Evaluation of Dynamic Modulus of Elasticity of Medium Density Fiberboard Panel from Longitudinal Vibration Tests on Specimens

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It is preferred to perform conformity assessment of wood-based panels on the whole panel without cutting it down to smaller pieces. The modulus of elasticity, a mechanical property of wood, was determined by longitudinal vibration testing with the full-size panel, and the results were compared with results of tests of prismatic beams. The Brancheriau's correction coefficient was used to compensate for errors from cross-sectional dimension variations and errors from Poisson's ratio. Longitudinal excitation of the panels along the length was shown to be successful in evaluating the modulus of elasticity. However, strong correlations obtained from plate and beam comparisons along the width of the panels are promising.

Keywords: Composite; Longitudinal vibration; MDF; NDT; Plate; Wood

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INTRODUCTION

To be judged successful, a nondestructive test (NDT) of wood must provide suitable information without causing any failure or change in the nature of the specimen. Since a test specimen is typically cut from a larger specimen, the first step of destruction is manually enforced during fabrication of the valuable merchandise. In industrial practice, when such destruction is small, the method is sometimes falsely considered as a nondestructive evaluation. Resisto-graph drillings for standing tree assessment (Costello and Quarles 1999) and screw withdrawal tests to estimate the shear strength of wood (Divos *et al.* 1998) might be considered as two outstanding examples. Despite these kinds of informalities, researchers are working to develop NDT techniques to be absolutely nondestructive as implied by their name.

For medium density fiberboard (MDF), the modulus of elasticity is the most important mechanical parameter, and it is highly correlated with another key attribute, the modulus of rupture. These parameters must be evaluated by accredited import/export inspection bodies to judge whether or not wood specimens meet the applicable standards. Nowadays, when following standard procedures, it is common to use a static bending method that results in failure. If forced or free vibration of a free bar is conducted as an alternative, there is destruction involving the initial cutting down of the whole MDF board into smaller prismatic beams. The present research aims to find a solution to enable nondestructive evaluation of the modulus of elasticity in whole full-sized panels of MDF.

The idea of modulus of rupture estimation from modulus of elasticity in wood and wood based composites, in combination with internal friction, has been previously reported by Bodig and Jayne (1993). At this stage, even the modulus of elasticity was being evaluated using a destructive static bending method. The dynamic modulus of elasticity was verified as being highly correlated with the corresponding quantity evaluated under static conditions (Bodig and Jayne 1993), then modified by correcting the coefficient to make it significantly equal to the static modulus (Brancheriau 2011). Eventually, the dynamic vibration test became certified as a standard test method (ASTM 2013) to evaluate the modulus of elasticity of wood. This means that the free vibration NDT method is considered as a standard substitute to use in place of the static bending destructive method in terms of the modulus of elasticity of wood.

Particle board panels were excited to generate a flexural vibration (Ghaznavi *et al.* 2013), but the consecutive flexural modes of vibration were hard to identify. Difficulties in interpretation were attributed to illusive mixing of flexural vibration modes with effects of consecutive torsional modes of vibration. A finite element method was applied to mathematically calculate the flexural modes, noting that there is always a relative shift of frequency between experimental and mathematical modal frequencies (Sobue *et al.* 2010; Roohnia *et al.* 2011b). So, the finite element method would not be helpful enough to identify the exact flexural modes of free plate vibration in practice.

When the longitudinal vibration approach was studied, it was considered that the wave propagation in the axial direction of a plate must be very similar to that along a beam axis. Based on the stress wave dynamic Eq. 1, the longitudinal wave velocity is dependent on sound traveling distance and longitudinal modal frequency (Brancheriau and Bailleres 2002),

$$V = 2Lf \tag{1}$$

where V is wave velocity in (m/s), L is sound traveling distance (specimen length) in (m), and f is frequency of the 1st mode of longitudinal vibration in (Hz). Taking into account the density of media, the modulus of elasticity is evaluated as follows,

$$E = \rho V^2 \tag{2}$$

where E is the dynamic modulus of elasticity in (Pa) and ρ is density in (kg/m^3). The variations in cross-sectional dimensions are not considered in these global formulae, but differences in cross-sectional dimensions may create different values of error in modal evaluations. The correction coefficient due to cross-sectional variations in dimensions as well as the effect of Poisson's ratio have been reported by Rayleigh (1877) and improved by Brancheriau (2011) for wood,

$$f = \frac{1}{2L}\sqrt{\frac{E}{\rho.C}}, \qquad C = 1 + \frac{\pi^2}{AL^2}(I_Z \nu_{xy}^2 + I_y \nu_{xz}^2) \tag{3}$$

where C is Brancheriau's correction coefficient for the dynamic modulus of elasticity, A is cross section area in (m^2), I is the moment of inertia in (m^4) and, ν is Poisson's ratio (with regards to coordinates illustrated in Fig. 1).

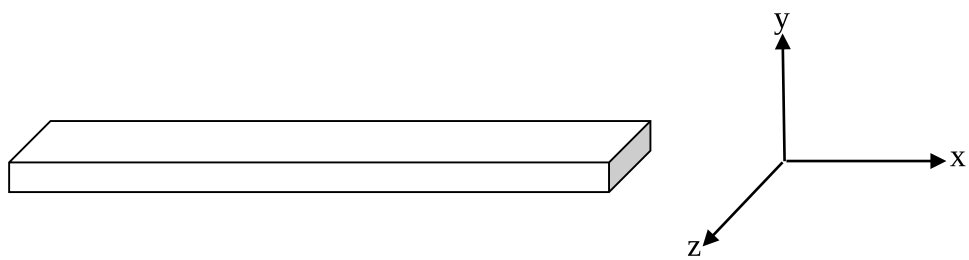

Fig. 1. Geometric description in the case of an orthotropic beam of rectangular cross-section

The equation may be simplified for MDFs. Poisson's ratio in MDF is not significantly affected by density or moisture content (Ganev *et al.* 2005; Sebera *et al.* 2014). Meanwhile, a plate of MDF might be considered as an isotropic or a flat isotropic material in certain cases (Bodig and Jayne 1993). So, the difference between ν_{xy} and ν_{xz} would not be very far from zero even if the plate of MDF is not accepted as an absolute isotropic material. Sebera *et al.* (2014) has reported Poisson's ratios for a variety of MDF panel thicknesses in which the differences in Poisson's ratios are very small.

With regards to what has been mentioned, the dynamic modulus of elasticity should be obtainable from longitudinal vibration of MDF plates, taking into account the necessary corrections in terms of cross-sectional dimensions. This approach has been taken in the present study.

EXPERIMENTAL METHOD

Materials

A plate of premium grade MDF was selected from a lot of commercial MDF panels, made in Iran. Its nominal dimensions were 244 cm × 122 cm × 1.6 cm (Length × Width × Thickness). The panel was divided along the length and width into four plates of 100 cm × 60 cm × 1.6 cm. Then, each of the smaller plates was cut down again to 50 cm × 30 cm × 1.6 cm. At the end of the cutting scenario, four prismatic beam were obtained from these small plates, two along the length and two along the width of the whole plate, measuring 4.5 centimeters wide (Fig. 2.). In other words, the cutting scenario resulted in the whole plate, being divided into 4 plates then divided into 16 plates and finally divided into 64 prismatic beams.

All specimens were kept in a conditioning chamber (65±5% relative humidity, 20±1 ^{o}C temperature) until the mass stopped changing. The conditioning period lasted three weeks, by which time the equivalent moisture content was stabilized. After conditioning, the test specimens were ready to be subjected to the vibration test. For this particular case, based on the reports by Ganev 2005 and Matsumoto and Nairn 2009, the Poisson's ratio was assumed to be 0.33.

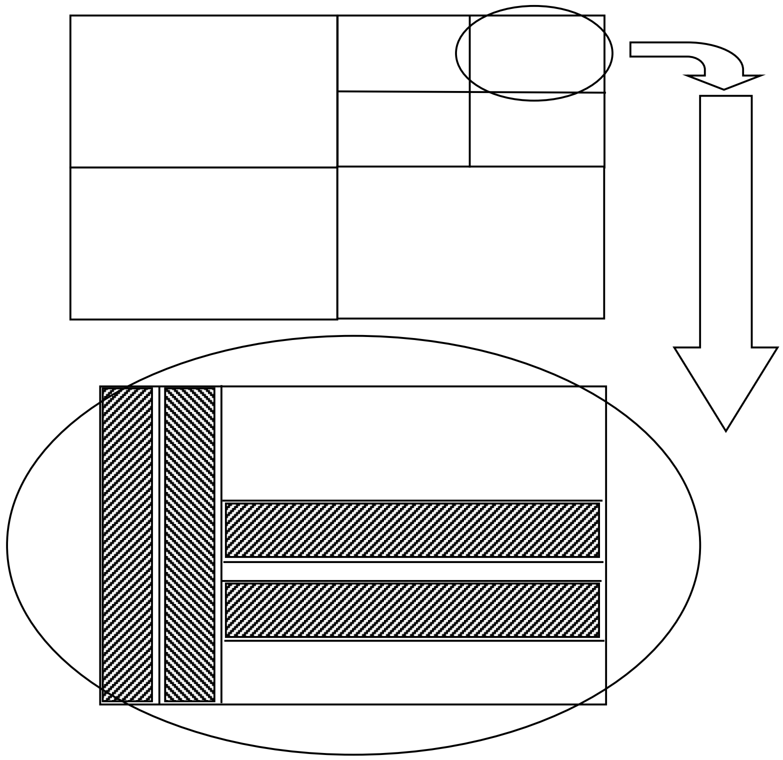

Fig. 2. Cutting scenario; the whole plate (MDF1) was divided into 4 (MDF2) then 4 smaller plates (MDF3) and then 4 prismatic beams with lengths oriented individually along the length or width of the whole panel (MDF4)

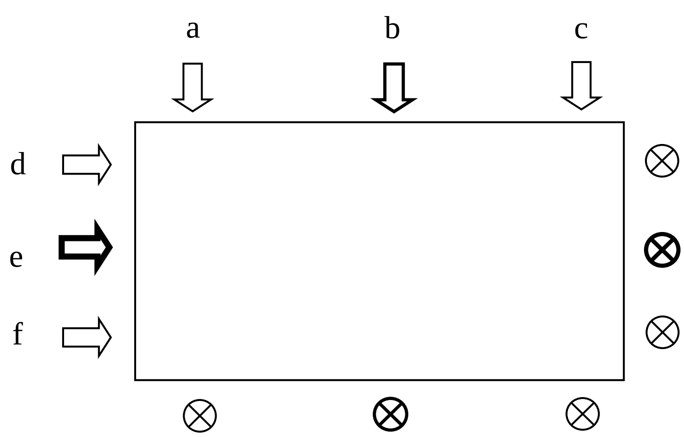

Fig. 3. Knocking and recording scenario on the whole plate in a, b, c, d, e and f directions; arrows are knocked perpendicular to thickness, parallel to the surface; the crossed-circles are the microphones. The smaller plates were knocked and recorded in shown in bold locations, in b and e directions, only.

Method

Longitudinal vibration tests (Brancheriau and Bailleres 2002; Labonnote *et al.* 2013a,b) were performed on free plates and beams using a LSTRESS portable system setup

(Fig. 4.), a release of NDTLAB® (Roohnia *et al.* 2006; Roohnia 2007; Roohnia *et al.* 2011a). To simulate the free boundary conditions, the plates rested on soft thin rubber positioned at the nodes of the first mode. The plates were excited by a single tap of a light hammer in order to stimulate the longitudinal vibration. The knock and recording locations were at the middle of the width or length except for the whole plate, which was knocked and recorded by a unidirectional microphone at three points within the length or width parallel to the vibration axis (Fig. 3.). The sampling frequency was 44100 Hz. The frequency of the first longitudinal mode was evaluated using a Fast Fourier Spectrum (FFS) and saved. Applying Brancheriau's correction coefficient, the axial moduli of elasticity were estimated using Eqs. 1 to 3. The relative repeatability and reproducibility of the LSTRESS test system, for dynamic modulus of elasticity of MDF beams, were 1% and 2%, respectively.

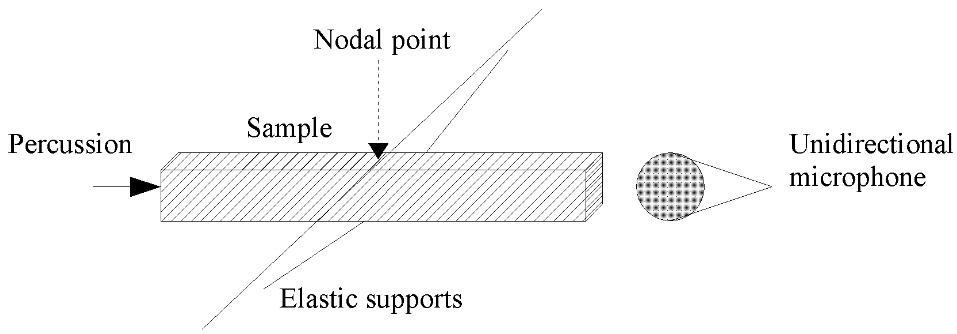

Fig. 4. Experimental setup, free-free bar in longitudinal vibration

Scatter plots were used to indicate the correlations between the obtained plate and beam vibration results. The elastic moduli along the width was also compared to that obtained along the length. In indicated models, the slope of trend is chosen for comparison. A discussion of the elastic moduli correlations also ensues.

RESULTS AND DISCUSSION

For convenience, the whole initial panel was named MDF1, and this was divided into four plates of MDF2. Each MDF2 was divided into four plates of MDF3, and finally each MDF3 was cut into four prismatic beams of MDF4 (Fig. 2.).

Figure 5 shows the correlations between the modulus of elasticity obtained from MDF3 plates and MDF4 prismatic beams. Even before considering the correction coefficient of cross-sectional dimensions, the longitudinal excitation along the length of the plate was successfully used to evaluate the axial modulus of elasticity. After applying the correction, the results from the plate were even more comparable to those obtained from the beams. It was also revealed that the modulus of elasticity was approximately 10% greater along the width of the whole panel. To test the possibility of elastic moduli evaluations from the longitudinal vibration of plates, the MDF2 plates were also compared to similar evaluations of the prismatic beams.

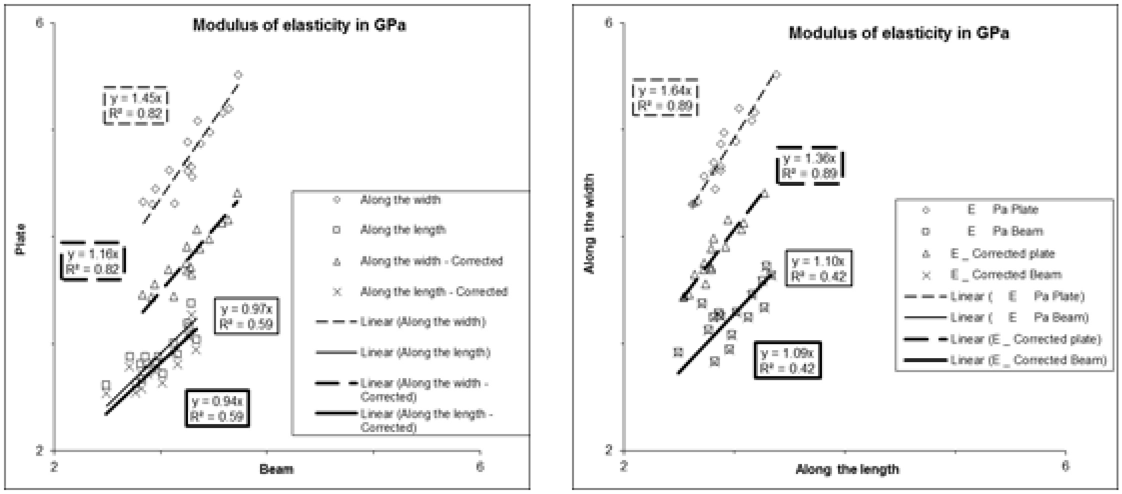

Fig. 5. Comparing the smallest plates (MDF3) with the prismatic beams (MDF4), with and without Brancheriau's correction coefficient

Considering Fig. 6 for the MDF2 plates versus the MDF4 prismatic beams, it was revealed that the longitudinal vibrations along the length of the panels were successfully employed in estimating the modulus of elasticity of the MDF panels. The correction coefficient of cross-sectional dimensions was positive for the approach, but still the vibration along the width showed a different relation. However, the correlation between them remained strong. Comparing the beam specimens showed that, for the present case study, the modulus of elasticity along the width was approximately 10% greater than that of its perpendicular axis, parallel to the length.

The reason behind the difference in the experimental values along the width still remains unclear; however, the strong correlation between the plate and the beam in terms of moduli of elasticity along the width appears promising.

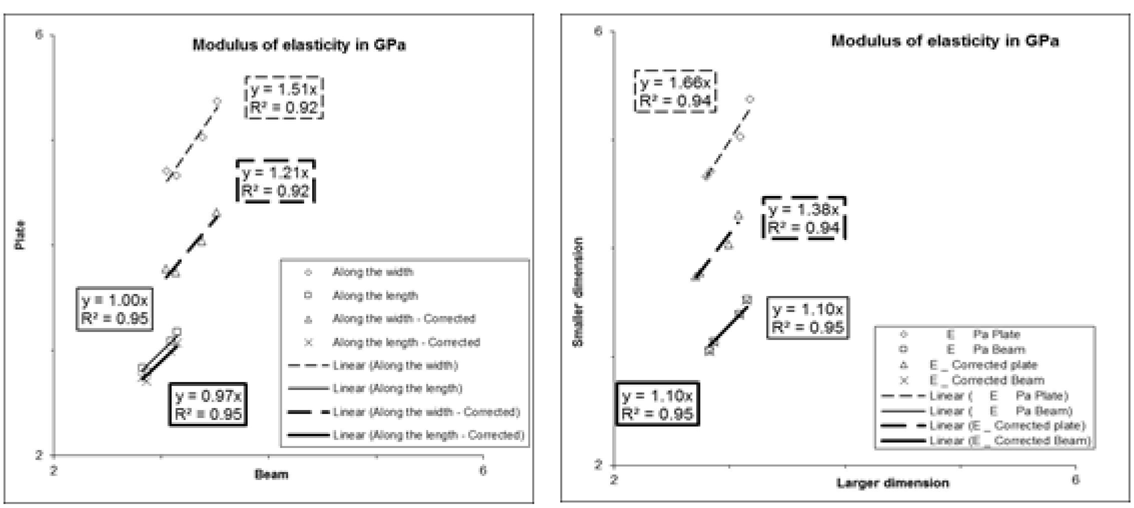

Fig. 6. Comparing the MDF2 plates with the prismatic beams (MDF4), with and without Brancheriau's correction coefficient

With the study of the whole plate (Fig. 7.), a similar result was obtained. The Brancheriau's correction coefficient successfully corrected the modulus of elasticity values obtained along different axes of vibration. The longitudinal vibration along the width resulted in some scatter in the modulus of elasticity data when compared to the actual value, while the vibration along the length was successful in its predictions of the modulus.

Most of the time, the moduli of elasticity obtained from the plate's longitudinal vibration along the length (after Brancheriau's correction) were a bit smaller than the beam values (5%, approximately).

Considering Fig. 7, it was revealed that knocking the thickness in every axis along the length is a valid approach in evaluating the dynamic modulus of elasticity of MDF panels, and the test is comparable to that of prismatic beams.

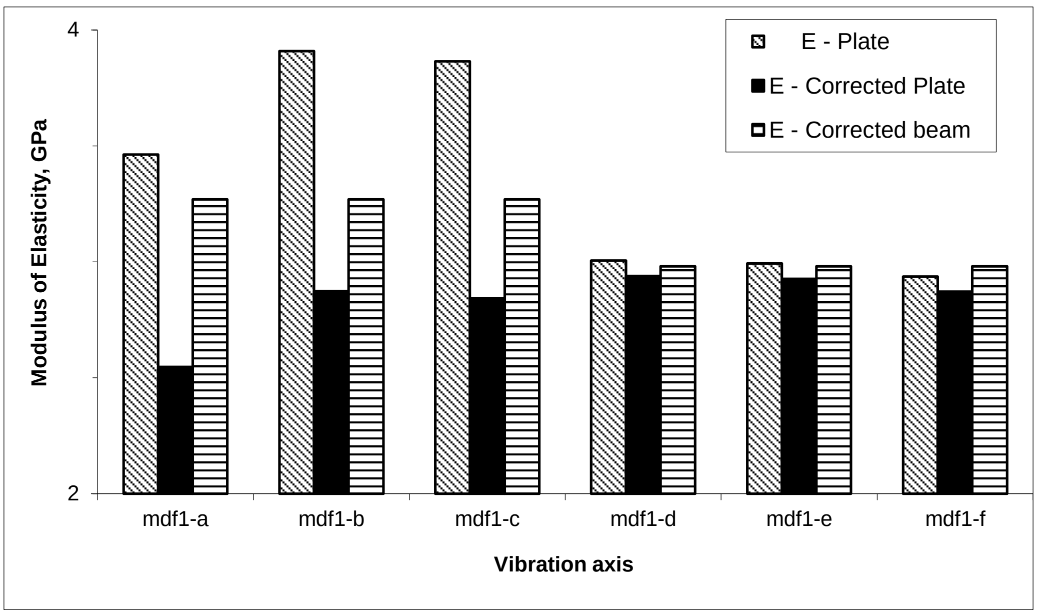

Fig. 7. Comparing vibration axes along the width and length. a, b, and c correspond to vibration along the width; d, e and f along the length. Brancheriau's correction coefficient was successfully homogenized the obtained results in whole plate vibration.

CONCLUSIONS

1. The longitudinal excitation along the largest side of an uncut panel (or "plate") of medium-density fiberboard (MDF) was successful in evaluating the axial modulus of elasticity of the MDF panel.
2. The correction coefficient of cross-sectional dimensions was positive for the approach, but still the vibration along the width showed an unknown relationship. Nevertheless, the fitted determination coefficient was strongly promising.

3. For the whole plate along different axes of vibration, the Brancheriau's correction coefficient was used successfully to correct the values of modulus of elasticity. The longitudinal vibration along the width resulted in some scatter in the values when compared to the actual modulus of elasticity, while the vibration along the length was better.
4. The obtained moduli of elasticity from longitudinal vibration of the plate along the length (after Brancheriau's correction) were always a bit smaller than the beam values. Considering normal differences between dynamic and static values of elastic moduli, this difference might be neglected in practical approaches.
5. Exciting the thickness at every arbitrary axis along the length (*i.e*. *d*, *e*, or *f*) is a viable approach to evaluate the dynamic modulus of elasticity of MDF panels.

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