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The effect of geometric structure on stiffness and damping factor of wood applicable to machine tool structure

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Abstract — *Stiffness and vibration damping capability are important criteria in design of machine tool structure. In other sides, the weight of machine tool structure must be reduced to increase the handling capability. This paper presents an analysis of the effect of geometric structure on stiffness and vibration damping of wood structure. The stiffness was analysed using numerical method, so called finite element method (FEM), while the vibration damping capability was experimentally tested. Vibration testing was also performed to wood structures with sand powder filled into its rectangular hole to observe the its effect on damping factor. Simulation results show that the cross ribs structure yielded minimum mass reduction ratio compared to the three square holes as well as the single rectangular hole structures. While the vibration test results explained that the damping factor of Shorea laevis wood was higher than that Hevea braziiensis wood. The use of sand powder as vibrating mass in closed-box structure effectively increased the damping capability, for single rectangular hole structure the damping factor was increased from 0.048 to 0.079.*

Keywords — *Shorea laevis, Hevea braziiensis, stiffness, damping factor, machine tool structure*

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I. Introduction

Wood is a natural material commonly used as building construction. Various woods have been sold commercially with low cost compared to metal materials. In engineering application, production process of wood material is easier than metal, so that it also reduces the cost production. This paper presents the results of stiffness analysis using FEM and experimental testing of vibration damping of wood structure aimed to develop main structure of machine tool.

When a structure is vibrated, its damping capability reduces the amplitude of oscillation and changes the vibration energy into heat. Damping factor is defined as a loss factor or energy loss ratio that was referred to energy transformed into other energy along one cycle vibration (Ouis, 2002).

Many research works have been conducted in developing measurement method and observation damping capability of wood materials, mechanical characteristic and other aspects which affects it. Measurement of damping factor by means of measuring decrement of vibration response has been studied by Ciornei *et al* (2009). In this work, vibration response was measured using piezoelectric transducer and transferred to a storage data oscilloscope. Then the vibration database was processed into a computer system to determine vibration damping through logarithmic decrement method and displayed as data interpretation. Logarithmic decrement is an internal damping indicator of the material and its oscillated frequency determines elastic constant of probe and longitudinal elastic modulus of the wood.

There are three factors which affect on vibration damping characteristic of wood material, namely: geometric sample, material properties toward scatter and scatter absorption. Scatter and scatter absorption characteristic depend on frequency of vibration, anisotropic direction and wood species (Buccur, 2006).

Effect of notch on elastic modulus and vibration damping factor was studied by Hossein *et al* (2011). This research work used a wood rectangular bar of *Cupressus arizonica*. He used five sample wood plants with diameter around of 36 cm, and cut them on temperature of 21^{o}C and the moisture content of 65%. The experiments was based on free vibration mode with bending test model. The results show that the elactic modulus as well as vibration damping factor decreased significantly if notch achieved higher than 60%. Spectrum modes of Fast Fourier Transform (FFT) of un-notch specimens shown the symmetrical condition, while for notch specimens, FFT spectrum was un-symmetric.

In development of machine tool structure, Nakaminami *et al* (2007) investigated the design method of multi axis machine tool structure. They analysed the static and dynamic stiffness and also the movement accuracy using FEM. The results showed that the use of box structure gives maximum accuracy and productivity applicable to multi axis machine tool (Nakaminami *et al*, 2007). In experimental analysis, internal damping concept of machine tool structure was proposed by Slocum *et al* (2003). They used an internal beam in liquid media which was localized in machine tool structure (Slocum *et al,* 2003). In addition, material modification of machine tool structure was also developed by Lee *et al* (2004). They used reinforced composite for high speed milling machine which substitutes cast iron material. This investigation showed that the weight of structure was reduced around 30%, and the damping capability was increased from 1.5 – 5.7 without reducing stiffness. Positioning accuracy was also increased to 0.5 m for displacement of 300 mm (Lee *at al*, 2003). Wakasawa *et al* (2004) proposed the method of increasing damping capacity in machine tool structure by using balls packing. In structures closely packed with balls, various damping characteristics appear in correspondence with the ball size and other conditions. The results showed that the dimension of ball was an important factor in this method. Excitation of structure is required to achieve an optimum packing ratio where the maximum damping capacity is obtained. For a 50% packing ratio, this excitation process is not necessary to obtain a stable damping capacity (Wakasawa *et al*, 2004).

To increase the dynamic stiffness of machine tool, testing method of dynamic characteristic of machine tool was proposed by Koci (2003). While, the nodal analysis concept to yield frequency modus for operated machine tool was developed by Harms (2006).

This paper proposes the use of wood material for machine tool structure. This work is aimed to investigate the effect of mass reduction on static stiffness and damping capability through variation of geometric structure. The wood materials used in this experiment were *Hevea braziiensis* and *Shorea leavis*.

II. Materials and Methods

Stiffness is a major criterion of machine tool structure to produce high dimension accuracy of cutting product. The other side, the weight of machine tool structure must be minimized to reduce the cost production and to increase handling capability. Due to the minimum weight and maximum stiffness requirements, a various geometric model of machine tool structures of wood (Figure 1) was analysed and simulated using FEM. Static load simulation of modelled structures were 15 kg located at the middle position.

Every specimens was tested by vibration test to calculated the damping factor. Set-up of vibration testing is depicted in Figure 3. The tests were run for four locations of specimens with the similar relative position from the accelerometer. Vibration response data were acquired and stored in computer through data acquisition device of Spectra Quest. The presentation of vibration transient response is shown in Figure 4. Determination of the damping factor was conducted by calculating logarithmic decrement of sequenced amplitudes as presented in Eqs. (1)-(3).

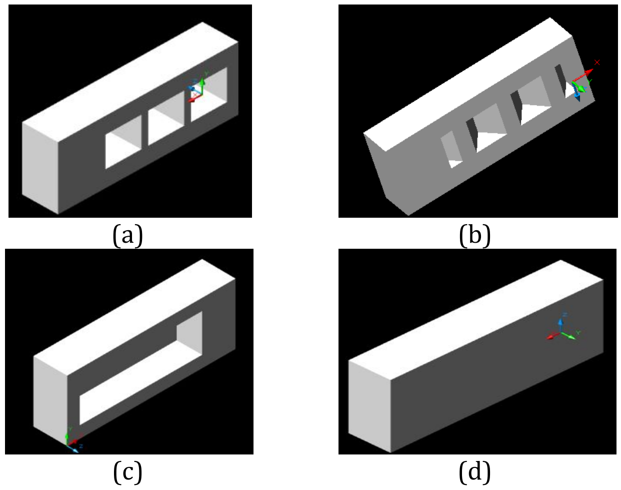


Figure 1. Structure model for stiffness simulation and vibration testing: a. Three square-holes structure, b. Cross ribs structure, c. Single rectangular-hole structure, d. Closed-box structure.

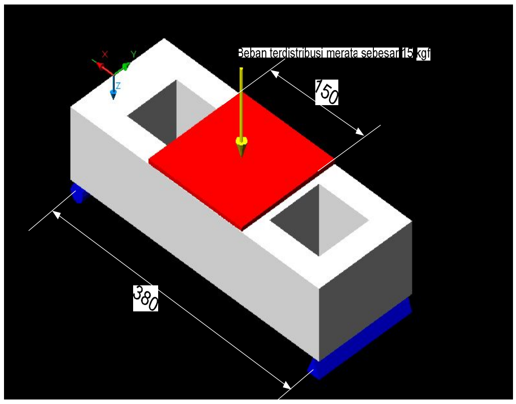


Figure 2. Free body diagram of stiffness simulation.

Figure 3. Set-up of the vibration test of the wood structure.

The effect of vibrating mass in closed-box structure on damping factor was also observed. The sand powder of 0.3 mm particle size was filled into single rectangular-hole and cross ribs structure as presented in Figure 5a. Holes, then was covered using wood plate (Figure 5b) and vibration test was conducted using hammer and accelerometer sensor to obtain vibration transient response. The similar procedures of logarithmic decrement were used to calculate the damping factor of structures under test.

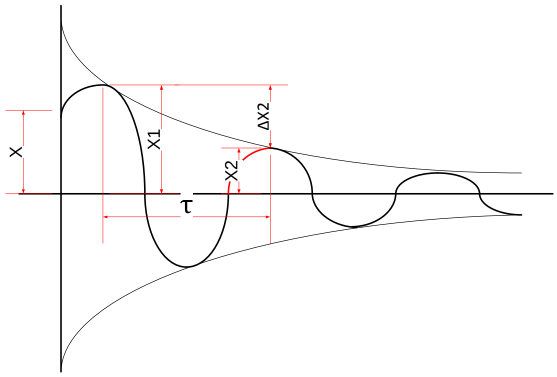


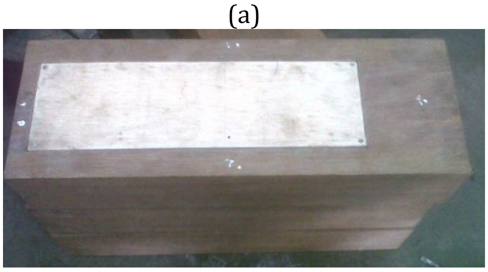
Figure 4. Transient vibration response data used to determining decrement logarithmic.

$$\delta = \ln \frac{1}{\,} = \ln e^{\varphi f \tau} = \text{..........................}(1)$$

$$= \frac{2\pi}{f\sqrt{1-\varphi^2}} = periode \quad e \quad r\text{.......................}(2)$$

$$\delta = \frac{\pi\varphi}{\sqrt{1-\varphi^2}}\text{..}(3)$$

(a)

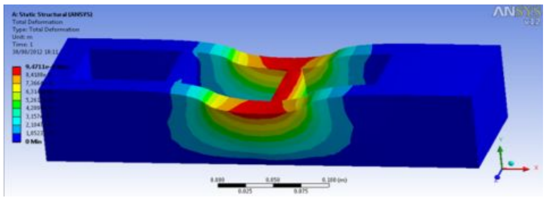


(b)

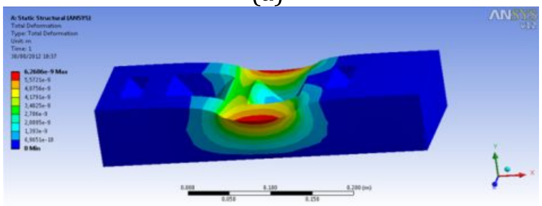
Figure 5 a. Structure with sand powder, b. The cover of wood plate.

III. Results and Disccusion

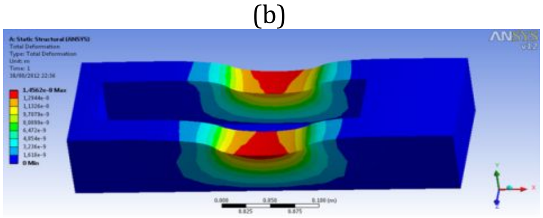
In the structure, stiffness can be represented by deflection when the structure was loaded by static load. The simulation of deflection contour of each structures are shown in Figures 6a-6d. Table 1 summarizes the maximum deflection of each specimens when the load was applied. Observing the results, the cross ribs structure yielded the minimum reduction of deflection per unit mass. Therefore, the cross ribs structure models is better than the single rectangular hole as well as three holes structure.



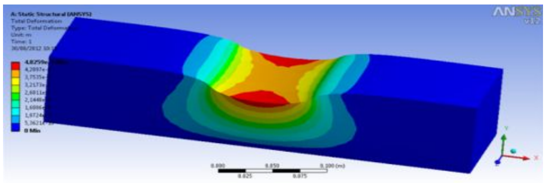
(a)



(b)



(c)



(d)

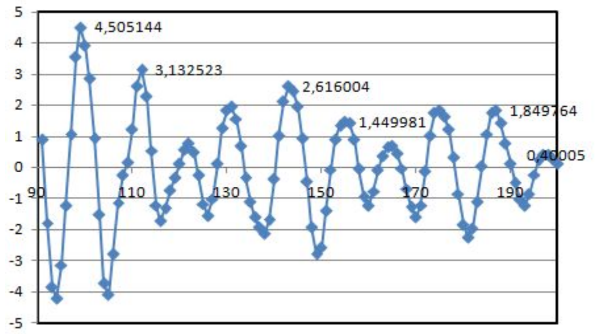
Figure 6. The simulation results of structure deflection: a. Three square-holes structure, b. Cross ribs structure, c. Single rectangular-structure, d. Closed box strcuture.

Table 1. The maximum deformation of structure variation caused by static load of 15 kg (*Shorea leavis*)

No	Structural Model	Max deformation (δ_{maks}) x e-9	Mass a (kg)	$\Delta \delta/\Delta m$ x e-9
1	Three holes structure	9,4711	2,9	3,3179
2	Cross ribs structure	5,572	3	0,5738
3	Single hole structure	14,6	2,6	5,7494
4	Closed-box structure	4,826	4,3	-

Vibration measurement of each specimens was executed for four locations with the same relative position between stimulated point and accelerometers. The vibration transient response reconstruction of measurement data is depicted in Figure 7. The cross ribs structure gave the higher damping factor than the single as well as three holes structures, that was around of 0.063. The damping factor of all structure are presented in Table 2. These data shows that the damping factor does not clearly correlate with the percentage of wood volume. The geometric structure is the dominant factor which affects on the damping capability.

The damping factor of *Shorea laevis* wood is higher than *Hevea braziiensis* wood. The calculation gave results of closed-box structure of *Shorea laevis* and *Hevea braziiensis* woods are 0.065 and 0.045, respectively.



Gambar 7. Plotting vibration transient response data.

TABLE 2. The Damping Factor of Four structures of Shorea leavis and Hevea braziiensis

No	Ribbing Structure	% wood volume	Damping factor
1	Three holes- *Shorea leavis*	70,62937	0,044309
2	Cross ribs- *Shorea leavis*	83,36429	0,063796
3	Single hole- *Shorea leavis*	65,58129	0,048145
4	Closed-box-*Shorea laevis*	100	0,065197
5	Closed-box -*Hevea braziiensis*	100	0,045203

The use of vibrating mass actually increased damping capability of the structures. The addition of vibrating mass in single rectangular hole structure (with mass of 2,9 kg) enhanced the damping factor from 0.048 to 0.079 (around of 1,64 times). While for cross ribs structure, correlation between vibrating mass addition and damping factor is depicted in Figure 8. This figure shows that the increasing of vibrating mass is proportional with the enhancement of the damping factor.

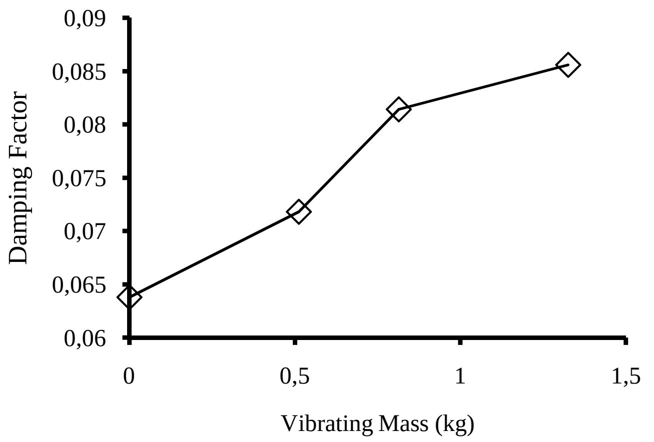


Figure 8. Correlation between vibrating mass and damping factor of cross ribs structure.

The enhancement of damping capability is caused by vibrating mass follows this phenomenon: when force was stimulated to the structure, all the particles mass vibrates with random vibration mode. The damping capability were produced by the different phase of this vibration.

IV. CONCLUSIONS

Cross ribs structure is the best model of wood machine tool structure which gives minimum weight and maximum stiffness compared to single and three holes structures. Damping factor cannot be correlated to the mass as well as the volume of wood but it closely correlates to the geometric structure. The addition of vibrating mass is effective method to increase damping capability of wood structure.

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