

## **EFFECT OF KNOTS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF SCOTS PINE (*PINUS SYLVESTRIS* L.)**

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### **ABSTRACT**

This study evaluated the some physical and mechanical properties of Scots pine (*Pinus sylvestris* L.) wood which has varying amounts of knot area in comparison with control specimens. Wood specimens (prepared according to ISO and Turkish Standard) classified to four different groups based on the knot area in the cross sections (0-25%, 26-50%, 51-75%, and 76-100%) and control specimens were subjected to some physical and mechanical tests. These tests were density, shrinkage, bending, modulus of elasticity in bending, impact bending, compression parallel to grain, tension perpendicular to grain, and hardness. Results showed that density of wood specimens increased as knot area in the cross sections increased. But, shrinkage decreased. Bending strength, modulus of elasticity (MOE), and impact bending values of wood specimens decreased dramatically as knot area increased. Compression strength parallel to grain values of wood specimens containing highest amount of knot area (76-100%) were found to be less compared to control specimens without knots. But, decreasing of between other groups was not important statistically. While values of tension strength perpendicular to grain were not different statistically between 0-25 % and control specimens, 51-75 % and 76-100 % specimens, values of decreasing of between other groups were found to be important statistically. Hardness in the knotted area on the specimens increased however hardness in the knot-free area was lower.

KEY WORDS: Scots Pine (*Pinus sylvestris* L.), knots, density, strength, shrinkage

### **INTRODUCTION**

The ability of wood to resist loads is greatly affected by a number of factors including the presence or absence of defects such as knots. Knots are bases of limbs imbedded in the tree trunk and show different characteristics from stem and roots. The form, size, and number of knots in the tree depend on tree species, age of tree, site conditions, stand composition, etc. Knots are usually considered as defect since they cause losses in value of wood. Knots, the most common defect in timber, lumber, an any other wood based products, are more dense and harder and contain more resin and reaction wood than that of the surrounding wood tissue. Depending on

the location in wood, type, size, position, and number, knots diminish strength properties of wood. Besides mechanical properties, knots affect sawing, planning, gluing, finishing, drying, and shrinkage of wood. Knots do not lower the stiffness of a timber appreciably, but they reduce its tensile strength. Hence, they are of greater significance in joists, beams and similar timbers, than they are in columns. In beams, the weakening influence of knots is greatest when they occur in the vicinity of the maximum bending stress and on the bottom of the beam (tension zone); they are of less importance when they occur near the top of the beam (compression zone). Reduction in strength properties, resulting from knots, increases at a faster rate than the proportional increase in area of the knot (Desch 1973)

A study on effect of knots on tensile strength by Takeda and Hashizume (1999) showed that knots were the most important influence on tensile strength of all the physical properties, including annual ring width, density, etc.

Knots reduce the modulus of rupture of wood considerably if they are located in the tension zone near the critical cross section (Kollmann and Côte 1968). Boumann 1992 determined the following modulus of elasticity values: for clear air-dry pine wood (D: 0.60 g.cm<sup>-3</sup>) E<sub>1</sub>: 16180 MPa, but for the same wood with one knot on the compression zone E<sub>1</sub>: 15020 MPa.

Graf (1929, 1938) determined that the tensile strength of the selected pine wood containing only a very small knot reached only about 50 % of the tensile strength of clear wood without any knot. For the same wood with many larger knots this strength reduction ratio was 85 %. Whereas the compressive strength was much less affected by the knots.

In this study, we evaluated the effects of knots on some physical and mechanical properties of Scots pine wood using small wood specimens. The specimens were classified to four different groups depending on the surface area of knots in the cross sections of the specimens.

## MATERIAL AND METHODS

Scots pine (*Pinus sylvestris* L.) lumber was obtained from a local timber supplier in Turkey. Small wood specimens were cut from the lumber according to location of the knots on the lumber for physical and mechanical tests. Following physical and mechanical tests, the specimens were sorted based on knots' area ratio in the cross sections appeared in the failure point of the specimen in the mechanical tests and the specimens were classified as follow:

<u>Specimen group</u>	<u>Knots' area ratio in the cross sections (percentage of whole cross section)</u>
Control	Knot-free
I	0-25%
II	26-50%
III	51-75%
IV	76-100%

In this study, specimens with sound and intergrown knots were used.

Tests of density, radial and tangential shrinkage, compression strength parallel to grain, bending strength, modulus of elasticity (MOE), impact bending, tensile strength perpendicular to grain, and hardness were carried out based on International Standards (ISO) and Turkish Standard (Density ISO 3131/1975, Shrinkage ISO 4469/1981, Compression strength parallel

to grain TS 2595/1977, Bending strength ISO 3133/1975, Modulus of elasticity ISO 3349/1975, Impact bending ISO 3348/1975, Tensile strength perpendicular to grain ISO 3346/1975 and, Hardness ISO 3350/1975).

The data were analyzed using analysis of variance (ANOVA) and Duncan tests in order to determine any statistically significant differences between and among the specimen groups.

## RESULTS AND DISCUSSION

The average physical and mechanical properties of the wood specimens are given in Tab. 1 and Tab. 2, respectively. The results showed that knot formation increased air-dry density of the specimens. Compared to control specimens (knot-free), air-dry density of the wood specimens in the groups I, II, III, and IV increased 34%, 62%, 78%, and 94%, respectively. In general, the wood of the branches is heavier than that of the trunk. Knot is a branch that is included in the wood of a tree stem by growth around its base. Thus the knot areas in the cross section of samples increases, the density of wood specimens increases.

*Tab. 1: Effect of knots on the physical properties of the Scot Pine*

	Air-dry density	Radial shrinkage	Tangential shrinkage
	g.cm <sup>-3</sup>	%	%
Control	0.487 (0.0042)* A**	3.9 (0.67) A	7.1 (1.26) A
I	0.655 (0.116) B	4.2 (0.69) A	6.7 (0.96) A
II	0.793 (0.098) C	3.5 (0.59) B	5.4 (0.95) B
III	0.867 (0.127) D	3.5 (0.5) B	4.1 (0.77) C
IV	0.945 (0.110) E	2.8 (0.57) C	3.9 (0.78) C

\*Numbers in parentheses are standard deviations.

\*\*Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test.

*Tab. 2: Effect of knots on the mechanical properties of the Scot Pine*

Compression strength		Tensile strength	Bending strength		MOE		Impact bending	
			Knots on compression zone	Knots on tension zone	Knots on compression zone	Knots on tension zone	Knots on compression zone	Knots on tension zone
		MPa				J.cm <sup>-2</sup>		
Control	39.7 (4.92)* A**	2.87 (0.46) A	75.0 (11.0) A	75.0 (11.0) A	8568.3 (1318.0) A	8568.3 (1318.0) A	4.5 (0.88) A	4.5 (0.88) A
I	31.5 (5.69) B	3.33 (0.55) A	68.8 (12.5) B	59.1 (12.2) B	7120.2 (1413.4) B	6732.8 (1303.0) B	3.6 (0.74) B	3.2 (0.67) B
II	29.5 (5.48) B	2.88 (0.46) B	44.2 (11.1) C	39.8 (7.7) C	5238.2 (886.8) C	4740.5 (982.8) C	2.8 (0.55) C	2.2 (0.45) C
III	30.2 (6.26) B	2.61 (0.49) C	36.6 (7.7) D	27.9 (5.1) D	4063.0 (705.5) D	3055.3 (620.8) D	1.8 (0.36) D	1.5 (0.33) D
IV	33.7 (6.0) C	2.41 (0.49) C	25.3 (4.9) E	18.8 (3.7) E	2638.0 (526.9) E	2140.8 (450.9) E	1.2 (0.27) E	1.0 (0.24) E

\*Numbers in parentheses are standard deviations.

\*\*Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test.

In general, as knot areas in the cross section of samples increases, radial and tangential shrinkage-decreases. This decrease is higher in tangential direction than that in radial direction. Differences between group I and control group were not important statically in radial and tangential shrinkage. The grain is deflected around knots leaving local areas of cross grain which affect shrinkage properties.

Our results suggest that knots have an adverse effect on the mechanical properties tested (Fig. 1). Strength loss was greater for bending, MOE, and impact bending in the event that knots located in where tensile zone of the samples. Compared to control specimens, bending strength decreased about 75% (knot on tension zone) and 66 % (knot on compression zone) in the specimens containing the highest knot area (76-100%). Decreases in MOE value showed similar trends in the corresponding wood specimens. In the specimens belonging to specimen group IV, impact bending decreased 75 % (knot on tension zone) and 72% (knot on compression zone) compared with these properties of control specimens.

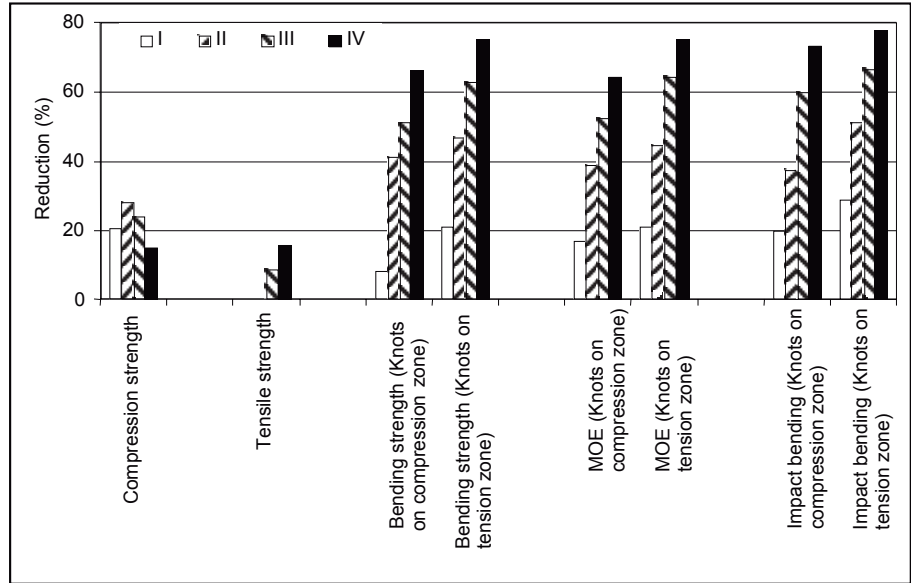


Fig. 1: Reduction Ratios  
 I : 0 - 25%, II: 26 - 50%, III: 51 - 75%, IV: 76 - 100%

Decreases in compression strength were less than those in bending, MOE, and impact bending strength values. No statically significant differences were found among the specimen groups I, II, and III. Compared to control specimens, compression strength decreased significantly about 15% in the specimens containing the highest knot area (76-100%). Strength losses were the least for tensile strength perpendicular to grain and no strength losses were seen in the specimens between control and I, III-IV.

Hardness was tested on the wood tissues, knotted area, and areas of fiber deviation in the specimens. Hardness values of the specimens are shown in Tab. 3. Statistically significant

differences were found among the groups in radial hardness values. In tangential section hardness, statistically significant differences were found among the groups between knotted areas and normal wood tissues. Compared to hardness in the normal wood tissues of the specimens, hardness in the knotted areas was considerably higher. However hardness in the areas of fiber deviation in the specimens decreased compared to the values in knotted areas. In addition, hardness in normal wood tissues in cross sections was higher than those in radial and tangential sections.

Because of heterogeneity they introduce, knots have a major influence on the mechanical properties of wood. Grain distortion in the vicinity of the knot introduces a zone of severe stress concentrations as well as anisotropic behavior. Wood material containing knots almost always fail at loads which are but a fraction of clear wood ultimate stresses (Bodig and Jayne 1993).

*Tab. 3: Hardness values of the Scots Pine*

Section	Area	Hardness
Cross section		MPa
	normal wood tissue	33.7 (3.84)*
Radial section	knot area	87.6 (17.16) A**
	area of fiber deviation	39.2 (8.95) B
	normal wood tissue	25.82 (3.81) C
Tangential section	knot area	81.9 (19.6) A
	area of fiber deviation	40.2 (8.99) AB
	normal wood tissue	26.5 (4.73) B

\*Numbers in parentheses are standard deviations.

\*\*Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test.

## CONCLUSIONS

Knots are portions of branches that become incorporated into the tree trunk during growth and influence the strength properties of a piece wood to a varying degree, depending on their size and position. Knots reduce the strength of wood principally because of interrupting the direction of grain, localized steep slope of grain concentrates around knots. The effect of a knot on strength depends on the proportion of the cross section of the given piece occupied by the knot, and on its relative location in the piece.

As the proportion of knot on the cross section increases, density increases. Shrinkage values are not different especially in the specimens containing small knots.

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