ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 13 N° 2 2017
pp. 21-26

INFLUENCE OF MOISTURE CONTENT ON SOME ELASTIC CONSTANTS OF BLACK PINE SUBJECTED TO COMPRESSION

Ergün GÜNTEKIN*
Assoc. Prof. Dr. - Department of Forest Products Engineering, Faculty of Forestry
Address: Suleyman Demirel University, Isparta, Turkey
E-mail: rgngntkn@gmail.com

Seda DEMIRATLI
Graduate Student - Suleyman Demirel University
Address: 32260 Isparta, Turkey

Abstract:
Moisture content is an important factor influencing physical and mechanical behaviors of wood materials. This research aimed at quantifying effect of moisture content on some orthotropic mechanical properties of Black pine wood. The elastic properties investigated include E_L, E_R, E_T, υ_{LR}, υ_{LT}, υ_{RL}, υ_{RT}, υ_{TL} and υ_{TR} under compression. Compression strength in all orthotropic directions was also studied. Specimens were cut from sapwood of pine logs and sorted into four matched MC groups. Clear wood samples were conditioned at 20°C and 45%, 65%, 85%, 95% RH and subjected to compression tests. A bi axial extensometer was used to measure active and passive strain during loading. Young modulus, Poisson ratios, and compression strength were calculated and compared for all orthotropic directions. Results indicated that elastic and strength properties are significantly different in principal directions. Both Young's modulus and compression strength of the samples tested were strongly affected by moisture content. Both properties decrease seemingly linear with increasing moisture content. Poisson ratios seem to be insensitive to the MC changes.

Key words: *moisture content; elastic constants; Poisson's ratio; black pine.*

INTRODUCTION

Wood is a popular construction material which its mechanical properties strongly influenced by surrounding relative humidity. Thus mechanical properties of wood are adjusted by its moisture content (MC) in practical use, particularly in structural applications. MC is known to be one of the major strength and stiffness reducing factors (Ross 2010). Most of the strength and elastic properties of wood vary inversely with the MC of the wood below fiber saturation point (Panshin and de Zeeuw 1980). Above fiber saturation point the mechanical properties are constant with changes in MC. At very low MC (0-10%), some strength properties may decrease again after reaching a maximum value (Ross 2010). The various mechanical properties have a different sensitivity to changes in MC, with strength properties more sensitive than stiffness properties and static properties more sensitive than dynamic properties (Dinwoodie 2000).

A detailed discussion on the influence of MC on mechanical properties of wood can be found in earlier studies conducted by Gerhards (1982), Green and Kretschmann (1994), Kretschmann and Green (1996), and recent investigations of Hering *et al*. (2012a and 2012b), and Ozyhar *et al.* (2013). While the influence of MC on the mechanical behavior of wood in the L direction is relatively well understood (Gerhards 1982), investigations on the behavior in the perpendicular directions (R and T) are less investigated. The understanding of moisture dependent orthotropic behavior of wood species is necessary for advanced computational models such as finite elements used in engineering analysis.

The mechanical investigation regarding Turkish wood species generally concerned with behavior at constant MC of 12%. Although data needed for three dimensional modeling of mechanical behavior depending on the MC change, a few references is available for this purpose (Güntekin *et al.* 2015, Güntekin *et al.* 2016a, Güntekin *et al.* 2016b).

OBJECTIVE

The purpose of this study was to determine a set of elastic and strength parameters in compression tests at different moisture conditions. The parameters evaluated and reported here comprise the Young's modulus, Poisson's ratios, and compression strengths in principal directions.

MATERIALS AND METHODS

Small clear wood specimens were prepared from black pine (*Pinus nigra* Arn. subsp. Pallasiana (Lamb.) Holmboe) logs harvested from Bucak Forest District in Turkey. They were approximately 70cm in

* Corresponding author

diameter. The logs were sawn into radial or tangential planks. Only sapwood lumbers were used in order to prepare small clear specimens. 80 samples with nominal dimensions of 20x20x60mm for each direction (*L*, *R*, *T*) from the planks were prepared. Before testing, compression specimens were randomly divided into four groups and conditioned in climatic chambers at 45, 65, 85 and 95% relative humidity (RH) at a temperature of 20°C. After the specimen had reached equilibrium MC, uniaxial compression tests were carried out using a universal testing machine. All tests were performed at standard climatic conditions (65% RH and 20°C). To minimize the influence of the MC change, specimens were tested immediately after removal from the climatic chamber. Wood MC was determined by the oven-drying method. The feed rate was defined in such a way that the failure of the specimen should be reached in 90 (±30) s. The strains were measured using a biaxial extensometer. Apparent densities of the samples were calculated using the stereometric method. The stress-strain curves obtained were used in order to evaluate Young's modulus, Poisson ratios and strength properties of the specimens. 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, υ_{ij} = 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, *L* (longitudinal), *R* (radial) or *T* (tangential) and υ with the first subscript being the direction of load, and the second subscript being the perpendicular direction of measured dimension change.

Since the strength behavior of wood in *R* and *T* directions is obscure, maximum compression strength (CS) was calculated using 0.2% yield values using following formula.

$$\sigma_{UCS} = P_{max}/A \tag{3}$$

where: σ_{UCS} represents yield strength, P_{max} is the yield load and A is the cross-sectional area of the specimen.

A one-way layout ANOVA analysis was performed on each direction using SAS statistical analysis software to interpret effects of MC on the properties measured of the clear wood samples.

RESULTS AND DISCUSSIONS

A typical stress-deformation curve that is used to determine Young's modulus, Poisson ratios and compression strength of specimens tested in compression test is shown in Fig. 1. Average values of densities, moisture content, Young's modulus, compression strength and Poisson' ratios of the specimens tested are presented in Table 1-3. Coefficient of variation in Young's modulus values ranged from 18% to 39%. The ratio of Young's modulus in *L*, *R* and *T* directions was approximately 19:3:1 which is similar to softwood species reported in Wood hand book (Ross 2010). E_L is usually 10 to 20 times higher than E_R, and E_R is double E_T (Bodig and Jayne 1982). In general, Young's modulus in all anatomical directions tended to decrease at higher MC as expected. ANOVA results indicated that the three Young's modulus values are affected by moisture content significantly. (Pr>F = 0.001; R^2 = 0.93). Young's modulus in the direction perpendicular to the grain (*R*, *T*) changes with MC at higher rates. The specimens conditioned at 85% and 95% did not produce values of Young's modulus significantly different. Similarly, specimens conditioned at 45% and 65%. Fig. 2 shows that Young's modulus in principal directions conforms closely to straight-line relationships with moisture content.

Full elastic constants for Black pine grown in Turkey are not available. The only investigated elastic property available is modulus of elasticity (MOE) in bending and it varies between 6000 to 11000N/mm^2 depending upon the geographic region.

Poisson ratio was assumed to be 0.3 for most application in structural analysis of wood because data are not available for Black pine. It was found that Poisson ratio varies from 0.045 in *LT* plane to 0.88 in *TR* plane. Comparing with available the average Poisson ratios presented by Ross (2010), the calculated Poisson ratios for Black pine are almost twice. There is no reasonable explanation for the extreme Poisson's ratios. However, it should be noted that perfect elastic orthotropic symmetry assumption for wood may not be fully satisfied. Coefficient of variation in Poisson's ratios ranged from 11% to 47%. Wide variation in the Poisson's ratios of wood due to a high coefficient of variation was also presented by Hering *et al.* (2012a);

Jeong *et al.* (2010); Mizutani and Ando (2015); Ozyhar *et al.* (2013). The Fig. 3 shows fluctuations due to the MC for the Poisson ratios.

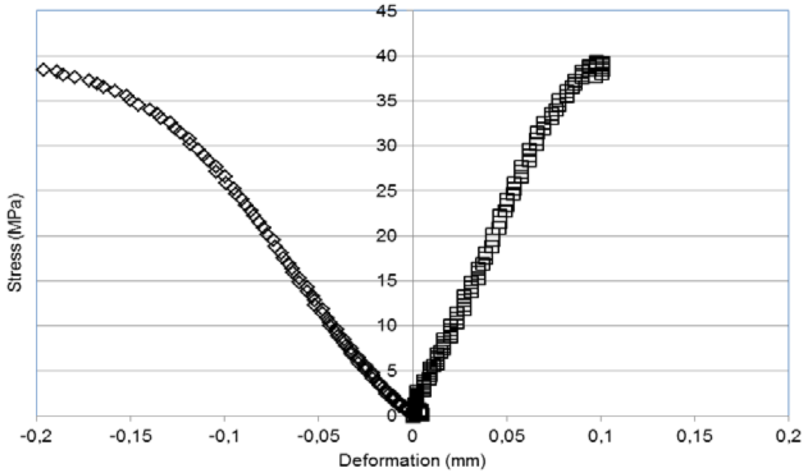

Fig. 1.
Load – deformation diagrams used to calculate Young's modulus, Poisson ratios and compression strength properties of the samples.

Table 1

Average values determined in L directions

Density (g/cm³)	*Relative Humidity (%)*	*MC (%)*	*E_L (N/mm²)*	*CS (N/mm²)*	*υ_{LR}*	*υ_{LT}*
0.48	*45*	*8.1*	*9151 (21)**	*46 (9.1)*	*0.65 (26.8)*	*0.70 (22.8)*
0.56	*65*	*11.75*	*8534 (19.12)*	*36.95 (5.7)*	*0.68 (16.9)*	*0.74 (15.45)*
0.47	*85*	*17.8*	*5116 (18.08)*	*25.82 (8.87)*	*0.62 (24.4)*	*0.66 (33.85)*
0.50	*95*	*23.5*	*4608 (20.21)*	*20.6 (6.65)*	*0.73 (11.6)*	*0.74 (24.69)*

**values in parenthesis represent the coefficient of variations*

Table 2

Average values determined in R directions

Density (g/cm³)	*Relative Humidity (%)*	*MC (%)*	*E_R (N/mm²)*	*CS (N/mm²)*	*υ_{RT}*	*υ_{RL}*
0.48	*45*	*8.1*	*1734 (27.7)**	*8.55 (4.49)*	*0.74 (13.2)*	*0.123 (39)*
0.55	*65*	*11.75*	*1386 (31.45)*	*7.88 (4.54)*	*0.64 (28.1)*	*0.06 (42.2)*
0.61	*85*	*17.8*	*892 (39.72)*	*7.13 (8.9)*	*0.59 (33.08)*	*0.123 (27)*
0.58	*95*	*23.5*	*652 (23.4)*	*4.43 (3.78)*	*0.76 (17.2)*	*0.083 (43.6)*

**values in parenthesis represent the coefficient of variations*

Table 3

Average values determined in T directions

density (g/cm³)	*Relative Humidity (%)*	*MC (%)*	*E_T (N/mm²)*	*CS (N/mm²)*	*υ_{TR}*	*υ_{TL}*
0.51	*45*	*8.1*	*426 (24.2)**	*6.98 (5.01)*	*0.71 (12)*	*0.066 (40)*
0.53	*65*	*11.75*	*444 (22.9)*	*7.11 (8.16)*	*0.65 (26.36)*	*0.061 (45.62)*
0.53	*85*	*17.8*	*241 (21.38)*	*4.43 (2.4)*	*0.81 (34.08)*	*0.045 (39.75)*
0.51	*95*	*23.5*	*188 (20.23)*	*3.31 (4.5)*	*0.88 (13.46)*	*0.061 (47.1)*

**values in parenthesis represent the coefficient of variations*

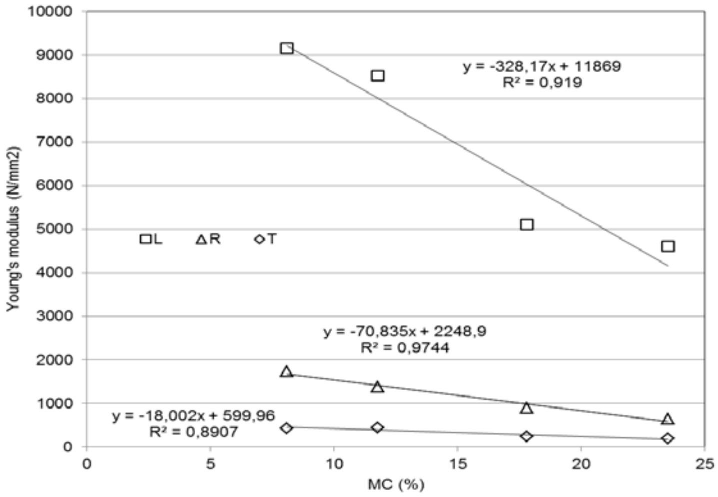

Fig. 2.
Comparison of the moisture-dependent Young's modulus for Black Pine.

ANOVA results indicated that the effect of MC on Poisson's ratios is not significant for the MC levels tested. Only the Poisson's ratio in *TR* plane seemed to be slightly correlated with MC showing an increase with increasing MC. The other Poisson ratios are not well correlated with MC showing some fluctuations with MC. Although no significant effects of MC on Poisson's ratios *LR*, *TR*, and *RT* were reported in the study of Drow and McBurney (1954); a slight decrease in Poisson's ratios with increasing MC was reported by Hering *et al.* (2012a), a small increase with increasing MC was presented by Güntekin *et al.* (2016b), and a significant effect of MC on Poisson's ratios was presented by Mizutani and Ando (2015) for wider range of MC (0-177%). According to Ross (2010) Poisson's ratios vary within and between species and are influenced by MC and specific gravity.

Test results show that compression strength parallel to the grain is much greater than that of perpendicular to the grain as expected. This is due to the alignment of wood fibers. Depending on the type of timber, the ratio of compression strength parallel to the grain to that perpendicular to the grain varies between 4.8 and 12.4 (Aydın *et al.* 2007). Black pine used in this study yielded a ratio of 4.6 at 11.75% MC. The compression strength perpendicular to the grain is particularly important property for the all contact points between wood members of the structures. Results indicated that the three compression strength values are significantly affected by MC. ($Pr<F = 0.001$; $R^2 = 0.98$). There is no data available on the compression strength of perpendicular directions for Black pine. Fig. 4 presents that the relationship between compression strength and MC is nearly a straight-line for all directions. Compression strength values nearly doubles when MC of the specimens drops to 8% from 23.5%.

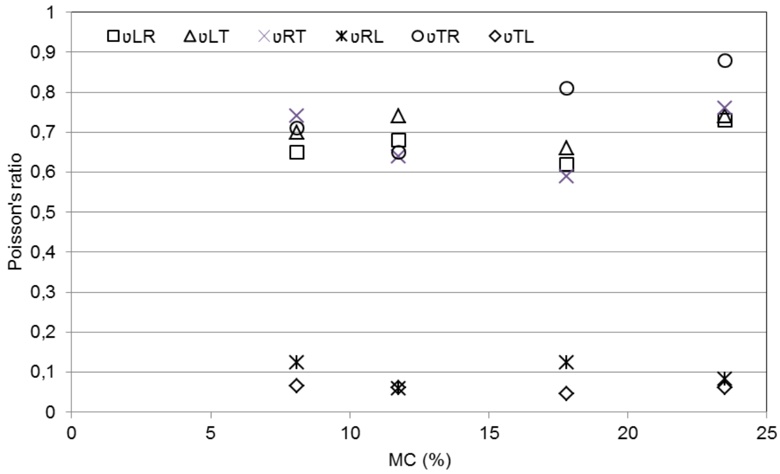

Fig. 3.
The influence of MC on Poisson ratios.

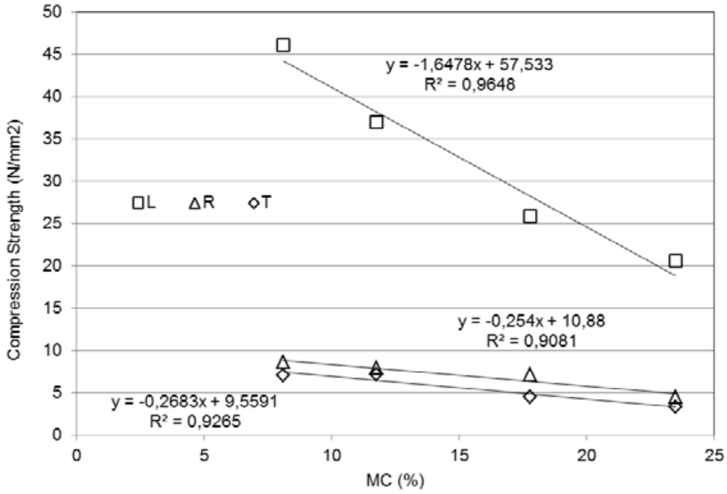

Fig. 4.
Comparison of moisture-dependent compression strength values for Black pine.

CONCLUSIONS

In this work, Young's modulus, Poisson rations and compression strength were measured in thee anatomical direction for black pine. The results of this study show that elastic properties and compression strength values in three principal directions of black pine are significantly different. The results also indicate that significant influence of MC on both the Young's modulus and compression strength is clearly visible. The Young's modulus values in the radial and tangential directions are affected by the MC to a significantly higher level than longitudinal Young's modulus. The affect of MC on compression strength was more severe than those in radial and tangential directions. Poisson's ratios of black pine calculated in the study are insensitive to the MC levels measured. Results of the study can be utilized in three dimensional modeling of mechanical behavior for black pine.

ACKNOWLEDGEMENT

The data presented here are a part of the project sponsored by TÜBİTAK 214O708 and COST FP 1402.

REFERENCES

Aydın S, Yardımcı MY, Ramyar K (2007) Mechanical properties of four timber species commonly used in Turkey. Turkish J Eng Env Sci 31:19-27.

Bodig J, Jayne BA (1993) Mechanics of wood and wood composites. Krieger Publishing Company. USA.

Dinwoodie JM (2000) Timber: Its Nature and Behavior. E & FN Spon, London.

Drow JT, McBurney RS (1954) The elastic properties of wood Young's moduli and Poisson's ratio of sitka spruce and their relations to moisture content. Rep. 1528-A. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 13 p.

Gerhards CC (1982) Effect of moisture content and temperature on the mechanical properties of wood: An analysis of immediate effects. Wood and Fiber Science 14(1):4-36.

Green DW, Kretschmann DE (1994) Moisture Content and the Properties of Clear Southern Pine. Res. Pap. FPL-RP-531. USDA Forest Service Forest Prod. Lab., Madison, WI.

Güntekin E, Aydın TY, Niemz P (2015) Prediction of compression properties in three orthotropic directions for some important Turkish wood species. BioResources 10(4):7252-7262.

Güntekin E, Aydın TY, Niemz P (2016a) Some orthotropic elastic properties of *Fagus orientalis* as influenced by moisture content. Wood Research 61(1):95-104.

Güntekin E, Aydın TY, Niemz P (2016a) Some orthotropic mechanical properties of Sessile oak *(Quercus petrea)* as influenced by moisture content. Eurasian Journal of Forest Science 4(1):40-47.

Hering S, Keunecke D, Niemz P (2012a) Moisture-dependent orthotropic elasticity of beech wood. Wood Sci Technol 45:927-938.

Hering S, Saft S, Resch E, Niemz P, Kaliske M (2012b) Characterization of moisture-dependent plasticity of beech wood and its application to a multi-surface plasticity model. Holzforschung 66:373-380.

Jeong GY, Hindman DP, Zink-Sharp A (2010) Orthotropic properties of loblolly pine (*Pinus taeda*) strands. J Mater Sci (45):5820–5830.

Kretschmann DE, Green DW (1996) Modeling moisture content-mechanical property relationships for clear Southern Pine. Wood and Fiber Science 28(3):320-337.

McBurney RS, Drow JT (1962) The elastic properties of wood: Young's moduli and Poisson's ratios of Douglas-fir and their relations to moisture content. Report No. 1528-D. U.S. Dept. Of Agriculture, Forest Service, Forest Products Laboratory Madison, Wisconsin.

Mizutani M, Ando K (2015) Influence of a wide range of moisture contents on the Poisson's ratio of wood. J Wood Science (61):81-85.

Panshin AJ, de Zeeuw C (1980) Textbook of Wood Technology. McGraw-Hill, Inc. New York.

Ozyhar T, Hering S, Niemz P (2013) Moisture-dependent orthotropic tension compression asymmetry of wood. Holzforschung 67(4):395-404.

Ross RJ (2010) Wood Handbook: Wood as an Engineering Material. General Technical Report FPL-GTR 190, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.