The Mechanical Properties of Heartwood and Sapwood of Flooded gum (*Eucalyptus grandis*) Grown in Karabucak, Turkey

Bekir Cihad BAL[1*], İbrahim BEKTAŞ[1]

Abstract

In this study, some mechanical properties of heartwood and sapwood of *Eucalyptus grandis* grown in Karabucak, Turkey were determined. Mechanical properties, such as modulus of rupture, modulus of elasticity, impact bending strength, tension strength (perpendicular and parallel to grain), compression strength, shear strength, and static hardness were measured. According to the test results the sapwood samples provided better mechanical properties than the heartwood samples. It can be concluded that the lower mechanical properties of the heartwood samples were due to the presence of high proportion of juvenile wood in the heartwood.
Keywords: E. grandis, heartwood, mechanical properties, sapwood

Türkiye, Karabucak'ta Yetişen Okaliptüs Grandis'in Öz Odun ve Diri Odununun Mekanik Özellikleri

Özet

Bu çalışmada, Türkiye-Karabucak'ta yetişen Okaliptüs grandis'in öz odun ve diri odununun bazı mekanik özellikleri belirlenmiştir. Eğilme direnci, elastikiyet modülü, dinamik eğilme direnci, liflere paralel ve liflere dik çekme direnci, basınç direnci, makaslama direnci ve statik sertlik ölçülmüştür. Test sonuçlarına göre; diri odun örnekleri öz odun örneklerinden daha iyi mekanik özellikler vermiştir. Öz odun örneklerinin mekanik özelliklerinin düşük olması, öz odun bölgesinde genç odunun yüksek miktarda bulunmasından kaynaklandığı söylenebilir.
Anahtar kelimeler: Okaliptüs grandis, öz odun, diri odun, mekanik özellikler

Introduction

The acreage covered by naturally-grown forests is decreasing tremendously due to the extensive use of wood and the rapid growth of the population (Anonym, 2006). To overcome the wood shortage, fast-growing tree plantations are being established in many parts of the world. One of the preferred fast-growing tree species is the eucalyptus species. The paper industry is one of the major users of land area for the production of fast-growing trees. Only a small proportion of fast-growing trees, such as eucalyptus trees, are used for the production of other products, such as charcoal, sawn logs, panel products, and reconstituted boards (Cossalter and Pye-smith, 2003). It is important to determine the properties of such species if they are to be used in these additional applications.

Many scientist have studied the anatomy of eucalyptus trees (Santos et al, 2004; Lima et al, 2010), and other researchers have studied their physical and mechanical properties as well as their use in composite manufacturing (Mengeloğlu and Karakuş, 2008), laminated timber (Castro and Paganini, 2003), and furniture (Acosta et al, 2007). The research results have indicated that the physical, mechanical, and anatomical properties of eucalyptus tree differ depending on where they were grown. Thus, many researchers have conducted studies on the same species that were grown in different parts of the world.

In Turkey, eucalyptus trees were first introduced in 1885 by a French company that was working on the railroads (Adalı, 1944). The first *E. camaldulensis* plantation was developed in Tarsus-Karabucak in 1939. The Turkish government established the Eastern Mediterranean

[1] KSU, Faculty of Forestry, Department of Forest Products Engineering, 46060, Kahramanmaraş, Turkey
[*]Corresponding author: bcbal@hotmail.com

Forestry Research Institute in 1967 for conducting research on eucalyptus trees. Since then, the Institute has conducted experiments on 191 eucalyptus species from 609 origins (Özkurt, 2002). An average annual increment of 35 m^3 ha^{-1} for *E. camaldulensis* and 50 m^3 ha^{-1} for *E. grandis* were determined (Gürses et al, 1995) . There are some differences in the properties of *E. camaldulensis* and *E. grandis*. Some of the differences in the physical and chemical properties of *E.camaldulensis* and *E.grandis* grown in the Karabucak region were determined (Ayata, 2008).

Based on the last official data provided in 1993, there are 20 000 ha eucalyptus plantations in Turkey, and most of them are in the Tarsus-Karabucak region (Gürses et al, 1995). In addition, an important project was conducted to use *E.grandis* wood in pulp and paper industry by MOPAK group (Anonym, 2012).

The determination of the properties of these trees is important if their usage areas are to be increased. The objective of this study was to determine some of mechanical properties of heartwood and sapwood from *E. grandis* grown in Tarsus-Karabucak, Turkey.

Materials and Methods

Materials

The trees used in this study were obtained from Tarsus-Karabucak region in Turkey. In this research, five 10-year-old trees were used (diameter at breast height: 29-31 cm and total height: about 25-27 m). Logs were cut from the trees at a height from 2 to 4 m for use in determining the mechanical properties. From these logs, timbers that were 8 cm wide were cut and air dried. After the timbers had been completed air drying, heartwood and sapwood samples were prepared separately from each group. With the exception of the samples used for the sorption experiment, the samples were conditioned at 20 ± 2 °C and 65 ± 5% relative humidity.

Methods

Mechanical properties, such as modulus of rupture (MOR), modulus of elasticity in bending (MOE), impact strength (σ_i), tension strength perpendicular to grain ($\sigma_{T\perp}$), tension strength parallel to grain ($\sigma_{T/\!/}$), compression strength parallel to grain ($\sigma_{C/\!/}$), and shear strength parallel to grain (on the radial surface) ($\sigma_{S/\!/}$) were determined according to TS 2474, TS 2478, TS 2477, TS 2476, TS 2475, TS 2595, and TS 3459 standards, respectively. Static hardness (H) (Janka hardness) was determined based on the TS 2479, and H_{TS}, H_{RS}, and H_{CS} are hardness on the tangential surface, radial surface, and cross-section, respectively.

In the bending strength and impact strength tests, the loads were applied in the tangential direction. After the tests, the moisture content of the samples was determined, and the strength values were corrected as indicated in equation (1) according to the relevant standards:

$$\sigma_{12} = \sigma_M (1 + \alpha (M - 12)) \quad (1)$$

Where σ_{12} is the strength at 12% moisture content (N mm^{-2}), σ_M is the strength at moisture content (N mm^{-2}), α is a constant, and M is the moisture content (%).

The SPSS program was used for statistical analysis. The independent-sample T-test was used to determine the differences between mechanical properties of sapwood and heartwood (α = 0.05). A linear regression model was used to analyze the relationship between density and mechanical properties that were measured.

Results

The mechanical properties of the *E.grandis* sapwood and heartwood are given in Table 1. Based on the statistical analysis, there was a statistically significant difference between sapwood and heartwood samples ($P < 0.01$ in MOR and MOE; $P < 0.001$ in the others). Mechanical properties (MOR, MOE, $\sigma_{C//}$, $\sigma_{S//}$, $\sigma_{T//}$, $\sigma_{T\perp}$, σ_i, H_{TS}, H_{RS}, and H_{CS}) of sapwood were determined to be greater than those of heartwood. The impact bending of sapwood was 66.2% significantly higher than that of heartwood.

Table 1. Mechanical properties of *Eucalyptus grandis* wood

		MOR	MOE	$\sigma_{C//}$	$\sigma_{S//}$	$\sigma_{T//}$	$\sigma_{T\perp}$	σ_i	H_{TS}	H_{RS}	H_{CS}	D_o*
				$N\ mm^{-2}$				$kgm\ cm^{-2}$		$N\ mm^{-2}$		Kg/m^3
Sapwood	x	100	10074	60	10	103	5	0.95	57	48	53	634
	s	19	1931	9	3	16	1	0.2	15	16	13	90
	n	30	30	143	30	27	25	30	24	24	24	150
Heartwood	x	84	8412	52	8	83	3.7	0.57	41	32	39	517
	s	19	1872	9	1	12	0.8	0.2	10	8	7	62
	n	30	30	143	30	28	30	30	24	24	24	150

MOR: modulus of rapture, MOE: modulus of elasticity in bending, σ_i: impact strength, $\sigma_{T\perp}$: tension strength perpendicular to grain, $\sigma_{T//}$: tension strength parallel to grain, $\sigma_{C//}$: compression strength parallel to grain, $\sigma_{S//}$: shear strength parallel to grain, H_{TS}: hardness on the tangential surface, H_{RS}: hardness on radial surface, H_{CS}: hardness on cross section, x: mean values, s: standard deviation, n: the number of samples *D_o values were adopted from Bal and Bektaş (2012)

The relationships between oven-dried density and MOR (A) and between oven-dried density and MOE (B) were determined through regression analysis, and the results are presented in Figure 1. There was a strong positive correlation between density and MOR (A) and MOE (B) ($P < 0.001$).

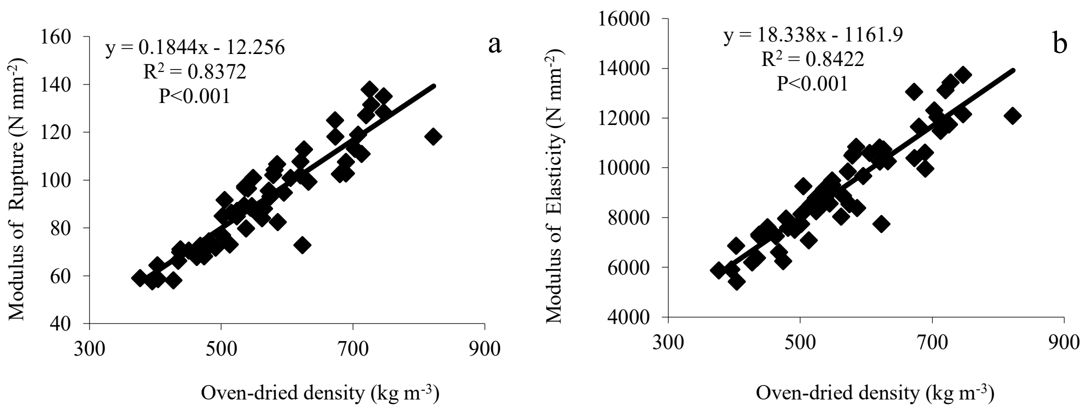

Figure 1. Relationships between (a) oven-dried density and MOR and (b) oven-dried density and MOE

Relationships between density and compression strength (A) and between density and impact bending (B) are presented in Figure 2, which provides the regression equation, the R^2 value, and the probability value. There is a strong, positive correlation between oven-dried density and compression strength and between oven-dried density and impact bending. Compression strength and impact bending of sapwood were determined to be higher than they were for heartwood.

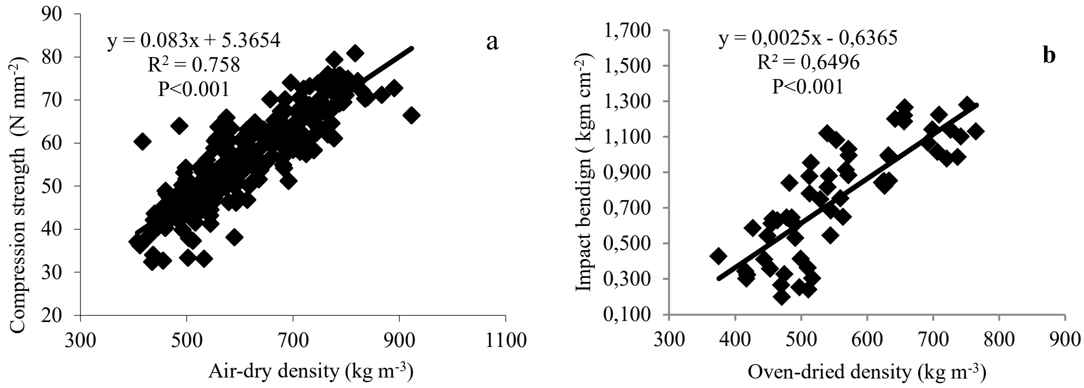

Figure 2. Relationships between (a) density and compression strength and (b) and impact bending

Figure 3 (A) shows a diagram and some other statistical parameters of static hardness. The relationship between air-dried density and static hardness measured from the radial surface (RS), tangential surface (TS), and cross-sectional surface (CS) were statistically significant ($P < 0.001$). The best correlation was determined in the tangential surface (R^2 = 0.929).

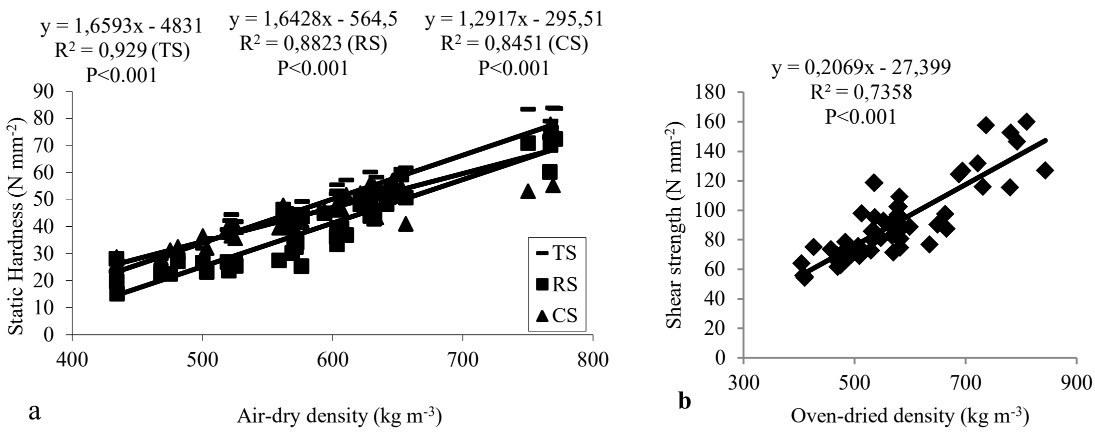

Figure 3. Relationship between (a) density and hardness, (b) density and shear strength

Figure 3 (B) shows a diagram, regression equation, R^2 and probability value of shear strength. The relationship between oven-dried density and shear strength was determined to be statistically significant ($P < 0.001$), and a strong positive correlation was determined (R^2 = 0.7358).

Discussion

The variation in density plays an important role in determining mechanical properties of wood. This is especially obvious for species such as eucalyptus, which is a fast-growing tree that has a significant quantity of low-density, juvenile wood. According to Malan (1995) and Githiomi and Kariuki (2010) high-density mature wood begins to form about 5 to 8 years in *E.grandis*.

The mechanical properties of sapwood and heartwood from *E. grandis* were determined. The mechanical properties of sapwood, in general, were higher than those of heartwood. It is believed that the presence of juvenile wood in heartwood caused this difference. It is known that juvenile wood has shorter fibers, thinner cell walls, and lower density than mature wood in *E. grandis* (Bhat et al, 1990; Lima et al, 2010; Bal, 2012). It also reported that juvenile wood has considerably different physical and anatomical properties than mature wood. Specific gravity, strength, cell length, and the thickness of the cell wall increase in the radial direction as juvenile wood matures (Green et al, 1999).

In the present study, the average values of MOR were similar to those reported for *E. grandis* wood (Santos et al, 2004; Lemanih and Bekele 2004). It was determined that MOE and MOR values were higher in the "330" clone than in some other clones. The "330" clone has very high density compared to others (Casro and Paganini, 2003).

It was determined the shear strength to be 12.61 N mm^{-2} (Santos et al, 2004). This result was higher than that of the present study. This may have resulted from the fact that our tests were conducted on radial or tangential surfaces. Generally, shear strength parallel to the grain is greater on the radial surface than on the tangential surface because of resistance of the latewood in the annual ring. This factor has been accounted for in some other research studies. It was measured shear strengths of 10.7 N mm^{-2} and 11.3 N mm^{-2} on the radial and tangential surfaces, respectively (Acosta et al, 2007) and these differences in the juvenile and mature wood of 10 different species were determined (Bao et al,2001).

The greatest static hardness values were measured in the tangential surface. In general, the greatest static hardness values were determined in cross sections of the wood. However, in fast-growing trees, density increases from pit to bark in the radial direction (Baht et al, 1990; Bal et al, 2011). The density of measuring point of the tangential surface was higher than that of cross section. This might be the reason for determining greatest values in the tangential surfaces.

Conclusions

In this study, mechanical properties of *E. grandis* wood grown in Karabucak region were determined. The relationships between oven-dried and air-dried densities and mechanical properties were calculated. The following conclusions were drawn:

Mechanical properties of *E. grandis* were affected by the presence of juvenile wood in the heartwood.

The mechanical properties of heartwood were lower than those of sapwood. The correlations between oven-dried density and mechanical properties were strong, and they were statistically significant.

Although *E. grandis* is a very fast-growing tree, the mechanical properties of *E. grandis* were determined to be superior to those of some other species of trees.

It is recommended that *E. grandis* heartwood not be used in important places when it can be subjected to dynamic loading, because it has a low impact bending value.

Acknowledgement

The authors thank the Kahramanmaraş Sütçü İmam University Research Fund for the financial support (Project No: 2009/3-2D).

References

Acosta, M. S., Marco, M., Piter, J. C., Zitto, MAS., Villalba, D. I., Carpineti, L. 2007. "Physical and mechanical properties of Eucalyptus grandis x E. Tereticornis hybrid grown in Argentina", IUFRO All Division 5 Conference, Taiwan.

Adalı, F. 1944. "Health Tree; Eucalyptus", Publications Directorship of Agriculture Ministry, Practical Books, No: 3, Istanbul, P: 146.

Anonym, 2006. Forestry Special Commission Report, 9th Development Plan, DPT, Ankara.

Anonym, 2012. "Eucalyptus grandis plantations project", www.mopak.com.tr, erişim: 25.06.2012.

Ayata, Ü. 2008. “A Research of Eucalyptus (Eucalyptus Camaldulensis and Eucalyptus Grandis) Wood Properties and Their Use in The Paper Industry”, Msc Thesis, Institute of Natural and Applied Sciences, Kahramanmaraş Sütçü İmam University, Kahramanmaraş, Turkey.

Bao, F. C., Jiang, Z. H., Jiang, X. M., Lu, X. X., Luo, X. Q., Zhang, S. Y. 2001. “Differences in wood properties between juvenile wood and mature wood in 10 species in China”, Wood Sci Tech 35: 363-375,

Bal, B. C., Bektaş, İ., Tutuş, A., Kaymakçı, A. 2011. The Within-Tree Variation in Some Physical Properties in Eucalyptus Grandis Grown in Karabucak Region, Düzce University Journal of Forestry, 7 (2):82-88.

Bal, B. C. 2012. Genç odun ve olgun odunun lif morfolojisindeki farklılıklar üzerine bir araştırma, Düzce University Journal of Forestry, 8 (2):29-35

Bal, B. C., Bektaş, İ. 2012. The physical properties of heartwood and sapwood of E**ucalyptus grandis,** Proligno 8 (4):35-43.

Bhat, K. M., Bhat, K. V., Dhamodaran, T. K. 1990. “Wood density and fiber length of Eucalyptus grandis Grown in Kerala, India”, Wood Fiber Sci J 22 (1):54-61.

Castro, G., Paganini, F. 2003. “Mixed glued laminated timber of poplar and Eucalyptus grandis clones”, Holz als Roh- und Werkstoff 61: 291–298.

Cossalter, C., Pye-Smith, C. 2003. Fast-wood Forestry: Myths and Realities. Center for International Forestry Research, Jakarta, Indonesia.

Githiomi, J. K., Kariuki, J. G. 2010. Wood basic density of E. Grandis from plantations in central rift valley, Kenya: variation with age, height level and between sapwood and heartwood, J of Trop For Sci 22(3): 281–286.

Gürses, M. K., Gülbaba, A. G., Özkurt, A. 1995. “Report about improves eucalyptus cultivation in Turkey”, Journal of DOA V: 8.

Green, D. W., Winandy, J. E., Kretschmann, D. E., 1999.“Mechanical Properties of Wood, Wood Handbook, Wood as Engineering Material”. FPL, 11-2, Madison.

Lemenih, M., Bekele, T. 2004. “Effect of age on calorific value and some mechanical properties of three Eucalyptus species grown in Ethiopia”, Biomass Bioenergy 27: 223 – 232,

Lima, I. L., Longuı, L. E., Junıor, L. S., Garcia, N. J., Florsheim, S. M. B. 2010c. “Effect of fertilization on cell size in wood of Eucalyptus Grandis Hill Ex Maiden”, Cerne, Lavras, 16(4):465-472.

Malan, F. S. 1995. Eucalyptus Improvement For Lumber Production, Semınárıo Internacıonal De Utılızação Da Madeıra De Eucalıpto Para Serrarıa.Sao Paulo.

Mengeloğlu, F., Karakuş, K. 2008. “Some properties of eucalyptus wood flour filled recycled high density polyethylene polymer-composites”, Turk J Agric For 32: 537-546.

Özkurt, A. 2002. “Eucalyptus plantations in Turkey: Problems and opportunities”, Journal of DOA, V: 8. Tarsus.

Santos, PET., Geraldi, I. O., Garcia, J. N., 2004. “Estimates of genetic parameters of wood traits for sawn timber production in Eucalyptus grandis”, Genet Mol Biol, 27(4):567-573.