WOOD RESEARCH
63 (6): 2018
1059-1070

MOISTURE DEPENDENT ELASTIC CONSTANTS OF PARTICLEBOARD LAYERS BY ULTRASOUND AND COMPRESSION TESTS

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(Received November 2017)

ABSTRACT

Elastic constants of particleboard layers were investigated using by means of ultrasonic waves and compression tests under different humidity regimes. Three Young's modulus, three shear modulus and six Poisson ratios were determined. Three longitudinal and six shear wave velocities propagating along the principal axes of anisotropy, and additionally, three quasi-shear wave velocities at 45° angle with respect to the main axes of anisotropy were measured. Compression tests were also conducted in order to measure the accuracy of ultrasonic method. Comparing with calculated values, the predicted Young's modulus values in the principle directions are acceptable. The shear values calculated using ultrasonic method are higher than those determined from compression tests, particularly in the perpendicular directions. Some of the Poisson's ratios predicted by ultrasound seem to be extreme. The influence of moisture content on Poisson's ratios is variable. It can be concluded that ultrasonic method can be used as alternative in determination of elastic modulus for particleboard layers at different moisture conditions. The accuracy of ultrasound for determining the Poisson's ratios of particleboard layers is questionable.

KEYWORDS: Particleboard layers, elastic constants, ultrasound, compression, moisture content

INTRODUCTION

Particleboard consisted of wood particles that are bonded together by a synthetic adhesive under pressure and temperatures. One of the most important benefits of wood composites comes from the fact that their properties can be engineered (Irle and Barbu 2010). Wood composites used to be assumed isotropic, which needed only two elastic constants to be needed in predicting their mechanical behavior. This assumption oversimplifies the structure of particleboard, which considered a plane isotropic material. However, a detailed investigation of elastic properties would be beneficial. Most studies in the literature dealt with only modulus of elasticity in bending. 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 (Bodig and Jayne 1993, Janowiak et al. 2001, Bucur 1992, 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.

Elastic constants can be determined using static-destructive and non-destructive methods. Janowiak et al. (2001) investigated orthotropic behavior of structural composite lumbers in flexure. Wilczyński and Kociszewski (2011) applied compression test in order to determine elastic constants of particleboard. Plenzler et al. (2017) studied elastic properties of OSB layers using tension tests. Use of non-destructive testing and non-destructive evaluation in the field of wood and wood-based materials is advancing every day (Brashaw et al. 2009, Dündar and Divos 2014). Investigations using ultrasound on the determination of elastic properties of wood based composites have been carried out since the 1980's for the use of Christoffel's equations to determine the elastic constants. Bucur (1992) used ultrasonic method to characterize anisotropy of structural flakeboard. Najafi et al. (2005) used ultrasonic technique for the mechanical characterization of commercial particleboard. All of the investigations have shown that wood based composites have some degree of anisotropy.

Elastic constants of particleboard layers have been only studied by Wilczyński and Kociszewski (2011) at constant humidity conditions. Knowing these properties, more detailed stress analysis especially for joints can be conducted using advanced numerical solutions. The mechanical properties of wood-based panels significantly depend directly on their moisture content (MC), and indirectly on the relative humidity (RH) in which they are used (Niemz 2010, Kociszewski 2014). Although wood based composites have slightly lower equilibrium moisture content, the change due to the moisture in the properties is unavoidable. The moisture dependent orthotropic behavior of particleboard has not been thoroughly investigated nor has elasticity data widely reported. The purpose of this study was to investigate moisture dependent elastic constants of particleboard layers using ultrasonic method and compression tests.

MATERIALS AND METHOD

Commercial particleboard manufactured by ORMA Company with three layers was used in the study. The face and core layers were mechanically separated and glued in order to achieve homogenous layer properties. A PVA adhesive was used in reconstruction. The thickness of the face and core layers were approximately 2 and 10 mm, respectively. Similar methodology in preparation of samples which used in the study of Wilczyński and Kociszewski (2011) was applied. For ultrasonic testing, roughly 18 mm cubic samples for x, y, z and with 45° angle in planes xy, yz, xz from the outer and inner layers were prepared.

The number of replication was 10 for the ultrasonic measurements. Longitudinal and shear wave velocities propagating along the principal axes of anisotropy, and additionally, quasi-shear wave velocities at 45° angle with respect to the principal axes of anisotropy were measured using EPOCH 650 ultrasonic flaw detector. The longitudinal wave frequency was 2.25 MHz, and the transversal (shear) wave frequency was 1 MHz. To ensure coupling between the specimen and the sensors during measurements, a gel medium was used. A small pressure by hand was also applied.

The orthotropic elastic behavior can be described by Hooke's three-dimensional law of elasticity and is expressed by its compliance matrix (S_{ij}). The compliance matrix consists of twelve constants which nine are independent; three modulus elasticity or Young's modulus (E_x, E_y, E_z), three modulus of rigidity (G_{xy}, G_{xz}, G_{yz}) and six Poisson's ratios (three of them are independent; υ_{xy}, υ_{xz}, υ_{yz}). Stiffness matrix, C, was determined based on the velocities and by using the Christoffel tensor (Bucur 2006).

$$[C] = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{21} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{31} & C_{32} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \tag{1}$$

Where the terms of the main diagonal were defined as follows:

$$C_{11} = C_{XX} = \rho V_{XX}^2$$
$$C_{22} = C_{YY} = \rho V_{YY}^2 \tag{2}$$
$$C_{33} = C_{ZZ} = \rho V_{ZZ}^2 \tag{3}$$
$$C_{44} = C_{YZ} = (\rho V_{YZ}^2 + \rho V_{ZY}^2)/2 \tag{4}$$
$$C_{55} = C_{XY} = (\rho V_{XZ}^2 + \rho V_{ZX}^2)/2 \tag{5}$$
$$C_{66} = C_{XY} = (\rho V_{XY}^2 + \rho V_{YX}^2)/2 \tag{6}$$

$$C_{23} = \sqrt{\left(C_{22} + C_{44} - 2\rho V_{YZ/YZ}^2\right)\left(C_{33} + C_{44} - 2\rho V_{YZ/YZ}^2\right)} - C_{44} \tag{8}$$

$$C_{13} = \sqrt{\left(C_{11} + C_{55} - 2\rho V_{XZ/XZ}^2\right)\left(C_{33} + C_{55} - 2\rho V_{XZ/XZ}^2\right)} - C_{55} \tag{9}$$

$$C_{12} = \sqrt{\left(C_{11} + C_{66} - 2\rho V_{XY/XY}^2\right)\left(C_{22} + C_{66} - 2\rho V_{XY/XY}^2\right)} - C_{66} \tag{10}$$

where: ρ - the density of the wood ($kg \cdot m^{-3}$),
$V\alpha$ - the wave velocity in the α direction (quasi-transverse shear waves,) ($m \cdot s^{-1}$),
C_{ij} - the terms of the main diagonal in the matrix.

$$C^{-1} = S \tag{11}$$

The coefficients of the stiffness matrix are related to the elastic constants expressed in the terms of the compliance matrix:

$$[S] = \begin{bmatrix} \frac{1}{E_X} & -\frac{\upsilon_{21}}{E_Y} & -\frac{\upsilon_{31}}{E_Z} & 0 & 0 & 0 \\ -\frac{\upsilon_{12}}{E_X} & \frac{1}{E_Y} & -\frac{\upsilon_{32}}{E_Z} & 0 & 0 & 0 \\ -\frac{\upsilon_{13}}{E_X} & -\frac{\upsilon_{23}}{E_Y} & \frac{1}{E_Z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{YZ}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{XZ}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{XY}} \end{bmatrix} \tag{12}$$

Samples with nominal dimensions of approximately 18 x 18 x 65 mm for each direction (x, y, z) and with 45° angle in planes xy, yz and xz from the layers were prepared for compression test. The number of replications for principal and angular directions was 20 and 10, respectively. Before testing, specimens were randomly divided into three groups and conditioned in climatic chambers at 45, 65 and 85 % relative 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. 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:

$$E_i = \frac{\Delta\sigma_i}{\Delta\varepsilon_i} = \frac{\sigma_{i,2}-\sigma_{i,1}}{\varepsilon_{i,2}-\varepsilon_{i,1}} \quad i \in R,\ L,\ T \tag{13}$$

$$\upsilon_{ij} = -\frac{\varepsilon_j}{\varepsilon_i}, \quad i, j \in R,\ L,\ T \text{ and } i \neq j \tag{14}$$

where: Ei is elastic modulus, υ_{ij} is 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:

$$G_{xy} = \frac{\tau_{LR}}{\gamma_{LR}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{15}$$

$$G_{xz} = \frac{\tau_{LT}}{\gamma_{LT}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{16}$$

$$G_{yz} = \frac{\tau_{RT}}{\gamma_{RT}} = \frac{\sigma_V}{2\,(\varepsilon_H - \varepsilon_V)} \tag{17}$$

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).

RESULTS AND DISCUSSION

Average values for sound velocity (SV) and moisture dependent elastic constants determined for outer and core layers of particleboard specimens tested are presented in Tabs. 1 - 4.

Tab: 1: Sound velocities ($m \cdot s^{-1}$) measured at different moisture content of particleboard face layers.

MC	V_{11}	V_{22}	V_{33}	V_{66}	V_{55}	V_{44}	V_{12}	V_{13}	V_{23}
6.2	2350 (4)*	2311 (5)	910 (5)	1387 (6)	915 (5)	897 (7)	1195 (7)	799 (6)	765 (8)
8.5	2294 (5)	2277 (5)	861 (6)	1365 (5)	888 (7)	853 (6)	1097 (6)	771 (6)	746 (8)
12.0	1996 (7)	1972 (9)	670 (9)	1022 (6)	675 (6)	642 (9)	762 (8)	459 (7)	435 (9)

* Values in parenthesis are coefficient of variations

Tab. 2: Moisture dependent elastic constants of particleboard face layers as determined by ultrasound.

MC	E_x	E_y	E_z	G_{yz}	G_{xz}	G_{xy}	υ_{xy}	υ_{xz}	υ_{yx}	υ_{yz}	υ_{zx}	υ_{zy}
6.2	3454	3182	592	660	687	1577	0.58	0.40	0.56	0.80	0.060	0.124
8.5	3019	2900	547	597	647	1528	0.73	0.39	0.72	0.66	0.055	0.094
12.0	1399	1257	147	338	374	856	0.98	2.78	0.95	3.45	0.31	0.40

Tab. 3: Sound velocities ($m \cdot s^{-1}$) measured at different moisture content of particleboard core layers.

MC	V11	V22	V33	V66	V55	V44	V12	V13	V23
6.7	1990 (8)*	1815 (11)	678 (10)	1172 (10)	682 (13)	635 (9)	925 (12)	566 (11)	525 (15)
10.1	1850 (11)	1644 (17)	658 (14)	1095 (12)	662 (13)	619 (13)	826 (12)	518 (18)	498 (14)
13.5	1394 (15)	1204 (17)	471 (15)	841 (14)	505 (16)	460 (14)	701 (14)	434 (13)	410 (19)

* Values in parenthesis are coefficient of variations

Tab. 4: Moisture dependent elastic constants of particleboard core layers as determined by ultrasound.

MC	E_x	E_y	E_z	G_{yz}	G_{xz}	G_{xy}	υ_{xy}	υ_{xz}	υ_{yx}	υ_{yz}	υ_{zx}	υ_{zy}
6.7	1329	1041	165	198	228	673	0.67	0.96	0.56	1.29	0.11	0.18
10.1	1044	845	145	188	215	588	0.72	1.41	0.57	1.10	0.18	0.18
13.5	766	572	98	104	125	347	0.53	0.61	0.40	0.52	0.07	0.08

Elastic constants calculated from the compression tests are presented in Tabs. 5 and 6.

Tab. 5: Moisture dependent elastic constants of face layers determined by compression test.

MC	E_x	E_y	E_z	G_{yz}	G_{xz}	G_{xy}	υ_{xy}	υ_{xz}	υ_{yx}	υ_{yz}	υ_{zx}	υ_{zy}
6.3	3415 (17)*	3146 (16)	440 (11)	349 (12)	399 (16)	1410 (15)	0.67 (21)	0.48 (19)	0.37 (15)	0.56 (17)	0.055 (32)	0.066 (37)
8.2	3005 (14)	2742 (17)	417 (21)	274 (19)	312 (25)	1288 (29)	0.65 (19)	0.3 (27)	0.33 (32)	0.77 (29)	0.124 (38)	0.09 (42)
12.1	1243 (18)	1184 (13)	197 (29)	220 (21)	238 (31)	709 (32)	0.25 (26)	0.24 (28)	0.21 (35)	0.46 (22)	0.077 (41)	0.07 (43)
65 % RH[1]	4480	3760	454	338	345	1670	0.252	0.374	0.206	0.346	0.04	0.045

* Values in parenthesis are coefficient of variations, [1] Wilczyński and Kociszewski (2011)

Tab. 6: Moisture dependent elastic constants of core layers determined by compression test.

MC	E_x	E_y	E_z	G_{yz}	G_{xz}	G_{xy}	υ_{xy}	υ_{xz}	υ_{yx}	υ_{yz}	υ_{zx}	υ_{zy}
6.5	1362 (18)*	1184 (21)	89 (20)	221 (17)	248 (22)	755 (18)	0.33 (19)	0.36 (27)	0.28 (22)	0.55 (21)	0.055 (34)	0.043 (45)
10.2	1023 (22)	862 (29)	78 (25)	184 (21)	227 (25)	608 (29)	0.43 (32)	0.27 (28)	0.53 (36)	0.32 (19)	0.051 (37)	0.066 (49)
13.7	578 (26)	533 (32)	36 (34)	32 (30)	40 (32)	336 (27)	0.7 (28)	0.43 (31)	0.75 (26)	0.23 (33)	0.032 (44)	0.035 (59)
65 % RH1	1820	1470	231	171	200	692	0.323	0.334	0.249	0.307	0.041	0.049

*Values in parenthesis are coefficient of variations,[1] Wilczyński and Kociszewski (2011)

The density of the whole particleboard panel which the specimens were prepared was 0.65 g·cm^{-3}. Test results indicate that there is significant difference between the density of outer and core layers. The average density of the outer layer was 0.82 g·cm^{-3}, and the average density of the core layers was 0.49 g·cm^{-3} at 65 % relative moisture content. The sound velocities in main directions and between outer and core layers are also significantly different. The coefficient of variations for the sound velocities was less than 20%.

Comparing to solid wood, the equilibrium moisture contents of the particleboards layers used in the study are lower. 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 particle drying, adhesive and hot-pressing (Niemz 2010). The lower moisture content of outer layers can also be explained with the higher percentage of adhesives than core layers as generally applied during manufacturing of particleboard.

In general, the results indicate clear differences between the V11 along the main directions (V11> V22> V66>V55>V33>V44). The corresponding stiffness values are arranged in the following order: C11>C22>C66> C55>C33> C44 at 65 RH %. This is similar to those reported by flake-board (Bucur 1992) and whole particleboard (Najafi et al. 2005). Comparing with solid woods, particleboard has relatively low sound velocities in every direction (Bucur 2006). Sound travels at the lowest speed in the thickness (z) direction probably due to the gaps or voids encountered. For solid wood; the sound velocities in radial direction are usually around a third of the longitudinal wave velocity. Radial velocity is approximately 50% higher than tangential velocity for solid wood (Beall 2002). For particleboard, the difference between longitudinal and perpendicular velocities is smaller indicating uniform properties between the x and y directions. The difference is extreme in the thickness (z) direction.

The ultrasound velocity of the solid wood is affected by about 0.45 to 0.8 percent per percent of MC change in the hygroscopic range (Llana et al. 2014). The influence of moisture on sound velocity of particleboard is considerably greater. The sound velocity in the outer layers increases more than 2 % for longitudinal waves and more than 5 % for shear waves within the measured MC range. The increase is even more severe for the core layers. This could be explained by swelling of the particles during moisture up-taking. The swelling is often accompanied with internal bond failure and thus internal structure change (Wu and Suchsland 1997, Wu and Piao 1999). Thus sound velocities of particleboard are expected to be remarkably altered by moisture changes as compared to solid wood. Similar values of increase due to the MC change were also observed for stress wave velocity of the particleboard (Han et al. 2006).

For both the face and core layers the Young's modulus Ex is higher than the Young's modulus Ey and Ez as expected. For the face layers; the ratio of Young's modulus in x, y and z directions for face layers is nearly 7.2:6.5:1, respectively (at 65% RH) showing high anisotropy. The ratio of the Young's modulus in x, y and z directions determined from sound velocities is 5.5:5.4:1, respectively indicating lower anisotropy comparing to the compression tests. Wilczyński and Kociszewski (2011) reported that Ex is 13-14% higher than Ey, and Ez is nearly one tenth of Ex for the face layers. For the core layers; the ratio of the Young's modulus in x, y and z direction is 13:11:1 showing higher anisotropy than face layers. The ratio of the Young's modulus in x, y and z directions determined from sound velocities is 7:5.8:1. The coefficient of variations for the Young's modulus varied from 11 % to 29 %.

Although density of the face layers is % 39 higher than core layers (at 65 % RH), the differences between the Young's modulus of the core and face layers (65- 81 %) are greater than the difference between the densities of these layers. The difference is more apparent in the z direction. The Young's modulus of the core layers ranges from 18 % to 34% of those of the face layer determined in compression tests. It seems that the Young's modulus of particleboard layers is not only depends on the density but also other factors such as adhesive amount used in the manufacturing.

In general, Young's modulus in all directions is decreasing dramatically with increasing MC Figs. 1 and 2 show that the decrease is highly linear. For the face layers; with a decrease of 63% in the measured MC range, the decrease is most significant for the Ex followed by Ey (62%) and Ez (55%). The percentages of decrease in Young's modulus determined from ultrasonic method in the x, y and z directions are 59, 60 and 75%, respectively. For the core layers; with a decrease of 59% in the measured MC range, the decrease is most significant for the Ez followed by Ex (57%) and Ey (54%). The percentages of decrease in Young's modulus determined from ultrasonic method in the x, y and z directions are 42, 45 and 40%, respectively.

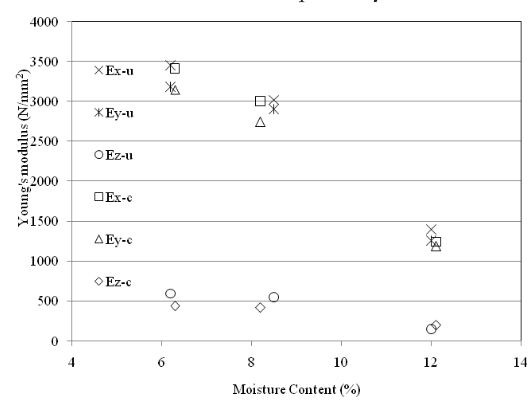

Fig. 1: Moisture dependent Young's modulus of face layers determined by ultrasound (u) and compression (c) tests.

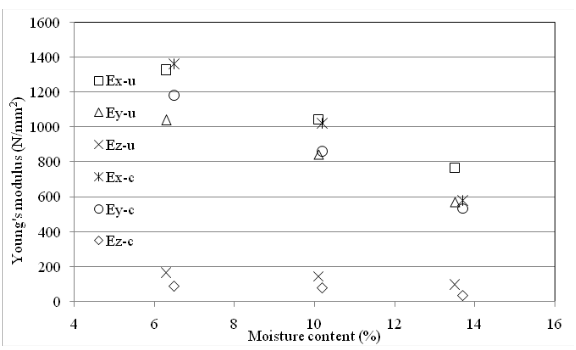

Fig. 2: Moisture dependent Young's modulus of core layers determined by ultrasound (u) and compression (c) tests.

Comparing with the predicted Young's modulus in main directions using ultrasound, values obtained with compression tests are mostly lower. According to Bucur (2006) the Young's modulus obtained from the ultrasonic technique are greater than the static modulus, although the dynamic and static modulus are generally strongly correlated. It is known that dynamically determined elastic properties are increased by 10% to 20% compared with values calculated from static tests (Keunecke et al. 2011).

For the face layers; shear modulus determined from shear velocities in xy, xz and yz planes are higher than values calculated from compression tests, particularly in xz and yz planes. Sound velocity determined shear values are mostly lower for the core layers. This could be due to the voids or gaps inherited in the structure of core layers because of larger particles used in the manufacturing.

The shear values of the core layer range from 47 % to 73 % of those of the face layer at 65 % RH. The shear values in the perpendicular planes are much smaller than that of parallel plane. They are only 21% and 24% of the Gxy for the face layer, and 30% and 37% of the Gxy for the core layer. Similar values also reported by Wilczyński and Kociszewski (2011).

The shear values decrease proportionally with increasing the moisture content of the layers. For the face layers; with a decrease of 49 % in the measured MC range, the decrease is most significant for the Gxy followed by Gxz (40 %) and Gyz (36 %). For the core layers; the change is more dramatic which is in the range of 55% and 85% for Gxy and Gyz. Kociszewski (2014) reported that the change in the moisture content of the panel by 1% results in the change of shear modulus by about 4.7% using twisted square plate method for the whole panels. The results of this study present higher percentage due to the MC changes. The coefficient of variation ranged from 15% to 32% for the shear values. Figs. 3 and 4 present the relationship between shear values and moisture content.

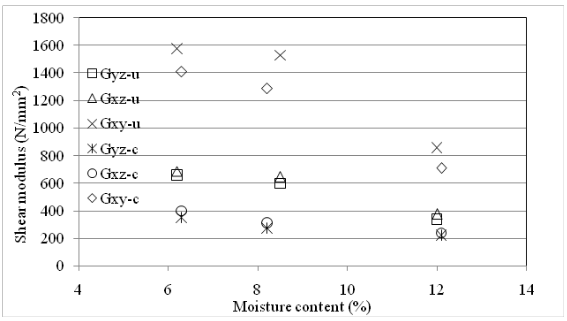

Fig. 3: Moisture dependent shear modulus of face layers determined by ultrasound (u) and compression (c) tests.

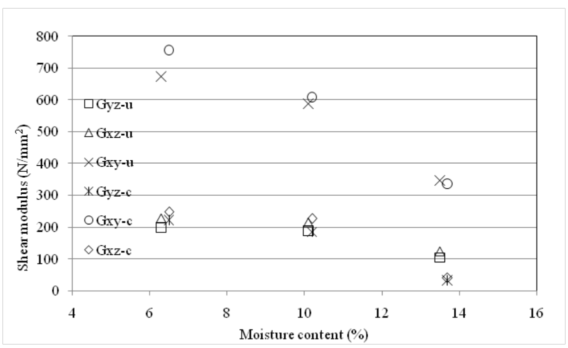

Fig. 4: Moisture dependent shear modulus of core layers determined by ultrasound (u) and compression (c) tests.

Relationship between board properties and manufacturing variables makes it complex to predict shear properties of particleboard and the comparison of shear properties collected from different test methods. It is also difficult to make direct comparisons between the results of individual research efforts because of the stress distributions inherent to the test setups (Harrison 2006).

The ultrasound method predicted higher Poisson's ratios than compression tests. Some of the Poisson's ratios predicted by ultrasound are largely different than corresponding values determined in compression tests. Prediction of the Poisson's ratios using ultrasound is questionable. There is no logical explanation for extreme values. Extreme results of Poisson's ratios determined by ultrasound were also reported for structural flakeboard by Bucur (1992) and whole particleboard by Nejafi et al. (2005). Bodig and Jayne (1993) regarded wood composites as isotropic materials and assumed values both for υ_{xy} and for υ_{xz} in the range of 0.1 to 0.3. Moarcas and Irle (1999) presented similar values for corresponding Poisson's ratios. Most of the Poisson's ratios determined in compression in this study are also slightly higher than those reported by Wilczyński and Kociszewski (2011). The Poisson's ratios of the face layer are usually greater than those of core layers. The coefficient of variation for the Poisson's ratios was in the range of 18% to 59%.

The effect of MC on the Poisson's ratios is not consistent. For the face layers; while Poisson's ratios predicted by ultrasound seem increasing with increasing moisture content, Poisson's determined from compression tests mostly decreasing with increasing moisture content. For the core layers; no clear tendency of moisture content-Poisson's relationship exists. Conflicting results for the relationship of moisture and Poisson's ratios in the literature can be found (Hering et al. 2012, Ozyhar et al. 2013, Mizutani and Ando 2015, Kretschmann and Green 1996). The inconsistency of MC effect may be explained by high variation in the Poisson's ratios.

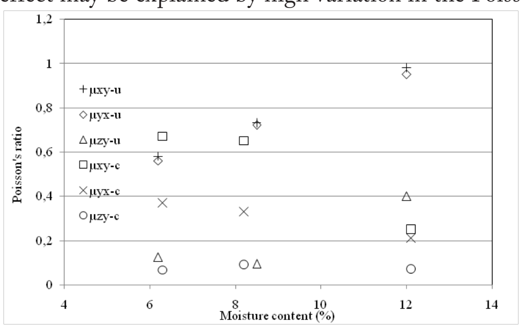

Fig. 5: Moisture dependent Poisson's ratios of face layers determined by ultrasound (u) and compression (c) tests.

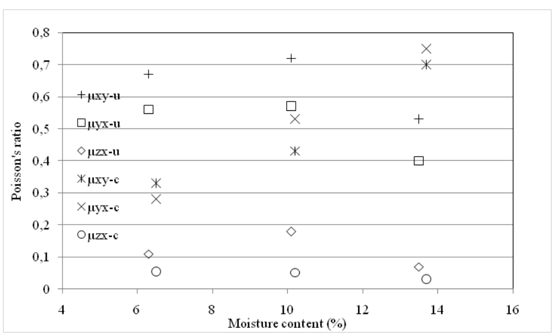

Fig. 6: Moisture dependent shear modulus of core layers determined by ultrasound (u) and compression (c) tests.

Figs. 5 and 6 present the relationship between moisture content and Poisson's ratios. In the figures, some values are illustrated in order to prevent confusion.

CONCLUSIONS

Moisture dependent elastic constants of particleboard layers were investigated using non destructive ultrasound and compression tests. Both Young's modulus and shear modulus determined using ultrasound and compression are compatible. Some of the Poisson's ratios predicted using ultrasound is extreme. Increase of moisture content significantly decreases Young's modulus and shear modulus for particleboard layers. Influence of moisture content on Poison's ratios is variable. The predicted Poisson's ratios are increasing with increasing moisture content while calculated Poisson's ratios from compression tests are mostly decreasing. The prediction of Poisson's ratios using ultrasound is questionable, particularly for the high moisture contents. Results of the study can be used in advanced modeling of particleboard panels under various loading conditions and moisture.

ACKNOWLEDGEMENT

The data presented here produced by a project sponsored by Technological and Research Council of Turkey (TUBITAK - 214O623).

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