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Research Article

The Effect of the Fiber of Wood and Connection Tools on the Vibration Characteristics of Gofasa Wood (*Vitex cofassus)*

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Abstract: The aim of this study was to determine the characteristics of vibration transmission of Gofasa wood (vitex cofassus), which the primary material used in wooden shipbuilding in Maluku. The improvement of the connections of wood has an influence on the stiffness values of the binding system because of its mechanical properties. In this research, the excitation test was carried out on the connection with Radial-Radial (RR), Tangential-Tangential (TT) and Radial-Tangential (RT) fiber direction to see the effect of the orientation of the wood fiber on the vibration characteristics. The excitation test to the specimens using bolt, nail and peg connections was conducted to see the effect of the fastening tool on vibration characteristics. The results of the tests showed that the dynamic stiffness of the RR connection using a bolt had the highest value at the four measurement points exceeding the dynamic stiffness of the material without connections. Dynamic stiffness k of the TT connections using a nail had the highest value and k with the RT joint recorded the highest value using the peg connection tools. This study shows that the determination of the direction of the fiber and the type of connecting devices have an effect on the magnitude of the vibration transmission. This research indicates that vibration characteristic can be using as a reference in determining the appropriate connection tool to be used on wood material based on the fiber direction.

Keywords: Connection tools, excitation test, fiber direction, vibration characteristics

INTRODUCTION

The mechanical properties of wood are different in the three direction axes, because of this several researchers have carried out experiments using various methods to obtain better results. (Aira *et al*., 2014; Bucur and Rasolofosaon, 1998; Longo *et al*., 2012; Ismail *et al*., 2013; Moubayed *et al*., 2014). Dickinson and Di Blasio (1986) carried out a study on Flexural Vibration and Buckling on isotropic and orthotropic materials using the Rayleigh-Ritz method. Nakao *et al*. (1987) used the viscoelastic theory and Winandy (1994) carried out experiments according to the elasticity of the wood material; this could be obtained by using three elasticity modulus values E, three rigidity values G and six poison's ratio values μ. Three-dimensional nonlinear orthotropic Finite element material model for wood (Tabiei and Wu, 2000) is another method to find mechanical properties of wood. Ellingwood (1997) used the Load Resistance Factor Design (LRFD) method in the planning of timber constructions. Bos and Casagrande (2003) stated that the Rayleigh-Ritzs method was very useful in estimating the frequency resonance of orthotropic devices. Craik and Galbrun (2005) carried out research concerning vibration transmission in wooden connections. Study and measurement of wood (Roohnia *et al*., 2007; Wang *et al*., 2012; Mohd Akil Tan *et al*., 2011) showed that the vibration technique could be used to determine the properties of wood and the result is valid.

This study wishes to discuss the influence of fiber direction and connecting tools on the vibration transmission characteristic specifically of Gofasa wood (vitex cofassus) as a material that is using in ship building, connected using sloped notches. The connecting tools used were bolts, nails and pegs.

MATERIALS AND METHODS

Test model of specimens: The test model used the standard ASTM (Fig. 1). The section of the model has a sloped notch where bolts, nails and pegs were the

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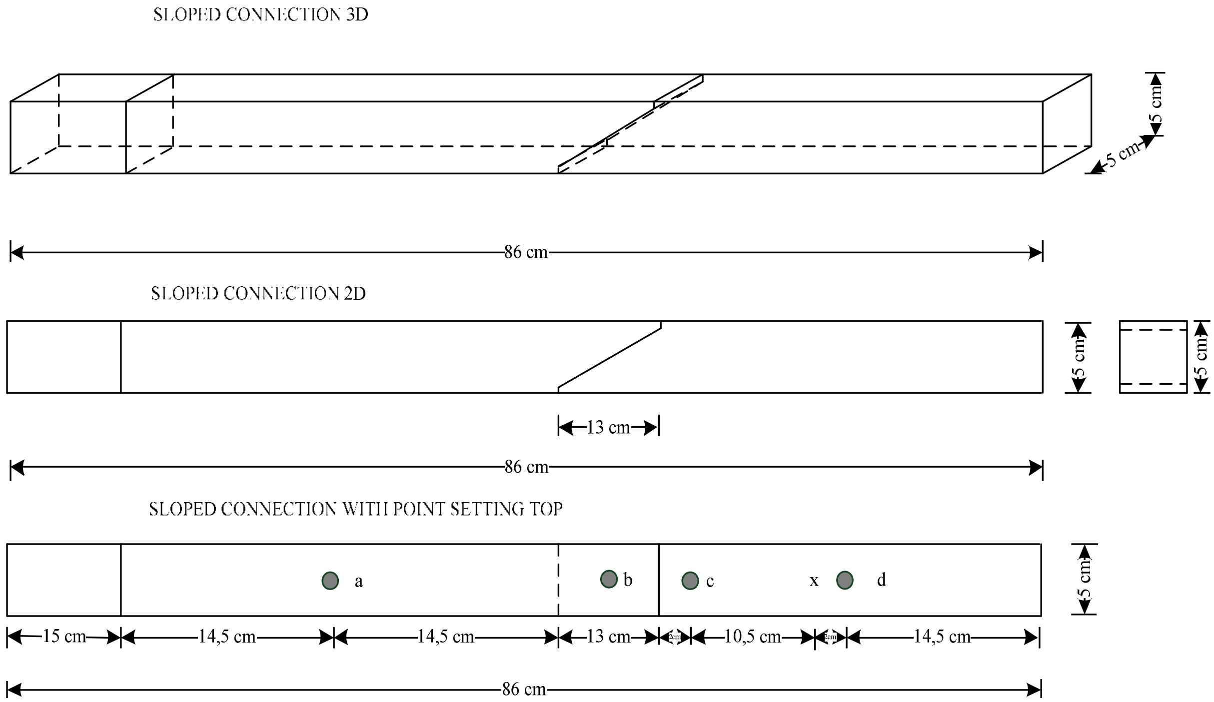


Fig. 1: Dimensions of the test material

connecting tools used with a variation of the connections depending on the fiber direction of the wood Radial-Radial (RR); Tangential-Tangential (TT) and Radial-Tangential (RT).

Specifications of the material used in the tests: The bending test used the three point loading method which was carried out to obtain the elasticity of the material in the radial and tangential directions. The elasticity modulus value obtained for the radial fiber direction was E_R 12411,231 Mpa; σ_R 90,611 Mpa and the tangential grain direction was E_T 12599,690 Mpa; σ_T 89,950 Mpa. The Gofasa wood (*vitex cofassus*) had a density of 1,04 g/cm^3. The connection model used was based on the identification of the type of connecting model that is most use in building traditional wooden ships.

The setting of the excitation test: Model chosen was the sloped notch design. The excitation tests of nine specimens were the test for transmissibility and two samples without connections in the radial R and tangential T direction.

These tests were carried out to determine the vibration characteristics of each specimen according to its fiber direction observed with each of the different connecting tools in this case bolts, nails and pegs. Four measurement points were set. Figure 1 was show the setting of the measurement points. Each test was carried out 8-10 times at each measurement point so that the six best points could be taken. Characteristics of materials can be using vibration technique (Mohd Akil Tan *et al*., 2011). Excitation test using the hammer impact test (Fig. 2). Mathematical analysis program is using to transform the results of the excitation test. The test using the cantilever beam vibration technique (Wang *et al*., 2012).

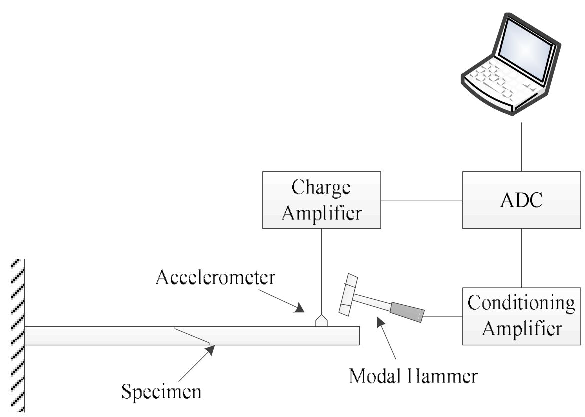


Fig. 2: Setting and excitation test

RESULTS AND DISCUSSION

The improvement of wood connections has an influence on the stiffness of the binding system because of its mechanical properties. The vibration of the main engine in wooden ships can be reduced by using absorbers from the rubber on the part of the foundation (Lekatompessy *et al*., 2013). Lin *et al*. (2009), have carried out research or study concerning vibration and vibration control of ship structures that are 30 m in length. It shows that the flow of the energy from the engine vibrations to the ship structure could be control with modifying the stiffness of the support structure. Some research on bolt as a connecting tool has been done with different methods such as researchers following: Analysis tool uses Elasto-plastic bolt modeling (Kharouf *et al*., 2003); Analysis of bolted wood connections using other method is non-linear material models (Oudjene and Khelifa, 2009); Prediction of the load carrying capacity of bolted timber

Table 1: Vibration parameter of fiber direction RR, TT and RT using bolts as the connecting tool

Number wood	Point	F_0 (N)	Peak ω_0 (Hz)	a (m/N)	k (N/m)	2ξ	ξ	FT (N)	TR
1	a	8.008	47	4.129E-10	2.422E+09	0.030	0.015	7.765	0.970
	b	9.597	47	1.067E-09	9.371E+08	0.025	0.013	9.355	0.975
	c	8.615	47	2.001E-09	4.998E+08	0.025	0.013	8.396	0.975
	d	9.019	47	2.365E-09	4.229E+08	0.042	0.021	8.636	0.958
2	a	7.895	46	1.081E-09	9.251E+08	0.028	0.014	7.671	0.972
	b	9.606	45	3.674E-09	2.722E+08	0.042	0.021	9.207	0.958
	c	9.919	45	5.748E-09	1.740E+08	0.039	0.019	9.536	0.961
	d	8.503	45	9.239E-09	1.082E+08	0.034	0.017	8.215	0.966
3	a	7.609	52	1.300E-09	7.695E+08	0.020	0.010	7.457	0.980
	b	9.560	52	4.466E-09	2.239E+08	0.018	0.009	9.388	0.982
	c	9.372	52	6.826E-09	1.465E+08	0.018	0.009	9.203	0.982
	d	8.566	52	1.039E-08	9.628E+07	0.018	0.009	8.409	0.982

Table 2: Vibration parameter of fiber direction RR, TT and RT using nails as the connecting tool

Number wood	Point	F_0 (N)	Peak ω_0 (Hz)	a (m/N)	k (N/m)	2ξ	ξ	FT (N)	TR
4	a	7.273	47	2.305E-09	4.338E+08	0.018	0.009	7.143	0.982
	b	8.786	47	9.158E-09	1.092E+08	0.018	0.009	8.631	0.982
	c	9.279	47	1.317E-08	7.590E+07	0.018	0.009	9.115	0.982
	d	9.930	47	2.033E-08	4.920E+07	0.018	0.009	9.754	0.982
5	a	7.147	50	1.432E-09	6.985E+08	0.020	0.010	7.007	0.980
	b	8.243	49	5.752E-09	1.738E+08	0.036	0.018	7.947	0.964
	c	8.761	49	9.393E-09	1.065E+08	0.031	0.015	8.490	0.969
	d	8.779	49	1.544E-08	6.478E+07	0.025	0.012	8.563	0.975
6	a	6.593	48	1.986E-09	5.034E+08	0.019	0.009	6.470	0.981
	b	7.556	48	8.449E-09	1.184E+08	0.018	0.009	7.420	0.982
	c	8.024	48	1.240E-08	8.063E+07	0.018	0.009	7.879	0.982
	d	7.652	48	1.902E-08	5.257E+07	0.018	0.009	7.512	0.982

Table 3: Vibration parameter of fiber direction RR, TT and RT using pegs as the connecting tool

Number wood	Point	F_0 (N)	Peak ω_0 (Hz)	a (m/N)	k (N/m)	2ξ	ξ	FT (N)	TR
7	a	6.582	56	2.356E-09	4.244E+08	0.015	0.007	6.486	0.985
	b	8.733	56	8.448E-09	1.184E+08	0.015	0.008	8.601	0.985
	c	8.996	56	1.161E-08	8.613E+07	0.016	0.008	8.855	0.984
	d	8.274	56	1.646E-08	6.076E+07	0.016	0.008	8.140	0.984
8	a	6.760	48	2.075E-09	4.819E+08	0.020	0.010	6.626	0.980
	b	9.487	48	6.471E-09	1.545E+08	0.018	0.009	9.315	0.982
	c	9.354	48	1.022E-08	9.787E+07	0.018	0.009	9.184	0.982
	d	9.644	48	1.541E-08	6.491E+07	0.019	0.010	9.459	0.981
9	a	7.340	51	1.337E-09	7.481E+08	0.022	0.011	7.178	0.978
	b	8.925	51	4.948E-09	2.021E+08	0.028	0.014	8.675	0.972
	c	9.305	51	6.661E-09	1.501E+08	0.032	0.016	9.011	0.968
	d	8.339	51	9.568E-09	1.045E+08	0.034	0.017	8.056	0.966

Table 4: Vibration parameter for wood without a connection

Number wood	Point	F_0 (N)	Peak ω_0 (Hz)	a (m/N)	k (N/m)	2ξ	ξ	FT (N)	TR
R	a	6.024	57	2.698E-09	3.706E+08	0.025	0.012	5.876	0.975
	b	9.407	57	9.254E-09	1.081E+08	0.020	0.010	9.224	0.980
	c	8.184	57	1.272E-08	7.864E+07	0.019	0.009	8.029	0.981
	d	8.715	57	1.743E-08	5.738E+07	0.019	0.010	8.548	0.981
T	a	8.519	56	1.386E-09	7.217E+08	0.021	0.011	8.339	0.979
	b	10.546	56	6.442E-09	1.552E+08	0.019	0.010	10.344	0.981
	c	9.619	56	1.110E-08	9.005E+07	0.020	0.010	9.430	0.980
	d	8.623	56	1.623E-08	6.161E+07	0.020	0.010	8.450	0.980

joints (Daudeville *et al*., 1999); and using multiply-bolted joints under lateral force perpendicular to wood grain (Yasumura and Daudeville, 2000). This research mainly observed the stiffness of the material as a result of the difference in the fiber direction and the connecting tools used. The parameter value that used is taking from the data obtained from the results of the excitation test. The data is sorting according to the analytic needs. This study proves the influence of the wood fiber direction and tools continued used to the characteristics of vibration that occurs in the system. Yasumura and Daudeville (2000) has studied use multiply-bolted joints under lateral force perpendicular to wood grain while in the tangential direction of the fibers of this study was also reviewed and continued tool used not only screws but also nails and pegs. The results compared with the vibration characteristics of wood materials without the connection to obtain valid results. Table 1 to 4 shows the result.

Analysis of the fiber direction using a bolt as the connecting tool: The data for the graph was take from the lowest frequency or the first modus ω_0 (axis x) and the amplitude value (axis y). For the wooden specimens 1, 2 and 3 at the measurement point a the ω_0 values can be seen in Fig. 3a. The strength of the force at point a can be seen in Fig. 3b while the Inertance value can be seen in Fig. 3c. Other data from measurement point b through to d were recorded and collated in the same manner and was viewing in Table 1. This research using Experimental Modal Analysis (EMA) (Schwarz and Richardson, 1999) to find vibration characteristics. The value of the stiffness of the material in the EMA was obtaining from the Inertance value (H) where the stiffness was calculating as follows:

$$k = \frac{1}{H}\ m/s^2 \quad (1)$$

Transmission force F_T can be calculated by using the following equation:

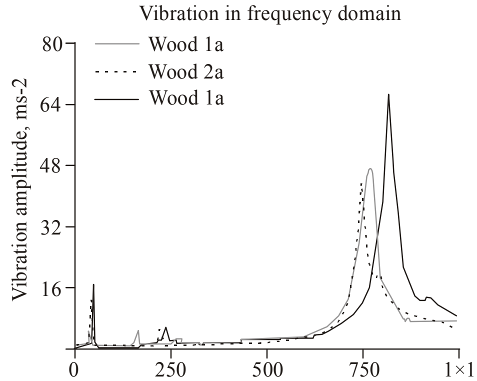
$$F_T = kA\sqrt{1 + \left(2\xi\frac{\omega}{\omega_0}\right)^2} \quad (2)$$

Whereas the transmission ratio value (TR) is the ratio of the transmission force value (F_T) to the amplitude excitation force (F_0), that is:

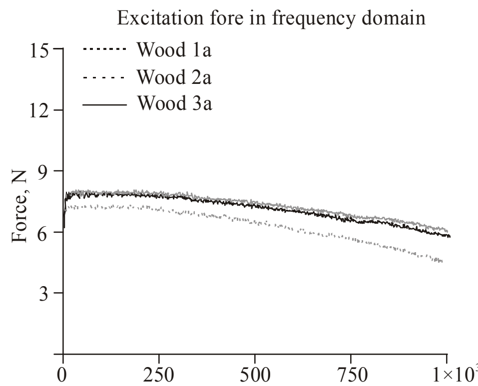
$$TR = \frac{F_T}{F_0} \quad (3)$$

Transfer Function (H) in the form of compliance a natural frequency is a ratio between the response (A) towards the excitation force (F), as follows:

$$a = \frac{A}{F}\ (m/N) \quad (4)$$



(a)



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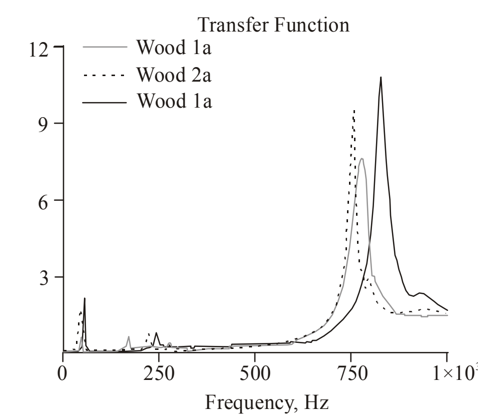


(c)

Fig. 3: Graph of the excitation tests on wood 1, 2 and 3 at measurement point a; (a): Graph of vibration in the frequency domain; (b): Graph of excitation in frequency domain; (c): Graph of transfer function

Whereas the damping ratio ξ is obtained with the half-power bandwidth method (Fig. 4):

$$\eta = \frac{\omega_2 - \omega_1}{\omega_0} = 2\xi \quad (5)$$

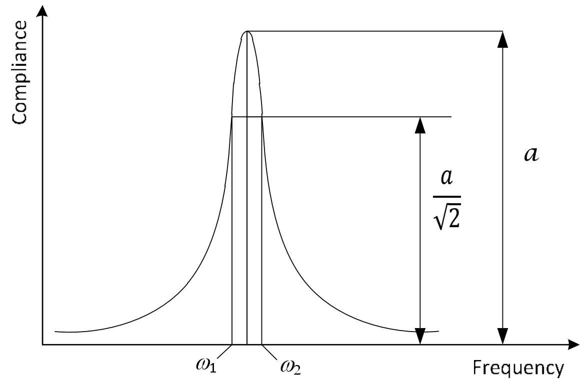


Fig. 4: Half power bandwidth method (Suhardjono *et al*., 2008)

Dynamic stiffness k is obtained from the ratio of the excitation Force (F) that is given to the response (A) which occurs or the inverse of compliance, as follows:

$$k = \frac{F}{A}\ (N/m) \tag{6}$$

Wood with a connection according to the RR fiber direction has the highest dynamic stiffness value k (Fig. 5a) when a bolt is used as a connecting tool, it is even greater at all measurement points than the dynamic stiffness of wood that has no connections at all.

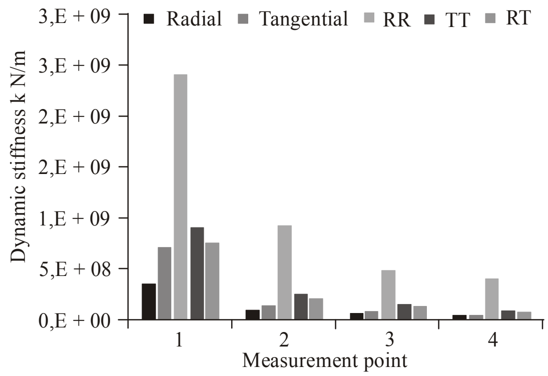
This result demonstrates that it is good to use a bolt as connecting tools to improve the stiffness of the connection with the RR fiber direction of the wood.

The transmission capacity is highest in the wood with the RT fiber direction but TR <1, this can be seen in Fig. 5b.

The natural frequency ω_0 is highest in the wood with the RT fiber direction (Fig. 5c). A change in the fiber direction has a significant influence on the natural frequency value of the connection, but it is still less that the ω_0 value of wood that has no joints. The research that has been done before by some researchers of the bolt connection states that the value of stiffness is affected through connection used (Daudeville *et al*., 1999; Yasumura and Daudeville, 2000; Kharouf *et al*., 2003; Oudjene and Khelifa, 2009). This study reinforces the results of the research before and complementing what has not been done in which not only the bolts used but also the nail and peg.

Analysis of fiber direction using a nail as the connecting tool: Figure 6 has shown the results of the excitation tests on wood 4, 5 and 6 at the measurement point a using a nail as the fastening devices. Table 2 shown the complete data.

The use of different connecting tools influenced dynamic stiffness of material k where the highest value was in TT fiber direction (Fig. 7a) although the k value did not exceed that of wood without a connection.



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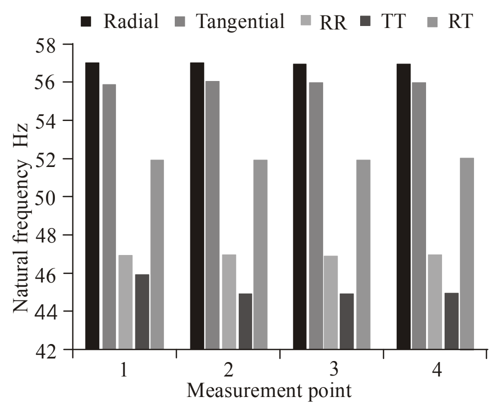

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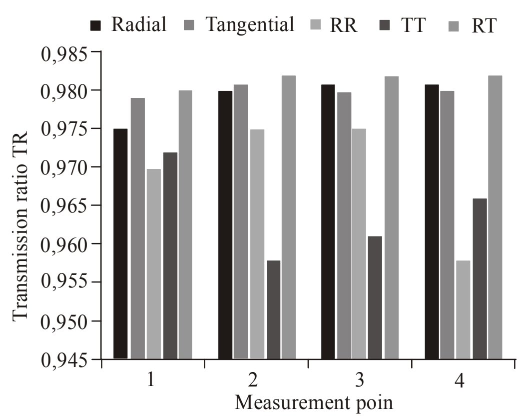


(c)

Fig. 5: Vibration characteristic of wood using bolts connection with various fiber direction; (a): Dynamic stiffness; (b): Natural frequency; (c): Transmission ratio

The transmission ratio TR was highest when using RR fiber direction (Fig. 7b) but the value TR<1. The natural frequency ω_0 connection using TT direction (Fig. 7c) had the highest value compared to the other fiber direction, but the difference in the amount was

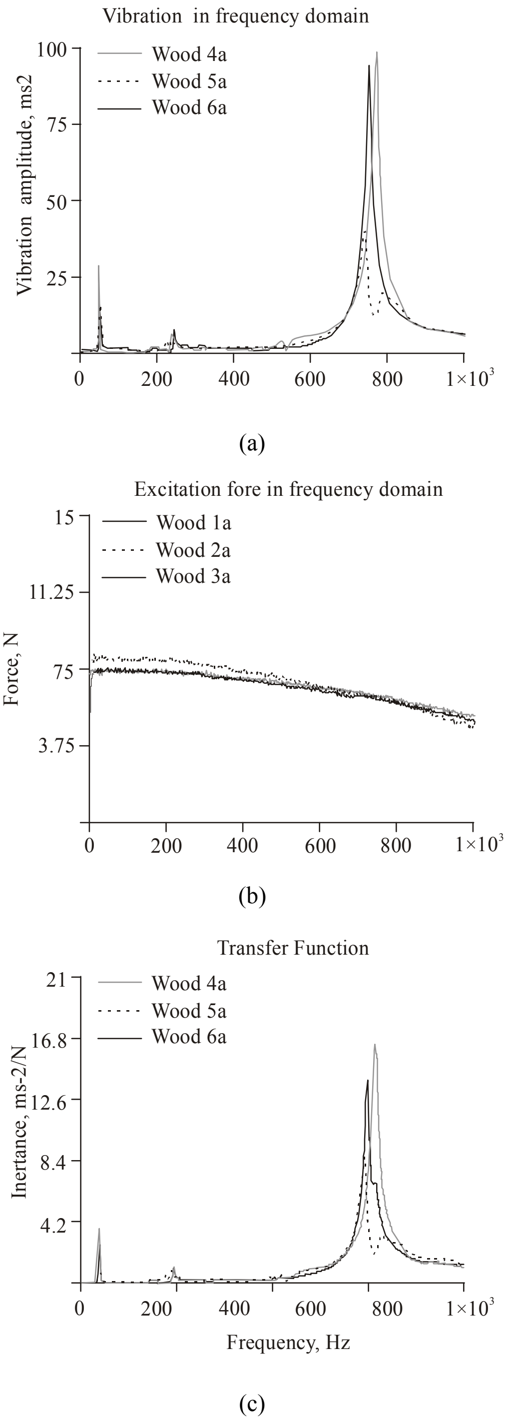


Fig. 6: Graph of the excitation tests on wood 4, 5 and 6 at the measurement point a; (a): Graph of vibration in the frequency domain; (b): Graph of the excitation in the frequency domain; (c): Graph of the transfer function

quite significant compared to wood without a connection. There has been no specific research on nail as the grafting tool on wood materials.

Analysis of fiber direction using a peg as a connecting device: Figure 8 shown the results of the

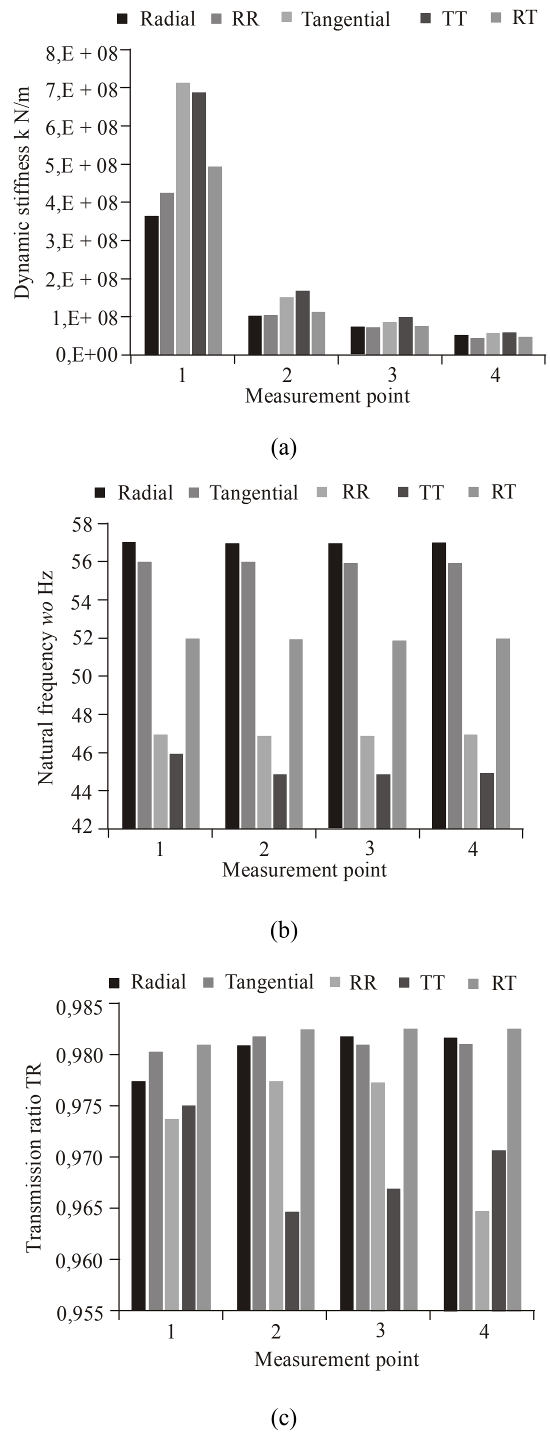
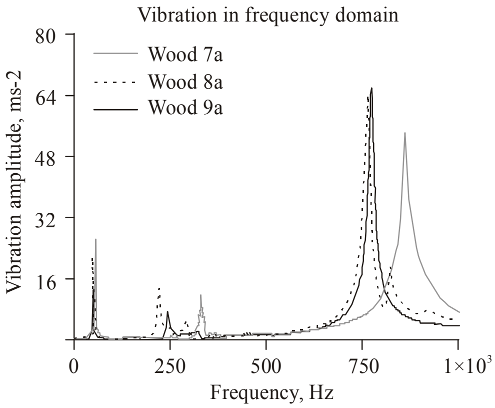


Fig. 7: Vibration characteristic of wood using nails connection with various fiber direction; (a): Dynamic stiffness; (b): Natural frequency; (c): Transmission ratio

excitation tests on wood 7, 8 and 9 at the measuring point a using a nail as a fastening tool. Table 3 shown the complete data.

It's good to use the peg connecting tool in RT fiber direction because it has the highest dynamic stiffness



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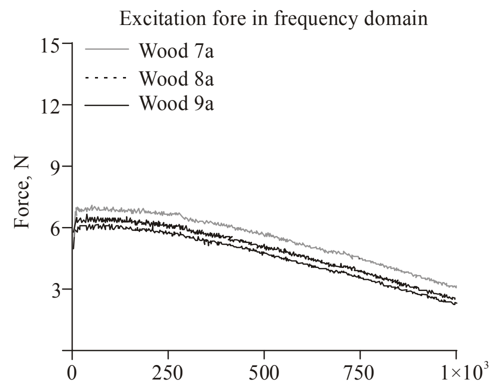

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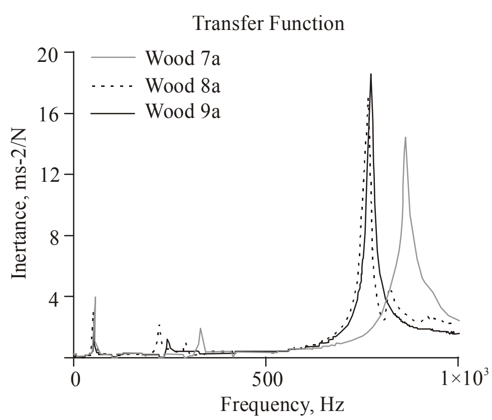
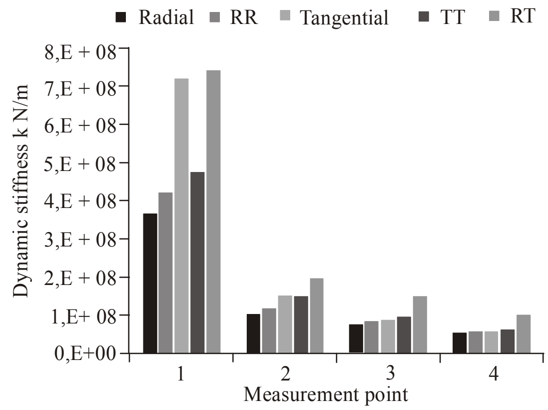
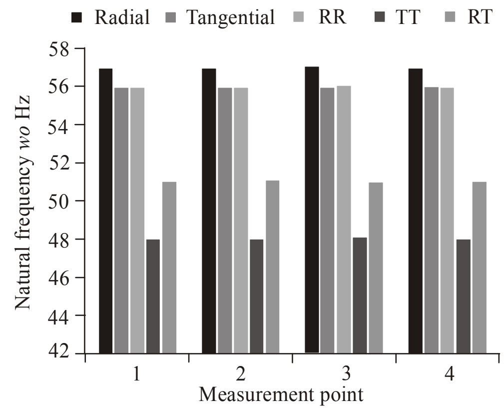


(c)

Fig. 8: Graph of excitation test on wood 7, 8 and 9 at measurement point a; (a): Graph of vibration in the frequency domain; (b): Graph of excitation in the frequency domain; (c): Graph of transfer function



(a)



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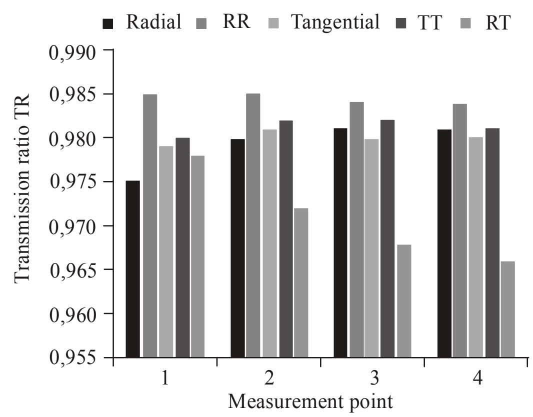

(c)

Fig. 9: Vibration characteristic of wood using pegs connection with various fiber direction; (a): Dynamic stiffness; (b): Natural frequency; (c): Transmission ratio

(Fig. 9a). Otherwise, TR has the smallest stiffness value (Fig. 9b). The use of a peg influences the w0 value (Fig. 9c) where the highest score was found in the RR fiber direction connection which had the same ω_0 value as tangential grain direction of wood without a connection. The joint with TT and RT fiber direction are significantly different from wood without a connection. There has been no specific research on the peg as the grafting tool on wood materials.

Analysis of fiber direction without connections: As a reference, the test results with the wood material connection, compared to wood without the connection.

This analysis is done to see changes in vibration characteristics.

CONCLUSION

This research proves that the use of different fiber direction and connect tools has a significant influence on the vibration parameter values those being the dynamic stiffness value k, natural frequency ω_0, transmission ratio TR and damping ratio ξ. The vibration characteristics can be used as a reference in deciding which connecting tools are suitable for connecting two pieces of wood based on the fiber direction and model available. This research has only tested the sloped notch connection model. It would be nice if this research could be continued to consider other connection types.

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