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NOTE

Relation between the dynamic modulus of elasticity and the static modulus of elasticity, the modulus of rupture of mandarin peel–sawdust composite board

Cheng-Yuan Li[1] · Chun-Won Kang[2] · Ho-Yang Kang[3] · Sang-Sik Jang[3]

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Abstract This study was conducted to determine the relation between the dynamic modulus of elasticity and the static modulus of elasticity, and the relation between the dynamic modulus of elasticity and the modulus of rupture of mandarin peel–sawdust composite boards. The result of this study was as follows: There was highly close linear correlation between the dynamic modulus of elasticity and the static modulus of elasticity, modulus of rupture of the mandarin peel–sawdust composite boards with the density of 0.4, 0.5 and 0.6 g/cm^3, and the mandarin peel content of 10, 20, 30 and 40%, thus, the static modulus of elasticity and the modulus of rupture can be predicted from the dynamic modulus of elasticity measured by free vibration test using resonance frequency.

Keywords Mandarin peels · Dynamic modulus of elasticity · Static modulus of elasticity · Modulus of rupture · Resonance frequency

Introduction

The interest in wood and wood-based products for use in building materials is increasing due to concerns with human health. Appropriately harvested wood products also offer the advantage of being borne of a renewable resource. Whereas worldwide production of wooden building materials has decreased due to industrialization, and this trend is expected to continue into foreseeable future. Also, the prices of wooden raw materials are increasing, which hampers the growth of the wood product business. Therefore, it is necessary to develop methods and technology for recycling wooden waste materials, such as wood product production waste, wooden construction waste, and biomass materials. The availability of mandarin peel (one kind of orange peel) and sawdust among those reusable materials was observed [1] because there was abundant sawdust and mandarin peels to be exploited in Korea.

In our previous study [1], the physical property of mandarin peel–sawdust composite boards was investigated at different mixing ratio of orange peel and sawdust. Meanwhile, the researches on a vibration test—which is non-destructive test method, easy to be operated, accurate and reproducible—to predict the bending strength of material have been extensively conducted [2, 3].

Based on the previous results, this study was carried out to determine the relation between the dynamic modulus of elasticity (dMOE) and the static modulus of elasticity (sMOE), and the relation between the dMOE and the modulus of rupture (MOR) of mandarin peel –sawdust

✉ Chun-Won Kang
kcwon@jbnu.ac.kr

Cheng-Yuan Li
lswforest@hotmail.com

Ho-Yang Kang
hykang@cnu.ac.kr

Sang-Sik Jang
ssjang@cnu.ac.kr

1 Jilin Provincial Key Laboratory of Wooden Materials Science and Engineering, Beihua University, Jilin 132013, People's Republic of China

2 Department of Housing Environmental Design, Research Institute of Human Ecology, College of Human Ecology, Chonbuk National University, Jeonju 561-756, Korea

3 Department of Forest Products, College of Agriculture and Life Sciences, Chungnam National University, Daejeon 305-764, Korea

composite boards with the density of 0.4, 0.5 and 0.6 g/cm^3, and the mandarin peel content of 10, 20, 30 and 40% to predict the sMOE and MOR through analysis of the correlation between dMOE and sMOE, MOR of the boards, measured by free vibration test using resonance frequency.

Materials and methods

Materials

Radiata pine (*Pinus radiata*) sawdust and mandarin peels were dried to the moisture content of 9% and pulverized using a crusher, and then screened using a 20 mesh wire screen, respectively. The urea–formaldehyde resin (solids content of 99%, E1) was used as adhesive for the composite board.

Specimen preparation

Mandarin peel–sawdust composite boards with the dimension of 35 cm × 35 cm × 1.1 cm, and with target density of 0.4, 0.5 and 0.6 g/cm^3 were manufactured using 10% of resin content, and 20, 30, and 40% of mandarin peel content as percent weight of the boards, respectively. Total number of the boards was 180 pieces, which consisted of 12 kinds of boards and 15 pieces for each kind. Screened sawdust, mandarin peel, and urea resin were mixed and then hot pressed at 150 °C to form composite boards. The hot pressing was performed in three steps, first at a pressure of 44.1 MPa for 9 min, then at 34.3 MPa for 2 min, and finally at 19.6 MPa for 1 min, with a total pressing time of 12 min.

Test of dynamic MOE

The dMOE in the longitudinal direction was estimated from the transverse vibration of the small beam with free–free conditions. The specimen was supported by two strings, as shown in Fig. 1. Supporting positions were 0.224 of total length from both ends. These positions are a nodal point for the first mode of this free vibration. On one of the beam ends, the impulse hammer tapped the specimen, and the accelerometer (B&K) detected the signal from the center of the beam. The multichannel signal analyzer (Type 3065, B&K) received these two signals simultaneously, and the frequency response function curve between impulse hammer and transducer was achieved. From the spectral analysis, the resonance frequency of transverse vibration was estimated, and the dMOE was calculated using the following formulae. Here, the influence of concentration mass by accelerometer and shear stress were not considered.

$$E_d = 48\pi^2 \rho l^4 f^2 / n^4 h^2, \tag{1}$$

where E_d = dMOE, f = resonance frequency ($f = f_0(1 + \alpha h^2/l^2)$, here, f_0 = natural frequency from analyzer, α = a constant, 8.2, h = thickness of specimens), l = length of the specimen, ρ = density of specimens, h = thickness of specimens, and n = a constant (4.73 for the fundamental mode of vibration).

Test of MOR and sMOE

Three-point bending tests were performed using a Universal Testing Machine (AGS-10 KN, Shimazu Corporation, Japan). The MOR in bending was estimated at the 165 mm of span and a 10 mm/min crosshead speed according to KSF 2208 [4]. The proportional limit, ultimate load, and deflection were obtained from load–deflection curves, and the sMOE and MOR were calculated as follows:

$$E_s = Pl^3/4bh^3w, \tag{2}$$

here E_s = sMOE, P = load, l = length of specimen, b = width of specimen, h = thickness of specimen, w = displacement.

$$\sigma_b = 3PL/2bh^2, \tag{3}$$

here σ_b = bending stress, P = maximum load, L = length of span, b = width of specimen, h = thickness of specimen.

Results and discussion

The dMOE of mandarin peel –sawdust composite boards was in range of 214.47–1327.28 MPa, the sMOE was in range of 94.09–487.56 MPa, and the MOR was in range of 1.30–6.62 MPa. The regression equations between the mechanical properties and the density of the board were as following:

$$y = 0.3478x + 34.64\ (4), \quad R^2 = 0.8911, \tag{4}$$

here x = density, y = dMOE

$$y = 0.0047x + 0.6221\ (5), \quad R^2 = 0.8597, \tag{5}$$

here x = density, y = sMOR

$$y = 0.0047x + 0.6221\ (5), \quad R^2 = 0.8009, \tag{6}$$

here x = density, y = MOR

The coefficient of determination value (R^2) between the dMOE, sMOE and MOR, and the density all showed above the value of 0.8 when the density was 0.4, 0.5 and 0.6 g/cm^3 and the mandarin peel content was 10, 20, 30, and

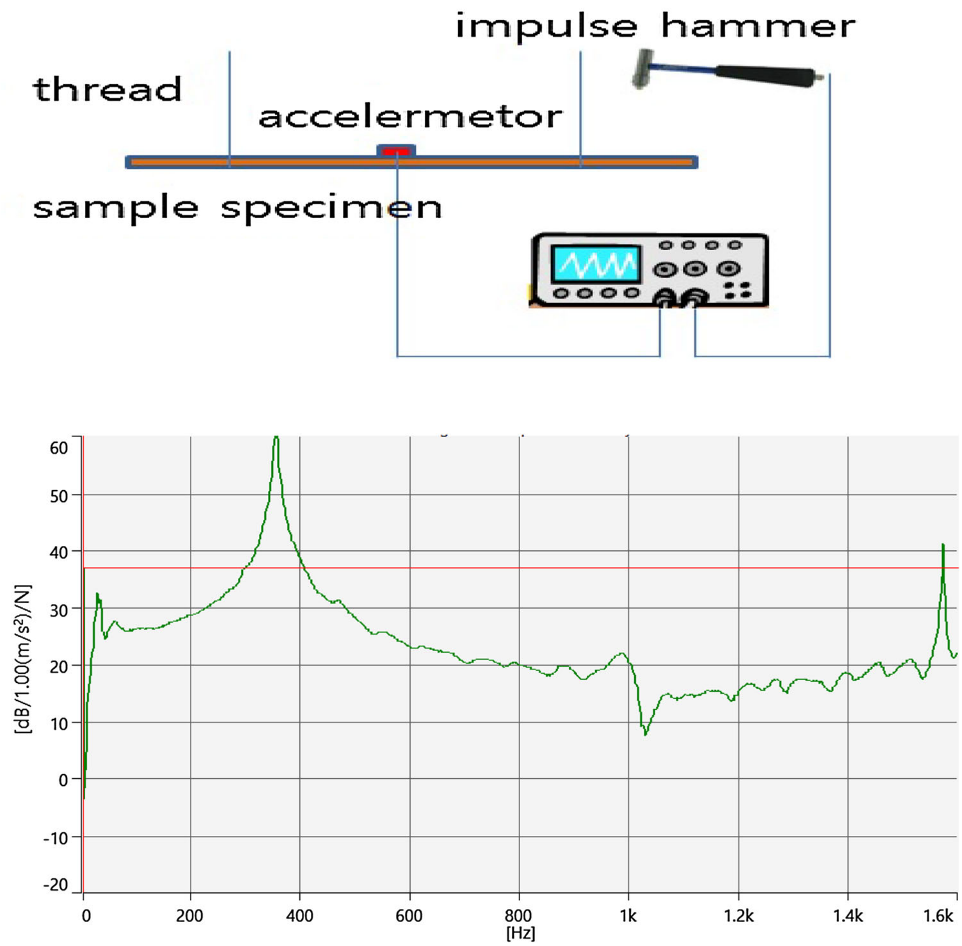

Fig. 1 Schematic diagram for dynamic modulus of elasticity measuring apparatus and typical frequency response function curve

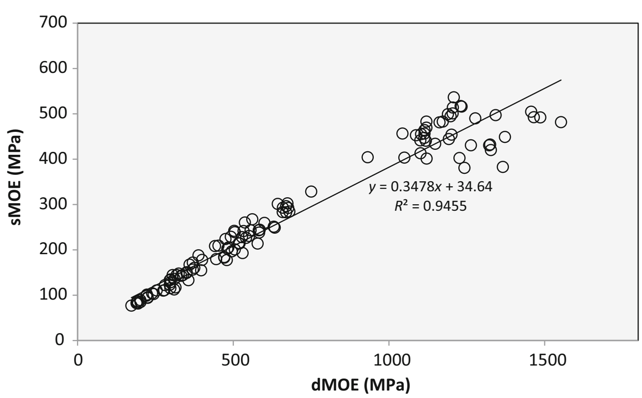

Fig. 2 Relation between the dynamic modulus of elasticity (dMOE) and the static modulus of elasticity (sMOE) of mandarin peel–sawdust composite boards

40%. These all show highly close linear correlation between the dMOE, sMOE and MOR, and density.

Relation between dMOE and sMOE

Regression model of the dMOE and sMOE of mandarin peel–sawdust composite boards is shown in Fig. 2. Correlation Analysis for the relation between the dMOE and sMOE is described in Eq. 7

$$y = 0.3478x + 34.64, \quad (7)$$

here $x =$ dMOE, $y =$ sMOE, $R^2 = 0.9455$.

R^2 between the dMOE and sMOE of the boards showed the value of 0.9455 when the density was 0.4, 0.5 and 0.6 g/cm^3 and the mandarin peel content was 10, 20, 30, and 40%. This presents highly close linear correlation between the dMOE and sMOE.

Relation between dMOE and MOR

Regression model of the dMOE and MOR of mandarin peel–sawdust composite boards is presented in Fig. 3. Correlation Analysis for relation between the dMOE and MOR is shown in Eq. 8

$$y = 0.0047x + 0.6221, \quad (8)$$

here $x =$ dMOE, $y =$ MOR, $R^2 = 0.8601$.

R^2 between the dMOE and MOR of the boards showed the value of 0.8601 when the density was 0.4, 0.5 and 0.6 g/cm^3 and the mandarin peel content was 10, 20, 30,

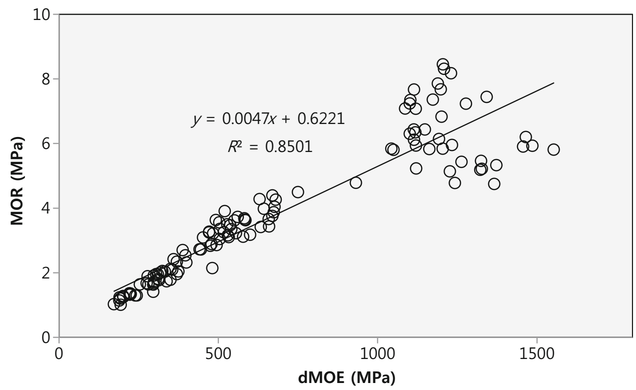

Fig. 3 Relation between the dynamic modulus of elasticity (dMOE) and the modulus of rupture (MOR) of mandarin peel–sawdust composite boards

and 40%. This presents highly close linear correlation between the dMOE and MOR.

R^2 between the dMOE and sMOE, and between the dMOE and MOR all showed high values. These indicate that the relation between the dMOE and sMOE, and relation between the dMOE and MOR of mandarin peel–sawdust composite boards have highly close linear correlation. This is in agreement with the results of the relation between the dMOE and sMOE of the green tea-wood fiber composite board [5]. Therefore, it is suggested that the sMOE and MOR can be predicted from the dMOE of mandarin peel–sawdust composite boards, measured by free vibration test using resonance frequency.

Conclusion

This study was conducted to determine the relation between the dMOE and sMOE and the relation between the dMOE and MOR of mandarin peel–sawdust composite boards. The results of this study were as follows.

There was highly close linear correlation between the dMOE and the sMOE, MOR of the mandarin peel–sawdust composite boards with the density of 0.4, 0.5 and 0.6 g/cm^3, and the mandarin peel content of 10, 20, 30 and 40%. Therefore, the sMOE and MOR can be predicted from the dMOE of the mandarin peel–sawdust composite boards measured by free vibration test using resonance frequency.

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