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Measurement of the in-plane shear modulus of medium-density fibreboard by torsional and flexural vibration tests

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ABSTRACT

The in-plane shear modulus (IPSM) of medium-density fibreboard (MDF) was obtained via a torsional vibration (TV) test using the specimen with various configurations and a subsequent numerical analysis. Because the out-of-plane shear modulus (OPSM) of MDF was much lower than the IPSM, the difference between the IPSM and OPSM had to be considered in the TV test. Therefore, the OPSM value was measured from the flexural vibration (FV) tests, and it was applied for the calculation of the IPSM value. The experimental and numerical results indicated that the TV test is effective to obtain the IPSM of MDF accurately under various configurations of the specimen.

1. Introduction

There are several experimental methods to determine the shear modulus of solid wood and wood-based materials [1]. For medium-density fibreboard (MDF), it is important to know the in-plane shear modulus (IPSM) accurately because the MDF is subjected to the in-plane shearing force when it is used as a structural wall. In a previous study, the IPSM of MDF was measured with the flexural vibration (FV) method based on Timoshenko's vibration theory [2]. The results obtained suggested that the IPSM is dependent on the specimen configuration such that the length of the specimen must be less than 7.5 times the height to measure the IPSM accurately. Nevertheless, the restriction of the specimen configuration should also be a drawback, and it is desirable to measure the IPSM value accurately using the specimens with various configurations. A torsional vibration (TV) test can induce a pure shear stress condition in the specimen so it may be promising for measuring the IPSM value accurately.

There are many examples of measuring the shear modulus of solid wood by the TV test because the shear moduli in the longitudinal–radial (LR) and longitudinal–tangential (LT) planes are relatively close to each other [3–9]. Even when supposing that the shear moduli in the LR and LT planes are equal to each other, the error induced by the approximation can be restricted. For MDF, however, this approximation is null because the IPSM is much larger than the out-of-plane shear modulus (OPSM). Another attempt of the TV test was conducted using a thin square plate specimen to reduce the effect of OPSM [10–12]. In this method, however, the accuracy of the IPSM value cannot be expected when the aspect ratio of the specimen is not large enough. Therefore, it is often difficult to measure the IPSM of MDF accurately by the TV test.

In spite of these difficulties, the TV test is still attractive for measuring the IPSM of MDF because it can induce a pure shear stress condition in the specimen, as described above. In this study, TV and FV tests were performed on MDF specimens with various configurations, and the IPSM values were obtained by three different analyses. The validity of the analysis methods was examined by comparing their results with finite element (FE) calculations. The

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objective of this study was to use the TV test for determining the IPSM of MDF.

2. Torsional vibration (TV) equation

Fig. 1(a) shows the diagram of the torsional vibration (TV) test. As shown in this figure, the x, y, and, z directions are defined as the length, width, and thickness of the specimen, respectively. When the first TV mode, the resonance frequency of which is defined as f_T, is excited in the specimen with the length, width, and thickness of L, a, and b, respectively, the shear modulus in the length–width (xy) plane, G_{xy}, is derived as:

$$G_{xy} = \frac{4\pi^2 J L f_T^2}{K} \tag{1}$$

where

$$J = \frac{ab\left(a^2 + b^2\right)}{12} \tag{2}$$

and

$$K = \frac{ab^3}{3}\left[1 - \frac{192b}{\pi^5 a}\sqrt{\frac{G_{xy}}{G_{xz}}}\sum_{n=1}^{\infty}\frac{\tanh\frac{(2n-1)\pi a}{2b}\sqrt{\frac{G_{xz}}{G_{xy}}}}{(2n-1)}\right] \tag{3}$$

In this study, the G_{xy} and G_{xz} values correspond to the in-plane shear modulus (IPSM) and out-of-plane shear modulus (OPSM) of the MDF panel, respectively.

As described above, in several previous studies for measuring the shear modulus of solid wood by a single TV test, the G_{xy} and G_{xz} values are regarded as equal to each other [3–9]. For the MDF panel, however, this method is not effective because the G_{xy} value of the MDF panel is much larger than the G_{xz} value. Therefore, multiple vibration tests are required to separate the G_{xy} and G_{xz} values from each other. Suzuki and Okohira [13] conducted static torsional tests of the specimens with multiple aspect ratios. Although this method can be applied for the torsional vibration method, there is an inconvenience in that multiple specimens with different configurations should be prepared. In the ordinary MDF, however, the Young's modulus in the length and width directions of the panel (MOE) is usually larger than the OPSM, as demonstrated below. Therefore, the G_{xz} value can be obtained accurately by the FV method. When using the G_{xz} value obtained by the FV method, the G_{xy} value can be determined from Eq. (1) without using multiple specimens with different aspect ratios. Nakao et al. conducted the FV tests for solid wood to determine the G_{xy}/G_{xz} ratio, and the shear modulus in the LR plane was determined by the TV test using the G_{xy}/G_{xz} value [14].

3. Finite element analysis (FEA)

Three-dimensional (3D) FEA was performed independently of the TV and FV tests, the details of which are described below, using the FEA program ANSYS 12. Fig. 2 shows the homogeneously divided FE mesh of the specimen. Similar to the definitions in previous studies [2,15,16], the directions along the length, width, and thickness of the board, which correspond to the x, y, and z directions, respectively, as shown in Fig. 1, were defined as the L, T, and Z directions, respectively. The lengths in the L (x), T (y), and Z (z) directions were defined as L, a, and b, respectively. In the model, L = 300 mm, b = 12 mm, and the value of a was varied from 10 to 60 mm with an interval of 10 mm. The model consisted of eight-node brick elements. It was confirmed that the mesh size was fine enough and that the effect of mesh size could be ignored. The Young's moduli in the L, T, and Z, directions were defined as E_L, E_T, and E_Z, respectively. The shear moduli in the LT, LZ, and TZ planes were defined as G_{LT}, G_{LZ}, and G_{TZ}, respectively, whereas the Poisson's ratio in these planes were defined as ν_{LT}, ν_{LZ}, and ν_{TZ}. Table 1 lists the derived elastic constants of MDF. The values of E_L, E_T, G_{LT}, and ν_{LT} were taken from [2], the G_{LZ} and G_{TZ} values were from [17], and the E_Z value was from [18]. The ν_{LZ} and ν_{TZ} values were assumed to be equal to ν_{LT} in this study. In the thickness direction of actual MDF, a density profile exists so that it is better to consider the profile of the elastic properties in the thickness direction [18,19]. Nevertheless, it was

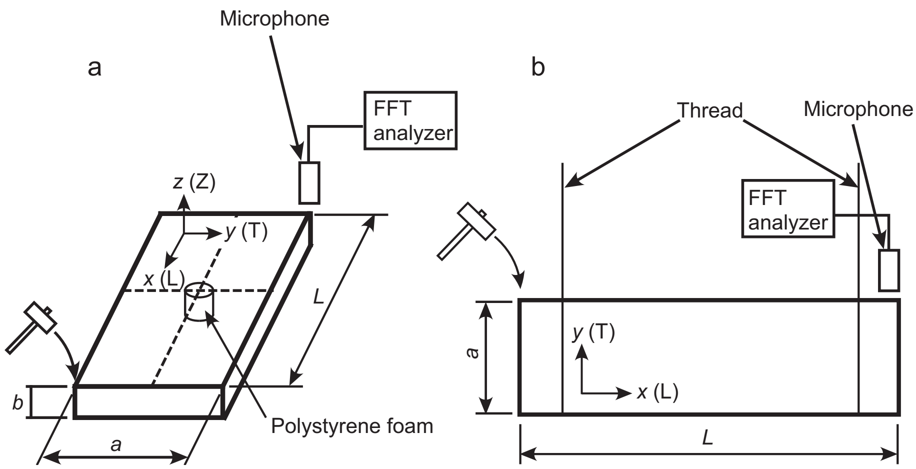

Fig. 1. (a) and (b) Diagram of the torsional vibration (TV) and flexural vibration (FV) tests, respectively.