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DETERMINATION OF FATIGUE AND STATIC STRENGTH OF SCOTS PINE AND BEECH WOOD

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ABSTRACT

In this study, fatigue and static strength of Scots pine (*Pinus sylvestris* L.) and beech (*Fagus orientalis* L.) woods were investigated. The fatigue and static strength were conducted using a three point bending test-rig. The specimens were prepared according to ISO 3129 (1975) and fatigue and static bending test were carried out according to ISO 3133 (1975). The fatigue test was carried out at 80, 70, 60, 50 and 40 % stress level that corresponded to specific percentage of material's ultimate strength modulus of rupture (MOR). However the microstructures of fatigue failures were observed by using scanning electron microscope (SEM). The results were indicated that, the fatigue life of Scots pine wood amounted to over 1 million cycle when the stress level was 40 % of MOR for Scots pine and 50 % MOR for Beech. In general, fatigue life decreased as stress level increased and vice versa. The allowable design stress is based on some percentage of MOR for furniture design. On this account, the allowable design stresses for Beech and Scots pine could be set at 50 and 40 % respectively.

KEYWORDS: Fatigue, static, Scots pine, beech, modulus of rupture.

INTRODUCTION

The strength of wooden furniture is dependent on the strength of individual component and the joints holding these components together. Therefore, knowing the behavior of wooden furniture parts under static and cyclic loading is important. However, having allowable design stresses for components of wooden furniture are fundamental to the design of safe, efficient furniture (Zor and Tankut 2012). The studies showed that, although the material withstand to a specific load in a short time, the cycling loadings results in fatigue failure, as the joints and components undergoes a steady reduction in load withstand capacity due to incremental damage accumulated over time. For this reason, apart from the stress-strain values, the cyclic load capacity of material also should take into consideration for decide to behavior of wooden material under cyclic load (Eckelman 1988). The fatigue is the main reason of deformation in the furniture components. Therefore the fatigue behavior and allowable design stresses of furniture components are very important.

Fatigues failures regularly occur in furniture construction, especially at the joints, although member failures have also been reported to a lesser extent (Ratnasingam et al. 1997; Huber and Eckelman 1999). Failure of the side rail to back post joint in chairs is one example. Failure of solid wood furniture parts is less common than joint failures because member strength to joint strength ratios is normally high (Bao and Eckelman 1995). 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 (Ratnasingam and Ioras 2010).

According to Mcnatt (1970), fatigue strength of hardboard to be about 10 million cycles at stress level about 40 to 45 percent of the static strength of material in tension the Stress versus fatigue life expressed as number of cycle curves obtained were similar to curves for solid wood specimens loaded in tension parallel to grain.

Fatigue of materials is a common problem of members or structures which are subjected to cyclically impose loading (Sandor 1972). Studies dealing with fatigue behavior and allowable design stresses for wood and wood-base composites are very limited. Even when wood was used in the aircraft industry, fatigue was considered insignificant or at least covered by safety factors accounting for creep. As a result, very little work has been carried out on the fatigue response of wood (Tsai and Ansell 1990, Eckelman et al. 1996).

Several studies are available in literature regarding the fatigue behavior of wood. However, there are no studies available about the behavior of fatigue and static strength of Scots pine and beech wood. In this direction, the aim of this study is to examine the fatigue and static strength of Scots pine and beech wood. However, stress-life (S-N) curve results of this study also were aimed for use in the computer aided design (CAE) program of furniture components to saving time and materials. Furthermore very little research has been published on the microstructure of wood specimens. In this study, the microstructure of fatigue failure areas was observed by scanning electron microscope (SEM).

MATERIAL AND METHODS

Scots pine and beech wood were obtained from the local market supplier and the these test specimens were prepared for static bending test in accordance with the ISO 3133 (1975) for experimental samples as described in Eckelman et al. (2001). All the specimens were kept in a conditioning room at 20±2°C temperature and 65±5 % relative humidity for about 6 month to ensure constant weight. The specimens of the size 20x20x30 mm were used to determine air dried density in accordance with the ISO 3130 (1975) and ISO 3131 (1975).

Static bending test

The static bending test specimens were conducted in accordance with the ISO 3133 (1975) for experimental samples and 2x20 pieces of each of the wood specimens were prepared for bending test. Fig. 1 shows the method of bending test. The bending stress can be calculated as;

$$\sigma_e = (3/2) \times (F_{max} \times Ls / b \times h^2) \qquad (N.mm^{-2}) \qquad (1)$$

where: b - the section width,
h - the section height,
L - the length of the specimen.

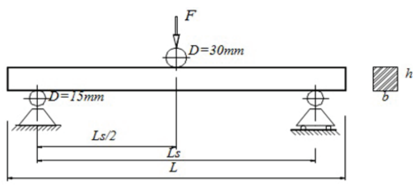

Fig. 1: The schematic representation of three point bending test.

The elasticity module can be calculated as;

$$E = F \times Ls^3 / 4 \times b \times h^3 \times \Delta f \qquad (N.mm^{-2}) \qquad (2)$$

where: E - the elasticity module ($N.mm^{-2}$),
F - the applied force (N),
Ls - the gap between points of support (mm),
b - the width of specimen (mm),
f - the displacement (mm),
h - the height of specimen (mm).

Bending test was carried out at room temperature at a crosshead speed of 5 $mm.min^{-1}$ by a MTS (100kN Servo-Hydraulic) test machine.

Fatigue test

All the specimens were subjected at different stress level (40, 50, 60, 70 and 80 %), expressed as a percentage of their respective average MOR. These load level were chosen based on the previous study by Bao and Eckelman (1996). Loads were applied to the specimens by Servo-Hydraulic test machine.

During fatigue test the Servo-Hydraulic system exerted and released non-reversal load at rate of 2 Hz frequency. Limit switches were used to stop the test when the appeared crack. After fatigue test, S-N curve were obtained.

SEM observation

Zeiss Ultra Plus Field Emission Scanning (FESEM) electron microscope was used for observations of the wood structure.

The working distance (distance between the surface of the specimen and the front surface of the objective lens) was 10 mm. The accelerating voltage of FESEM was the 10 kV. The SEM images of specimens were observed by secondary electron (SE2) detector.

RESULT AND DISCUSSION

Fatigue and bending test

Tab. 1 shows the bending test result for Scots pine and beech wood specimens used in this study. Generally, beech specimens exhibited the higher MOR and MOE values compared to Scots pine specimens. However the density of beech also is higher than density of Scots pine. Therefore the results show that, the static bending stress and elastic modulus of materials depend on density of materials.

Tab. 1: MOR, MOE and density average value of test specimens.

Material	Density ($g.cm^{-3}$)	MOR ($N.mm^{-2}$)	MOE ($N.mm^{-2}$)
Scots pine	0.52	104.2±3.57	11250.9±459.1
beech	0.64	120.8±9.05	13808.9±539.5

MOR= Modulus of rupture, MOE= Modulus of elasticity

Tab. 2 shows the average fatigue life of the Scots pine and beech specimens at each of different loading levels. The fatigue tests were continued until an appeared crack.

Tab. 2: Fatigue strength average value.

S. Level	Scots pine		beech	
	B. Stress	Average	B. Stress	Average
80	83.2	259285.8± 6901.4	96	318529.4± 6620.6
70	72.8	425037.4± 4312.9	84	628843.6± 1389.9
60	62.4	604484.4± 5989.7	72	854190.4± 1589.6

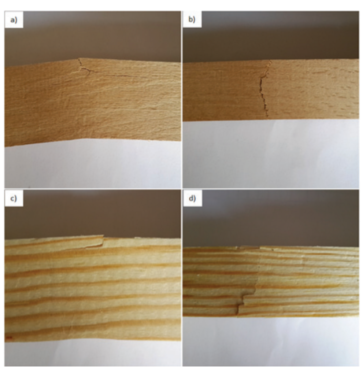

Fig. 2: Image of cracks; a) cross side of beech, b) bottom side of beech c) cross side of Scots pine, d) bottom side of Scots pin.

Fig. 2 shows the image of cracks. The results indicate that fatigue life decrease as the level of stress increased similar to the report by Bao et al. (1996). At a stress level of 40 % of its MOR, the Scots pine specimens had 1 million or more cycles in fatigue life. But beech specimens tested at 50 % of MOR had fatigue lives of at least 1 million cycles. Fatigue failures began to occur as the stress level was or above 40 % of Scots pine specimen's average MOR. However fatigue failures began to occur as the stress level was above 50 % of beech specimen's average MOR.

The inverse relationship between fatigue life and applied stress level was adsorbed for specimens tested. This tendency is seen in Figs. 3 and 4 and a linear trend was evidenced in S-N scatter plot. It can be conclude that, at a stress level of 40 % of average MOR, both Scots pine and beech survived a million test cycles. However at a stress level of 50 % of its MOR, the beech specimens had 1 million or more cycles in fatigue life. The fatigue test results have showed that, as the applied stress levels increase, the fatigue life decrease. Although, at a stress level of 40 % of its MOR Scots pine specimens had 1 million or more cycles in fatigue life, at the 50 % (or above) number of cycles does not exceed 1 million similarly.

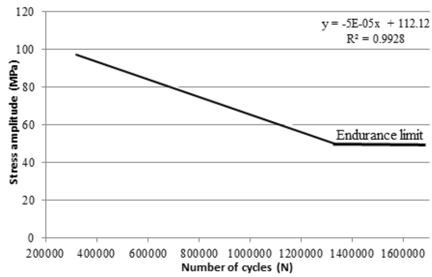

Fig. 3: Fatigue life (S-N curve) of beech.

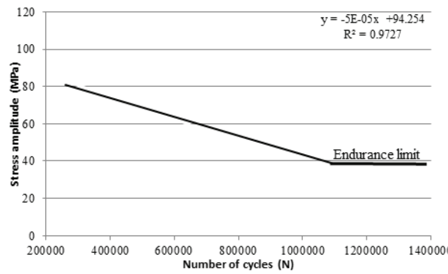

Fig. 4: Fatigue life (S-N curve) of Scots pine.

SEM Analyses

The SEM image of specimens has taken on bottom side of cracks as shown in Fig. 2 and the morphology of cracks after the fatigue test failure has given in Figs. 5 and 6.

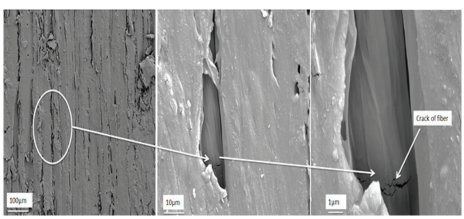

Fig. 5: SEM image of longitudinal-radial sections of Scots pine.

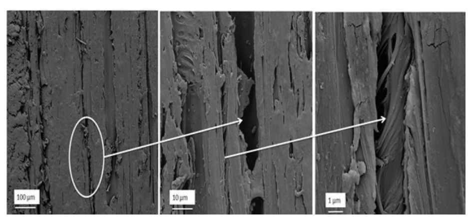

Fig. 6: SEM image of longitudinal-radial sections of beech.

Although, the beech showed buckling and ductile fracture, the Scots pine has showed brittle fracture. It can be attributed to density and type of cells and thickness of walls. Kunesh (1968) noticed that in wood specimens a failure first starts from buckling of rays in a layer and results in progressive failure by buckling of the rays throughout the specimen. However, Inoue et al. (1996) has concluded that, the cell walls were usually deformed elastically and some cell wall fractures (cracks, snaps, and disconnections of the cell walls) were observed in the wood specimens.

CONCLUSIONS

In this study, S-N curve were determined for five levels of the maximum load as a function of the average static bending failure load. The bending and fatigue strength of beech is higher than Scots pine. However the density of beech also is higher than density of Scots pine. Hence, the test results show that, static bending stress and fatigue stress of materials depend on density of materials. For furniture design, fatigue stress of materials must be taken into account instead of static stress. The fatigue results show that, fatigue strength of Scots pine and beech provides an important data for the rational development of allowable design stresses. However, the optimum life of these specimens can be determined with the fatigue results.

The SEM analysis of specimens have showed that, the type of cellular failure textures were different in Scots pine and beech specimens. This is evidence of density difference and thickness of cells. The Scots pine has more brittle fracture than beech.

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