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Variation in the Wood Physical and Mechanical Properties of *Zelcova carpinifolia* Trees along Longitudinal Direction

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Abstract: In the present study, variations of the physical and mechanical properties of elm wood (*Zelcova carpinifolia*) along longitudinal direction were studied. For this purpose, 5 normal trees were selected from Noshahr region in north of Iran. From each of tree, three discs were cut at 25%, 50% and 75% of stem height. The physical properties such as oven-dry density (733 Kg/m^3), volumetric shrinkage (8.98%) and volumetric swelling (9.78%) and the mechanical properties including modulus of rupture (128.93 N/mm^2), modulus of elasticity (9738.05 N/mm^2), compression parallel to the grain (29.73 N/mm^2), compression perpendicular to the grain (12.33 N/mm^2), shear parallel to the grain (14.19 N/mm^2) were determined. Analysis of variance (ANOVA) indicated that the stem height had significant effect on modulus of elasticity, while hadn't effect on the physical features and other wood mechanical properties. Overall, the wood physical and mechanical properties decreased along longitudinal direction from the base to the up of stem height. The relationship between oven-dry density-volumetric shrinkage and density at 12% moisture content-mechanical properties were determined by regression analyses. It was found that there are positive relationship between oven-dry density and volumetric shrinkage in elm wood, while the correlation between wood density at 12% moisture content and all of mechanical strength weren't significant except in static bending (modulus of elasticity and modulus of rupture).

Key words: *Zelcova carpinifolia* · Physical properties · Mechanical properties

INTRODUCTION

Most of Iran's 7.3 million hectares of forests are found in the North, bordering the Caspian coastal plain and on the northern slopes of the Alborz mountain range. The Northern forest of Iran covered with Astara in northwestern of Guilan province to Golidaghi part in east of Golestan province. The length of these forests is 800 km and the width is 20 to 70 km. Three major provinces, Guilan, Mazandaran and Golestan are covered with dense forests, snow-covered mountains and impressive sea shores. This region is called the Hyrcanian forests and is the primary production region in the country. These forests comprise a little more than 1.9 million hectares of almost 100 percent hardwoods, primarily beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*). Other marketable species include maple (*Acer insigne*), oak (*Quercus castanefolia*), alder (*Alnus subcordata*), elm (*Zelcova carpinifolia*), ash (*Fraxinus excelsior*) and iron wood (*Parrotia persica*). The small percentage of softwoods include cypress (*Cupresuss sempervirens*), juniper (*Juniperus polycarpos*) and yew (*Taxus bacata*) [1]. There is not any detailed and original previous research reporting important wood properties (physical and mechanical properties) in Iran. The objectives of this study were to examine some physical and mechanical properties of elm wood (*Zelcova carpinifolia*) and to determine the relationship between wood density and volumetric shrinkage and mechanical properties in elm wood (*Zelcova carpinifolia*).

MATERIALS AND METHODS

In this research, 5 normal trees of elm wood (*Zelcova carpinifolia*) were selected in north of Iran (Noshahr region). From each of tree, three logs were cut at 25%, 50% and 75% of stem height. The age, height and diameter of trees were 51 years-old, 15 m and 40 cm. The annual rainfall and average temperature was 1300 mm and 16°C, respectively.

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Physical Properties: Rough boards at 25 mm thickness were radially sawn in the four direction of radius. Then test specimens were cut from these rough boards having dimensions of 20 ×20 × 20 mm according to the ASTM d143-94 and used for measuring the oven-dry density, volumetric shrinkage and volumetric swelling. The specimens were soaked in distilled water for 72 h to ensure that their moisture content was above the fiber saturation point. Then the dimensions in all three principal directions were measured with a digital to the nearest 0.001 mm. specimens were weighed to the nearest 0.001 g for saturated volume was calculated based on these dimension measurements. Finally, the samples were oven dried at 103 ± 2°C to 0% moisture content. After cooling in desiccators, the oven-dry weights of the specimens were measured.

$D_O = (M_O \div V_O) \times 100$
$\beta_V = [(V_S - V_0) / V_S] \times 100$
$\alpha_v = [(V_S - V_0) / V_0] \times 100$

Where D_O, D_b, B_v, α_v, M_O, V_O, V_s and M_{max} are the oven dried density, basic density, volumetric shrinkage, volumetric swelling, dried weight, dried volume of specimen, the saturated volume of specimen and Maximum moisture content, respectively.

Mechanical Properties: From each of logs, testing samples were taken from mature wood to calculated mechanical properties such as static bending (modulus of elasticity and modulus of rupture), compression parallel to the grain, compression perpendicular to the grain, shear strength parallel to the grain according to the ASTM-D 143-94. The age demarcation point between juvenile and mature wood was estimated at around 25 years (Clark and Saucier 1989). 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. The humidity moisture content and wood density at 12% moisture content of all samples were 12-13% and 850 Kg m^{-3}.

Statistical Analysis: To determine the effect of stem height on the physical and mechanical properties, statistical analysis was conducted using the SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. Duncan'smultiple range test (DMRT) was used to test the statistical significance at the $\alpha = 0.05$ and $\alpha = 0.01$ levels. The linear regression model was used to analyze the relationship among the wood's various properties.

RESULTS

Physical Properties: The descriptive statistics for the physical properties of elm wood were given in Table 1. Analysis of variance (ANOVA) indicated that the effect of longitudinal direction on the wood density, volumetric shrinkage and volumetric swelling were significant (Table 2) The values of oven-dry density, volumetric shrinkage and volumetric swelling were determined 775 Kg m^{-3}, 8.86% and 9.73%. A positive relationship was found between wood density and volumetric shrinkage ($R^2 = 0.303$) in elm wood (Figure 1).

Table 1: Descriptive statistics for physical properties of elm wood

Longitudinal direction	Oven-dry density (Kg m^{-3})	Volumetric Shrinkage (%)	Volumetric swelling (%)
25%	784.4±42.39 (731.1-880.4)	9.15±1.07 (7.41-10.85)	10.09±1.30 (8.01-12.17)
50%	776.7±31.82 (727.6-824.5)	8.91-0.667 (8.22-10.41)	9.79±0.811 (8.96-11.62)
75%	755.9±40.77 (713.59-834.9)	8.60±0.705 (7.63-9.48)	9.42±0.844 (8.26-10.47)
Total	733.3±39.21	8.90±0.85	9.78±1.03

Mean± standard deviation (Min-Max)

Table 2: Analysis of variance between longitudinal direction and physical properties of elmwood

Physical properties		Sum of Squares	df	Mean Square	F
Oven-dry density	Between Groups	4206.936	2	2103.468	1.406 ^{ns}
	Within Groups	40394.660	37	1496.099	
	Total	44601.595	39		
Volumetric shrinkage	Between Groups	1.581	2	.790	1.089 ^{ns}
	Within Groups	19.601	37	.726	
	Total	21.182	39		
Volumetric swelling	Between Groups	2.348	2	1.174	1.102 ^{ns}
	Within Groups	28.760	37	1.065	
	Total	31.108	39		

Table 3: Descriptive statistics for static bending of elmwood

Longitudinal direction	MOR (N/mm^2)	MOE (N/mm^2)
25%	138.89±26.44 (98.59-187.33)	10750.50±1510.38 (8468.68-13583.09) b
50%	126.60±24.86 (85.07-177.52)	9578.27±1252.70 (7913.94-11680.09) ab
75%	123±29.95 (68.17-187.68)	9261.98±2001.25 (5494.88-13734.04) a
Total	128.93±28.30	9738.05±1831.17

Mean± standard deviation (Min-Max)

Table 4: Analysis of variance between longitudinal direction and static bending in elmwood

Properties		Sum of Squares	df	Mean Square	F
MOR	Between Groups	2646.421	2	1323.211	1.691 ns
	Within Groups	43038.839	55	782.524	
	Total	45685.260	57		
MOE	Between Groups	2.351E7	2	1.175E7	3.856*
	Within Groups	1.676E8	55	3047753.364	
	Total	1.911E8	57		

*Significant difference at 5% level

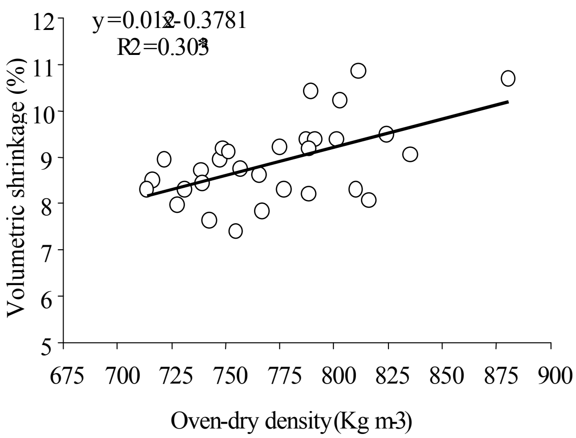

Fig. 1: The relationship between wood density and volumetric shrinkage

Mechanical Properties

Static Bending (Modulus of Rupture and Modulus of Elasticity): The descriptive statistics for modulus of elasticity and modulus of rupture of elm wood were given in Table 3. Analysis of variance (ANOVA) indicated that the effect of longitudinal direction on the modulus of rupture and modulus of elasticity were insignificant and significant, respectively (Table 4). The modulus of elasticity values along longitudinal direction were decreased from the base to the up of stem height. The relationship between the wood density at 12% moisture content and MOR and MOE was determined by regression analyses (Figure 2). It was found that there are significantly positive relationships between wood density and MOR ($R^2 = 0.173$) and MOE ($R^2= 0.136$). The average of modulus of rupture and modulus of elasticity of elmwood were calculated 128.93 and 9738.05 N/mm^2, respectively.

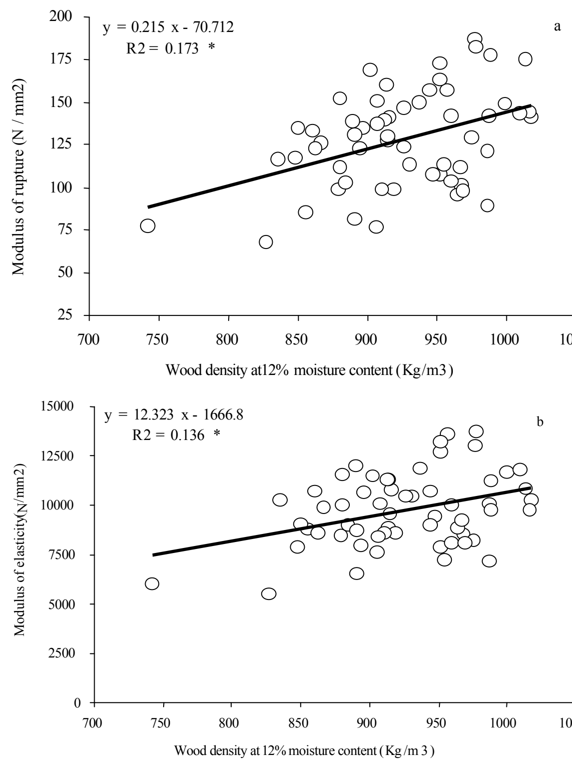

Fig. 2: The relationship between wood density at 12% moisture content and modulus of rupture (a) and modulus of elasticity (b) in elm wood.

Compression Parallel to the Grain: The descriptive statistics for compression strength parallel to the grain of elm wood were given in Table 5. Results of ANOVA indicated that the effect of longitudinal direction on the compression strength parallel to the grain weren't significant (Table 6). The relationship between the wood density at 12% moisture content and compression

Table 5: Descriptive statistics for compression parallel to the grain along longitudinal direction

Compression parallel to the grain (N/mm2)	Mean	SD	Max	Min
25%	30.77	4.38	24.36	40.32
50%	29.88	4.60	21.54	37.26
75%	28.52	2.52	22.60	31.17
Total	29.73	3.97	21.54	40.32

Table 6: Analysis of variance between longitudinal direction and compression parallel to the grain in elmwood

Source	Sum of Squares	df	Mean Square	F
Between Groups	38.440	2	19.220	1.231 ns
Within Groups	655.757	42	15.613	
Total	694.197	44		

Table 7: Basic statistics for compression perpendicular to the grain of elmwood

Compression perpendicular to the grain (N/mm2)	Mean	SD	Max	Min
25%	12.44	1.19	14.82	10.17
50%	12.36	1.93	15.38	9.39
75%	12.17	2.48	17.58	7.80
Total	12.33	1.88	17.58	7.80

Table 8: Analysis of variance between longitudinal direction and compression perpendicular to the grain

Source	Sum of Squares	df	Mean Square	F
Between Groups	0.538	2	0.269	0.072
Within Groups	152.904	41	3.729	
Total	153.442	43		

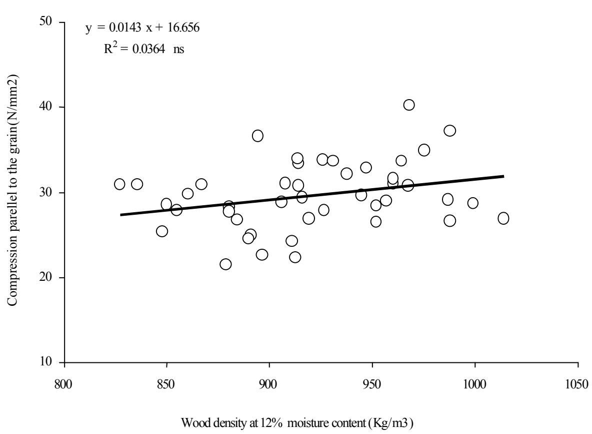

Fig. 3: The relationship between wood density at 12% moisture content and compression parallel o the grain

strength parallel to the grain was determined by regression analyses (Figure 3). According to this, there aren't significant relationships between wood density and compression strength parallel to the grain ($R^2 = 0.0364$). The average of compression strength parallel to the grain were calculated 29.73 N/mm^2.

Compression Perpendicular to the Grain: The descriptive statistics for compression perpendicular to the grain of elmwood were given in Table 7. Results of ANOVA indicated that the effect of longitudinal direction on the compression perpendicular to the grain weren't significant (Table 8). The relationship between the wood density at 12% moisture content and compression perpendicular to the grain was determined by regression analyses (Figure 4). According to this, there aren't significant relationships between wood density and compression perpendicular to the grain ($R^2 = 0.101$). The average of compression perpendicular to the grain were calculated 12.33 N/mm^2.

Shear Strength Parallel to the Grain: The descriptive statistics for shear strength parallel to the grain of elmwood were given in Table 9. Results of ANOVA indicated that the effect of longitudinal direction on the shear strength parallel to the grain weren't significant (Table 10). The relationship between the wood density at 12% moisture content and shear strength parallel to the grain was determined by regression analyses (Figure 5).

Table 9: Basic statistics for shear strength parallel to the grain of elmwood

Shear strength parallel to the grain	Mean	SD	Max	Min
25%	14.36	2.26	18.58	10.71
50%	14.25	1.89	17.79	9.61
75%	13.97	1.67	11.41	16.99
Total	14.19	1.92	18.58	9.61

Table 10: Analysis of variance between longitudinal direction and shear strength parallel to the grain

Source	Sum of Squares	df	Mean Square	F
Between Groups	1.255	2	0.628	0.163 ns
Within Groups	161.308	42	3.841	
Total	162.563	44		

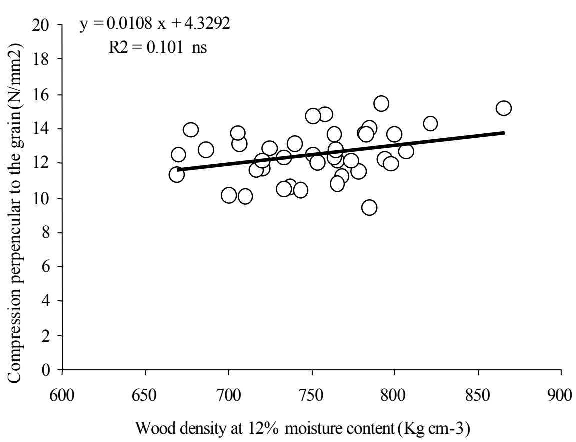

Fig. 4: The relationship between wood density at 12% moisture content and compression parallel to the grain

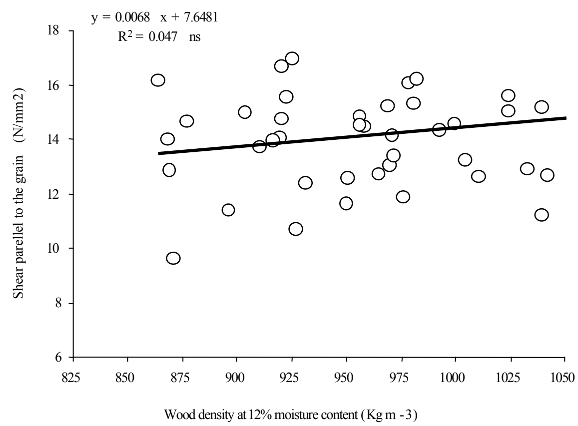

Fig. 5: The relationship between wood density at 12% moisture content and shear strength properties in elmwood

According to this, there aren't significant relationships between wood density and shear strength parallel to the grain ($R^2 = 0.047$). The average of shear strength parallel to the grain was calculated 14.19 N/mm^2.

DISCUSSION

In this study, the effect of stem height on the physical properties and mechanical features of elm wood (*Zelcova carpinifolia*) were studied. Analysis of variance indicated that the height hadn't significant effect on the wood properties except modulus of elasticity. Overall, the values of wood density and mechanical properties decreased along longitudinal direction from base to the up of stem height. This result was reported Panshin and de Zeeuw (1980) [2].

The volumetric shrinkage and swelling properties are affected by several wood factors, such as the heartwood to sapwood ratio or the fibrillar angle on the S_2 layer [3]. However, the most important parameter affecting wood shrinkage is the wood density [4]. In the present study, there are positive correlation between wood density and volumetric shrinkage in elm wood. These results were reported by Bektas and Guler 2001, Guler *et al*. 2007, Panshin and de Zeeuw 1980) [2-4].

Mechanical properties of elm wood (*Zelcova carpinifolia*) including modulus of rupture (128.93 N/mm^2) and modulus of elasticity (9738 N/mm^2) were determined. The modulus of rupture in elm wood is higher than the modulus of rupture in oak wood (*Quercus castaneaefolia,* 110 N/mm^2) [5] and hornbeam *(Carpinus betulus,* 116 N/mm^2) [5], while the modulus of elasticity in elm wood is higher than oak wood (*Quercus castaneaefolia*, 9047 N/mm^2) and is lower than hornbeam wood (*Carpinus betulus*, 11744 N/mm^2). Hornbeam and oak wood are important species in Iran for wood production and pulp and papermaking.

The relationship between wood density and mechanical properties within a species has been studied by many researchers. A significant linear relationship between wood density and mechanical properties of timber was reported by Shepard and Shottafer (1992) and Zhang (1995) [6-7]. Zhang (1997) showed that modulus of rupture and the maximum crushing strength in compression parallel to the grain are most closely and almost linearly related to wood density, whereas modulus of elasticity is poorly and least linearly related to wood density [8]. In the present study, there are positive relationships between wood density and static bending (modulus of rupture and modulus of elasticity). In addition, this relationship between density and modulus of rupture is stronger than the relationship between density and modulus of elasticity. In final, the relation between wood density and other mechanical properties isn't significant.

CONCLUSION

- The analysis of variance (ANOVA) indicated that the effect of stem height on wood physical properties and mechanical properties were not significant except modulus of elasticity.
- The values of modulus of elasticity decreased along longitudinal direction from the base to the up of stem height.
- The relationship between wood density and volumetric shrinkage is positive and significant.
- The relationship between wood density at 12% moisture content and static bending (modulus of rupture and modulus of elasticity) is positive and significant. The relationship between wood density and modulus of rupture is stronger than the relationship between wood density-modulus of elasticity. The relationships between wood density and other mechanical properties are not significant.
- Total of stem height parts can be utilized in more structural application due to good density and high mechanical properties. In addition, the strength properties of elm wood are higher or almost similar to mechanical properties in hornbeam and oak wood.

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