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

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Abstract

In this study, the influence of moisture content 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. Young's modulus ranged from 10305 to 6984 N/mm^2 in L direction, from 2032 to 1132 N/mm^2 in R direction and from 1208 to 715 in T direction. Compression strength varied between 48.5 and 25.5 N/mm^2 in L direction, 16.45 and 9.60 MPa in R direction, and 10.2 and 7.1 in T direction. Poisson's ratios are found to be in between 0.061 and 0.7. Results indicated that all properties of the samples tested were strongly affected by moisture content.

Keywords: sessile oak, orthotropic properties, moisture content

Özet

Bu çalışmada Türkiye'de yetişen önemli ağaç türlerimizden olan ve mobilya sanayisinde yaygın kullanılan sapsız meşe (*Quercus petrea*) odununun bazı ortotropik mekanik özellikleri üzerine rutubetin etkisi incelenmiştir. Çalışmada kayın odununun lif, radyal ve teğet yönlerdeki Young modülü, Poisson oranları ve basma dirençleri incelenmiştir. Bu özellikler sonlu elemanlar gibi üç boyutlu mekanik davranışın analizinde kullanılan nümerik yöntemleri için önemli parametrelerdir. Yaklaşık 20x20x60 mm ölçülerde hazırlanan deney örnekleri 20 °C sabit sıcaklık ve %50, 65, 85, 95 bağıl nem şartlarında 6-8 hafta bekletilerek basma testlerine maruz bırakılmış ve elastik ve direnç özellikleri ortaya konulmuştur. Çalışma sonuçları incelenen özelliklerin anatomik yönlerde önemli ölçüde farklı olduğunu ortaya koymuştur. Örneklerin ortalama elastikiyet modülleri L yönünde 10305 ile 6984 N/mm^2, R yönünde 2032 ile 1132 N/mm^2, T yönünde ise 1208 ile 715 N/mm^2 arasında değişmektedir. Direnç değerleri; L yönünde 48.5 ile 25.5 N/mm^2, R yönünde 16.45 ile 9.6 N/mm^2, T yönünde ise 10.2 ile 7.1 N/mm^2 arasında değişmektedir. Poisson oranları ise 0.061 ile 0.7 arasında değişmektedir. Çalışma sonuçları test edilen özellikleri önemli ölçüde rutubetten etkilendiğini göstermektedir.

Anahtar kelimeler: Sapsız meşe, ortotropik mekanik davranış, rutubet

INTRODUCTION

Wood always in equilibrium with the surrounding environment in use, and most of its properties are considerably affected by moisture content (MC). Most of its mechanical properties will vary inversely with the moisture below fiber saturation point (Panshin and de Zeeuw 1980). Above fiber saturation point the mechanical properties are not effected by changes in MC. Some strength properties may decrease again after reaching a maximum value in between MC of 0-10% (Ross, 2010). Strength properties are more sensitive to MC than stiffness properties and static properties are more sensitive than dynamic properties (Dinwoodie 2000).

Although the influence of MC on the mechanical behavior of wood in the longitudinal (L) direction is relatively well known, studies on the behavior in the perpendicular directions (R and T) are limited (Gerhards 1982). The interest on the moisture dependent orthotropic behavior is not new, but only few studies investigated 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, Güntekin et al. 2016). Furthermore, moisture-dependent wood strength in the R and T directions, remain unknown for most wood species. While selected moisture effected elastic properties for some wood species can be found in (Ross 2010), in general, only selected properties were tested for a given property–MC combination in most investigations. As a consequence, complete datasets including the moisture-dependent orthotropic behavior 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 used in engineering analysis. The mechanical investigation regarding Turkish wood species generally concerned with behavior at constant MC of 12 %. The properties investigated for the study comprise the Young's modulus, Poisson's ratios, and compression strengths in principal directions.

MATERIALS AND METHODS

Small clear wood samples which were 20 x 20 x 60 mm in dimensions prepared from Sessile oak (*Quercus petrea*) logs harvested from Devrek Forest District in Turkey. 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:

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

Figure 1. Compression test set up.

The Poisson's ratio ν, defined as

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

Where; ε_i represents the active strain component in the load direction and ε_j is the passive (lateral) 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.

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

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.

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. The densities of the investigated oak species grown in Turkey varies in between 0.59 and 0.74 g/cm^3. Coefficient of variation in Young's modulus values ranged from 12% to 33% which is acceptable for mechanical properties of wood.

The ratio of Young's modulus in L, R and T directions was approximately 8.5:1.6:1. According to Bodig and Jayne (1983) the ratio of Young's modulus in principal directions can be as much as 20:1.6:1. The only elastic property available for oak species grown in Turkey is modulus of elasticity in bending (MOE) which varies between 10000-13000 N/mm^2 at MC of 12%.

In general, Young's modulus in all anatomical directions tended to increase at lower MC as expected (Figure 2). 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 lower rates. The changing rates of Young's modulus due to 1 % MC in L, R and T directions were nearly 5, 4.3 and 4.2 %

respectively. Similar trend in mechanical properties due to the MC changes in R and T directions was reported by Gerhards (1982), Ross (2010), Hering et al. (2012a) and Ozyhar et al. (2013a).

The Poisson's ratios calculated from the compression tests are presented in Table 2. It was found that Poisson's ratio varies from 0.061 in TL plane to 0.7 in RT plane at MC of 12 %. The Poisson's ratios calculated for Sessile oak in this study in LT, RL and LR directions are similar for oak species reported by Ross (2010). But, they are different in TR, RT and TL directions. Coefficient of variation in Poisson's ratios ranged from 12% to 57%. Poisson's ratios in the TL and LR plane showed the highest coefficient of variation. High variability in the Poisson's ratios was also implied by Hering et al. (2012a), Ozyhar et al. (2013a), Jeong et al. (2010), Mizutani and Ando (2015). Poisson's ratios seem to be higher for higher MC values (Figure 3). ANOVA results indicated that the effect of MC on Poisson's ratios is significant for the MC levels tested. Although no profound effects of MC on Poisson's ratios LR, TR, and RT were found in the studies of Drow and McBurney (1954), a slight decrease in Poisson's ratios with increasing MC was reported by Hering et al. (2012a), and a significant effect of MC on Poisson's ratios was implied by Mizutani and Ando (2015) for wider range of MC (0-177 %).

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

20 °C, R.H. (%)		E_L	E_R	E_T
50	Mean	10305	2032	1208
	Cov (%)	30	21	12
	n	12	12	12
	Density (g/cm^3)	0.66	0.67	0.65
	M.C. (%)	12.1	11.6	11.9
65	Mean	9845	1883	1105
	Cov (%)	19	32	17
	n	12	12	12
	Density (g/cm^3)	0.67	0.68	0.67
	M.C. (%)	12.8	12.8	12.3
85	Mean	7850	1312	852
	Cov (%)	32	25	32
	n	12	12	12
	Density (g/cm^3)	0.69	0.72	0.68
	M.C. (%)	20.8	20.5	20.9
95	Mean	6984	1132	715
	Cov (%)	33	31	18
	n	12	12	12
	Density (g/cm^3)	0.71	0.75	0.69
	M.C. (%)	23.3	22.6	22.1

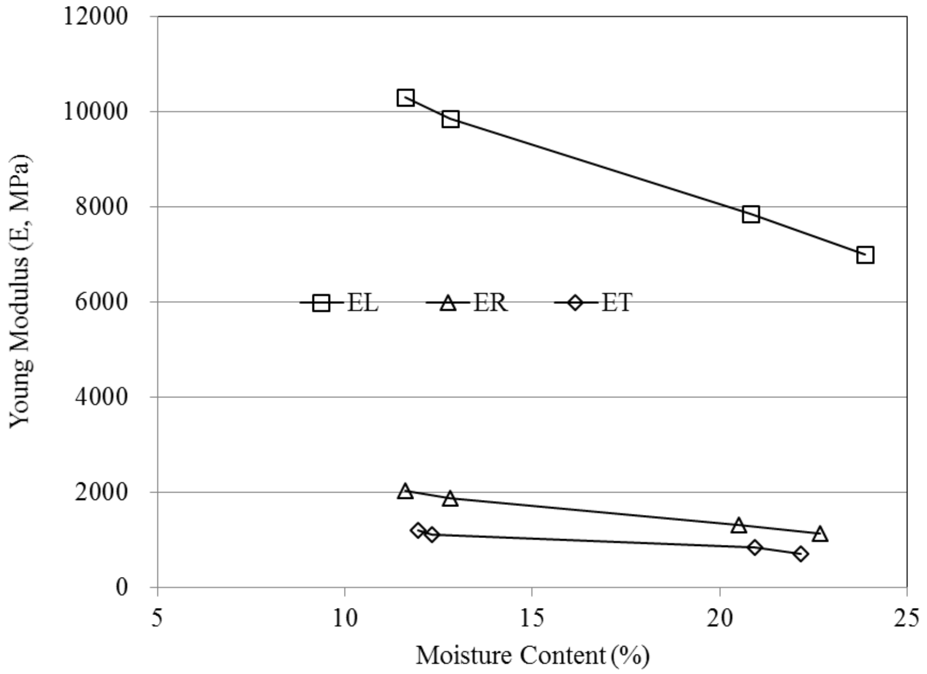

Figure 2. Influence of MC on Young's modulus in three orthotropic directions of sessile oak

Table 2. Poisson ratios for Sessile oak

R.H. (%)		ν_{TL}	ν_{RL}	ν_{TR}	ν_{RT}	ν_{LT}	ν_{LR}
50	Mean	0.061	0.082	0.41	0.7	0.42	0.36
	Cov (%)	24	19	12	20	31	28
	n	12	12	12	12	12	12
	Density (g/cm³)	0.65	0.67	0.65	0.67	0.66	0.66
	M.C. (%)	11.9	11.6	11.9	11.6	12.1	12.1
65	Mean	0.069	0.103	0.73	0.86	0.53	0.42
	Cov (%)	48	44	16	8	32	34
	n	12	12	12	12	12	12
	Density (g/cm³)	0.67	0.68	0.67	0.68	0.67	0.67
	M.C. (%)	12.3	12.8	12.3	12.8	12.8	12.8
85	Mean	0.08	0.11	0.79	0.93	0.68	0.59
	Cov (%)	57	45	39	36	22	21
	n	15	15	15	15	15	15
	Density (g/cm³)	0.68	0.72	0.68	0.72	0.69	0.69
	M.C. (%)	20.9	20.5	20.9	20.5	20.8	20.8
95	Mean	0.083	0.118	0.86	1.0	0.83	0.62
	Cov (%)	24	28	24	20	15	18
	n	15	15	15	15	15	15
	Density (g/cm³)	0.69	0.75	0.69	0.75	0.71	0.71
	M.C. (%)	22.1	22.6	22.1	22.6	23.3	23.3

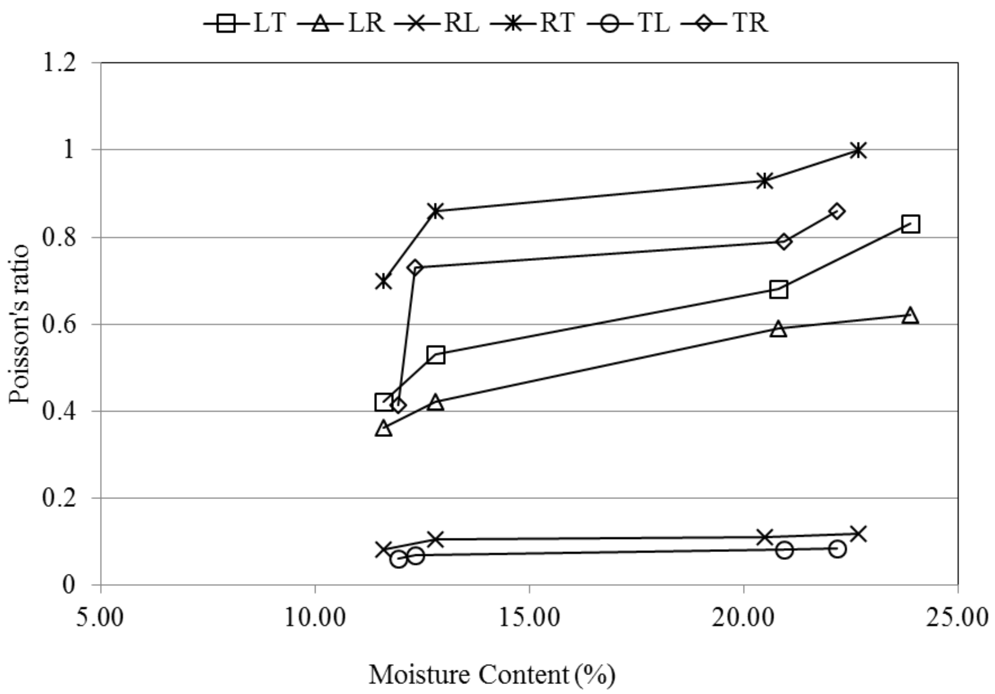

Figure 3. Influence of MC on Poisson's ratio for sessile oak

Average values for compression strength in L, R, T directions calculated in this study are shown in Table 3. The average compression strength of oak species varies from 51 to 75 N/mm² (Berkel 1970, Dündar 2002, Keskin 2004, Munoz and Gete 2011, Perçin et al. 2015). Sessile oak used in these tests appears to be somewhat lower in compression strength L direction than average reported in the literature. The ratio of compression strength in L, R and T directions was approximately 4.8:1.6:1. No data is available for compression strength in perpendicular directions. Figure 4 illustrates the change in CS due to the MC.

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 Sessile oak wood where exposed to structural loads and MC.

Table 3. Compression strength values for Sessile oak

R.H. (%)		E_L	E_R	E_T
50	Mean	48.5	16.45	10.25
	Cov (%)	24.20	8.33	13.21
	n	12	12	12
	Density (g/cm³)	0.66	0.67	0.65
	M.C. (%)	12.1	11.6	11.9
65	Mean	45.2	14.95	9.85
	Cov (%)	15.11	7.45	17.61
	n	12	12	12
	Density (g/cm³)	0.67	0.68	0.67
	M.C. (%)	12.8	12.8	12.3
85	Mean	28.4	10.23	7.55
	Cov (%)	13.79	12.63	25.98
	n	14	15	15
	Density (g/cm³)	0.69	0.72	0.68
	M.C. (%)	20.8	20.5	20.9
95	Mean	25.5	9.60	7.14
	Cov (%)	11.54	13.65	28.50
	n	14	15	12
	Density (g/cm³)	0.71	0.75	0.69
	M.C. (%)	23.3	22.6	22.1

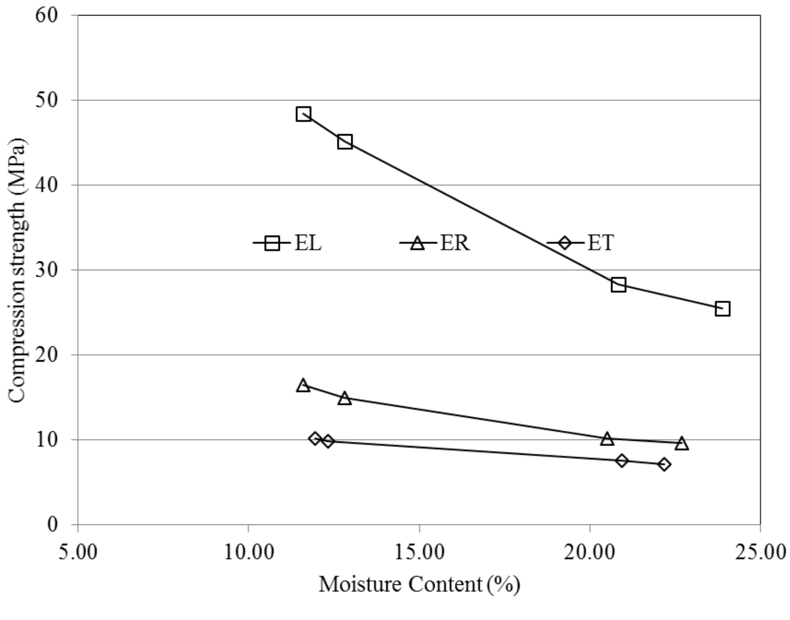

Figure 4. Influence of MC on Compression strength in three orthotropic directions of sessile oak

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