Nondestructive Methods for Evaluating Mechanical Properties of Wood Electromagnetic Shielding Composite

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Abstract

Radiations from different electrical devices cause electromagnetic interference which will affect the performance of other electromagnetic devices and cause concerns to public health. The Aluminum plates used for electromagnetic shielding were laminated with thin plywood to prepare a new kind of wood-based composite. Two non-destructive testing (NDT) methods (Metriguard and Cantilever Beam Vibration) and a static bending testing method were used to evaluate the dynamic modulus of elasticity (DMOE) and static modulus of elasticity (MOE) of raw plywood and the composites. The results indicated that there were good relationships between DMOE and MOE of raw plywood and composites except for the composites which its surface was aluminum plates. The cantilever-beam vibration method was found to be the better way to predict MOE.

Introduction

The continuing increase in the use of electronic devices has led to directives and world wide technical standards for enforcing the reduction of electromagnetic (EM) environmental pollution (Gabriella, T, 2007; Tsai, H.C. 2007). EM shielding is the most effective method to prevent the electromagnetic radiation from passing through the blocking media (or shield). Up to now, the products for EM shielding are mainly metals which are porous, coating form, and composite materials which are a mixture of polymer and carbons (Chung D.D.L, 2000). Aluminum offers attractive properties for this application, such as low density, recyclability, corrosion resistance, durability, ductility, formability and high specific electrical conductivity. Aluminum has been widely used in the area of electromagnetic compatiable because of its high specific electrical conductivity. In this paper, a new kind of electromagnetic shielding wood composites was prepared with veneers and aluminum plates. The presence of aluminum layers could improve the strength of wood composites and the composites can be used as structural materials which have the function of EMS.

Nondestructive evaluation, by definition, is the science of identifying physical and mechanical properties of a piece of material without altering its final application capabilities (Ross et al., 1998), and such evaluations are achieved by nondestructive testing (NDT) techniques. Using nondestructive evaluation techniques to predict the material properties of wood is a very important procedure in wood industry. Great progress has been made on testing and evaluating the wood mechanic properties by NDT technology. NDT technology have been investigated extensively during the past few decades and have shown much promise for predicting the mechanical properties of wood. A variety of wood-based materials ranging from small, clear wood specimens to wood-based composites have been investigated. (Wang et al. 2001; Ross et al. 2005). However, no studies

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have been expended to investigate the use of these techniques to evaluate the wood-based composites laminated with metals. The primary objective of this study is to investigate the dynamic MOE of veneer and composites by two NDT methods, Metriguard, and Cantilever beam vibration. The findings of this study can provide scientific references for quickly testing the composite and selecting appropriate means of NDT.

Material and Methods

Material/Sample Preparation

Aluminum Plate (1 100) obtained from the MCMASTER-CARR company, ELMHURST, USA, was used as the conductive layer due to its superior electrical property. The thickness of the aluminum plate was 0.5 mm and 1 mm. The density was 2.7 g/cm^3 and its modulus of elasticity was 69 GPa. Isocyanate resin (MDI) was provided by HUNTSMAN, New Jersey and USA. The density of the MDI resin was 1.2 g/cm^3, its solid content was 100 %, and the boiling point was up 300 °C. Plywood with the dimension of *500* mm × 500 mm × 4.55 mm were provided by Homedepot Company (Wisconsin, USA).

Figure 1 shows the constructions of the composites by laminating plywood with the aluminum plates under hot-pressing for *25* seconds. The pressing temperature was 180 ℃ and the press pressure was 1MPa. The usage of MDI resin was 25 g/m^2 for each bonding line. It was noted that the plywood needed be pre-pressed in hot plate to eliminate the internal stress caused by different deformations during the hot-pressing. The moisture content of plywood was 4 %. The basic situation of the testing specimens was presented in **Table 1.** Fifteen replicated plywood specimens were cut from three plywood panels. Three wood electromagnetic shielding composite panels were prepared for each run and four replicated specimens were cut from each panel.

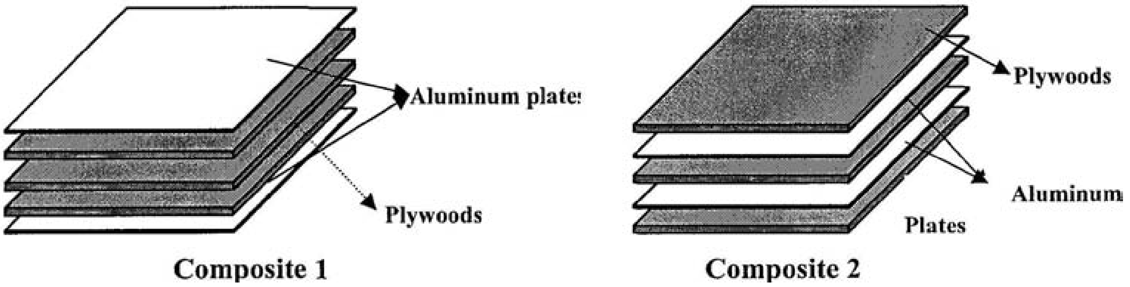

Figure 1. —*Construction of Wood Electromagnetic Shielding Composite*

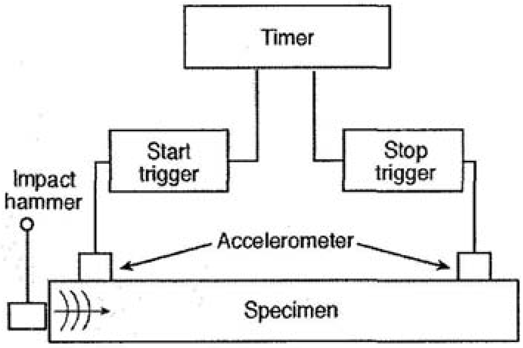

Figure 2. —*Technique used to measure impact-induced stress wave transmission time in woodproducts*

Table 1. - *The basic situation of the test specimens*

Type	Number	Density(g/m^3)	Length (mm)	Width (mm)	Thickness (mm)
Plywood (along the grain)	15	0.51	254.0	50.8	4.55
Plywood (Transverse the grain)	15	0.53	254.0	50.8	4.55
Composite 1,A+P+P+P+A	12	0.87	548.2	76.2	14.55
Composite 2,P+A+P+A+P	6	0.74	548.2	76.2	14.90

Note: *P represents the plywood and A represents Aluminum Plates.*

Testing methods of the dynamic modulus of elasticity

Metriguard

Metriguard, a stress wave timer, is developed on the basis of the relationship among propagation time of longitudinal stress wave, material density and MOE. The whole device is fixed at the highest level for the purpose of being unaffected by background vibration and maximizing sensitivity. The device measures the transit time of the stress wave generated by a ball hammer through the length of the sample what is used to calculate the wave velocity which is shown in **Figure 2.** The stress wave modulus is calculated by using the following Equation [1]:

$$DMOE_m = C^2 \rho / g \qquad [1]$$

Where:

DMOE$_m$ is the stress wave modulus of elasticity (GPa)

C is the velocity of stress wave (m/s)

ρ is the material density (kg/m^3)

g is the acceleration due to gravity (9.8 m/s^{-2}).

Cantilever-Beam vibration method (Turk, C *et al.* 2007)

The definition of a cantilever beam is one in which displacement and angular deflection at the supported end remains zero, whereas the other end is free to translate. **Figure 3** (Turk, C. 2008.) shows the device. The specimen is clamped to the slider through a plate-and-screw assembly. A torque wrench is used to apply a consistent force on one end of the specimen. On the other end of the specimen, an adjustable height laser-displacement measuring assembly is mounted perpendicular to the specimen to adjust the input signal from the laser, apply a pre-load or displacement to the end of the specimen, and serve as a mount for the triggering mechanism. The laser measures displacement of the beam tip as a function of time and calculate the frequency. The bulk modulus of elasticity can be calculated by the following Equation [2]:

$$DMOE_c = \frac{m}{L}\frac{12}{bt^3}(2\pi f)^2\left\langle\frac{l}{1.875^2}\right\rangle^2 \qquad [2]$$

Where:

DMOEc is the bulk modulus of elasticity (N/m^2)

f is the detected frequency of the first natural mode of vibration (Hz)

1 is the unclamped or “free” length of the cantilever beam (m)

m is the mass of the specimen (kg)

L is the complete length of the specimen (m)

b is the width of the specimen (m)

t is the thickness of the specimen (m).

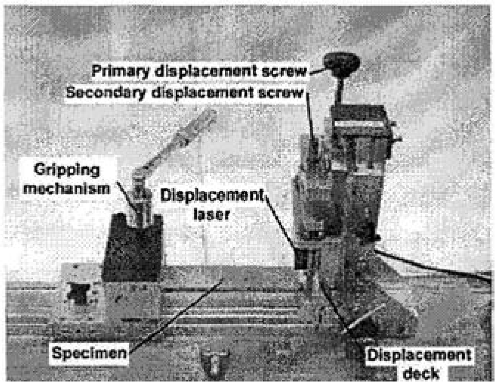

Figure 3. –*Cantilever beam vibration tester shown with a specimen in position*

Static bending

To obtain the static bending properties of all specimens, the specimens are tested in accordance with ASTM D198 (the third-point loading method) (ASTM, 1996). The static modulus of elasticity (MOE) was calculated by the following Equation [3]:

$$MOE = \frac{pa(3L^2 - 4a^2)}{48\Delta I} \qquad [3]$$

Where:

P is the load at proportional limit, a the distance from the end support to the nearest load point (a = L/3),

L is the span of specimens between supports

Δ is the midspan deflection and I is the moment of inertia.

Results and Discussion

Comparative analysis of Plywood and wood electromagnetic shielding composite panels

Two dynamic MOE values and MOE values of plywood and wood electromagnetic shielding composite panels were measured by the above three testing methods. Test results were shown in **Table 2.** It was found that the DMOEm, DMOEc and MOE value showed the following trend: DMOEm > MOE> DMOEc. It were also found that the DMOEm, DMOEc and MOE values for the plywood which was along the grain were greater than that of plywood which was transverse the grain. The difference in MOE between along the grain and transverse the grain was caused by anisotropy of wood materials (the special internal structure of wood).

For wood electromagnetic shielding composite panels, the values of DMOEm exceeded the MOE by about 19.0-38.6 %. The values of DMOEc exceeded the MOE by about 5.7-27.3 %. The values of DMOEm were greater higher than the values of MOE. In comparison to the DMOEm of wood electromagnetic shielding composite panels, the DMOEc of wood electromagnetic shielding composite

Tabel 2.—*The dynamic and static modulus of elasticity of all samples*

Type	*MOE*			*DMOE$_m$*			*DMOE$_c$*		
	Mean (GPa)	*S* (GPa)	*CV* (%)	*Mean* (GPa)	*S* (GPa)	*CV* (%)	*Mean* (GPa)	*S* (GPa)	*CV* (%)
Plywoods (along the grain)	7.44	1.32	17.68	5.92	0.92	15.51	6.29	0.94	14.88
Plywoods (Transverse the grain)	4.05	0.76	18.91	5.00	0.63	12.61	3.83	0.45	11.86
Composite 1,A+P+P+P+A	12.95	1.03	7.97	17.93	0.55	3.06	15.44	0.50	3.26
Composite 2,P+A+P+A+P	6.51	0.85	13.02	10.51	0.61	5.78	5.11	0.64	12.45

Note: *S is the standard deviation, CV is the variation coefficient, DMOE$_m$ is the stress wave modulus of elasticity, DMOE$_c$ is cantilever-beam vibration modulus of elasticity, MOE is the static modulus of elasticity, P represents the plywoods and A represents Aluminum Plates*

Correlation among the dynamic *MOE* and *MOE* for plywoods

Statistical correlation analyzed by linear regression was used to examine the relationship between the static and dynamic *MOE* measurements. In general, not only was the dynamic *MOE (DMOE, and DMOE,)* usually higher than the *MOE*, but it also had a close relationship with the *MOE* (Wang et al. 2008). As shown in the **Figure 4** to **Figure 7,** the determined correlation coefficient (R) were found to be 0.7355 *(DMOE$_m$* and *MOE)* and 0.8664 *(DMOE$_c$* and *MOE)* for plywoods which was along the grain, 0.4309 *(DMOE$_m$* and *MOE)* and 0.826 *(DMOE$_c$* and *MOE)* for plywoods which was transverse the grain (both at the 0.01 significance level). The linear regression analysis indicated a strong correlation between the dynamic *MOE* and *MOE* except for the plywoods which was transverse the grain *(DMOE$_m$* and *MOE).* It is mainly caused by the anisotropy of wood materials and the difference in testing principles. The testing means of Metriguard was based on the relationship among transmission speed, material density and *MOE* (Liang et al. 2007), but Cantilever-Beam vibration method was mainly based on the weight and frequency of materials.

The correlation analysis demonstrated that Metriguard and Cantilever-Beam vibration were feasible to predict *MOE* for plywood, and Cantilever-Beam vibration method had a higher precision degree than Metriguard for the prediction, as indicated by the maximum R value between *DMOE$_c$* and *MOE.*

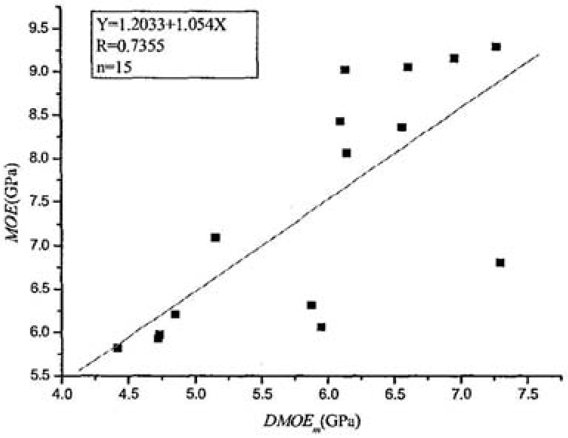

Figure 4. *—The correlation between the stress wave modulus of elasticity and static of modulus of elasticity (plywood, along the grain)*

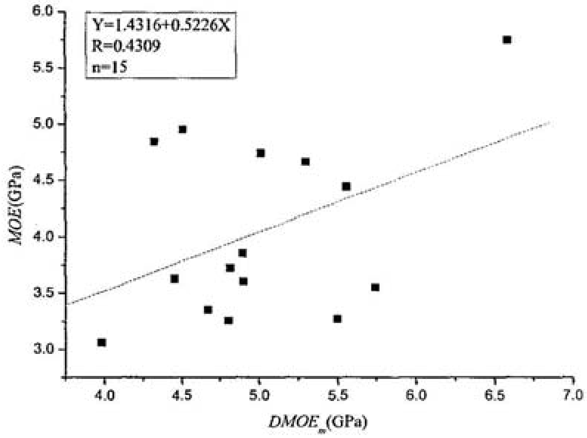

Figure 5. *—The correlation between the stress wave modulus of elasticity and static of modulus of elasticity (Plywood, transverse the grain)*

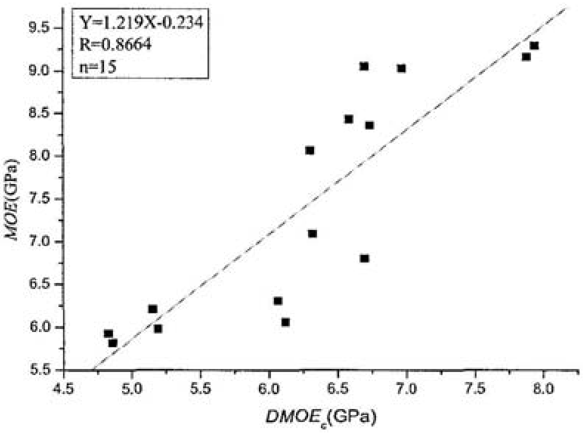

Figure 6. *—The correlation between the cantilever-beam vibration modulus of elasticity and static of modulus of elasticity (plywood, transverse the grain)*

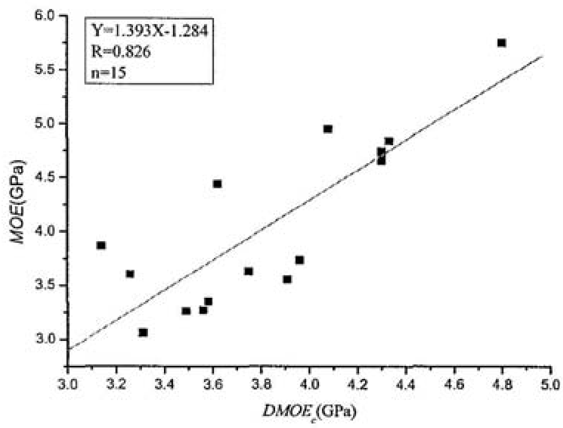

Figure 7. *—The correlation between the cantilever-beam vibration modulus of elasticity and static of modulus of elasticity (plywood, along the grain)*

Note: *$DMOE_c$ represents the cantilever beam modulus of elasticity, $DMOE_m$ represents the stress wave modulus of elasticity, MOE represents the static modulus of elasticity*

Correlation among the dynamic *MOE* and *MOE* for wood electromagnetic shielding composite

As shown in the **Figure 8** and **Figure 9,** the correlation coefficient (R) were found to be 0.4023 (DMOEc and MOE) and there was no liner relations between DMOEm and MOE for the composite 1. As for the Metriguard method, the wave transmission speed would be changed greatly because the surface of composite 1 was aluminum plate (great density difference between plywood and aluminum). As for Cantilever-Beam vibration method, the Laser-displacement is an important parameter to calculate the frequency of the testing material and it could not be measured accurately because of the reflection to laser by the aluminum plate on the surface. So it can be concluded that the Metriguard and Cantilever-Beam vibration method can not be used to predict the MOE of composite 1.

As shown in the **Figure 10** and **Figure 11,** the correlation coefficient (R) were found to be 0.9662 (DMOEm and MOE) and 0.9621 (DMOEc and MOE) for the composite 2 (both at the 0.01 significance level). The linear regression analysis indicated a strong correlation between the dynamic MOE (DMOEm and DMOEc) and MOE for the composite 2. As can be seen from the above information, the dynamic modulus of elasticity as determined by the Metriguard method was found to be the best single predictor of the MOE of composite 2.

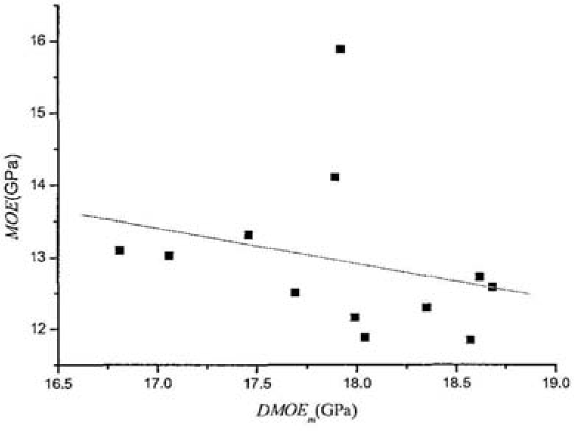

Figure *8.—The correlation between the stress wave modulus of elasticity and static of modulus of elasticity(compositel)*

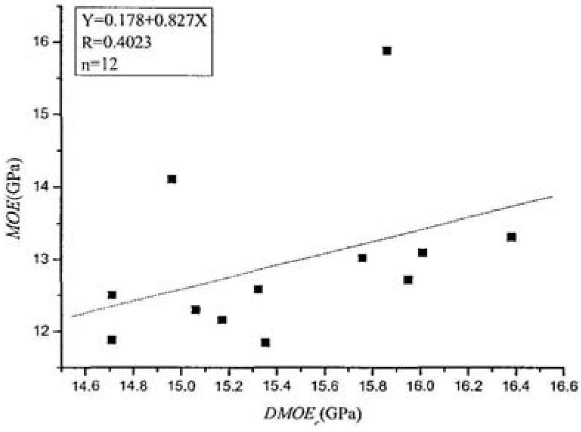

Figure *9.—The correlation between the cantilever beam modulus of elasticity and static of modulus of elasticity (compositel)*

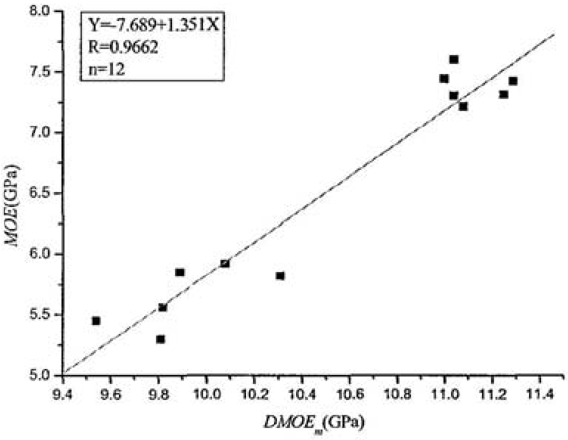

Figure 10. - *The correlation between the stress wave modulus of elasticity and static of modulus of elasticity (composite2)*

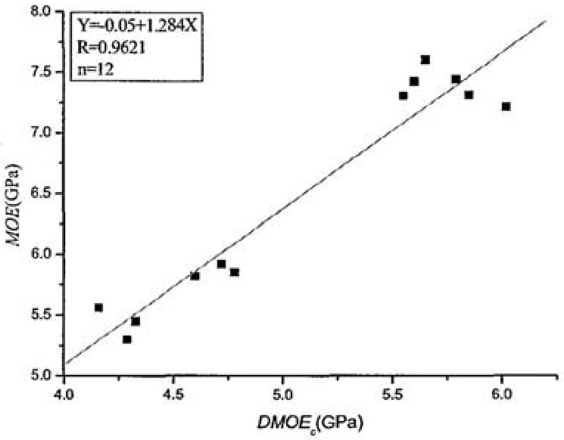

Figure 11. - *The correlation between the cantilever beam modulus of elasticity and static of modulus of elasticity (composite 2)*

Note: *$DMOE_c$ represents the cantilever beam modulus of elasticity, $DMOE_m$ represents the stress wave modulus of elasticity, MOE represents the static modulus of elasticity*

Conclusion

In this study, two non-destructive testing (NDT) methods (Metriguard and Cantilever-Beam Vibration) and static bending testing method were used to evaluate the dynamic modulus of elasticity *(DMOE)* and static modulus of elasticity *(MOE)* of raw plywoods and composites. Based on the experimental work, the following conclusions can be drawn:

1. The $DMOE_m$ was mostly greater than the *MOE* for the plywoods and composites and the $DMOE_c$ was close to the *MOE* in comparison to the $DMOE_m$.
2. The linear regression analysis indicated a strong correlation between the dynamic *MOE* and *MOE* except for the plywoods which was transverse the grain ($DMOE_m$ and *MOE*).The correlation analysis demonstrated that Metriguard and Cantilever-Beam were feasible to predict *MOE* for plywoods, and Cantilever-Beam vibration method had a higher precision degree than Metriguard for the prediction,
3. The Metriguard and Cantilever-Beam vibration method can not be used to predict the *MOE* of composite 1 which its surface was aluminum plate.
4. There were high correlations among the $DMOE_m$, $DMOE_c$ and *MOE,* especially between the $DMOE_m$ and *MOE,* and this was the best method to determine the *MOE* for the composite 2.
5. From the whole study it can be concluded that Cantilever-Beam vibration method was a better way to evaluate the the *MOE* for the all materials.

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