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Determination of some physical and mechanical properties of Calabrian pine (*Pinus brutia* Ten.) trees grown in the Denizli area of Turkey

Kadir Ozkaya

Pamukkale University, Denizli Vocational School of Technical Sciences, Department of Materials and Materials Processing Technology, 20070, Denizli, Turkey.

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The most extensive distribution of Calabrian pine (*Pinus brutia* Ten.) trees in the world is found in Turkey. This species varies depending on the regions in Turkey for growth features, such as climate, soil structure and slope. In this study, the technological properties of Calabrian pine (*Pinus brutia* Ten.) grown in the Denizli area were studied. Within the scope of the study, their physical properties, such as air-dried and oven-dried specific densities, swelling and shrinkage values were determined. Their mechanical properties, such as bending strength, modulus of elasticity in bending, parallel compressive strength to the fibers, parallel tensile strength to the fibers and shear strength in a radial direction were determined. The values obtained were compared with the Calabrian pine (*P. brutia* Ten.) trees grown in different regions.

Key words: Denizli, *Pinus brutia* Ten., physical properties, mechanical properties.

INTRODUCTION

Firstly, the rational and economic use of wood should be provided for meeting the demand for lumber from Turkey's forests, which is supplied by importing from abroad. The most effective way to solve the problem would be to set forth the various properties of Turkey's original tree species and to process the wooden raw materials according to these properties to provide for the manufacturing of products that can ensure the best performance in their place of use. Although, it is known that the properties of Turkey's original tree species have both genetic and ecologic elements and vary depending on the regions, very few studies have been made on this subject (Ilter et al., 2011). This species of Calabrian pine (*Pinus brutia* Ten.), by taking into consideration its distribution around the world and its intensity of distribution in Turkey, has been mentioned in the international literature as "Turkish red pine" and is one of Turkey's original tree species with a high economic value. Calabrian pine has been established in pure forests in the Mediterranean, Aegean and Marmara Regions of Turkey, while it is found sporadically and in groves in the coastal and inner parts of the Western and Central Black Sea regions (Ilter et al., 2011). The first studies related to the technical properties for broadening the areas of usage of this species of Calabrian pine, which is widespread in Turkey, date back to the 1950s (Berkel, 1957). Calabrian pine wood has a porous structure and since it is of medium density, it is appropriate for the production of wood-polymer composites (Yildiz, 1993). Since Calabrian pine has excessive resin in its structure, resin production from Calabrian pine does not cause any significant changes in its physical properties and produces an

E-mail: kadirozkaya@pau.edu.tr.

Table 1. Geographical and structural information for the trees used in the tests.

Geographical and structural properties of calabrian pine trees			
Regional Directorate	Denizli	Exposure	North
Operations Directorate	Eskere (Beyagac)	Location	Akcatas
Sub-district Directorate	Karacaoren	Soil structure	Serpentine
Division	56	1.30 m diameter (cm)	50
Latitude	37º 12' 04'' .4 N	Age	120
Longitude	28° 43' 04'' .6 E	Height (m)	20
Altitude (m)	950		

increase in its mechanical properties (Oktem and Sozen, 1996). Calabrian pine can be split open easily. This characteristic of Calabrian pine enables it to be used in cooperage and shipbuilding (Bektas et al., 2003).

The habitat is significant in the formation of the technological properties of trees. Consequently, the properties of Calabrian pine, just as for other tree species, vary according to growth regions (Bektas et al., 2003). For instance, as a result of the anatomical, physical and mechanical studies made on the Calabrian pine grown in the Datça, Marmaris region, it was understood that it could be utilized in producing wire poles, mine poles, constructive materials, yachts and boats, packing cases, fence pickets, cultivation tools, cases, and in the paper and cellulose industry (Bozkurt et al., 1993). Care should be taken in the area where Calabrian pine is grown, especially in places where it is exposed to the bending impact. The Hatay, Adana and Antalya regions could be recommended if Calabrian pine will be used in the areas that require static bending strength, such as mine poles, construction forms and bridges (Ilter et al., 2011).

While it was emphasized in the research studies made that regional differences were significant, a determination has not been made for the trees growing in the Denizli area, the starting point in the western Mediterranean region where the optimal growing conditions for Calabrian pine occur.

In this study, it was aimed to increase the industrial use of Calabrian pine by determining the technological properties of the Calabrian pine species grown in the Denizli area. For this purpose, the trees grown in the areas remaining between Beyağaç – Çameli – Acıpayam, where the most habitats in the Denizli area are found, have been studied.

MATERIALS AND METHODS

Four sample trees were selected by considering the habitat characteristics, such as direction, slope, altitude, diameter, density, etc. in the Eskere – Akçataş area, where the largest distribution of Calabrian pine is found. The areas from which the sample trees were taken and the general properties of tree species were determined according to the TS 4176 (ISO 4471) standards. The geographical and structural properties of the Calabrian pine (*P. brutia* Ten.) selected for the experimental materials used in the study have been given in Table 1.

Preparation of the specimens

After marking the bark on the north side of the trees, they were cut 0.30 m above the soil and their full-length was measured. Wheel-shaped sections 15 cm long were removed from the trunks of each sample tree once every 2 m by starting from 0.30 m high and 2-m. Long trunk sections were removed from each sample tree between 2 and 4 m. The north direction was marked on the transversal section of each piece and they were enumerated according to the sequence of removal. The 2 m long trunk sections were cut to a width of 6 cm in a north-south direction and east-west direction to determine the physical and mechanical properties. The pieces obtained were kept in a dry place for 3 months until they reached equilibrium moisture content (EMC).

Specimens were prepared from the 6 cm wide, 2-m long trunk sections for testing compressive strength, bending strength, tensile strength, shear strength, shrinkage and swelling and 15 cm high specimens from the trunk sections were prepared for testing air-dried and oven-dried density (Figure 1). All the specimens obtained were conditioned at a temperature of 20±2°C and a relative humidity of 65±5% until they reached an EMC.

Analysis of physical properties

Strips 2 cm wide in the north-south and east-west directions were removed from the 15 cm long tree trunk sections obtained from the sample trees for density measurements. Specimens measuring 20×20×30 mm were used according to the TS 2471 (ISO 3130) and TS 2472 (ISO 3131) standards to determine the air-dried (δ_{12}) and oven-dried (δ_o) densities of Calabrian pine.

Specimens prepared from the 1 m long tree trunks of Calabrian pine wood were used for the dimensional tests. Specimens measuring 30×30×15 mm were prepared according to the TS 4083 (ISO 4469) and TS 4084 (ISO 4859) standards to determine the amount of efficiency in the tangential and radial directions.

For the dimensional swelling test (α), the dimensions of the specimens were measured separately in the tangential and radial directions via digital calipers after being kept in a climatization chamber at a temperature of 20±2°C and a relative humidity of 65±5% until they reached the EMC of 12±2% (L_{12}). Later, when the same specimens reached the EMC of 21±2% in a climatization chamber at a temperature of 20±2°C and a relative humidity of 90±5%, they were measured again at the first measurement place (L_{21}) (Sogutlu, 2004).

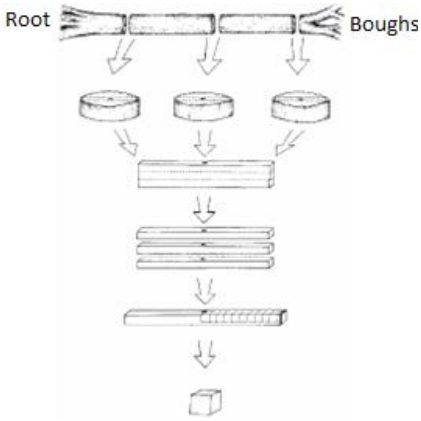


Figure 1. Specimen taking from the sample tree trunk for determining the physical properties (Dogdu, 2006).

The dimensional swelling percentages ($\alpha_{//}$) were calculated according to Formula 1.

$$\alpha// = \frac{L_{21} - L_{12}}{L_{12}} \times 100 \quad (1)$$

The amount of volumetric swelling (α_v) was obtained from the sum of the percentages of swelling in the tangential and radial directions (α_t, α_r) according to Formula 2.

$$\alpha_v = \alpha_t + \alpha_r \quad (2)$$

The amounts of dimensional shrinkage (β) were determined according to the principles stated in the TS 4083. The specimens were kept in a climatization chamber at a temperature of 20±2°C and a relative humidity of 90±5% until they reached the EMC and were measured separately in the tangential and radial directions (L_{21}). Later, when the same specimens reached the EMC of 7±2% at a temperature of 20±2°C and at a relative humidity of 30±5%, they were measured again at the first measurement place (L_7) (Sogutlu, 2004). The dimensional shrinkage percentages ($\beta_{//}$) were calculated according to Formula 3.

$$\beta// = \frac{L_{21} - L_7}{L_{21}} \times 100 \quad (3)$$

Separate values were calculated for the percentage of shrinkage in the tangential and radial directions (β_t, β_r). The amounts of volumetric shrinkage (β_v) were obtained from the sum of the percentages of shrinkage in the tangential and radial directions according to Formula 4.

$$B_v = \beta_t + \beta_r \quad (4)$$

A total of 24 specimens were utilized for each test to determine the physical properties. Of these, the results of 16 specimens that fulfilled the homogeneity of normality were evaluated.

Analysis of mechanical properties

Test specimens were prepared from the sample lumber in the dimensions of 6×200 cm for testing the mechanical properties of compressive strength, bending strength, tensile strength and shear strength (Table 2).

All the specimens were able to reach the EMC by being conditioned at a temperature of 20±2°C and a relative humidity of 65±5%. Subsequently, the tests were carried out via the tensile compression testing machine. The pace of the test was adjusted so that the specimens would break in 1.5 to 2 min and the strength at the instant of failure (F_{max}) was measured. A total of 20 specimens were utilized for each test to determine the mechanical properties. Of these, the results of 12 specimens that fulfilled the homogeneity of normality were evaluated.

Statistical analysis

Normality analysis was applied to the results obtained and extreme values were attained. Next, the one-sample T-test was applied for each test implementation separately and the statistical significance of the values was evaluated at an interval of confidence of 95%.

RESULTS AND DISCUSSION

According to the analysis results, all tests were found to be statistically significant ($p<0.05$). The analysis results of the tests carried out to determine the physical properties have been given in Table 3 and to determine the mechanical properties have been given in Table 4.

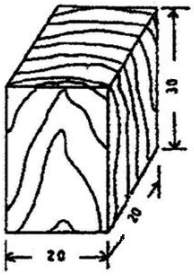
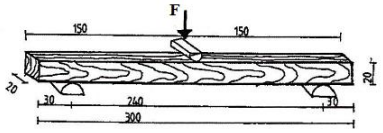
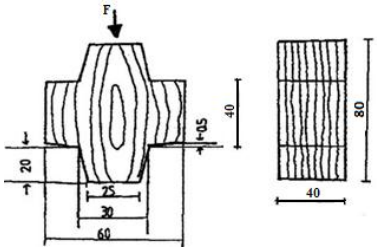
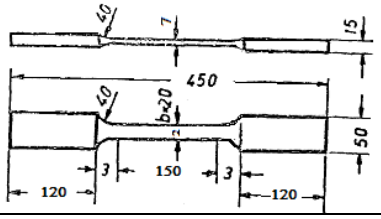
In Table 5, the values obtained in the study were compared with the values obtained in a study carried out by the Central Anatolia Forestry Research Institute of the Ministry of Forestry of the Republic of Turkey (Ilter et al., 2011).

According to the values of Calabrian pine trees grown in the Denizli area given in Table 5, the air-dried and oven-dried density values (0.567 g/cm^3, 0.532 g/cm^3) were higher than the trees in the Kahramanmaras area, but lower than in the Antalya and Samsun areas. However, the differences among the values were not very significant.

According to the swelling and shrinkage percentages, while the trees grown in Denizli area had the lowest values in a tangential direction, they had the highest values in a radial direction and volumetrically. The longitudinal values could not be compared, since they were not analyzed in the research carried out by the Institute. According to these results, if businesses prefer Calabrian pine, then they could utilize the trees grown in the Denizli area by using the tangential directions on large surfaces for outdoor furniture.

According to the mechanical properties, the Calabrian pine grown in Denizli area had the lowest values in bending strength and shear strength in a radial direction. This situation could result from the anatomical structure, especially from the chemical structures of Calabrian pines. According to the literature, properties of wooden material, such as density, temperature, moisture, knots and fiber direction affect its bending strength (Bozkurt and Erdin, 1997). However, the differences in resin and cellulose-lignin percentages are significant on bending strength (Ilter et al., 2011). The chemical components of

Table 2. Tests and types of specimens for determining the mechanical properties.

Tests	Standards	Type of specimen
Parallel compressive strength to the fibers ($\sigma_{B//}$)	TS 2595 (ISO 3797)	
MoR (σ_e) and MoE (E)	TS 2474 (ISO 3133), TS 2478 (ISO 3349)	
Shear strength in radial direction (σ_m)	TS 3459 (ISO 3347)	
Parallel tensile strength to the fibers ($\sigma_{ç\perp}$)	TS 2475 (ISO 3345)	

Calabrian pine woods should be analyzed in order to reach a firm conclusion on this issue.

The highest values from the mechanical test results were obtained in parallel compressive strength to the fibers and parallel tensile strength to the fibers. According to this result, the Calabrian pine trees grown in the Denizli area do not have sufficient strength for longitudinal strength to the fibers. If it is preferred as a construction material, especially for building construction and roofs, it should not be preferred for practices in a horizontal direction, such as beams.

Conclusion

In this study, some of the technological properties of Calabrian pine (*P. brutia* Ten.) trees grown in the Denizli area were investigated. Oven-dried and air-dried density values were significant criteria for determining the amount of raw material in its structure (Bozkurt and Erdin, 1997). These values are used to determine the productivity of cellulose in paper production and wood density should be between 0.300 to 0.600 g/cm^3 for commercial wood pulp (Gunduz, 1999). Therefore, the Calabrian pine trees grown in the Denizli area used in this study as the research material were found to be suitable for paper production. As its shrinkage and swelling values were low in a tangential direction but high in a radial direction and volumetrically compared to the other areas, by taking into account the use of direction, Calabrian pine could be preferred for outdoor applications such as arbor, benches and bridges, and for the furniture in damp places, such as bathrooms, saunas and kitchens. In this study, it was found that Calabrian pine trees grown in the Denizli area were less resistant against longitudinal loads to the fibers.

On the other hand, as they obtained better results against loads parallel to the fibers and tensile strength compared to the other areas, the use of Calabrian pine in the right direction should be considered in uses that require resistance to loads, such as prefabricated houses, roofs, wardrobe closets, bookcases and

Table 3. Descriptive statistics for the physical properties.

Properties		Sample size (N)	Arithmetic mean ($\overline{x}$)	Standard deviation (SD)	Variance (V)	Coefficient of variation (CV)	Min. value	Max. value
Air-dried density δ_{12} (g/cm^3)		16	0.567	0.032	0.001	5.643	0.520	0.630
Oven-dried density δ_0 (g/cm^3)		16	0.532	0.033	0.001	6.203	0.490	0.600
Swelling α (%)	α_t	16	7.813	1.059	1.122	13.554	6.330	9.510
	α_r	16	8.866	0.421	0.177	4.748	8.100	9.640
	α_v	16	16.679	0.888	0.788	5.324	15.210	17.910
	α_l	16	0.659	0.175	0.031	26.555	0.410	1.00
Shrinkage β (%)	β_t	16	6.753	0.859	0.738	12.720	5.300	8.65
	β_r	16	6.924	0.475	0.226	6.860	6.180	7.720
	β_v	16	13.677	0.963	0.928	7.041	12.240	15.630
	β_l	16	0.681	0.131	0.017	19.236	0.530	1.040

T, Tangential,; r, Radial; v, Volumetric; *l*, Longitudinal.

Table 4. Descriptive statistics for the mechanical properties.

Properties	N	$\overline{X}$	SD	V	CV	Min	Max
Modulus of elasticity in bending (MoE) (*E*) (N/mm^2)	12	9650.755	577.059	332997.583	5.979	8728.960	10743.720
Bending strength (MoR) (σe) (N/mm^2)	12	95.893	5.516	30.431	5.752	87.110	105.260
Shear strength in radial direction (σ_m) (N/mm^2)	12	6.613	0.525	0.275	7.939	5.623	7.320
Parallel compressive strength to the fibers ($\sigma_{B//}$) (N/mm^2)	12	60.674	3.297	10.872	4.036	56.640	65.570
Parallel tensile strength to the fibers ($\sigma_{ç\perp}$) (N/mm^2)	12	81.697	15.401	237.131	18.851	61.460	113.520

Table 5. Comparison of the properties of Calabrian pine grown in other areas.

Technological properties		Area (City)			
		Denizli	Antalya	Samsun	Kahramanmaraş
Physical properties	δ_{12} (g/cm^3)	0.567	0.580	0.588	0.530
	δ_0 (g/cm^3)	0.532	0.541	0.558	0.500
	α_t (%)	7.813	7.650	8.670	8.120
	α_r (%)	8.866	6.330	6.430	5.590
	α_v (%)	16.679	14.390	15.630	14.170
	α_l (%)	0.659	-	-	-
	β_t (%)	6.753	7.390	7.690	7.720
	β_r (%)	6.924	6.310	6.270	5.230
	β_v (%)	13.677	12.400	12.590	11.750
	β_l (%)	0.681	-	-	-
Mechanical properties	σe (N/mm^2)	95.893	112.306	102.311	99.9740
	σm (N/mm^2)	6.613	9.274	6.831	7.174
	$\sigma_{B//}$ (N/mm^2)	60.674	58.813	53.588	50.607
	$\sigma ç_\perp$ (N/mm^2)	81.697	78.103	72.430	77.203

transport boxes. In conclusion, the Calabrian pine (*P. brutia* Ten.) trees grown in the Denizli area have the technological values that could compete with trees grown in other areas.

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