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Dynamic determination of modulus of elasticity of full-size wood composite panels using a vibration method

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HIGHLIGHTS

- A dynamic testing method based on free vibration theory in a "free–free" support condition.
- Dynamic modulus of elasticity (MOE).
- Medium density fiberboard (MDF), particleboard (PB) and plywood (PW).
- A strong linear relationship was found between E_d and E_b for three types of full-size wood composite panels (MDF, PB and PW) tested.

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ABSTRACT

A vibration testing method based on free vibration theory in a "free–free" support condition was investigated for evaluating the modulus of elasticity (MOE) of full-size wood composite panels (WCPs). Vibration experiments were conducted on three types of WCPs (medium density fibreboard, particleboard, and plywood) to determine the dynamic MOE of the panels. Static bending test was performed on small specimens cut from the panels to determine the static MOE. A strong linear relationship was found between dynamic MOE of full size panels and static MOE of small specimens. Dynamic MOE of full-size WCPs was found 6.2% higher than the corresponding static MOE. This study demonstrated that free vibration method has a good potential to be used in WCP manufacturing facilities as a quality control procedure.

1. Introduction

As an engineered wood product, wood composite panels (WCPs) are widely used in furniture manufacturing, building construction, packaging, transportation and other industrial sectors [1]. Full-size WCPs refer to the panels with a standard size (length × width) of 2440 mm × 1220 mm that are most common in production sales. Modulus of elasticity (MOE) is a key index for evaluating the mechanical performance of WCPs. Studies have shown that MOE of a panel has a statistical linear relationship with other mechanical performance indices [2,3].

In WCPs manufacturing facilities, quality control procedures typically involved in mechanical testing of panels sampled from the production lines. According to the procedures, several small WCPs specimens need to be cut from different parts of a large-size panel, with a dimension of $(20\,h + 50) \times 50 \times h$ (unit: mm) of the length × width × thickness (h) [4]. The small specimens are then destructively tested in a testing machine to obtain the stiffness and strength properties. With the measurement results of several standard specimens, the overall stiffness and strength of full-size panels can be derived. This evaluation procedure is time-consuming, destructive in nature, and sometimes unreliable due to inherent variation within and between panels. Furthermore, the test results are usually not readily available to production personnel until some hours after the actual time of production, making the adjustment of production parameters difficult. From this standpoint, it is often desired to rapidly and nondestructively assess the mechanical performance of the full-size panels to complement their existing quality-control program in WCP facilities.

In recent years, many studies have been done on nondestructive evaluation of small wood composite specimens [5–13]. However, very limited information is available for nondestructive evaluation of full-size WCPs and other large-size WCPs. A technique that has

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been investigated is a torsional-bending vibration method [12,13]. During the testing, a large-size WCP member is clamped at one end like a cantilever beam, then an initial displacement is applied at one corner of the free end so that the panel is set into bending and torsional free vibrations. Through analysis of the vibration signals, MOE and shear modulus of the WCP member can be determined. In addition, based on the principle of static bending tests, several machine stress rating (MSR) equipment have been developed to nondestructively test full-size panels in manufacturing facilities [14,15]. For instance, through performing concentrated static, impact load and deflection test, a line of panel testing equipment called Metriguard Model 820 has been developed by Metriguard and TECO to acquire MOE of full-size wood panels [16].

In this study, we proposed a dynamic testing method, which is based on the vibration theory of a "free–free" support condition, as a potential quality control technique for WCP. The objective of this paper was to examine the feasibility and validity of the free vibration method for assessing the mechanical performance of full size WCP in production settings. More specifically, the first order natural vibration frequency of the full-size WCP supported on two nodal lines was measured and used to predict MOE of the panel. A total of 303 pieces of full-size WCP samples were tested using a laboratory testing apparatus. The panels tested include medium density fiberboard (MDF), particleboard (PB) and plywood (PW) panels with range of thickness specifications. The results of vibration testing on full-size panels were then compared with those of static bending tests performed on small specimens cut from the sample panels. The relationships between the results of these two testing methods were examined.

2. Theoretical basis

"Free–free" support refers to the panel being supported on its two nodal lines which are located at 22.4% and 77.6% of its length. A panel's free vibration under this support condition is called "free–free" support free vibration. Fig. 1 shows the first vibration mode of the full-size WCP under a "free–free" support condition. The first vibration mode of a full-size panel in this support condition is same as the vibration mode of a beam supported at the same position [17]. Therefore, the calculation method for MOE of the beam in this support condition can be used to calculate MOE of the full-size panels. And, this MOE corresponds to the modulus of elasticity in the length direction of the panel. In this paper, this MOE is called the dynamic MOE of the full-size WCP. Then, the dynamic MOE of the full-size WCP is calculated using Eq. (1) [18]:

$$E_d = \frac{f^2 M L^3}{12.65 I} \quad (1)$$

where E_d is the dynamic MOE of the panel (Pa), f is the first natural vibration frequency of the panel (Hz), M is the weight of the panel (kg), L is the length of the panel (m), I is the inertia moment of the cross section (m^4). And $I = \frac{bh^3}{12}$, b is the width of the panel (m), h is the thickness of the panel (m). When panel geometry size (L, b, h) is given, MOE of the panel can be calculated in the condition of detecting the first natural vibration frequency f and the weight M.

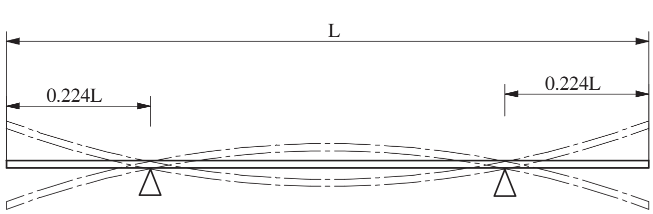

Fig. 1. First vibration mode of a full-size wood composite panel under "free–free" support condition.

This is theoretical basis for dynamic determination of MOE of the full-size WCP.

3. Materials and methods

3.1. Materials

A total of 303 pieces of full-size wood composite panels were used in this study, including 101 pieces of MDF panels with 6 different thicknesses (5, 8, 12, 16, 18, 20 mm), 100 pieces of PB panels with 6 different thicknesses (5, 9, 12, 16, 18, 25 mm), and 102 pieces of PW panels with 8 different thicknesses (5, 7, 9, 12, 15, 18, 20, 25 mm). The MDF panels were provided by a local MDF manufacturer, and the PB and PW panels were purchased from the local market. Table 1 shows the specifications of the full-size WCP samples. The length (L), width (b), and thickness (h) of the panel samples were measured prior to testing. Average density of the panels was calculated based on the weight and volume. The moisture contents of the panels were determined based on the National Standards of the People's Republic of China GB/T 17657-2013 [4].

Free vibration test was first conducted on each full size panel under the free–free support condition. Six small specimens were then cut from each full size panel according to the national standard [19,20]. Table 2 shows the dimensions of the small specimens for the three types of WCPs examined in this study. All small WCP specimens were then subject to a flatwise static bending test under a center loading.

3.2. Testing apparatus and dynamic detection test

We developed a vibration testing apparatus in the laboratory for evaluating the stiffness of full-size WCPs (Fig. 2). The apparatus consisted of two load sensors, one laser sensor and a supporting system. The load sensors located at the supporting rods were used to measure the weight of the panel being tested. Two supporting rods were used to provide line supports at the nodal lines of the panel. The laser sensor was located at the middle of the panel to sense the vibration displacement signal. A LabVIEW based software was written and used to collect and process both load and vibration signals and calculate MOE based on Eq. (1).

During the vibration test, a full size panel was placed on the supporting rods with the rods located at the nodal lines of the panel (22.4% and 77.6% of the length). The testing software was then initiated so that the computer was ready to collect the signals from the load censors and laser sensors. A mechanical displacement was applied on the edge of the panel pressing down with both hands, then by releasing the hands from the end of the panel, it's a free vibration of the panel generated. The vibration signal detected by the laser sensor was transmitted to the computer through a data acquisition card and processed through the LabVIEW software to obtain the first natural frequency of the panel vibration. Based on Eq. (1), the calculation module in the testing software calculated the dynamic MOE (E_d) of the panel tested.

3.3. Static bending test

To examine the validity of the vibration testing method that we proposed, we conducted static bending test on all the small specimens cut from the full size panel samples according to the testing standard of the People's Republic of China GB/T

Table 1
Specifications of full-size wood composite panels tested.

Panel code	Quantity (panels)	Panel average sizes (thickness × length × width, mm)	Average density (kg/m^3)	Average moisture content (%)
MDF5	10	5.92 × 1221.2 × 2442.7	763.69	9.0
MDF8	9	8.11 × 1220.8 × 2442.2	818.91	4.0
MDF12	25	11.94 × 1220.4 × 2439.7	788.20	6.8
MDF16	41	15.98 × 1220.0 × 2442.4	745.01	4.9
MDF18	7	18.04 × 1220.6 × 2439.4	793.41	4.7
MDF20	9	19.88 × 1220.3 × 2441.4	697.63	9.0
PB5	8	4.64 × 1221.8 × 2444.9	730.54	9.0
PB9	15	9.00 × 1222.9 × 2442.2	658.03	4.5
PB12	17	12.20 × 1223.1 × 2442.2	707.68	4.1
PB16	25	16.04 × 1223.1 × 2441.0	698.96	4.3
PB18	25	18.03 × 1220.2 × 2437.0	656.06	5.7
PB25	10	25.05 × 1220.9 × 2440.7	680.68	6.8
PW5	7	4.98 × 1218.6 × 2439.4	513.51	9.0
PW7	8	6.52 × 1218.9 × 2437.9	527.16	9.5
PW9	19	9.42 × 1219.1 × 2438.1	505.33	9.4
PW12	7	11.34 × 1224.9 × 2438.9	529.04	9.0
PW15	19	14.45 × 1220.8 × 2439.3	507.66	10.5
PW18	18	17.04 × 1221.1 × 2438.4	521.67	8.6
PW20	8	19.46 × 1218.0 × 2439.4	509.85	9.0
PW25	16	24.36 × 1219.2 × 2439.5	529.77	9.8