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Static and Fatigue Strength of Oil Palm Wood Used in Furniture

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Abstract: A study was undertaken to evaluate the edge-wise static and fatigue strengths of oil palm wood, as the material is being promoted for furniture applications. The static and fatigue tests were conducted using a 3-point bending test-rig. The fatigue test was carried out at selected stress levels that corresponded to specific percentages of the material's ultimate strength (Modulus of Rupture (MOR)). The results showed that Oil Palm Wood (OPW) had a much lower bending and ultimate strength compared to the other common furniture wood materials, due to its lower density. In terms of it's the fatigue strength although oil palm wood showed lower fatigue resistance compared to the other common wood materials used in furniture. The result found that fatigue life of OPW amounted to over 1 million cycles when the stress level was 30% of the MOR for OPW, but decreased to 203,000 cycles for OPW at a stress level of 50%. On this account, the allowable design stresses for the OPW could be set at 40% of its MOR. Although, the study showed that OPW does not perform as well as other common wood materials used in furniture, with a larger safety factor, OPW can be successfully used as an alternative furniture material.

Key words: Load, cyclic, static, wood, furniture

INTRODUCTION

The need for low-cost educational furniture has been growing rapidly over the years and while the total value of educational furniture in Malaysia in 2008 was estimated to be US 25 million, within the South East Asian region this amount could be close to US$ 200 million per annum (Ratnasingam and McNulty, 2009). With a growing population, the market for education furniture in the region is expected to increase in years to come, thereby increasing the demand for solid wood resources, which has been the traditional raw material for such furniture. Although studies on alternative raw materials for the manufacture of educational furniture has been undertaken elsewhere (Eckelman *et al*., 2001), the furniture manufacturing industry in the Malaysia has been dependent primarily on Rubberwood (*Hevea brasiliensis*) and a mixture of hardwoods from the natural forests (Ratnasingam and McNulty, 2009).

In recent years, the biomass from the oil palm (*Elaeis guineensis*) plantations in Malaysia, particularly the trunk is increasingly used as the raw material for the saw-milling industry (Ratnasingam *et al*., 2007). Extensive research into the use of the oil palm trunk for lumber production over the last few decades has resulted in its recent commercialization success (Ratnasingam *et al*., 2007). Consequently, the Oil Palm Wood (OPW) has emerged as an alternative raw material for the rapidly growing furniture industry in Malaysia, which is becoming increasingly concerned about the future supply of raw materials (Ratnasingam and Wagner, 2009). Although, the diminishing supply of wood resources from the natural forest was expected to be offset by the increased supply of Rubberwood (*Hevea brasiliensis*) from the extensive tract of rubber plantation in the country, the recent conversion of rubber land to oil palm plantation has significantly reduced the supply of Rubberwood. Inevitably, emergence of the oil palm wood as a potential raw material for the furniture industry is timely and could alleviate the raw materials supply concerns (Ratnasingam *et al*., 2007). Although, the strength and working properties of the oil palm wood has been studied (Ratnasingam *et al*., 2008; Ratnasingam and Wagner, 2009) the behavior of this material under static and cyclic loads experienced in furniture construction has not been examined.

The strength of wooden furniture is dependent on the strength of the individual components and the joints holding these components together (Huber and Eckelman, 1999). However, earlier study have found that the main cause of furniture failure is the cyclic loadings acting upon joints and components, as reflected in furniture

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service conditions (Ratnasingam *et al*., 1997; Huber and Eckelman, 1999). The cyclic loadings results in fatigue failure, as the joints and components undergoes a steady reduction in load bearing capacity due to the incremental damage accumulated over time. A review of earlier study also shows that studies on the fatigue behavior and allowable design stresses of furniture components are very limited (Kyanka, 1980; Sugimoto *et al*., 2006). Bao and Eckelman (1996), who investigated the fatigue properties of composites (particleboard, medium density fibreboard and oriented strand board) at the various percentages of its ultimate strength suggested that the allowable design stresses for composites might be considered from the fatigue life of the material at various stress level. Fatigues failures regularly occur in furniture construction, especially at the joints, although member failures have also been reported to a lesser extent (Huber and Eckelman, 1999). The use of wood composites with Modulus of Rupture (MOR) substantially lower than that of solid wood, could lead to increased member failures at load levels below the static ultimate strength of the material (Bao and Eckelman, 1996). Thus it is important that the allowable design stresses for the oil palm wood be evaluated due to its different properties in comparison to the other common furniture wood materials The desirable allowable design stress for the oil palm wood should be set at levels that ensure their survival under the repetitive cyclic loading, often endured by the furniture during its service. Therefore, the objective of this study was to establish the allowable design stresses under cyclic loading for the OPW in comparison to the other common furniture wood materials. This information will be useful for manufacturers who intend to use oil palm wood for optimal furniture frame design and construction.

MATERIALS AND METHODS

Commercial grade lumber of the five most common furniture wood materials (namely, Rubberwood (*Hevea brasiliensis*), Nyatoh (*Palaquium gutta*), Light Red Meranti (*Shorea platyclados*), Ramin (*Gonystylus bancanus*) and Sepetir (*Sindora coriacea*)) and OPW of the size 30×60×000 mm^3 were obtained from a local materials supplier. All the samples were kept in a conditioning room at 20°C and 65% relative humidity, for about two months to ensure a final moisture content of 12±2%. All static-bending tests were carried out on an INSTRON universal testing machine, while the edge-wise fatigue tests were conducted with a specially designed air-cylinder loading system. All the experimentations were carried out at the Materials Testing Laboratory of the Science Company Inc., in Singapore, between June and October of 2009. The controlled environment in the testing facility ensured that the properties of the materials were kept constant during the test duration, which is important as strength properties of materials is influenced by humidity and temperature (Ratnasingam *et al*., 1997).

One hundred pieces of each of the experimental material were first ripped full length to a final dimension of 25×50 mm and then cross cut at mid length to form two matched pieces. One of the matched pieces was tested in bending in order to determine its density, moisture content and ultimate bending strength, while the remaining matched piece was used in the fatigue test. All the parts were coded accordingly to designate the test pieces. The dimensions of the specimens were in accordance to the dimensional requirements of components used in the manufacture of educational furniture frames in the country (Ratnasingam and McNulty, 2009). The static bending tests were conducted in accordance with the ISO 3133 (1975) for experimental samples as described in Bao and Eckelman (1996) and Eckelman *et al.* (2001) and the value of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) was established through calculation from the load-deflection curve after each test.

All the specimens were subjected to six different stress levels (i.e., 30, 40, 50, 60, 70 and 80%), expressed as a percentage of their respective average MOR. These load levels were chosen based on the previous study by Bao and Eckelman (1996) and after discussions with educational furniture manufacturing experts. Loads were applied to the specimens by means of air cylinders. A support span of 900 mm was used in keeping with the overall configuration of the test equipment. During the fatigue test, the air cylinder system exerted and released a non-reversal load at a rate of 20 cycles per minute. Mechanical counters recorded the number of cycles completed. Limit switches were used to stop the test when the specimen failed, or when 1 million cycles were completed.

RESULTS

Table 1 shows the bending test results for all the specimens used in the study. Generally, the wood

Table 1: Average values of physical and mechanical properties of specimens

Materials	Density ($kg\ m^{-3}$)	Moisture content (%)	MOR	MOE
			----------($N\ mm^{-2}$)------	
Rubberwood	580±6.71	12.14±0.11	58±2.31	8940±233
Light red meranti	575±6.11	12.41±0.09	75±2.56	11200±253
Nyatoh	675±6.05	12.05±1.02	79±2.43	12980±265
Sepetir	690±7.12	12.75±1.15	92±3.55	13900±260
Ramin	675±5.07	12.30±1.14	88±2.81	15900±278
OPW	510±5.22	12.47±0.17	31±2.03	4324±198

Valus are represent as Mean±SD

Table 2: Average values of fatigue life at different stress levels for different specimens

Stress level	RW	LRM	NY	SPT	RM	OPW
30% of MOR	17.4	22.5	23.7	27.6	26.4	9.3
No. of Cycles	> 1000000	>1000000	>1000000	>1000000	>1000000	>1000000
40% of MOR	23.2	30.0	31.6	36.8	35.2	12.4
No. of Cycles	> 1000000	>1000000	>1000000	>1000000	>1000000	489,100
50% of MOR	29.0	37.5	39.5	46.0	44.0	15.5
No. of Cycles	650,000	760,000	805,100	855,100	910,550	203,000
60% of MOR	34.8	45.0	47.4	55.2	52.8	18.6
No. of Cycles	285,000	343,000	347,000	385,000	387,000	145,000
70% of MOR	40.6	52.5	55.3	64.4	61.6	21.7
No. of Cycles	160,000	187,105	198,550	220,000	241,000	75,000
80% of MOR	46.4	60	63.2	73.6	70.4	24.8
No. of Cycles	105,000	118,900	125,100	128,055	131,100	37,000

MOR expressed in N mm^{-2}. Results were significantly different at $p<0.05$. RW: Rubberwood, LRM: Light red meranti, NY: Nyatoh, SPT: Sepetir, RM: Ramin, OPW: Oil palm wood

materials exhibited the higher bending strength (MOR) and bending stiffness (MOE) values compared to the OPW, as expected. The MOR value of the OPW averaged 31 N mm^{-2}, while its MOE averaged 4324 N mm^{-2}. On the other hand, the average MOR for the other wood materials was 78.4 N mm^{-2}, with an average MOE of 12584 N mm^{-2}. The performance of the wood materials was however in the flowing order: Ramin>Sepetir>Nyatoh>Light Red Meranti>Rubberwood. These values were found to be statistically significant at $p<0.05$, indicating that the static strength properties between the different materials are different.

Table 2 shows that fatigue life of the OPW specimens for each of the different loading levels. Results indicate that at 30% of the ultimate strength, all the specimens could be expected to have a fatigue life above 1 million cycles. However, when the stress level was increased to 50% of the MOR, fatigue life decreased to an average of 203,000 cycles for OPW, while the other wood materials showed a fatigue life of more than 500,000 cycles. At higher stress levels, the fatigue life of all specimens was significantly reduced further. Similar to the static strength, the wood materials outperformed the OPW in terms of fatigue resistance. Statistically the results were found to be significant at $p<0.05$, indicating markedly different fatigue strength among the materials used in this study. Nevertheless, the results suggest that the order of fatigue strength among the wood materials were quite similar to the trend shown in the static strength.

DISCUSSION

If the loading to which a piece of furniture is subjected were static or almost static without any kind of cyclic loading, then the allowable design stress for the components could be determined from a consideration of the ultimate bending strength of the material and the desired factor of safety (Eckelman, 1988). If however the components are subjected to repeated live-loading environment, as it often the case for educational furniture, it is more reasonable to use fatigue strength rather than static strength to determine working stresses (Ratnasingam *et al.*, 1997). Thus, when repeated loading cannot be ignored, allowable design stress should be taken as the percentage of ultimate strength that will ensure that the expected fatigue life of the components will exceed the expected number of service-life load cycles.

Test results indicate that fatigue life regularly decreased as the level of stress increased, similar to the report by Bao and Eckelman (1996). The study also reveals that solid wood specimens out-performed the OPW specimens at all levels of stress, clearly reflecting the superior fatigue resistance of solid wood materials (Eckelman, 1974; Thompson *et al.*, 2002, 2005; Sugimoto and Sasaki, 2006; Sugimoto *et al.*, 2006). At a stress level of 40% of its MOR, the OPW had a fatigue life of almost 500,000 cycles, while the other solid wood specimens all had 1 million or more cycles in fatigue life. Therefore, OPW could be used in furniture, where the repeated live-loading does not exceed 40% of the material's ultimate strength. The results of this study suggest that OPW has fatigue strength similar to that of wood-based panels, as previously reported by Bao and Eckelman (1996) and Sugimoto and Sasaki (2006).

It is difficult to estimate the number of load cycles to which a piece of furniture will be subjected to in service. The number of cycles that a piece of furniture must withstand to pass accepted performance tests is well defined, however. For instance, the number of cycles stipulated in the British Standard BS 4875 for chairs and settees is 200,000 cycles (BSI, 1972). Hence, the allowable design stresses for the OPW furniture components might be set at 40% of the MOR of the material. The values obtained could then be further reduced, if desired, to take into account an appropriate safety factor and other adjusting factors required in the educational furniture frame design procedures (Ramirez-Coretti *et al.*, 2009).

Design implications: In most furniture designs, the components are often oversized to accommodate the aesthetic needs of the joint construction. Such oversized components, while not contributing to the overall strength of the furniture, also results in wasteful application of the material (Ratnasingam *et al*., 1997; Huber and Eckelman, 1999). On this premise, it is apparent that OPW sized according to their fatigue strength can be effectively used as furniture components in the manufacture of low-cost education furniture construction, especially for school chairs and desks. Nevertheless, the fact that oil palm has a markedly different anatomical structure, which impairs its static and fatigue strength in comparison to solid wood materials (Ratnasingam and McNulty, 2009), suggested that furniture constructed from oil palm wood should include a higher factor of safety to accommodate the repeated live-loadings experienced in service. The vascular bundles, which constitute the building blocks in oil palm, embedded in a matrix of parenchyma cells, which in turn renders it with a lower ability to absorb repetitive loadings (Sreekala *et al*., 1997; Kärenlamp *et al*., 2003). Nevertheless, with properly sized members and well-constructed joints, OPW could be successfully used in the manufacture of educational furniture that should be able to surpass the general acceptance standards of educational furniture in many countries within the South East Asian region. It must however be recognized that from an economical perspective, as long as the cost of OPW remain competitive to support the need for larger sized components with a higher margin for safety, its application in the furniture industry may still be a viable option.

CONCLUSION

Oil palm wood was subjected to edge-wise static load and constant amplitude cyclic load in an effort to investigate the fatigue properties of this material, in comparison to the other common furniture wood materials. Results of cyclic loading analyses suggest that fatigue life regularly decreases as the level of stress increases. When considering cyclic load effects, the allowable design stress for oil palm wood should be no more than 40 percent of its MOR, respectively. This number would provide furniture manufacturers a quick reference to estimate the appropriate sizes of oil palm wood furniture components that would satisfy the different GSA performance testing acceptance levels of educational furniture.

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