SOME ORTHOTROPIC MECHANICAL PROPERTIES OF SESSILE OAK (*QUERCUS PETREA)* AS INFLUENCED BY MOISTURE CONTENT

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Abstract

In this study, the influence on some orthotropic mechanical properties of sessile oak which is one of the most important wood species grown in Turkey and common in the furniture industry have been investigated. The properties studied include Young's modulus, Poisson's ratios and compression strength of oak wood in three anatomical directions. These properties are important input parameters for three dimensional modeling of mechanical behavior in advanced computer programs such as finite elements. The samples which were approximately 20 x 20 x 60 mm in dimensions were conditioned at 20 °C and 50, 65, 85, 95 % relative humidity conditions for 6-8 weeks and subjected to compression tests in order to determine elastic and strength properties. Results indicate that properties investigated significantly differ among all anatomical directions. Moisture content significantly influences both Young's modulus and compression strength. Poisson's ratios are less sensitive to moisture changes. Young's modulus ranged from 8035 to 5016 MPa in *L* direction, from 2001 to 1132 MPa in *R* direction and from 1249 to 715 in *T* direction. Compression strength varied between 37.57 and 25.32 MPa in *L* direction, 14.32 and 9.60 MPa in *R* direction, and 10.23 and 7.14 in *T* direction. Poisson's ratios are found to be in between 0.05 and 0.675.

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1. INTRODUCTION

Wood always equilibrates to a wide range of moisture content (MC) levels in use, and most of its properties are considerably influenced by the MC. Particularly regarding the properties and the use of wood in structural applications, MC is known to be one of the major influencing factors (Ross, 2010). Most of the strength properties and elastic properties of wood vary inversely with the MC of the wood below fiber saturation point (FSP) (Panshin and de Zeeuw, 1980). Above fiber saturation point the mechanical properties are constant with changes in moisture content. 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).

The effect of MC on the mechanical properties of wood is extensively studied over the last decades. A detailed discussion can be found in Gerhards (1982), Green and Kretschmann (1994) and Kretschmann and Green (1996). In general, most mechanical properties were found to increase as MC decreased FSP to 6%, and they reach a maximum about 6 percent

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MC. This reduction in mechanical properties is presumably a result of drying degrade that occurs at low MC levels.

While the influence of MC on the mechanical behavior of wood in the L direction is relatively well known (Gerhards, 1982), investigations on the behavior in the perpendicular directions (R and T) are limited. The interest on the moisture dependent orthotropic behavior is not new. So far, only few studies studied moisture dependent elastic properties of wood in the R and T directions (McBurney and Drow, 1962; Hering et al. 2012a; Hering et al. 2012b; Ozyhar et al. 2013a; Ozyhar et al. 2013b). Furthermore, moisture-dependent wood strength in the R and T directions, remain widely unrevealed for most wood species. The usable data are limited to a few references (Kretshmann and Green, 1996; Ozyhar et al. 2013a; Ozyhar et al. 2013b). While selected moisture dependent elastic properties for some wood species can be found in (Kretshmann and Green, 1996; Ross, 2010), in general, only few properties were tested for a given property–MC combination in most investigations. As a consequence, comprehensive datasets including the moisture-dependent orthotropic elastic and strength values are missing for most wood species. Elastic and strength properties based on the three dimensional approach are essential input parameters required 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, no information is available for this purpose. In this study, a set of elastic and strength parameters is determined in uniaxial compression tests at different moisture conditions. The parameters evaluated and reported here comprise the Young's moduli, Poisson‘s ratios, and compression strengths in all orthotropic directions.

2. MATERIALS AND METHODS

Small clear wood samples were prepared Sessile oak (*Quercus petrea*) logs harvested from Devrek Forest District in Turkey. They were approximately 50 cm in diameter. The logs were transferred and sawn to lumber. Lumbers were cut into small clear specimens which were 20 x 20 x 60 mm in dimensions. Before testing, compression specimens were randomly divided into four groups and conditioned in climatic chambers at 50, 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 Zwick 100 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 evaluated using the digital image correlation (DIC) technique. A high contrast random dot texture was sprayed on the surface of the specimen with air-brush to ensure the contrast needed for the evaluation of the displacements. Pictures were taken with a frequency of 4 Hz of the cross-sectional surface area of the specimen during testing (Figure 1). By means of the mapping software (VIC 2D, Correlated Solution), the surface strains were calculated from the displacements that occurred during deformation. A more detailed description of the strain computation by the DIC technique is given in Keunecke et al. (2008). The stress-strain curves obtained were used in order to evaluate Young's moduli and strength properties of the specimens. The Young's modulus was calculated from the ratio of the stress σ to the strain ε measured in the linear elastic range:

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

Figure 1. Compression test set up.

The Poisson's ratio ν, defined as

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

Where; ε_i represents the passive strain (lateral) component in the load direction and ε_j is the active strain component, which was determined in the linear elastic range from the linear regression of the passive–active strain diagram. Since the strength behavior of wood in R and T directions is obscure, maximum compression strength 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.

Analysis of variance (ANOVA) general linear model procedure was run for data with SAS statistical analysis software to interpret effects of MC on the properties measured of the clear wood samples.

3. RESULTS AND DISCUSSIONS

Average values for Young's modulus of the specimens tested are presented in Table 1. There was a good match among the density values in the different MC groups. In comparison to available literature references at similar MC, the measured density values were comparable. Coefficient of variation in Young's modulus values ranged from 12% to 37% which is acceptable for mechanical properties of wood. In general, Young's modulus in all anatomical directions tended to increase at lower MC as expected. The three Young's moduli values are affected by moisture, but to a different degree. Young's modulus in the direction perpendicular to the grain (R, T) changes with MC at higher rates. The changing rates of Young's modulus due to 1 % MC in L, R and T directions were nearly 3.6, 4.3 and 4.2 % respectively. Similar trend in mechanical properties due to the MC changes was reported by Gerhards (1982), Ross (2010), Hering et al. (2012a) and Ozyhar et al. (2013a).

Table 1. Young's moduli values (N/mm^2) for Sessile oak

R.H. (%)		**E_L**	**E_R**	**E_T**
50	Mean	8305	2001	1249
	Cov (%)	30	21	12
	n	14	15	15
	Density (g/cm^3)	0.65	0.72	0.67
	M.C. (%)	12.27	11.60	11.95
65	Mean	7691	1883	1033
	Cov (%)	21	31	15
	n	14	15	15
	Density (g/cm^3)	0.66	0.73	0.67
	M.C. (%)	12.81	12.81	12.33
85	Mean	6583	1312	892
	Cov (%)	32	25	32
	n	14	15	15
	Density (g/cm^3)	0.68	0.72	0.68
	M.C. (%)	20.81	20.50	20.93
95	Mean	5016	1132	715
	Cov (%)	37	31	18
	n	14	15	12
	Density (g/cm^3)	0.70	0.79	0.68
	M.C. (%)	23.38	22.67	22.16

The Poisson's ratios calculated from the compression tests are presented in Table 2. Poisson ratio was assumed to be 0.3 for most application in structural analysis of wood and wood framed structures such as furniture frames wood because there was no data available for Sessile oak. It was found that Poisson's ratio varies from 0.05 in TL plane to 0.675 in RT plane. Poisson's ratios of Sessile oak found to be similar to those reported for red and white oak species (Ross, 20110). Coefficient of variation in Poisson's ratios ranged from 14% to 55%. The influence of MC on Poisson's ratios is not significant. Average values for compression strength in L, R, T directions calculated in this study are shown in Table 3. Sessile oak used in these tests appears to be somewhat lower in compression strength L direction than average reported by Merela and Cufar (2013). The ratio of compression strength in L, R and T directions was approximately 3.8:1.4:1. The changing rates of compression strength due to 1 % MC in L, R and T directions were nearly 3.1, 3.2 and 2.7 %, respectively.

4. CONCLUSIONS

The results of this study reveal that elastic properties and compression strength in three anatomic directions of Sessile oak are significantly different. The results also indicate that significant influence of MC on both the elastic and strength behavior is clearly visible. The results found in the study affirm the importance of knowing the MC dependency of the mechanical behavior of wood and provide data for numerical simulations taking into account the hygroscopic nature of wood. Results of the study can be utilized in advanced modeling behavior of oak wood where exposed to structural loads and MC.

Table 2. Poisson ratios for Sessile oak

R.H. (%)		ν_{TL}	ν_{RL}	ν_{TR}	ν_{RT}	ν_{LT}	ν_{LR}
50	Mean	0.066	0.074	0.668	0.675	0.506	0.453
	Cov (%)	28	21	18	15	17	27
	n	11	9	11	9	12	12
	Density (g/cm^3)	0.67	0.72	0.67	0.72	0.65	0.65
	M.C. (%)	11.95	11.60	11.95	11.60	12.27	12.27
65	Mean	0.050	0.072	0.610	0.579	0.493	0.450
	Cov (%)	55	25	15	16	21	30
	n	10	10	10	10	12	12
	Density (g/cm^3)	0.67	0.73	0.67	0.73	0.66	0.66
	M.C. (%)	14.33	13.78	14.33	13.78	13.81	13.81
85	Mean	0.059	0.077	0.485	0.505	0.550	0.434
	Cov (%)	37	24	17	32	14	37
	n	12	9	12	9	11	11
	Density (g/cm^3)	0.68	0.72	0.68	0.72	0.68	0.68
	M.C. (%)	20.93	20.50	20.93	20.50	20.81	20.81
95	Mean	0.059	0.061	0.459	0.562	0.481	0.466
	Cov (%)	30	30	21	22	46	23
	n	13	9	13	9	12	12
	Density (g/cm^3)	0.68	0.79	0.68	0.79	0.70	0.70
	M.C. (%)	22.16	22.67	22.16	22.67	23.38	23.38

Table 3. Compression strength values for Sessile oak

R.H. (%)		**E_L**	**E_R**	**E_T**
50	Mean	37.57	14.32	10.23
	Cov (%)	24.20	8.33	13.21
	n	15	15	15
	Density (g/cm^3)	0.65	0.72	0.67
	M.C. (%)	12.27	11.60	11.95
65	Mean	34.86	12.76	9.08
	Cov (%)	15.11	7.45	17.61
	n	15	15	15
	Density (g/cm^3)	0.66	0.73	0.67
	M.C. (%)	12.81	13.78	13.33
85	Mean	27.20	10.23	7.55
	Cov (%)	13.79	12.63	25.98
	n	15	15	15
	Density (g/cm^3)	0.68	0.72	0.68
	M.C. (%)	20.81	20.50	20.93
95	Mean	25.32	9.60	7.14
	Cov (%)	11.54	13.65	28.50
	n	15	15	15
	Density (g/cm^3)	0.70	0.72	0.68
	M.C. (%)	23.38	22.67	22.16

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