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Relationship Between Number of Annual Rings in Sample Cross-Section and Static Bending Strength of Cypress Wood by Linear and Power Models

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Abstract: The strength of cypress wood (*Cupressus sempervirens L.*) was studied by static bending in Tangential direction. The dependence of the strength on the number of annual rings in sample cross-section was analyzed. Experiments were carried out with cypress wood samples, the cross-section of which contained from 6 to 44 annual rings. Average of density at 12% moisture content of Cypress wood is 666 kg/m^3. The strength of modulus of rupture and modulus of elasticity of the mentioned density in tangential direction were determined 44.58 MPa and 5.28 GPa, respectively. The wood strength values increased with increasing number of annual of annual rings in sample cross-section, when annual rings become narrower. The relationship between number of annual rings in sample cross section and wood strength was determined by linear ($Y = ax + b$) and power ($Y = ax^b$) regression. It was found that there were positive relationships between numbers of annual rings and wood strength. The power equation is better than the linear equation one at predicting mechanical properties in a species.

Key words: Cypress wood · Static bending strength · Annual rings

INTRODUCTION

Cupressus sempervirens L. family Cupressaceae, Mediterranean Cupresses, has been widely cultivated as an ornamental tree for millennia miles away from its native range, mainly throughout the central and western Mediterranean region, in north Libya, South Greece, turkey, western Syria, Lebanon and western Jordan and in other areas with similar hot, dry summer and mild, rainy winter, including California, south Africa, northern Iraq, south of Caspian sea coasts and southern Australia and Italy. Cypress wood is versatile, easy to work with hand and machine tools and possible to nail, stain and polish well. It can be used for structural and nonstructural applications including general construction and furniture making purposes. Its texture is fine and uniform and its grains are usually straight [1, 2, 3]. Cypress wood is one of softwood species with gradual transition from early wood to late wood [1].

Wood is one of the most widely used materials not only in wood processing industry, but also in other fields of industry (construction, chemistry, machinery etc.) [4, 5]. Wood as material is very advantageous: it is easily processed (compared to metals and stone), is strength resistant, is hardly affected by acids and alkali, has low heat conductivity, is characterized by good adhesion properties, pleasant appearance and good finishing [6]. However, it has some negative features: under changing moisture content wood swells or shrinks, its strength, hardness and other mechanical properties differ in different directions; usually wood has defects which worsen the quality of wood and its products [7]. Therefore, to use this material properly and efficiently, it is necessary to know its physical and mechanical properties.

Wood density is a commonly used wood quality indicator that is related to other wood properties, such as timber strength and shrinkage, as well as pulp yield and properties [8]. Wood density is mainly influenced by genotype, ageing of the cambium and growth rate [9]. In conifers, increased growth rate usually leads to a greater increase in earlywood (low density) than in latewood (high density) formation and also delays the transition from juvenile wood to mature wood [10, 11].

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Wood resistance to compression (as well as other physical and mechanical properties) depends also on its microstructure. Dimensions of individual structural elements of wood influences its strength, i.e. the more elements and the thicker their walls, the higher is wood strength. On the base of presented data [12], it is stated that increase of wall thickness of late tracheids by 36% for pine wood and by 30% for larch wood, density increases respectively by 18 and 20%. Width of annual rings also influences physical and mechanical properties of wood. The distinctness of annual rings in various species differs. Their width varies. It depends not only on the tree species, but also on the age, climate, growth conditions, *etc*. In the wood of ring-porous deciduous the width of annual rings is greater in places where late wood is more developed. Great influence on wood strength has the amount of late wood in annual rings. The color of early and late wood in deciduous trees is almost the same, but its density differs. Early wood is much more porous. It is especially obvious in the cross-sections of oak and ash wood. Late wood is essentially comprised of mechanical elements; therefore its density and mechanical properties are 2-3 times higher than those of early wood [7].

The site variations had significant effect on the annual ring width, density and mechanical strength properties of planted cypress wood in north of Iran. The values of annual ring width were increased, by increasing altitude. The mechanical strength properties and wood density due to increasing of annual ring width were decreased [13]. Juodeikiene and Norvydas (2005) reported the compression perpendicular strength values decreased by increasing number of annual rings in sample cross-section in tangential and radial directions of oak wood and radial direction of ash wood [14].

Cupressus sempervirens L. is one of the four native softwoods which comprise about 0.5% of the forest covered in Iran, which are in the Hassanabad of Chalous in the western part of Mazandaran in north of Iran. Several studies were conducted in Iran and around the world using locally grown cypress species to determine their properties. Thus, the aim of this work is to determine static bending strength cypress wood and its dependence on the number of annual rings in sample cross-section.

MATERIALS AND METHODS

In this research, 5 normal cypress trees were randomly selected at the natural Hassanabad-Chalous forest, which is located in the western part of Mazandaran province in the north of Iran. These trees have been for 100-105 years at this site. The annual rainfall and annual average temperature (1976-2010) was 350 mm and 14°C. October and November are high-rain months and June and July are low-rain months. The temperature reaches its maximum level in June, July and August. These trees were cut for this study in January 2010. One 50 cm log was removed from each tree at breast height. The log was used for static bending tests to calculate the modulus of elasticity and the modulus of rupture. The specimens were taken from mature wood. The age demarcation point between juvenile and mature wood was estimated at around 25 years [15]. According to the ASTM-D143-94 standard (second method), the sample dimensions were 25 × 25 × 410 mm for static bending strength tests, such as modulus of rupture (MOR) and modulus of elasticity (MOE). The prepared samples were then conditioned in a room at a temperature of 20°C and 65 ± 5% relative humidity until the specimens reached an equilibrium moisture content of about 12%. The load was applied in the tangential direction. Also, the wood density of samples was determined in mentioned moisture content. Number of annual rings in the cross-section of samples varied from 6 to 44. Cross-section of the samples is too small to eliminate the influence of ring crookedness. According to the number of annual rings in the cross-section, cypress wood samples were divided in to 4 groups (Table 1).

Statistical Analysis: Was conducted using the SPSS program in conjunction with analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to test statistical significance at the $\alpha = 0.05$ level. The simple linear and power regression model (REG procedure) was used to analyze the relationship between number of annual rings and wood density and static bending strength and also between wood density at 12% moisture content and static bending tests. Equations for linear and power models regressions is $Y = ax + b$ and $Y = ax^b$, respectively.

Table 1: Grouping of samples according to the number of annual rings in sample cross-section

Groups	1	2	3	4
Number of annual rings in sample cross-section	6…10	11…20	21…30	31…44

RESULTS

Wood Density at 12% Moisture Content: Results of ANOVA indicated that there are significant differences between number of annual rings and wood density in tangential direction (Table 1), such that by increasing of number of the annual rings, the values of wood density of cypress wood also were increased. The mean of wood density at 12% moisture content in tangential direction was 559-723 kg/m^3 (Figure 1). The results of correlation showed that the positive relationship between number of annual rings and wood density in both model, but these correlations in power model (R^2 = 0.710) is stronger than linear regression (R^2 = 0.597) for cypress wood. The equations of linear and power models were shown in Figure 2.

Modulus of Rupture (MOR): Results of ANOVA indicated that there are significant differences between number of annual rings and modulus of rupture in tangential direction (Table 2), such that by increasing of number of annual rings, the values of modulus of rupture of cypress wood were increased. The mean of modulus of rupture in tangential direction was 30.31-55.28 MPa (Figure 3). The results of correlation showed that there are positive relationship between number of annual rings and modulus of rupture in both model, but these correlations in power model (R^2 = 0.381) is stronger than linear regression (R^2 = 0.356) for cypress wood. These equations for linear and power models were shown in Figure 4. In addition, the relationship between density at 12 % moisture content and modulus of rupture (MOR) is positive (Figure 5).

Modulus of Elasticity (MOE): Results of ANOVA indicated that there are significant differences between number of annual rings and modulus of elasticity in tangential direction (Table 3), such that by increasing of number of annual rings, the values of modulus of elasticity of cypress wood were increased. The mean of modulus of elasticity in tangential direction was 4-6.30 GPa (Figure 6). The results of correlation showed that there are positive relationship between number of annual rings and modulus of elasticity in both model,

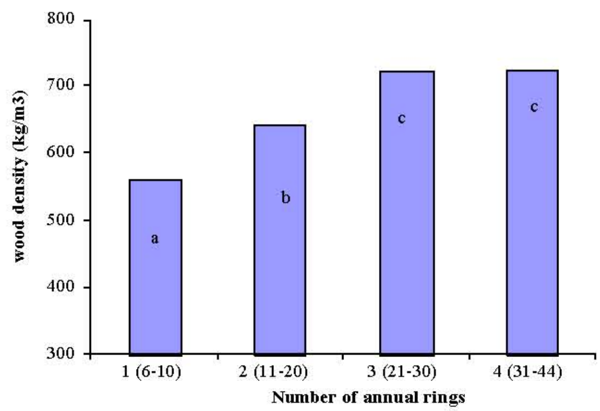

Fig. 1: The average of density for cypress wood

Table 1: The analysis of variance between number of annual rings and wood density

Wood density (12%)	Sum of Squares	df	Mean Square	F
Between Groups	412879.012	3	137626.337	53.557**
Within Groups	200436.619	78	2569.700	
Total	613315.632	81		

**: Significant at 0.01

Table 2: The analysis of variance between number of annual rings and MOR

Modulus of rupture	Sum of Squares	df	Mean Square	F
Between Groups	7174.847	3	2391.616	13.695**
Within Groups	13621.268	78	174.632	
Total	20796.115	81		

**: Significant at 0.01

Table 3: The analysis of variance between number of annual rings and MOE

MOE	Sum of Squares	df	Mean Square	F
Between Groups	68.531	3	22.844	19.120
Within Groups	93.192	78	1.195	
Total	161.723	81		

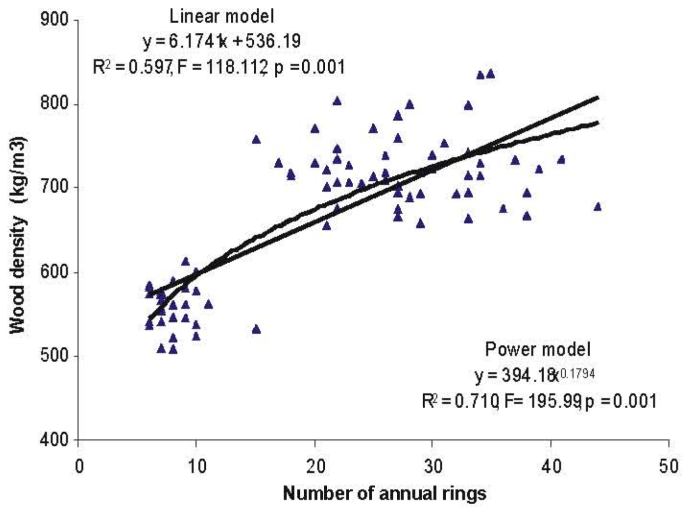

Fig. 2: The relationship between number of annual rings and wood density

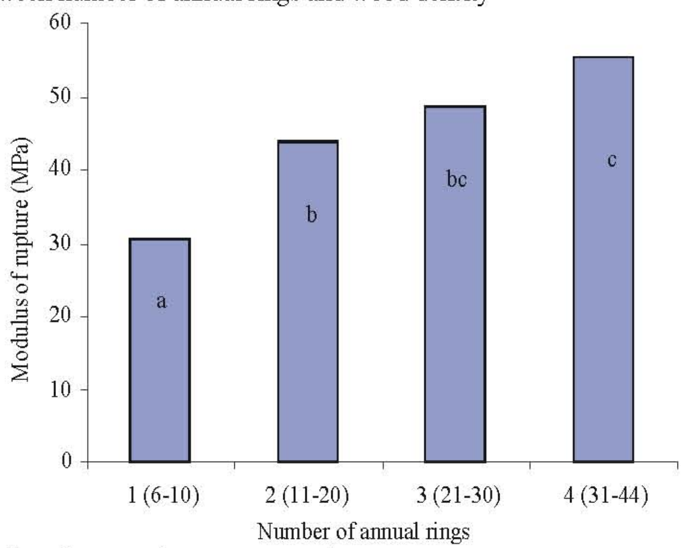

Fig. 3: The average of modulus of rupture for cypress wood

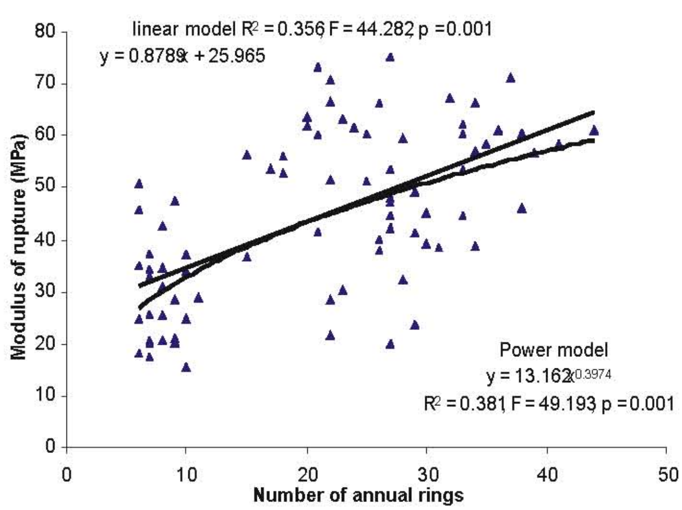

Fig. 4: The relationship between number of annual rings and modulus of rupture

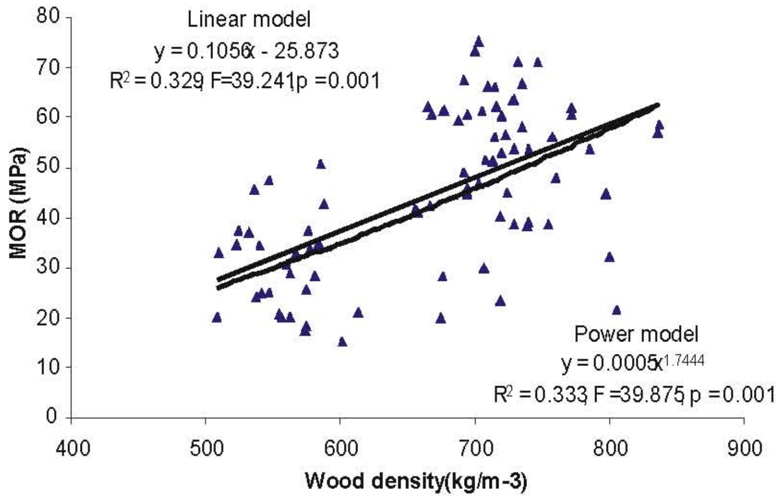

Fig. 5: The relationship between wood density and modulus of rupture

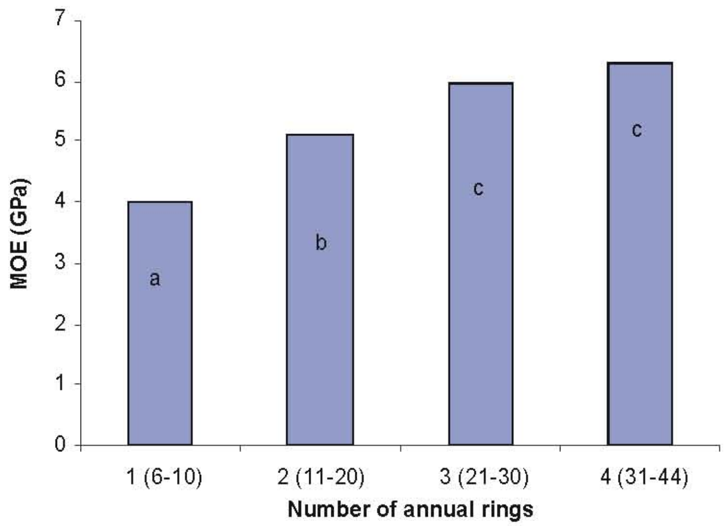

Fig. 6: The average of modulus of elasticity for cypress wood

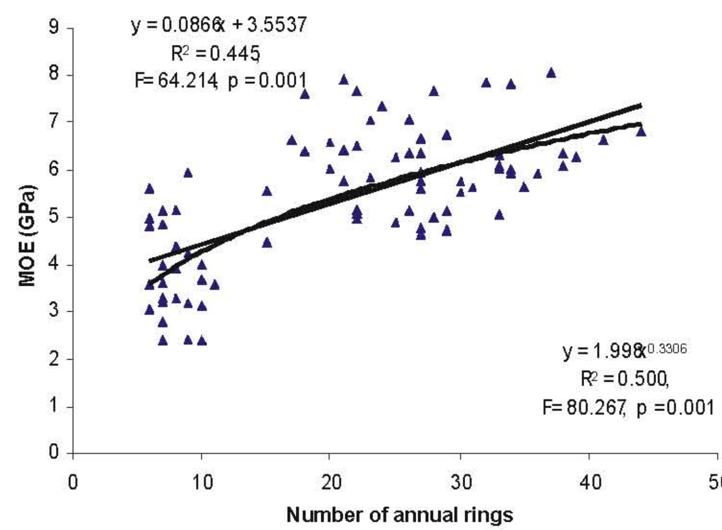

Fig. 7: The relationship between number of annual rings and modulus of elasticity

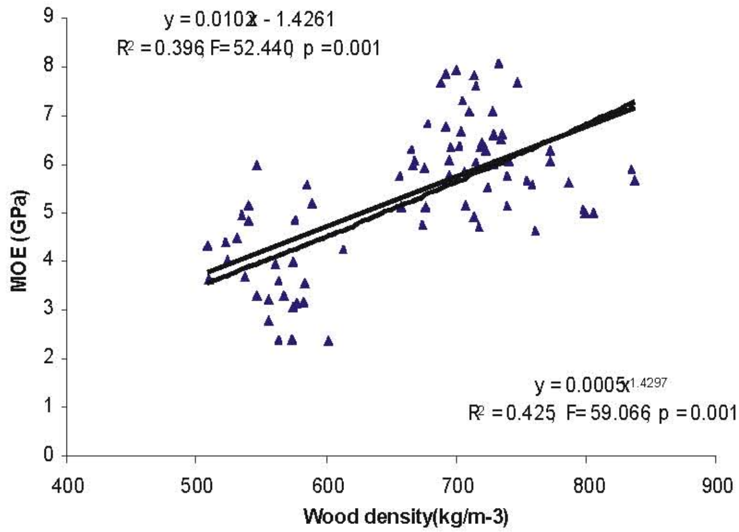

Fig. 8: The relationship between wood density and modulus of elasticity

but these correlations in power model (R^2 = 0.500) is stronger than linear regression (R^2 = 0.445) for cypress wood. The equations of linear and power models were shown in Figure 7. In addition, the relationship between the wood density at 12% moisture content and modulus of elasticity is positive (Figure 8).

DISCUSSION

The highest of wood density at 12% moisture content of cypress wood in tangential direction was 723 kg/m^3, when sample contains 31-44 rings. Here the tendency of strength increased with increasing number of annual rings in sample cross-section is observed. Strength when the number of annual rings is smaller or equal to 6-10, equals 559 kg/m^3 and it is by 23% less than strength when sample cross-section contains 31-44 rings.

The highest strength of MOR values of cypress wood in tangential direction was 55.28 MPa, when sample contains 31-44 rings. Here the tendency of strength increased with increasing number of annual rings in sample cross-section is observed. MOR is equal to 30.31 MPa when number of annual ring is 6-10 and this value decreases by 45% when there are 31-44 annual rings in the sample cross section.

The highest value of MOE of cypress wood in tangential direction was 6.3 GPa, when sample contains 31-44 rings. Here the tendency of strength increased with increasing number of annual rings in sample cross-section is observed. Strength when the number of annual rings is smaller or equal to 6-10 i. e equals 4 GPa and it is by 36 % less than strength when sample cross-section contains 31-44 rings.

The increase of number of annual rings in sample cross-section (from 6-44), i.e. the decrease width of annual rings, results on the increase strength of cypress wood in tangential direction. It is explained by the fact, that the width of annual rings in the wood of softwood deciduous is in places where early wood is worse developed and is characterized by 2-3 times lower density and worse mechanical properties than late wood [8, 16, 17]. In addition, there are positive relationship between specific gravity and mechanical properties. In determining the correlation the power equation is better than the linear equation predicting mechanical properties in a species, which these reported by Zhang (1997) [17]. The same has been established by this study. He stated that there are positive between wood density and MOR strength properties in softwood. But these correlations in softwoods with abrupt transition from early wood to late wood are stronger than softwoods with gradual transition from early wood to late wood [17].

CONCLUSION

This study examines the effect of number of annual rings on the wood density and mechanical properties of cypress wood in north of Iran. The following conclusions were obtained from this research:

- There was positive relationship between number of annual ring and wood density with mechanical properties of cypress wood in north of Iran. In other hand, the wood density and mechanical properties values were increased by increasing annual rings in softwood species.

- The correlations between the wood density and also number of annual rings in cross section with mechanical properties in power equation are stronger than linear model for cypress wood.
- Cypress wood with high number of annual ring is suitable than wood with low number of annual rings for structural applications.

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