of the Embedment Strength of Malaysian Hardwood

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Summary

Research on determining the embedment strength of Malaysia timber species is currently being conducted. Prior to this, there is no data on the embedment strength of Malaysian timber available as there are no study been conducted locally which emphasize in this area. The experimental works on determining this fundamental parameter of a connection are being carried out on selected species of local hardwood timber. The species selected represents various joints groups. Data and results were analysed and using the embedment strength values approaches which are similar to those adopted in Europe, the basic load of timber joints to be used in the limit state design method will be forwarded for consideration to be incorporated in the Malaysian code of practice.

1. Introduction

Nowadays, European Yield Model (EYM) which was proposed by Johansen is widely used in estimating the yield strength of joints. According to this model, embedment strength of timber and yield moment of the dowel influence properties for verifying the strength of the joints. Previously, various researches have been performed on determining the embedment characteristics of timber with dowel-type fasteners. A comprehensive study of embedment strength of softwood, hardwood, plywood and tempered hardboard with nails and bolts was conducted by Smith (Smith et. al., 1987). The embedment strength phrases in today's Eurocode 5 are based on these studies.

In the US, test on the embedment strength which focused on the effect of the differences between specific gravity, diameter of the dowel, and direction of the loading was performed (Wilkinson, 1991). The research focused on bolts and nails of various diameters with several hardwood and softwood species. The results however vary due to the differences in defining the yield load. Rammer meanwhile conducted tests on two hardwoods to determine the embedment strength based on an analysis of variance (ANOVA) at 0.05 level of confidence. (Rammer, 1999). Davis and Claisse (2000) performed the embedment test on bolted joint to solid timber, glulam, parallam and microlam. Effect of moisture content on the embedment strength had also being studied (Rammer and Winistrorfer, 2001).

Researchers in Japan conducted an inclusive survey using Japanese Pine (Sawata and Yasumura, 2003).They evaluated the differences between the 5% diameter offset test method and EN 383. In addition, an effort was made using a non-linear model based on Johansen theory to approximate the strength of bolted joints, (Sawata and Yasumura, 2003).

Although the research is popular worldwide, the scenario in Malaysia is different. To date, there is no data on the embedment strength of Malaysian timber available as there are no study been conducted locally which emphasize in this area. This study is a preliminary works for gathering data to establish the Malaysian Code of Practice for designing timber structures based on limit state design.

2. Experimental Programme

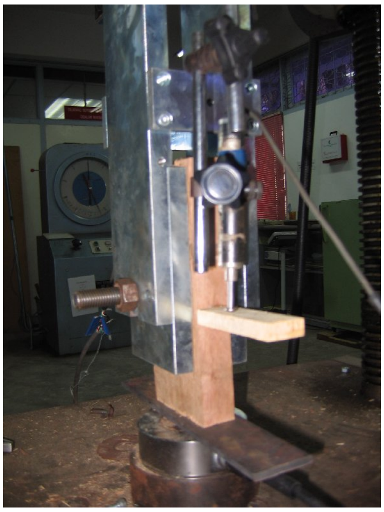

Fig 1 Test set-up

Embedment strength tests were conducted on three species of Malaysian hardwoods from various joints groups and densities i.e Kempas *(Koompassia malaccencis)*, Mengkulang *(Heritiera spp.)* and Pulai *(Alstonia spp.)*. These represent the heavy, medium and light hardwood. Three difference sizes of dowels were used which have nominal diameter 6, 8, and 12 mm. The dimensions of the specimen and the test procedure were in accordance with BS EN 383:1993, (Anon, 1993). The total specimens tested were 135 and all specimens were conditioned before and after preparations inside a controlled room with a temperature 20 ± 2 ^{o}C and relative humidity of 63 ± 2 % to avoid any changes in moisture content. The experimental set-up is shown in Fig.1.

Compressive load parallel to the grain at a constant rate were applied on the specimens. The deformations of the specimens were measured using Linear Variable Displacement Transducer (LVDT). Small samples near the failure zone were taken for moisture content and densities determination.

3. Results and Discussion

3.1 Results

According to the standard, the embedment strength, should be calculated using the following equation,

$$f_h = \frac{F_{\max}}{dt} \qquad [1]$$

where F_{max} is a maximum load from the test, d is a dowel diameter and t is the thickness of the test specimen. The typical load deformation curve is shown in Fig.2. The average values from the test results for each timber species are in Table 1.

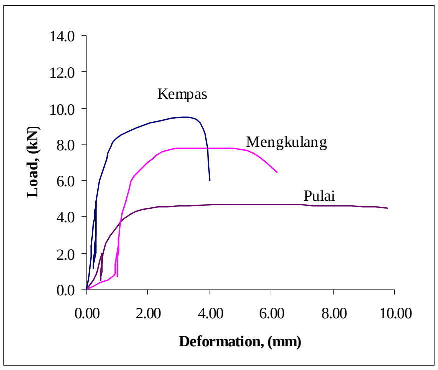

Fig 2 Load deformation curve

Table 1 Summary of test results

Species	Dowel diameter (mm)	Total samples	Average F_{max} (kN)	Average f_h (N/mm^2)	Density (kg/m^3)	Moisture content (%)
Kempas	6	15	6.32	87.78	887.59	11.05
	8	15	11.12	86.88	782.57	10.96
	12	15	24.81	86.15	866.02	11.31
Mengku lang	6	15	4.41	61.29	663.14	12.43
	8	15	7.59	59.28	637.93	12.21
	12	15	17.06	59.23	677.82	11.05
Pulai	6	15	2.71	37.64	450.42	11.02
	8	15	4.73	36.95	449.66	11.80
	12	15	8.69	30.17	377.49	10.36

3.2 Discussions

Fig. 3 represents the graph of the embedment strength, f_h against density, ρ. From this graph it can be seen that the density of timber directly influence the embedment strength for Malaysian hardwood. The embedment strength seems to increase linearly with the increase of density. The embedment strength for Kempas is the highest followed by Mengkulang and Pulai.

Fig. 4 shows the variation of embedment strength with dowel diameter. From this diagram, it can be seen that embedment strength decrease with increasing diameter.

Fig. 5 shows the relationship between embedment strength, density of timber and the dowel diameter. From these relationships, a formula that can be used to calculate embedment strength for Malaysian hardwood can be developed. The formula that best suited the relationship is given below,

$$f_h = 0.103(1-0.013d)\rho \quad [2]$$

Using Eq. 2, the theoretical value of f_h for each species and dowel diameter can be calculated. These values are tabulated in Table 2. The values show approximately 2-20% differences from the experimental results.

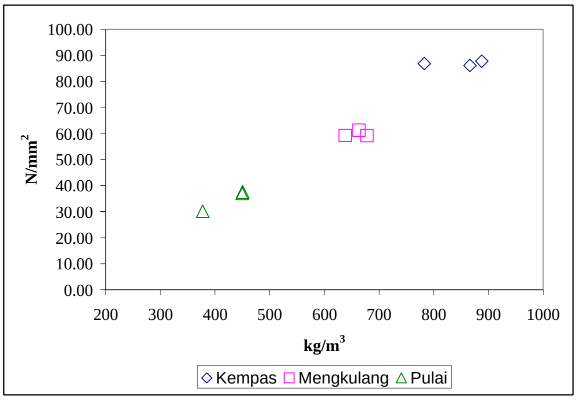

Fig 3 Embedment strength vs density

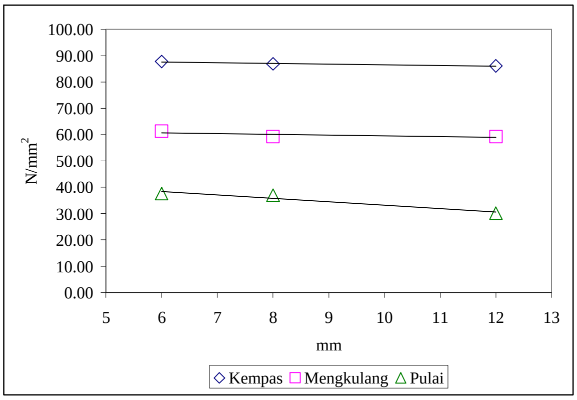

Fig 4 Embedment strength vs dowel diameter

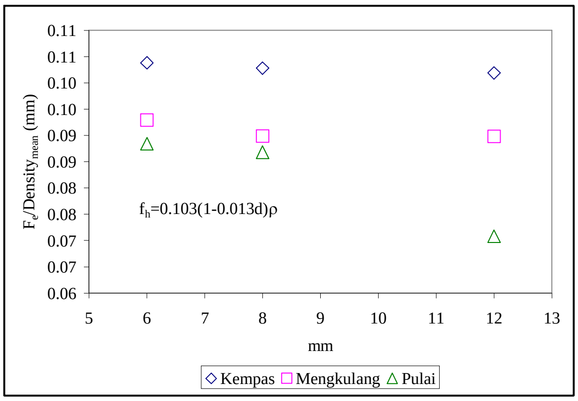

Fig 5 Relationship between embedment strength, density and dowel diameter

Table 2 Comparison between experimental and formula

Species	Dowel diameter (mm)	$f_{h, Eq.[2]}$ (N/mm^2)	$f_{h, exp}$ (N/mm^2)	Percentage differences (%)
Kempas	6	80.28	87.78	9.34
	8	78.02	86.88	11.36
	12	73.49	86.15	17.23
Mengkulang	6	62.64	61.29	2.16
	8	60.88	59.28	2.63
	12	57.34	59.23	3.30
Pulai	6	40.44	37.64	6.92
	8	39.30	36.95	5.98
	12	37.02	30.17	18.50

4. Conclusions:

The conclusions that can be drawn from the study are:

i) The embedment strength of Malaysian hardwood timber is affected by the density and dowel diameter.
ii) The equation that best described the embedment strength for Malaysian hardwood is f_h= 0.103(1-0.013d)ρ.

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6. References

[1] Smith I., Hilson, B. O. Whale, L. R. J. and Pope, D. J., 1987. Characteristic Properties of Nailed and Bolted Joints under Short-term Lateral Load. Part 3: Analysis and interpretation of embedment test data in terms density and related trends. *Journal of Institute of Wood Science,* 11(2), pp. 65-71.

[2] Wilkinson, T. L., 1991. Dowel Bearing Strength. *Research Paper FPL-RP-505. USDA Forest Service, Forest Product Laboratory,* Madison, WI. 9pp.

[3] Rammer, D. R., 1999. Parallel-to-grain Dowel-Bearing Strength of Two Guatemalan Hardwoods. *Forest Product Journal,* 49(6) pp. 77-87.

[4] Davis, T. J. and Claisse, P.A., 2000. Bolted joints in Glulam and Structural Timber Composites. *Journal of Construction and Building Materials.* 14 pp. 407-417.

[5] Rammer, D. R. and Winistorfer, S. G., 2001. Effect of Moisture Content on Dowel-bearing Strength. *Journal of Wood and Fiber Science*, 33(1), pp. 126-139.

[6] Sawata, K. and Yasumura, M., 2002. Determination of Embedding Strength of Wood for Dowel-type Fasteners. *Journal of Wood Science*, 48: pp 138-146.

[7] Sawata, K. and Yasumura, M., 2003. Estimation of Yield and Ultimate Strengths of Bolted Timber Joints by Nonlinear Analysis and Yield Theory. *Journal of Wood Science*, 49: pp 383-391.

[8] Anon, 1993. BS EN 383: *Timber structures-Test methods- Determination of Embedding Strength and Foundation Values for Dowel-type Fasteners,* United Kingdom, England.