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ELASTIC CONSTANTS OF MDF CORE AND FACE LAYERS DETERMINED BY COMPRESSION TESTS

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Abstract:
Elastic constants of MDF core and face layers were assessed by compression tests under constant humidity conditions (21ºC and % 65 RH). Three Young's modulus, three shear modulus and six Poisson ratios were determined. Whole MDF panels (1880x3660mm) were strip to face and core layers using table saw. The cores and faces were glued together in order to achieve homogenous material properties. 20x20x60mm samples were cut in principal and 45º directions order to evaluate elastic constants of the layers. Compression tests were conducted using a biaxial extensometer to gather stress-strain data. Most of the elastic constants of face and core layers are significantly different. The Young's modulus in perpendicular directions for both layers is inferior to those of parallel directions. The shear values of face layers are significantly higher than those of core layers. Some of the Poisson' ratios are similar. The data presented in the study can be used in advanced modeling of MDF panels where high accuracy is required.

Key words: *MDF core and face; elastic constants; compression tests.*

INTRODUCTION

Medium density fiberboard (MDF) consisted of wood fibers that are bonded together by a synthetic adhesive under pressure and temperature. One of the most important benefits of wood composites comes from the fact that their properties can be engineered (Irle and Barbu 2010). In most studies, wood composites are assumed isotropic, which needed only one Young's modulus and one Poisson's ratio to be needed in predicting their mechanical behavior. This assumption oversimplifies the behavior of MDF, which considered a plane isotropic material. However, a detailed investigation of elastic constants would be helpful. Most investigations in the literature deal with only modulus of elasticity in bending, and the Poisson's ratio accepted is 0.3. Further elasticity data would be valuable for more advanced engineering analyses (Janowiak *et al.* 2001). The values determined with bending tests are not in all cases convenient for modeling purposes since shear deformation sometimes cannot be separated (Bodig and Jayne 1993).

Studies conducted in the recent decades have shown that wood composites can be treated as orthotropic materials (Bucur 1992; Janowiak *et al.* 2001; Najafi *et al.* 2005; Wilczyński and Kociszewski 2011; Plenzler *et al.* 2017). Comparing to wood, literature is very scarce concerning elastic constants of wood-based composites. According to Ganev *et al.* (2005) the level of densification of each layer, its distance from the central plane and its thickness determine its specific effect on the overall MDF properties.

Elastic constants can be determined using static-destructive and non-destructive methods. Janowiak *et al.* (2001) investigated orthotropic behavior of structural composite lumbers in bending. Wilczyński and Kociszewski (2011) applied compression test in order to determine elastic constants of particleboard layers. Plenzler *et al.* (2017) studied elastic properties of OSB layers using tension tests. All of the investigations have shown that wood based composites have some degree of anisotropy.

OBJECTIVE

MDF was one of the most rapidly growing wood base products in the world and have been utilized in a wide range of applications especially furniture and flooring (Popovska *et al.* 2016). Full elastic constants of MDF faces and core has not been investigated, knowing these properties, more detailed stress analysis especially for joints can be conducted using advanced numerical solutions. The purpose of the study was to determine elastic constants of MDF layers which can be used in advanced numerical analysis.

MATERIALS AND METHOD

Commercial MDF panels were used in the study. The face and core layers were mechanically separated and glued in order to achieve homogenous layer properties. A PVAc adhesive was used in reconstruction. The density of the whole MDF panel which the specimens were prepared was 0.72g/cm^3. The MDF panel was manufactured using urea formaldehyde type resin. The thickness of the panel was 18mm. The thickness of the face and core layers were approximately 2 and 10mm, respectively. Similar methodology in preparation of samples which used in the study of Wilczyński and Kociszewski (2011) was applied.

Samples with nominal dimensions of approximately 18x18x65mm for each direction (x, y, z) and with 45° angle in planes xy, yz and xz from the layers were prepared for compression tests. The number of replications for principal and angular directions was 20 and 10, respectively. Before testing, specimens were conditioned in climatic chamber at 65% relative air humidity (RH) at a temperature of 21°C. After the specimen had reached equilibrium MC, uni-axial compression tests were carried out using a universal testing machine. All tests were performed at standard climatic conditions (65% RH and 21°C). The strains were measured using a biaxial extensometer (Fig. 1). Apparent densities of the samples were calculated using the stereo-metric method. The stress-strain curves obtained were used in order to evaluate Young's modulus, Poisson ratios and shear modulus of the samples. The following formulas were applied:

$$E_i = \frac{\Delta\sigma_i}{\Delta\varepsilon_i} = \frac{\sigma_{i,2}-\sigma_{i,1}}{\varepsilon_{i,2}-\varepsilon_{i,1}} \quad i \in R, L, T \tag{1}$$

$$\upsilon_{ij} = -\frac{\varepsilon_j}{\varepsilon_i}, \quad i,j \in R, L, T \text{ and } i \neq j \tag{2}$$

where: Ei = Elastic modulus, υij = Poisson ratios, and limits of proportionality were derived from the linear portion of the stress-strain curve. The elastic modulus is in the direction of the subscript, x (panel longitudinal direction), y (width) or z (thickness) and υ with the first subscript being the direction of load, and the second subscript being the perpendicular direction of measured dimension change. Shear modulus of the specimens with 45° angle in planes xy, yz and xz was determined using the following:

$$G_{xy} = \frac{\tau_{LR}}{\gamma_{LR}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{3}$$

$$G_{xz} = \frac{\tau_{LT}}{\gamma_{LT}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{4}$$

$$G_{yz} = \frac{\tau_{RT}}{\gamma_{RT}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{5}$$

where: σ_V = average vertical stress, ε_H = average horizontal strain, ε_V= average vertical strain. More detailed information on calculation of shear modulus from angled specimens in compression tests can be found in Aira *et al.* (2014).

Fig. 1.
Compression testing of MDF core layers using bi-axial extensometer.

RESULTS AND DISCUSSION

A typical stress-deformation curve that is used to determine the Young's modulus, Poisson ratios and shear modulus of specimens tested in compression test is shown in Fig. 2. Average values for elastic constants determined for face and core layers of MDF specimens tested are presented in Tables 1. The average density of the faces was 0.83g/cm^3 whereas the average density of the cores was 0.67g/cm^3. The coefficient of variations of the elastic constants tested varied from 12% to 35%.

Comparing to solid wood, the equilibrium moisture contents of the MDF layers used in the study are lower (Table 1). The moisture content of the wood base composites is lower than those of solid wood of the same species under the same conditions because of strong influence of drying, adhesive and hot-pressing (Niemz 2010).

Mechanical properties of wood based composites such as MDF are dependent upon the properties of the wood fibers and the way in which they are combined. It is well known that mechanical properties of MDF are mostly related to panel density, moisture content, adhesive type and ratio etc. While mechanical properties are increased with higher panel density, higher moisture content reduces most of the mechanical properties (Suchland and Woodson 1991).

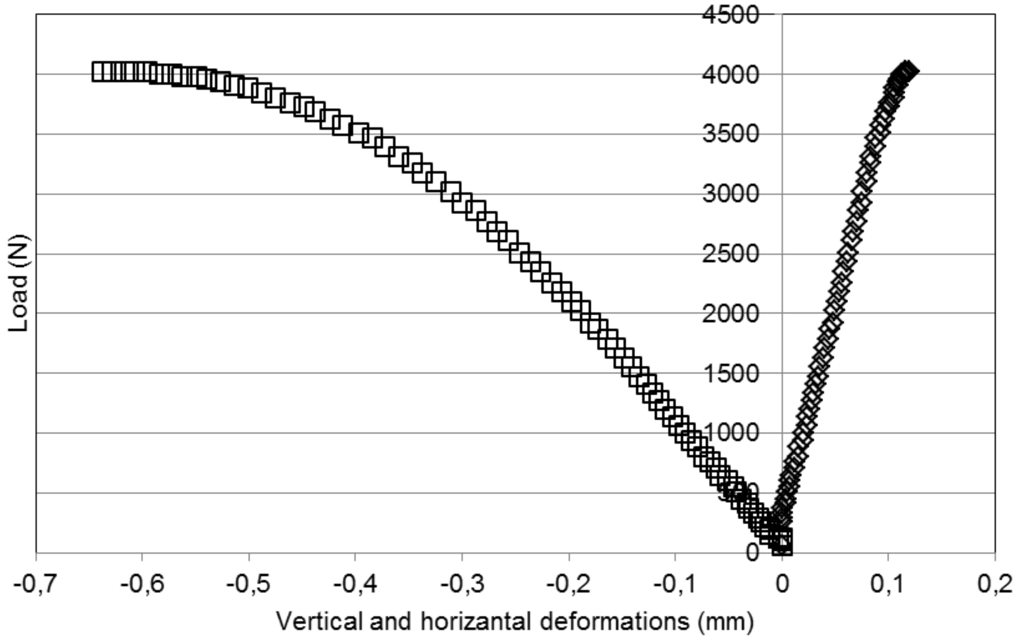

Fig. 2.
Load – deformation diagrams used to calculate Young's modulus, Poisson ratios and shear modulus properties of the face layers.

Table 1
Elastic constants of MDF face and core layers determined from compression tests

Elastic Constants	Density (gr/cm^3)	MC (%)	Face layers	Density (gr/cm^3)	MC (%)	Core layers
Ex (N/mm^2)	0.83	6.8	4100 (20)*	0.68	7.2	1950 (17)
Ey (N/mm^2)	0.84	6.6	3950 (35)	0.67	7.2	1890 (23)
Ez (N/mm^2)	0.83	6.8	350 (27)	0.67	7.1	150 (22)
Gxy (N/mm^2)	0.82	9.7	1650 (17)	0.67	7.3	1050 (21)
Gxz (N/mm^2)	0.83	9.7	250 (27)	0.67	7.2	110 (25)
Gyz (N/mm^2)	0.83	9.8	265 (31)	0.68	7.3	105 (17)
υxy	0.83	9.6	0.3 (27)	0.68	7.2	0.32 (12)
υyx	0.84	9.5	0.4 (28)	0.67	7.2	0.37 (27)
υzx	0.83	9.6	0.026 (29)	0.67	7.1	0.012 (37)
υzy	0.83	9.6	0.033 (48)	0.67	7.1	0.039 (52)
υxz	0.83	9.6	0.28 (17)	0.67	7.2	0.25 (28)
υyz	0.84	9.5	0.25 (27)	0.67	7.2	0.33 (26)

* Values in parenthesis are coefficient of variations

Although density of the face layers is 19% higher than core layers, the differences between the Young's modulus of the core and face layers (52-57%) are greater than the difference between the densities of these layers. The difference is more apparent in the z direction. Ganev *et al.* (2005) also reported that elastic constants of Ex and Ez are significantly related to whole panel density. The Young's modulus of the face layer in x and y directions are twice of those of the core layers. Wilczyński and Kociszewski (2007) found that bending properties of face layers are three times higher than those of core layers. There is no significant differences between the Young's modulus of x and y direction for face and core layers. Wilczyński and Kociszewski (2007) stated that the bending properties of MDF layers were almost isotropic in the planes of layers and very strongly anisotropic in the planes perpendicular to layers. Popovska *et al*. (2016) presented that there is no significant differences in the mean values of bending strength for whole MDF in different directions, but bending elasticity values were slightly different. The results of the study also show that the values of Young's modulus in the plane of the MDF layers are almost identical. This can be explained by no difference in fiber geometry and resin content throughout MDF panel thickness, along and across the forming direction; therefore, the differences between the layers are inherently settled by the compaction ratio (Ganev *et al.* 2005).

Shear properties of MDF is rarely investigated in the literature. There are several test methods for testing shear properties such as block shear, torsion tests, interlaminar shear and torsional or flexural vibration. In recent years, acoustic methods became popular because of easy of use. Each method has its peculiar advantages and disadvantages (Schulte and Frühwald 1996). It is difficult to make direct comparisons between the results of individual research efforts because of the stress distributions inherent to the test setups, but it can be concluded that shear properties of MDF is reflection of fiber geometry, resin content, resin type, density and compaction ratio.

In general, in plane shear modulus, Gxy is significantly higher than shear modulus values in perpendicular directions and shear modulus of the face layers are significantly higher than those of core layers. Shear properties of Gxz and Gyz were not significantly different. The differences in shear values of MDF layers can be explained by density or compaction ratio. According to Ganev *et al.* (2005) and Suzuki and Miyagawa (2003) shear modulus (Gxz) of whole MDF panels are increased with panel density. The influence of glue lines bonding for reconstructing of the layers on shear modulus is unknown. Young's modulus and shear modulus values for face and core layers are compared in Fig. 3.

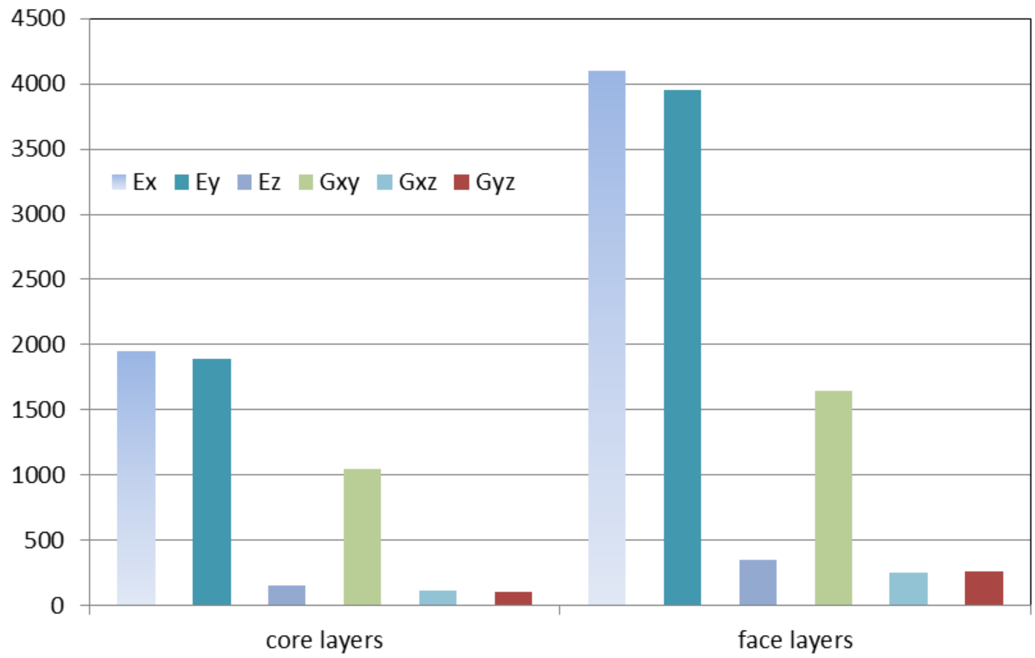

Fig. 3.
Comparison of the Young's modulus and shear modulus for face and core layers.

Wood based composites were considered as isotropic material and Poisson's ratio of 0.3 was assumed (Bodig and Jayne 1993), but investigations have shown that Poisson's value is within the range of 0.14–0.28 for this type of materials (Noboru and Taeko 2004). There is no standard test method for the determination of Poisson's ratio of wood-based materials.

In this study, the Poisson's ratios of face and core layers of MDF were not significantly different. The differences are only significant for those calculated for υzx υzy of face and core layers. Some of the calculated Poisson's ratios for the face and core layers of MDF are slightly higher than those reported for wood composites in the literature. Poisson's ratios υxy and υxz are similar to those reported by Ganev *et al.* (2015). According to Ganev *et al.* (2005) Poisson's ratios are independent from density. Sebera *et al.* (1024) also reported that Poisson's ratios of MDF reveal low correlations with vertical density profile.

CONCLUSIONS

Elastic constants of an industrial UF bonded 18mm MDF faces and core layers were investigated using compression tests. The Young's modulus and shear modulus of the face and core layers are significantly different. The relative differences between the Young's modulus and shear modulus were greater than the differences between the densities of the layers. The Young's modulus in x and y directions are identical for both face and core layers, thus layers can be assumed plane isotropic. Most of the Poisson's ratios of the both layers were not significantly different. Results of the study can be used in advanced modeling of MDF panels under various loading conditions where detailed results are required.

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