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Fatigue Strength of Mortise and Tenon Furniture Joints Made from Oil Palm Lumber and Some Malaysian Timbers

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Abstract: A study was undertaken to evaluate comparative bending and fatigue strengths of rectangular mortise and tenon furniture joints made from oil palm (*Eleais guineensis)* lumber against a few established furniture wood materials. This is owing to the fact that, although the rectangular mortise and tenon joints are the most commonly joints used in chair construction, studies on its strength under cyclic loading is very limited. The fact that furniture joints are the weakest link in the furniture structure, it is necessary to establish its strength performance especially under repeated loading as experienced by the chair in service. The results showed that the bending strength of the oil palm lumber joints were half the strength of the wooden joints. However, in terms of fatigue strength, joints made from oil palm lumber showed comparable performance with the other wood materials. The results also showed that the allowable design stresses for rectangular mortise and tenon joints could be set at 20% of its bending strength. This study has far reaching implications on furniture engineering as it suggest that proper joint design is mandatory not only to ensure the furniture's reliability in service, but also improve its aesthetic and production imperatives.

Key words: Static strength, fatigue, mortise and tenon, furniture, oil palm lumber, wood

INTRODUCTION

Furniture is considered a semi-rigid structure and is subjected to both static and cyclic loadings in service. In furniture engineering, it is common practice to size the joints to meet the aesthetic requirements of the furniture, although such joints may not necessarily be of optimal dimensions (Cai and Wang, 1993; Bao and Eckelman, 1996; Ratnasingam *et al*., 1997). However, in many instances these joints are over-sized, which has cost implications to the furniture manufacturer. Nevertheless, such over-sized joints are often overlooked as the joints are regarded to be the weakest link the furniture structure (Eckelman, 1999). Therefore, any under-sized joints are perceived to be counter-productive to the furniture engineering practice, as it may impair the final strength and reliability of the furniture while in service. Inevitably, the strength performance of furniture joints remains not well researched (Ratnasingam *et al*., 1997; Ratnasingam and Ioras, 2010).

Furniture is often produced using rectangular mortise and tenon joints, especially for joining the back leg and the side rail of chair frame construction (Eckelman, 1999). Factors such as the tightness of fit between the mortise and tenon, the density and moisture content of the material as well as the dimensions of the joints have been shown to have strong positive influence on the overall strength of such joints (Eckelman and Zhang, 1995; Erdil *et al*., 2005). Previous researches have shown that large dimensioned joints of tighter fitness, made from higher density wood material with lower moisture content, improved the overall strength of the joints significantly (Erdil *et al*., 2005). Although, the round mortise and tenon joints are efficient load bearers and are highly resistant to cyclic loading, Tankut and Tankut (2005) found that rectangular mortise and tenon joints to be 15% stronger due to the greater surface area for load distribution. Strong joints are essential in furniture as furniture failure often occurs at joints, which are subjected to both static and cyclic loads (Ratnasingam *et al*., 1997). Consequently, information on the strength performance of joints is important if a particular material is to be promoted as a furniture material.

In recent years, oil palm (*Eleais guineensis*) lumber has emerged as a potential raw material for the manufacture of educational school furniture in the South

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East Asian region, on the basis of its acceptable strength and working properties (Ratnasingam *et al*., 2007, 2008; Ratnasingam and Wagner, 2009). Although the static and fatigue strengths of furniture components made from oil palm lumber and other wood materials have been studied (Ratnasingam and Ioras, 2010), the strength performance of joints made from oil palm lumber remains unknown and the lack of information restricts its use in furniture frame construction (Haviarova *et al*., 2001; Ramirez-Coretti *et al*., 2009; Ratnasingam and McNulty, 2009). Therefore, a study was undertaken to evaluate the bending and fatigue strengths of rectangular mortise and tenon furniture joints made from oil palm lumber in comparison to the joints made other commonly used furniture wood materials such Rubberwood (*Hevea brasiliensis*), Nyatoh (*Pallaquim* sp.), Meranti (*Shorea* sp.) and Sepetir (*Sindora* sp.). The results of this study will provide fundamental information on the strength behaviour of furniture joints, which will in turn help optimize wooden furniture engineering design and construction.

MATERIALS AND METHODS

In this study, T-joints were assembled using the five different experimental materials (i.e., oil palm lumber, Rubberwood, Nyatoh, Meranti and Sepetir), glued together with a 40% solid content, two-part poly-vinyl acetate (PVAc) adhesive. All the experimental materials were sourced from a local wood supplier, while the adhesive was supplied by the Casco Nobel Adhesive Company in Malaysia. The joint components consisted of a 450 mm×30 mm×25 mm leg member and a 350 mm×55 mm×25 mm rail member. A total of 50 replicates were produced for each of the experimental material. The rectangular mortise were cut using a mortising machine and had a dimension of 40 mm in length, 20 mm in width and 12 mm in thickness. The tenons were cut using a single-end tenon machine to the dimension of 39.75 mm in length, 19.85 mm in width and 11.85 mm in thickness, to ensure a tight-fit of the joint. The components were stored in a conditioning room at 20°C and 65% relative humidity for a month, to achieve the target moisture content of 12%. The T-joints were then assembled, using the PVAc adhesive, which was applied liberally on to the surfaces of the tenon and mortise. The assemblies were pressed under a pressure of 3 N mm^{-2} for a period of 5 min, using pneumatic clamps. The excessive adhesive was wiped off from the surfaces of assemblies, which were then left in a conditioning room at 65% relative humidity and 20°C in temperature, for another month before testing. All testing were carried out at the Materials Testing Laboratory of Bio-Resources Engineering Inc. in Singapore.

25 T-joint specimens from each experimental material were tested in an INSTRON universal testing machine fitted with an aluminium alloy angle plate which held the leg section, while the rail section was loaded by means of a stirrup attached to the machine cross head which moved at 12 mm min^{-1} during the test (Fig. 1).

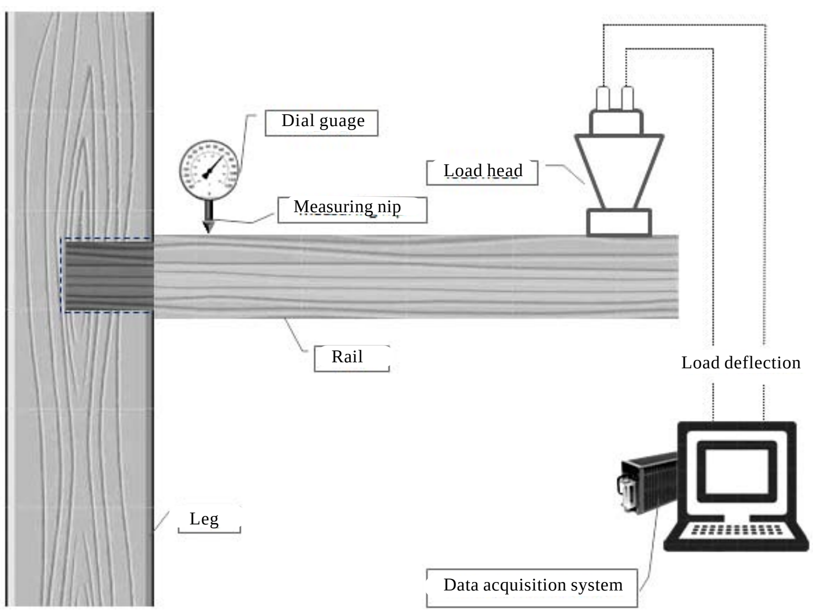

Fig. 1: Experimental set-up for bending test of joints

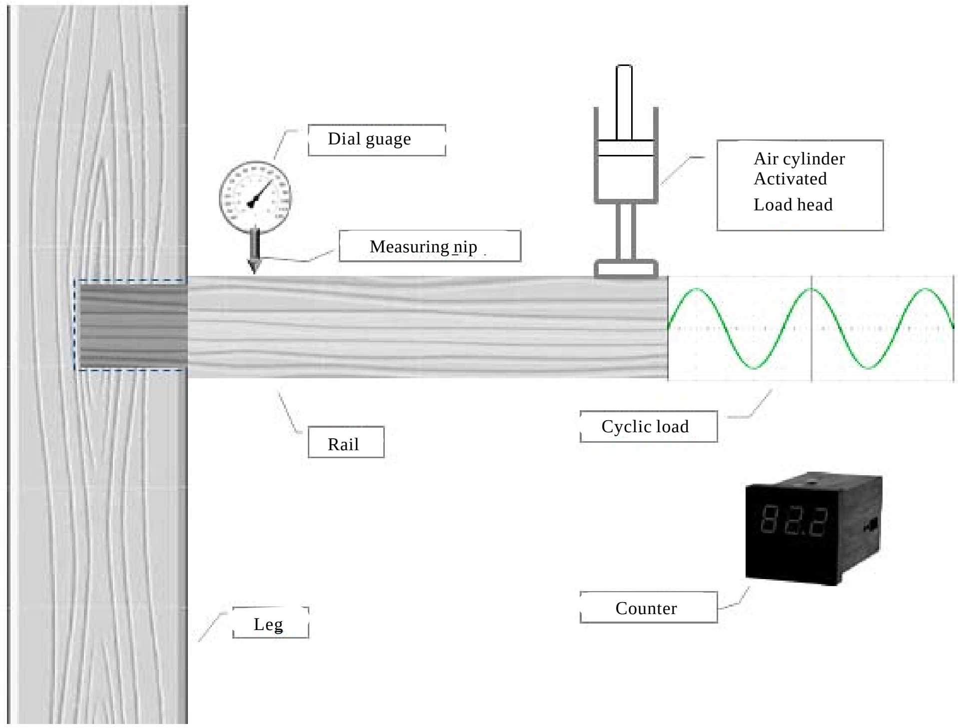

Fig. 2: Experimental set-up for fatigue strength test of joints

In this study, the ultimate moment capacity of the joint was calculated as the product of the joint failure load and the distance between the points of application of the load on the rail member (i.e., 310 mm) The ultimate moment capacity is taken to be equal to the bending moment or bending strength, as described in Tankut (2007) and Tankut and Tankut (2010). Therefore, in this study the load which produced a sudden discontinuity in the load/deflection curve during the testing, corresponding to the joint failure was noted and used to determine the bending strength in Nm.

The other 25 specimens of the T- joint from each of the experimental material were tested in a specially designed fatigue strength test rig, which applied a cyclic load by means of an air cylinder at a rate of 20 cycles per minute on to the rail section of the T-joint (Fig. 2). Air regulators were used to adjust the applied load, while mechanical counters kept track of the number of cycles the specimens survived during the test. A limit switch was attached to turn off the test when the dial gauge attached to the specimen recorded a deflection exceeding 5 mm at the joint. The fatigue load applied were 10, 15, 20, 25 and 30% of the bending strengths determined previously from the earlier tests.

RESULTS

The results of this study are presented in three parts.

Part I: Bending strength of joints: Table 1 shows the average bending strength of the joints made from the five different experimental materials used in this study. Generally, the bending strength of joints made from oil palm lumber was about half the strength of the joints made from the other wood materials. However, bending strength showed a linear relationship with density of the material and the bending strength of the experimental joints increased in the order of Sepetir>Nyatoh>Meranti >Rubberwood>OPL. This increasing trend in bending strength is possibly attributed to the correspondingly higher shear strength possessed by the materials, as suggested by Huber and Eckelman (1999) and Tunkut and Tunkut (2005). This argument is further supported by the fact that failure in the oil palm lumber joints were predominantly splits in the leg member, while in the other wood material joints, failure occurred primarily by tenon breakage. As suggested by Ratnasingam *et al.* (1997), failure by splitting in furniture joints is often attributed to the inherently low shear strength of the material, which cannot overcome the shearing forces acting on the joints.

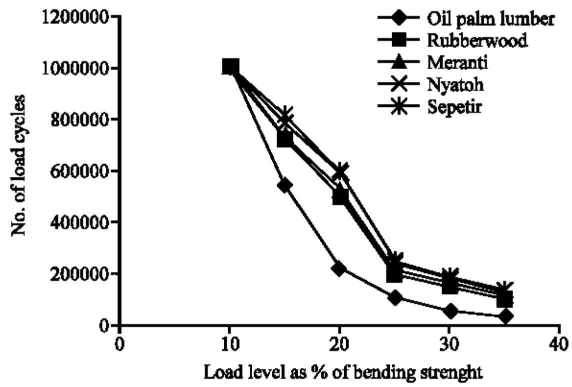

Fig. 3: Fatigue strength of furniture joints

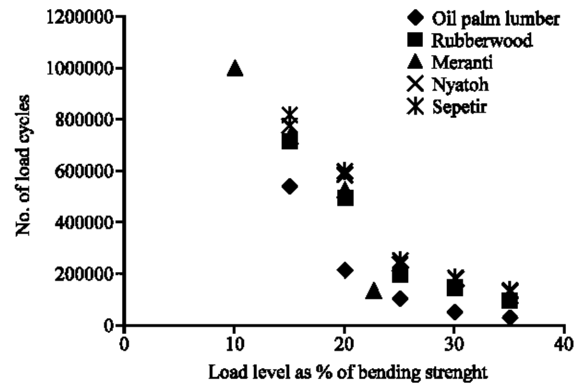

Fig. 4: Determination of allowable design stress for joints

Table 1: Comparative bending strength of joints

Material	Average density ($kg\ m^{-3}$)	Shear strength ($N\ mm^{-2}$)*	Bending strength (Nm)
Oil palm lumber	590	7	163.31 (51.33)
Rubberwood	640	11	287.15 (45.21)
Meranti	690	11.5	330.87 (44.53)
Nyatoh	735	12	367.19 (41.33)
Sepetir	780	13	417.11 (48.15)

*Shear strength values based on Ratnasingam and McNulty (2009). Average density determined on the basis of 25 samples. Values in parentheses indicate the standard deviation

The observed low shear strength of the oil palm lumber could be explained by the anatomical structure of the oil palm lumber, which impairs its shear strength and splitting resistance (Ratnasingam and Ioras, 2010).

Part II: Fatigue strength of joints: In terms of the fatigue strength, the results showed that the oil palm lumber specimens have similar strength performance compared to the solid Rubberwood specimens at the 10% load level, although it was not comparable to the other wood materials used in this study. Nevertheless, at the higher load levels, the specimens made from the other wood materials out-performed the oil palm lumber specimens (Fig. 3). Further, the result also reaffirms the previous findings that the fatigue strength of joints cannot be linearly related to its bending strength (Tsai and Ansell, 1990; Ratnasingam *et al.*, 1997).

Fatigue failure is a progressive, yet accumulative phenomenon (Tsai and Ansell, 1990; Thompson *et al.*, 2002, 2005) and in the case of furniture joints, the fatigue strength reduction in joints shows a steady trend until a point, when abrupt failure occurs. Under such behaviour, as long as the allowable design stress is not exceeded, the joints can be expected to perform throughout the service life of the product of stipulated in the standard (Eckelman, 1999). Further, it seem that the density and the anatomical structure of the material has a significant influence on the fatigue property of the material, as shown by the different fatigue strengths of joints made from the different materials (Eckelman, 1999).

Part III: Allowable design stress for joints: Based on the fatigue strength of the mortise and tenon joints from this study, the recommended allowable design stress for furniture joints could be set at 20% of its bending strength, which could ensure its compliance with the minimum 200,000 cycles of load (Fig. 4), required in most furniture performance testing standards (Eckelman, 1999).

Although the allowable design stress for furniture components could be set at 40% of its bending strength (Ratnasingam and Ioras, 2010), the allowable design stress for furniture joints are expectedly lower as joints are usually the weakest link in the furniture structure (Ratnasingam *et al.*, 1997).

Considering the fact that reports on the fatigue strength of furniture joints are sparse, the results of this study supports the findings of the few previous studies by Erdil *et al.* (2005), Tankut and Tankut (2005) and Tankut (2007), that reported that the allowable design stress for rectangular mortise and tenon furniture joints could be set between 15 to 30% of the bending strength. In fact, the results of this study provides evidence to support the recommendation that the allowable design stress for joints could be set at 20% of its bending strength, which narrows the working range provided in previous studies. Nevertheless, it must emphasized that in furniture engineering, joint design and dimensioning is often treated secondary to the aesthetic need of the furniture, which in turn leads to inappropriately engineered joints (Ratnasingam *et al.*, 1997). Therefore, this study provides fundamental information on the optimal design and dimensioning of rectangular mortise and tenon joints and recommends that the allowable design stress for rectangular mortise and tenon joint be set at 20% of its bending strength, to ensure better furniture engineering and construction.

Industrial implications: The current practice of furniture engineering focuses on product aesthetics rather that strength performance, often resulting in over-sized components and joints (Ratnasingam and McNulty, 2009). This is not only wasteful but is also not cost-effective manufacturing. Further, fatigue failure is the most common cause of failure in furniture, especially in chairs and therefore efforts to ensure the fatigue strength requirements of furniture are taken into consideration in its design and construction is of great importance (Kyanka, 1980). Against this background, this study shows that the recommended allowable design stresses for rectangular mortise and tenon furniture joints could be set at 20% of its bending strength to ensure the compliance of the furniture in terms of its strength requirements. Further, the study also shows that oil palm lumber can be used as a furniture material provided the allowable design stresses are taken into consideration in the furniture engineering and construction stages. Considering the fact that studies on the fatigue strength of furniture components and joints are very limited (Eckelman, 1974, 1988; Ratnasingam *et al*., 2010), the results of this study make important contributions towards a better understanding and design of furniture frames.

CONCLUSIONS

The results of the study shows that the fatigue strength of furniture joints can be taken as 20% of its bending strength and under such loading circumstances, the joints can be expected to withstand the 200,000 load cycles stipulated in furniture performance standards. Further, the study also shows that oil palm lumber can be used as a furniture material, provided the recommended allowable design stresses are adhered to, during furniture engineering and construction.

REFERENCES

Bao, Z.Z. and C.A. Eckelman, 1996. Fatigue and allowable design stresses for some wood composites used in furniture. Eur. J. Wood Wood Prod., 54: 377-382.

Cai, L. and F. Wang, 1993. Influence of the stiffness of corner joint on case furniture deflection. Eur. J. Wood Wood Prod., 51: 406-408.

Eckelman, C.A., 1974. Reasonable Design Stresses for Woods Used in Furniture. Agricultural Experiment Station, Purdue University, West Lafayette, Indiana, pp: 7-8.

Eckelman, C.A., 1988. Performance testing of furniture-Part I: Underlying concepts. For. Prod. J., 38: 44-48.

Eckelman, C.A. and J. Zhang, 1995. Uses of the general services administration performance test method for upholstered furniture in the engineering of upholstered furniture frames. Eur. J. Wood Wood Prod., 53: 261-267.

Eckelman, C.A., 1999. Performance testing of chairs. Holz Roh Werkst, 57: 227-234.

Erdil, Y.Z., A. Kasal and C.A. Eckelman, 2005. Bending moment capacity of rectangular mortise and tenon furniture joints. Forest Prod. J., 55: 209-213.

Haviarova, E., C.A. Eckelman and Y. Erdil, 2001. Design and testing of environmentally friendly wood school chairs for developing countries. Forest Prod. J., 51: 58-64.

Huber, H.A. and C.A. Eckelman, 1999. Wood technology in furniture failures. Wood Des. Focus: J. Contemporary Wood Eng., 10: 15-18.

Kyanka, G.H., 1980. Fatigue properties of wood and wood composites. Int. J. Fracture, 16: 609-616.

Ramirez-Coretti, A., R. Serrano-Montero, E. Haviarova, C.A. Eckelman and Q.C. Madriz, 2009. School furniture for developing countries: A field performance evaluation. For. Prod. J., 59: 17-21.

Ratnasingam, J., M. Perkins and H. Reid, 1997. Fatigue: Its relevance to furniture. Holz Roh Werkstoff, 55: 297-300.

Ratnasingam, J., K.A. Yap, T.T. Chew, S. Mohamed and S.R. Farrokhpayam, 2007. Oil Palm Biomass-From Waste to Wealth: The Tian Siang Story. 1st Edn., TS Publication, Kuala Lumpur, Malaysia, ISBN: 978 983 42986 78.

Ratnasingam, J., T.P. Ma, M. Manikam and S.R. Farrokhpayam, 2008. Evaluating the machining characteristics of oil palm lumber. Asian J. Applied Sci., 1: 334-340.

Ratnasingam, J. and K. Wagner, 2009. The market potential of oil palm empty-fruit bunches particleboard as a furniture material. J. Applied Sci., 10: 1974-1979.

Ratnasingam, J. and T. McNulty, 2009. The design and development of educational furniture from oil palm biomass. IFRG Report No. 4/09. Kuala Lumpur.

Ratnasingam, J. and F. Ioras, 2010. Static and fatigue strength of oil palm wood used in furniture. J. Applied Sci., 10: 986-990.

Tankut, A.N. and N. Tankut, 2005. The effects of joint forms and dimensions on the strength of mortise and tenon joints. Turk. J. Agric. For., 29: 493-498.

Tankut, N., 2007. The effect of adhesive type and bond line thickness on the strength of mortise and tenon joints. Int. J. Adhes., 27: 493-498.

Tankut, A.N. and N. Tankut, 2010. Evaluation the effects of edge banding type and thickness on the strength of corner joints in case-type furniture. Mater. Des., 31: 2956-2963.

Thompson, R.J.H., M.P. Ansell, P.W. Bonfield and J.W. Dinwoodie, 2002. Fatigue in wood-based panels. Part I: The strength variability and fatigue performance of OSB, chipboard and MDF. Wood Sci. Technol., 36: 255-269.

Thompson, R.J.H., M.P. Ansell, P.W. Bonfield and J.W. Dinwoodie, 2005. Fatigue in wood-based panels. Part II: property changes during fatigue cycling of OSB, chipboard and MDF. Wood Sci. Technol., 39: 311-325.

Tsai, K.T. and M.P. Ansell, 1990. The fatigue properties of wood in flexure. J. Mater. Sci., 25: 865-878.