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3種の主要な規格によるラワン5プライ合板および中密度繊維板(MDF)の厚さ方向の曲げ特性の測定

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Flatwise bending properties of Lauan five-ply wood and medium-density fiberboard obtained by the methods based on three major standards

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Abstract

A bending test was performed for Lauan 5-ply wood and medium-density fiberboard (MDF) with a thickness of 9 mm according to methods based on those used to determine three major standards (ASTM, JAS, and BS/EN). For the Young's modulus, the validity of the test was then examined by comparing the results with those from the flexural vibration test. The method based on that used to be determined in the JAS was most effective for determining the static Young's modulus. The proportional limit stress and bending strength obtained by the JAS-based method were smaller than those obtained by those based on the ASTM and BS/EN methods.

1. Introduction

To evaluate the mechanical properties of wood-based materials, a bending test is frequently conducted because of its simplicity. Bending test methods are determined in several major standards. Nevertheless, the test conditions determined are extremely different with each other, so the mechanical properties obtained based on the different methods are not comparable with each other. It is certain that these standardized methods have their advantages and drawbacks. To determine the mechanical properties of wood-based materials appropriately, however, these standards should be unified in the future. To achieve this aim, it is useful to reveal the differences between the mechanical properties obtained by the different methods.

In this study, static bending tests of plywood and medium-density fiberboard (MDF) were conducted according to methods determined by the American Society for Testing and Materials (ASTM), Japanese Agricultural Standards (JAS), and the British Standard (BS/EN), and Young's modulus, proportional limit stress, and bending strength were obtained. Independent of the static bending tests, Young's modulus was measured by a flexural vibration test and it was compared with those obtained by the bending tests.

2. Experiment

2.1 Materials

Lauan (*Shorea* sp.) 5-ply wood and MDF were investigated. The densities of these materials at a 12% moisture content were 0.50 ± 0.02 and 0.66 ± 0.01 g cm^{-3}, respectively. The plywood and MDF panels were fabricated in Ueno Mokuzai Kogyo Co., Himeji, Japan, and had the initial dimensions of $910 \times 1820 \times 9$ mm^3. The plywood, which was a JAS Certified Ordinary Plywood, consisted of five veneers; the surface veneers (layers 1 and 5), core veneer (layer 3), and the veneers adjacent to the surface and core veneers (layers 2 and 4) were approximately 1.5, 1.0, and 2.5 mm thick, respectively. Each veneer was bonded using urea-formaldehyde (UF) resin. The MDF was fabricated of softwood (typical fiber length 2-4 mm) and UF resin. These materials were stored at a constant 20°C and 65% relative humidity before and during the test, and test specimens were confirmed to be in an air-dried condition.

These conditions were maintained throughout the tests. The equilibrium MC condition was approximately 12%. Thirty-six specimens were cut from each plywood and MDF.

2.2 Flexural vibration tests

Young's modulus in the length direction of the specimen E_{vib} and the weak-axis shear modulus G_{vib} were determined by a free-free flexural vibration test. The details of the tests were similar to those of tests previously conducted (Yoshihara 2010).

2.3 Bending tests

In this study, bending tests were conducted according to the conditions based on those determined in major standards as follows:

(A) JAS 233: span = 45 times depth, four-point bending

(B) ASTM D 1037 or D 3043: span = 24 times depth, three-point bending

(C) BS/EN 310: span = 20 times depth, three-point bending

After conducting the flexural vibration tests, the specimens were separated into three groups. The average and standard deviations of the densities in these groups were similar to each other. In the bending test, the specimen was supported using a straight plate, and it was loaded by a loading nose with a radius of 15 mm at a crosshead speed of 10 mm/min. The deflection was measured by a linear variable differential transducer (LVDT) set below the midspan. From the load-deflection diagram, Young's modulus E_{b}, the proportional limit stress σ_{pl}, and the bending strength σ_{f} were obtained from the following equations based on elementary beam theory:

Four-point bending test corresponding to condition (A):

$$\begin{cases} E_{\mathrm{b}} = \dfrac{23L^3}{108BH^3}\cdot\dfrac{\Delta P}{\Delta\delta} \\ \sigma_{\mathrm{pl}} = \dfrac{P_{\mathrm{pl}}L}{BH^2} \\ \sigma_{\mathrm{f}} = \dfrac{P_{\mathrm{f}}L}{BH^2} \end{cases} \tag{1}$$

Three-point bending corresponding to conditions (B) and (C):

$$\begin{cases} E_{\mathrm{b}} = \dfrac{L^3}{4BH^3}\cdot\dfrac{\Delta P}{\Delta\delta} \\ \sigma_{\mathrm{pl}} = \dfrac{3P_{\mathrm{pl}}L}{2BH^2} \\ \sigma_{\mathrm{f}} = \dfrac{3P_{\mathrm{f}}L}{2BH^2} \end{cases} \tag{2}$$

where L is the span length, B is the beam width, H is the beam width (panel thickness), P_{pl} is the load at the proportional limit, P_{f} is the maximum load, and $\Delta P/\Delta\delta$ is the initial inclination of the load-deflection diagram. P_{pl} was defined by the intersection point between the load-deflection diagram and the straight line with the inclination of $0.97\Delta P/\Delta\delta$ (Yoshihara et al. 2003).

3. Results and discussion

Table 1 shows Young's modulus E_{vib}, the shear modulus G_{vib}, and the value of $E_{\mathrm{vib}}/G_{\mathrm{vib}}$ obtained by the flexural vibration tests. When $E_{\mathrm{vib}}/G_{\mathrm{vib}}$ is large, the influence of the deflection caused by the shearing force is emphasized so that the E_{b} value, the details of which are described below, cannot be obtained appropriately when using equations (1) and (2). The ratio of Young's modulus in the longitudinal direction to the shear modulus in the longitudinal-radial or longitudinal-tangential plane of solid wood usually varies from 5 to 25 (Hearmon 1948). As shown in Table 1, the $E_{\mathrm{vib}}/G_{\mathrm{vib}}$ value of the plywood significantly exceeds this range, so it was supposed that the static Young's modulus of plywood could not be obtained appropriately. In contrast, the $E_{\mathrm{vib}}/G_{\mathrm{vib}}$ value of the MDF is in the range described above. The results of bending tests using solid wood (Japanese fir) suggested that Young's modulus could be obtained appropriately when the span/depth ratio exceeded 35 and 20 in the three-point and four-point bending tests, respectively (Yoshihara and Matsumoto 1999; Yoshihara et al. 2003). This indicates that the static Young's modulus of MDF can be obtained appropriately under condition (A).

Table 1 Young's modulus E_{vib}, shear modulus G_{vib} and the value of $E_{\mathrm{vib}}/G_{\mathrm{vib}}$ obtained by the flexural vibration tests

	E_{vib} (GPa)	G_{vib} (GPa)	$E_{\mathrm{vib}}/G_{\mathrm{vib}}$
PW (L)	6.84 ± 0.28	0.22 ± 0.02	31.2 ± 3.3
PW (T)	6.35 ± 0.50	0.10 ± 0.01	64.2 ± 8.1
MDF	3.96 ± 0.12	0.20 ± 0.05	15.9 ± 2.9

PW (L) and PW (T) represent the plywood L-type and plywood T-type, respectively. Results are average ± SD.

Table 2 shows the bending properties of plywood and MDF obtained under conditions (A)-(C). The E_{b} values of plywood obtained under condition (A) coincide well with those obtained by the flexural vibration test E_{vib}, and a statistical analysis suggests that there is no significant difference between the values of E_{b} and E_{vib}. As described above, plywood has a large Young's modulus/shear modulus ratio, so there was a concern that the influence of deflection caused by shearing force would be significant. In condition (A), however, the static Young's modulus can be obtained appropriately. In contrast, the statistical analysis revealed that the value of E_b of MDF is smaller than that of E_{vib} at the significance level of 0.01. This phenomenon is discrepant from the expectation described above. From the results obtained here, it is difficult to reveal the reason for this discrepancy, and further research should be conducted to reveal the tendency found in the MDF.

Table 2 Bending properties of plywood and MDF obtained under the different conditions of static bending test.

TC	E_b (GPa)	σ_{pl} (MPa)	σ_f (MPa)
	Plywood L-type		
(A)	6.97 ± 0.41	28.4 ± 2.2	41.9 ± 2.9
(B)	5.02 ± 0.30	30.3 ± 1.5	42.9 ± 4.7
(C)	4.68 ± 0.17	31.9 ± 2.0	45.5 ± 6.2
	Plywood T-type		
(A)	6.37 ± 0.48	25.6 ± 9.3	30.8 ± 12.2
(B)	4.36 ± 0.36	37.9 ± 8.9	44.6 ± 10.1
(C)	3.77 ± 0.32	32.5 ± 6.8	38.3 ± 11.2
	MDF		
(A)	3.25 ± 0.35	12.3 ± 5.5	30.8 ± 8.9
(B)	2.80 ± 0.08	24.6 ± 2.9	39.7 ± 1.1
(C)	2.45 ± 0.08	23.1 ± 3.0	38.1 ± 1.2

TC represents the test condition. Results are average ± SD.

As for the proportional limit stress and bending strength, the values obtained under condition (A) are smaller than those obtained under the other conditions. This phenomenon is significant for the proportional limit stress σ_{pl} of MDF. In the three-point bending test, the bending strength is evaluated pointwise at the mid-span, whereas the bending strength is evaluated at the weakest point between the loading noses in the four-point bending test (Adams et al. 2003). Therefore, the strength properties obtained by the three-point bending test are usually larger than those obtained by the four-point bending test. Nevertheless, this tendency was not significant for solid wood (Yoshihara et al. 2003), so it may be applicable only to the strength properties of plywood and MDF. Further research should be conducted to elucidate this issue in more detail.

4. Conclusion

A static bending test was performed for plywood and MDF with a thickness of 9 mm according to the methods referring to those determined in three major standards, and Young's modulus, proportional limit stress, and bending strength were obtained. For the static Young's modulus, the validity of the test was then examined by comparing these results with those from the flexural vibration test. The four-point bending test based on that defined in the JAS was most effective for determining the static Young's modulus of plywood. Nevertheless, the proportional limit stress and bending strength obtained by the four-point bending test were markedly smaller than those obtained by the three-point bending tests based on the ASTM and BS/EN methods.

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