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Comparison of Modulus of Elasticity of Green Timber Using Static and Dynamic Testing

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ABSTRACT

Overseas, timbers are graded using machine stress grading where timbers are assigned to strength categories, which are established through empirical relationships between stress wave velocity (called non-destructive method (NDT)) and strength. However in Malaysia, the timbers are still graded based on visual inspection. This is due to the absence of data collected through non-destructive method. Longitudinal stress waves have great potential to be implemented as a quality control tool but more research is needed to enhance its application. This research project is to evaluate and compare the modulus of elasticity (MOE) in Malaysian Tropical timbers with moisture content in a range above 19% by using static and dynamic testing. From this study, it shows that the MOE static has no significant difference compared to the MOE value published in MS 544 even though the size of sample specimen is different. This result on tropical timber can be enhanced in future and has the probability to be a useful method in determining the MOE of timber since many published work on overseas timber has proved it. However, the use of ultrasonic pulse velocity (UPV) method for timber hardwood in Malaysia is still new and limited.

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INTRODUCTION

Overseas, timbers are graded using machine stress grading where timbers are assigned to strength categories, which are established through empirical relationships between stress wave velocity (called non-destructive method (NDT)) and strength. However in Malaysia, the timbers are still graded based on visual inspection. This is due to the absence of data collected through non-destructive method. Longitudinal stress waves have great potential to be implemented as a quality control tool but more research is needed to enhance its application. NDT techniques for timber differ greatly from those for homogeneous, isotropic materials such as metals, plastics, and ceramics. In such non-wood-based materials, whose mechanical properties are known and tightly controlled by manufacturing processes, NDT techniques are used only to detect the presence of discontinuities, voids, or inclusions. However, in timber, these irregularities occur naturally and may be further induced by degradative agents in the environment. The other factors that influence the propagation of ultrasonic waves in timber are physical properties of the substrate, geometrical characteristics of the species (macro and microstructures), conditions of the medium (temperature, humidity) and the procedure utilized to take the measurements (Kabir *et al*. 2012). Moisture is one of the many important variables that affect the magnitude of the stress-wave properties. Physical properties of timber such as electric conductivity, mechanical strength and elasticity are strongly dependent on the amount of water included (Simpson and Wang, 2010). For calculation of dynamic modulus of elasticity (DMOE) in green wood it is fundamental to consider the variation patterns of acoustic velocity with changes in moisture content above the fibre saturation point (FSP) and the variation patterns of green density.

A number of authors have observed the need for adjusting the DMOE calculated for wood above the FSP. Gerhards (1975) concluded that the variation in DMOE above FSP was driven mainly by moisture content and that DMOE should be corrected for moisture contents beyond 50%. Ross and Pellerin (1991) reanalyzing the data of Gerhards concluded that the sharp increase in DMOE above the FSP was

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related to changes in density. According to the results of Gerhards (1975) and his own work, Sobue (1993) concluded that above the FSP, DMOE increases as a result of the increased density as moisture content increases.

Moreover, with the relationship established between green and dry timbers may reduce the destructive test wastage in the future and helps site engineers to determine their timber grade by using in-situ NDT test. The grading of wood is usually done only after drying is completed. By doing this more energy are required. Significant savings can be achieved if the wood can be graded in the green state to predict the stiffness and strength properties after drying, and wood with inferior properties is discarded prior to drying. To enable the prediction of stiffness and strength properties in the dry state using wood in green state without damaging the wood, non-destructive method is a possible solution. The main objective of this study is to determine the static modulus of elasticity (MOE) and dynamic modulus of elasticity (DMOE) of Malaysian tropical green timbers with MC > 19%. This study also aims to compare and correlate the value of MOE and DMOE of green Malaysian tropical timber, as well as to analyse the correlation between MOEstatic and DMOE with moisture content. For this study, three (3) timber species were chosen and the information of the timbers is explained as following;

Kapur:

Kapur or its scientific name; Dryobalanopsaromatica is a very tall tree exceeding a height of 60 m and girth of 9 m. It also has yellowish-brown and well defined sapwood. It has moderately coarse and even texture. It also has straight or interlocked grain. (Gan *et al*., 1999). Figure 1 shows the appearance of Kapur on planed surface.

Fig. 1: Appearance of Kapur on planed surface (Gan *et al*., 1999).

Pauh Kijang:

Pauh Kijang in Figure 2 also known as Irvingiamalayana Oliv. Grow medium to large tree reaching 40 m tall and 300 cm girth. Timber for this type of species very hard and heavy. The colour of its heartwood is dark greenish-brown, sometimes with a dark grey-brown striped core whereas its sapwood paler and not well defined. (Gan *et al*., 2001).

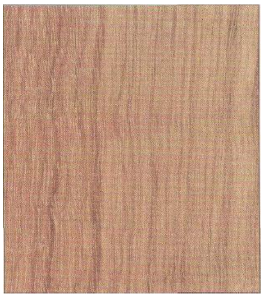

Fig. 2: Appearance of PauhKijang on planed surface (Gan *et al*., 2001).

Keruing:

Figure 3 shows appearance of Keruing where its scientific name is Dipterocarpus species. The colour of its heartwood is red-brown or purple-red-brown and distinct from the sapwood which is grey-brown. Texture of this timber is moderately coarse to coarse and even. (Choo *et al*., 2001).

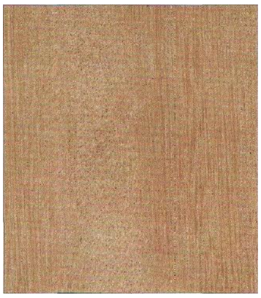

Fig. 3: Appearance of Keruing on planed surface (Choo *et al*., 2001).

Non- Destructive Test (NDT):

Overseas, timbers are graded using machine stress grading where timbers are assigned to strength categories, which are established through empirical relationships between stress wave velocity (called non-destructive method (NDT)) and strength. However in Malaysia, the timbers are still graded based on visual inspection. This is due to the absence of data collected through non-destructive method. Cheng and Hau (2003) studied on prediction of modulus of elasticity of Fibre Reinforced Polymer (FRP) reinforced-fast growing poplar glulam. The MOE of FRP is assessed through longitudinal vibration as dynamic testing and static bending test. Generally result from dynamic testing is higher than from static testing. Ross and Pellerin (1994) reviewed on several non-destructive method used for assessing wood members in structures. The study recommends that future NDT research should focus on stress wave techniques.

Niemz and Mannes (2012) reviewed on the non-destructive testing that can be used in wood and wood based materials based on their aims. Several methods can be done, for example to assess the strength of the timber the appropriate technique is by ultrasound. However, Ross and Pellerin (1994) also stated that it is difficult to assess the properties of timber using non-destructive technique as timber is differ from the homogenous and isotropic material. Being a natural material, the strength and stiffness properties of timber are varies among species and eventhough from the same trees. The strength characteristics of a piece of timber should be evaluated by non-destructive methods. It can be done through visual grading or mechanical grading or by combination of such methods (Firmanti *et al*., 2005).

Ultrasonic testing consists of the propagation of low amplitude waves through material to measure either or both the time of travel and any change of intensity of a given distance. NDT techniques for timber differ greatly from those for homogeneous, isotropic materials such as metals, plastics, and ceramics. Wood properties such as moisture content has a great effect in the ultrasonic pulse velocity compared to specific gravity cross section of the specimen (Calegari *et al*., 2011). Other than moisture content, density of the timber also affects the velocity of ultrasonic (Mishiro, 1996). He also reported that ultrasonic velocity in the tangential and radial directions increased with increased density.

Experimental works:

Three species of Malaysian tropical timbers in category of standard and better grade, heavy, medium and light Hardwood were used in this research. They were chosen based on the availability of Malaysian timber in the market.

Table 1: Test Requirements for the Structural Size Specimens.

Species	Sample Size (mm)	Amount	Strength Group	Density (kg / m^3)
Pauh Kijang	50 x 90 x1800	15	3	930- 1250
Kapur	50 x 90 x1800	15	4	575-815
Keruing	50 x 90 x1800	15	5	690 - 945
	Total	45		

To maintain the moisture content of timber, a conditioning process in a programmable chamber with 20°C and 90% relative humidity was done for 2 weeks. After conditioning process, the reading of moisture content, weight at desired moisture was taken and the ultrasonic velocity measurement also done after conditioning process. After undergone this process, timber were assumed in green state based on their moisture content (>19%). The density can be calculated from the Eq. 1.

Density = Mass/Volume , in (kg/m^3) Eq. 1

The Portable Non-Destructive Digital Indicating Tester (PUNDIT) UPV-E49 was used, with cylinder-shaped transducers as seen in Figure 4. Two piezoelectric transducers were placed in two opposite faces, as transmitter and receiver of 54 kH$_z$.

Fig. 4: Test equipment of UPV-E49 for NDT.

For prismatic, homogenous and isotropic elements and for those with section width smaller than the stress wavelength, the relation:

$E = \rho . v^2$, MPa Eq. 2

E represents the dynamic modulus of elasticity (N/mm²); v is the propagation velocity of the longitudinal stress waves (m/s) and ρ is the density of the specimens (kg/m³).

All timber beams were tested under four-point loading the test apparatus including roller supports was set up according to ASTM D-198 as shown in Figure 5.

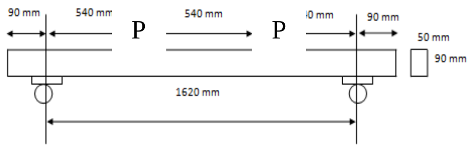

Fig. 5: Static Bending Test Setup.

Figure 6 (a) shows four linear variable differential transducers (LVDT) attached vertically to the timber beam were connected to the data logger to receive and record the deflection occurs during testing. Figure 6 (b) shows the data logger used to receive and record reading during testing. The testing been done using 250kN Universal Testing Machine (UTM). The physical measurements and moisture content for each specimen had been taken and recorded before testing while mode of failure were observed and recorded during the testing. MOE will be calculated according to Eq.3.

Modulus of Elasticity, MOE

$$MOE = \frac{23PL^3}{108bh^3\Delta}, MPa \qquad \text{Eq. 3}$$

where,

b= Width of the specimen (mm)
h= Depth of the specimen (mm)
P= Load at the proportional limit (N)
Δ= Deflection at the proportional limit (N)

L = Length of the span (mm)
a = Half shear span (mm)

Specimens for determining moisture content were prepared with specimen dimension of 25 mm thick, 50 mm wide and 90 mm long. The calculation of the moisture content is in accordance to Malaysian Standard, MS 544:2001, as shown in Eq. 4

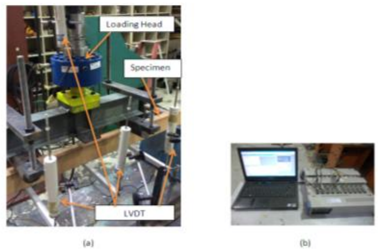

Fig. 6: (a) Static Bending Test Setup for Structural Specimen (b) Data Logger.

$$mc = (m_i - m_{od})/m_{od} \quad \times 100\% \qquad \text{Eq. 4}$$

Where;
m_i = initial mass, in grams, of the test specimens
m_{od}= mass, in grams, of oven-dry test specimens

The specimen were weighed as soon as it is cut by using weigh scale. After that it will be cleaned by a brush to remove the dust or residue that may affect the weight of the specimen and record the weight before place the specimens in an oven where temperature was maintained at 105±2 °C.

RESULTS AND DISCUSSIONS

Relationship of Moisture Content and Density of Timber:

Table 2 shows the moisture content and density of the timber tested. It can be seen that the moisture content of the timber does not follow the trend of the density although the timbers are having the same preconditioning. This may due to characteristic of the wood. Keruing has the lowest density value in conjunction to their strength group respectively.

Table 2: Average Moisture Content, Density and Strength Group of Green Timbers.

Species	Strength Group (SG)	Moisture Content (%)	Density (kg/m^3)
Keruing	SG5	24.15	733.83
Kapur	SG4	21.87	780.82
Pauh Kijang	SG3	27.32	1072.1

Bending Strength Properties of Timber Beam:

Figure 7 shows the general behavior of the load versus displacement graph from bending test for all timber species. The graph shows that the timbers have brittle behavior as the timber failed right after reached maximum load except for Kapur which indicates that the timbers are brittle materials. This finding is also similar to the finding found by Ahmad *et al*, (2012). The peak values and the length of displacement vary for each species. The graph also shows that Kapur has the steepest slope followed by Pauh and Keruing. This shows that Kapur is stiffer followed by Pauh Kijang and Keruing.

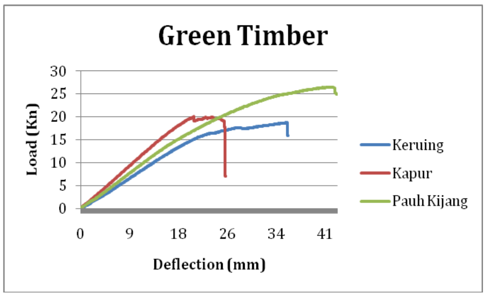

Fig. 7: Load versus Deflection of Green Timber.

Table 3: Bending Strength Properties of Green Timber.

	MOE (GPa)			MOE (MS 544)
Species	Mean (GPa)	S.D	COV (%)	Mean (GPa)
Keruing	9.742	1.211	12.43	10.2
Kapur	12.3	3.142	25.54	13.2
Pauhkijang	16.28	2.597	15.95	17.2

Table 3 shows the bending strength properties resulted from the experimental work conducted between the species for green timber.

In general, there is no significant difference in the MOE values found in this study and the value published in MS 544 Part 2 which indicate the consistency of the method and test samples . The MOE value of timber increases as the density increases. It was also found that the coefficient of variance (COV) of MOE and MOR of all timber species is within 12 to 25 percent which are considered acceptable for timbers (Anon, 1990; Ahmad *et al*, 2012).

Figure 8 shows the failure modes of bending specimens. From the overall observations, all the timber species have same modes of failure which are failed at the tension zone.

Effect of Moisture Content on the Modulus of Elasticity (MOEstatic):

From Table 2, the moisture contents for timbers in this study are clearly shows the timbers are in wet condition . Figure 9 and Figure 10 show the relationship between MOEstatic and DMOE green timbers with moisture content respectively.

Fig. 8: Mode of failure on bending.

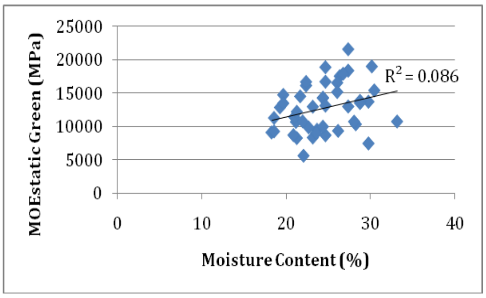

Fig. 9: MOEstatic Green Timber versus Moisture Content.

A correlation coefficient of zero reveals that no relationship exists between MOE and moisture content. A relatively poor relationship can be observed as the correlation between MOEstatic and DMOE with moisture content where r2 is only 0.086 and 0.188 respectively. Even though, there is no correlation between the MOEstatic and DMOE and moisture content for green timber, several aspects need to consider such as the density of the timber and variation in timber characteristic that may influence the DMOE of the timber hence effect the correlation.

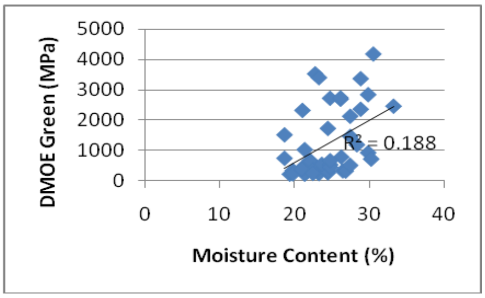

Fig. 10: DMOEstatic Green Timber versus Moisture Content.

From Table 4, it can be seen that the MOEstatic increases with increment of density respectively. The order of MOEstatic are PauhKijang>Kapur>Keruing. Oliveira and Sales (2006) states that density also has the effects on the modulus of elasticity as the density increase, the modulus of elasticity also will increase. Based on Table 5, there is no general trend in the DMOE value with density or moisture content. Kapur has lowest DMOE even though the density is higher than the density of Keruing. This shown that there is other factor that effect the reading of NDT.

Table 4: Static Modulus of Elasticity, Moisture Content and Density of all Timber Species.

	MOE (GPa)			
Species	Mean (GPa)	S.D	Moisture Content (%)	Density (kg/m^3)
Keruing	9.74	1.21	24.15	733.83
Kapur	12.3	3.14	21.87	780.82
PauhKijang	16.28	2.60	27.32	1072.1

Table 5: Dynamic Modulus of elasticity, Moisture Content and Density of all Timber Species.

	DMOE (GPa)			
Species	Mean (GPa)	S.D	Moisture Content (%)	Density (kg/m^3)
Keruing	2.67	3.96	24.15	733.83
Kapur	0.65	0.86	21.87	780.82
PauhKijang	1.68	1.29	27.32	1072.1

Relationship between DMOE (NDT) and MOEstatic (Static Bending):

From Table 6, it can be seen that the trend in the DMOE is different than the trend in MOEstatic.For DMOE, the order of DMOE is Keruing>PauhKijang>Kapur as compared to the order of MOEstatic where the order is PauhKijang>Kapur and Keruing. At this point of time it is quite difficult to explain the reason for this phenomenon as the testing specimens and conditions are the same. The possible reason to this situation is the sensitivity of the NDT equipment. From the analysis, it is also found that the coefficient of variance (COV) of all species for DMOE and MOE_{static} have large differences.

As for DMOE the coefficient of variance are within 77-148%. In contrast, the coefficient of variance of MOEstatic ranges from 10-26% which is within the acceptable range of coefficient of variance for solid timbers (Anon, 1990). The MOEstatic of Kapur is nineteen (19) times higher than the DMOE of. Yamasaki *et al*, (2014) states that it is velocity of wave propagation is strongly influenced by moisture content of the timber. Calegari *et al*, (2011) also states that moisture content has major influence in velocity of wave propagation while specific gravity has minor influence in velocity of wave propagation in timber. Several aspects need to be further study in order to get a relevant reading such as in terms of handling the equipment of UPV.

Table 6: Summary of DMOE and MOE_{static} of Structural Size Specimen from green Malaysian Tropical Timbers.

Species	Strength Grouping	DMOE			MOEstatic			Density (kg/m^3)
		DMOE (GPa)	S.D	COV (%)	Mean (GPa)	S.D	COV (%)	
Keruing	5	2.67	3.96	148	9.742	1.211	12.43	733.83
Kapur	4	0.647	0.86	132	12.3	3.142	25.5	780.82
Pauh Kijang	3	1.68	1.29	77	16.28	2.597	15.3	1072.1

Correlation between DMOE (NDT) and MOE (Static):

Figure 11 shows the relationship between DMOE versus MOEstatic, for individual species for green timber (before heat treatment).This reveals there is a modest correlation for PauhKijang (R=0.2). However there is no correlation has been found for Kapur whereas an insignificant correlation has been found for Keruing (R= 0.05). This can be seen from the R values which are very low, near to 0. Figure 12 shows the relationship between DMOE versus MOEstatic for all green timber. This reveals that there is no correlation can be made between MOEstatic and DMOE for green timber.

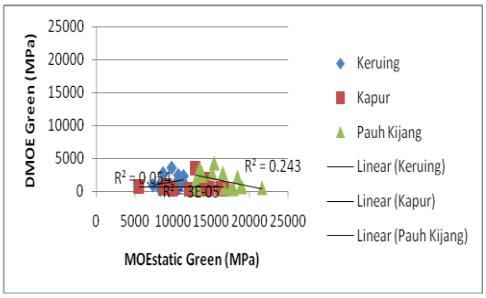

Fig. 11: DMOE versus MOEstatic, for Individual Species for Green Timber (Before Heat Treatment).

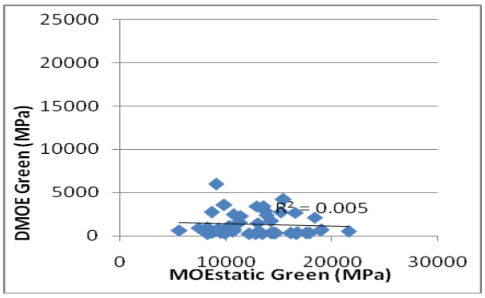

Fig. 12: DMOE versus MOEstatic, for all green timber specimens.

Conclusion:

The MOE_{static} has no significant difference compared to the MOE value published in MS 544 eventhough the size of sample specimen is different. However, the result for DMOE is poor as the value is very small compared to MS 544. This may due to the poor handling of the instrument used to determine the DMOE and the properties of timber itself that may influence the reading. This result on tropical timber can be enhanced in future and has the probability to be a useful method in determining the MOE of timber since many published work on overseas timber has proved it.

However, the use of ultrasonic pulse velocity (UPV) method for timber hardwood in Malaysia is still new and limited. There is no correlation can be made between MOEstatic and DMOE with moisture content. Even though, there is no correlation between the MOEstatic and DMOE with moisture content, several aspects need to consider such as the density of the timber and variation in timber characteristic that may influence the DMOE of the timber hence effect the correlation. Besides that, there is no correlation can be made between MOEstatic and DMOE of green Malaysian tropical timbers as r^2 value is too low and near to 0. In Malaysia, Non-Destructive Test (NDT) is widely used in concrete in order to determine the quality of the concrete. However, in case of using NDT in timber is still limited and is considered as new.

Therefore in order to get a relevant and excellent result, a thorough development of applicability of proper handling of tool and interpretation of sonic wave technique is a must. The responsible board such as Forest Research Institute Management (FRIM), Malaysia Timber Council (MTC) should develop a manual in using NDT as a measurement of strength properties of timber. This is because there is no proper manual specifying usage of NDT in timber in assessing timber strength properties. This is very important as through NDT a good estimation of the strength properties of Malaysian tropical timber can be developed without doing the static destructive test.

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REFERENCES

Ahmad, Z., H.P. San, F. Tahir, 2012. Flexural Strength of Laminated Veneer Lumber Made from Selected Tropical Hardwood. *Laminated Veneer*

Australian Journal of Basic and Applied Sciences, 9(24) Special 2015, Pages: 49-55

Lumber from Malaysian Tropical Timber. UiTM Press.

Anon., 1990. A Structural Timber Substitute Wood Based Panels. *Asia Pacific Forest Industries*, 50-53.

ASTM D198: 2009. *Standard Test Method for Static Test of Lumber in Structural Sizes* : Annual Book of ASTM Standard, 04. 10.

Calegari, L., D.A. Gatto, D.M. Stangerlin, 2011. Influence of Moisture Content, Specific Gravity and Specimen Geometry on the Ultrasonic Pulse Velocity in Eucalyptus Grandis Hill ex Maiden Wood. Brazilian Journal Wood Science, 64-74

Choo, K., S.C. Lim, K.S. Gan, 2001. Timber Notes-Medium Hardwoods II (Bekak, Derum, Keruing, Keruntum, Kulim). *Timber Technnology Bulletin*, 1-8.

Firmanti, A., E. Bachtiar, S. Surjokusumo, K. Komatsu, S. Kawai, 2005. Mechanical Stress Grading of Tropical Timbers without Regard to Species. *The Japan Wood Research Society*, 339-347.

Gan, K., T. Choo, S. Lim, 1999. Timber Notes - Medium Hardwoods I (Kapur, Kasai, Kelat, Keledang, Kempas). *Timber Technology Bulletin*, 1-8.

Gan, K., S. Lim, K. Choo, M. Jantan, 2001. Timber Notes - Medium Hardwoods IV (Merbatu, Merpauh, Mertas, Nyalin, Pauh Kijang). *Timber Technology Bulletin*, 1-8.

Gerhards, C., 1975. Stress wave speed and MOE of sweetgum ranging from 150 to 15 percent MC. *Forest Products Journal,25(4):* 51-57.

Hau, Y., 2003. *Malaysia Timber Council.* Throught Leadership Article: Retrieved from http://www.mtc.com.my

Kabir, M., D. Schmoldt, M. Schafer, 2012. Time domain ultrasonic signal characterization for defect in thin unsurfaced. *Wood and Fiber Science, 34(1):* 165-182.

Mishiro, A., 1996. Effect of Density on Ultrasonic Velocity in Wood. *Mokuzai Gakkaishi*, 887-894.

MS 544 Part 2: 2001. *Code of Practice for Structural Use of Timber*. Department of Standard. Malaysia. Department of Standard. Malaysia.

Niemz, P., D. Mannes, 2012. Non-destructive testing of wood and wood-based materials. *Journal of Cultural Heritage*, S26-S34.

Oliveira, F., A. Sales, 2006. Relationship between Density and Ultrasonic Velocity in Brazilian Tropical Woods. *Bioresource Technology,* 2443-2446.

Ross, R., R. Pellerin, 1991. NDE of green material with stress waves: preliminary results using dimensional lumber. *Forest Products Journal, 41(6):* 57-59.

Ross, R., R. Pellerin, 1994. *Nondestructive Testing for Assessing Wood Timber in Structures: A Review.* United States: Madison.

Simpson, W., 1999. Drying and Control of Moisture Content and Dimensional Changes. In *Wood Handbook- Wood as Engineering Material* (pp: 1-21). United States: Madison.

Sobue, N., 1993. Simulation Study on Stress Wave Velocity in Wood above Fiber Saturation Point. *Mokuzai Gakkaishi*, pp: 271-276.