RADIAL VARIATION IN WOOD STATIC BENDING OF NATURALLY AND PLANTATION GROWN ALDER STEMS

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This study was carried out to determine radial variation of wood density, modulus of elasticity (MOE), modulus of rupture (MOR) and stress at elastic limit in plantation and natural alder forests in the north of Iran. Testing samples were taken at breast height of the stem and in three radial positions (10, 50 and 90% of radius) from natural and plantation forests to determine wood mechanical strength properties, according to the ASTM standard. The analysis of variance indicated that planting conditions (natural and plantation forests), radial position and their interaction had no significant effects on the modulus of elasticity (MOE), modulus of rupture (MOR) and stress at elastic limit in alder wood, while only radial position had a significant effect on wood density. Wood density was increased along radial direction from the pith to the periphery for both planting conditions. Overall, the mechanical strength properties in the plantation forest were slightly higher compared to the natural forest. The relationship between wood density and mechanical properties were analyzed by linear regression. A positive relationship was found between wood density and mechanical properties for both planting conditions. This relationship was stronger in plantation grown, compared to naturally grown trees.

Keywords: *Alnus glutinosa*, static bending properties, natural forest, plantation forest

INTRODUCTION

There are two alder species – *Alnus subcordata* and *Alnus glutinosa* – in the Iranian forest ecosystem. The alder tree is a diffuse-porous hardwood species from Betulaceae family, which constitutes about 9 percent of the wood volume for northern forests, according to the Iranian forest organization. This species has high ability in nail keeping, good adhesiveness, high colorability and low durability. It is mostly used for box-making, water structures, boat-making, furniture, plywood and veneer.[1]

Wood quality can be measured directly by submitting timber to a large number of technical tests. However, many of wood characteristics, such as strength and elasticity properties, are related to density. This parameter is therefore a suitable index for predicting wood quality.[2] For specific species, wood density varies among trees due to genetic and environmental differences.[3] The relation between density and site index depends on growth rate, which makes the subject of a very complex discussion.[4] Wood density varies along longitudinal and radial directions from bottom to top and from pith to bark.[5] Variations of wood density may be directly related to the variation in cell wall percentage and changes in cell wall thickness, cell diameter and tissue proportions.[3]

A research on the comparison of wood properties of planted big-leaf mahogany in Martinique Island with naturally grown Mahogany from Brazil, Mexico and Peru (there are two age groups such as young trees [<40 years old] and old trees [>40 years old] for plantation trees) indicated that wood density of plantation trees (young and old trees) was lower than that of natural forest trees. Although the density of natural forest wood was higher than that of plantation trees, the difference in modulus of elasticity (MOE) was not significant. The static bending strengths (MOR) of young and old trees were significantly lower than that of natural forest trees.[6] In Turkey, the values of oven-dry density, basic density, volumetric shrinkage, volumetric swelling, fiber saturation point, modulus of elasticity and modulus of rupture were determined as, respectively, 0.454 g cm^{-3}, 0.399 g cm^{-3}, 12.62%, 13.78%, 32.87%, 8.61 GPa and 77.53 MPa for *Alnus glutinosa*.[7]

There are no reported studies on mechanical strength properties and other characteristics and differences between plantation and natural forests for *Alnus glutinosa* species in Iran. Therefore, this study focuses on *Alnus glutinosa* in order to: a) examine wood density, modulus of elasticity, modulus of rupture and stress at elastic limit along radial direction from the pith to the bark for both planting conditions (natural and plantation forests), and b) investigate the relationship between wood density and static bending strength for both cultivation methods (a species grown in two different ways).

EXPERIMENTAL

Materials

Materials originating from six alder trees (*Alnus glutinosa*) sampled from natural and plantation forests in the eastern part of Mazandaran province (Savadkouh region) in the north of Iran were studied. Logs and discs were cut at breast height for each of trees. Selected trees with straight trunks, normal branching and no disease or pest symptoms were felled. From each selected tree, a cross-section was extracted at the diameter at breast height (dbh), as well as a log from the tree base to dbh. The age of the alder was 20 years for plantation forest trees and 20-22 years for natural forest trees. The average of annual ring widths in the plantation and natural alder trees were of 6.95 and 6.86 mm, respectively. In this region, the average air temperature is of 11.2 °C and the total annual rainfall of 386 mm/year. The altitude is of 120 m for the plantation forest and 350 m for the natural forest. The soil of the region is similar for both planting sites.

Methods

Static bending properties

Wood samples for testing were taken along the radial direction from pith to bark (three positions from pith 10, 50, 90%) to determine static bending properties according to the ASTM–D143-94 standards.[8] The dimension of the samples were of 25×25 mm in cross-section and 410 mm in longitudinal direction. The length span was of 360 mm, to determine the modulus of elasticity (MOE), modulus of rupture (MOR) and stress at elastic limit. The prepared samples were then conditioned at the temperature of 20±2 °C and at 65±5% relative humidity until the specimens reached an equilibrium moisture content of about 12%. Three different static bending strength parameters, fiber stress at elastic limit (FS at LP in MPa), modulus of rupture (MOR in MPa) and modulus of elasticity (MOE in MPa) were computed using the equations:

$$\text{FS at LP} = 3 \times P \times l / 2 \times b \times h^2$$
$$\text{MOR} = 3 \times P_{max} \times l / 2 \times b \times h^2$$
$$\text{MOE} = P \times l^3 / 4 \times D \times b \times h^3$$

where P – load at the limit of proportionality (kN); Pmax – maximum load (kN), l – span of the test specimen (mm), b – breadth of the test specimen (mm), h – depth of the test specimen (mm) and D – deflection at the limit of proportionality (mm).

Finally, after failure of the mechanical strength samples, the specimens were taken to examine wood oven-dry density based on the ISO-3131 standard (20 × 20 × 20 mm). 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. The values of the wood oven-dry density were calculated using the following equation:

$$\text{Oven-dry density (g cm}^{-3}) = \text{dried weight/dried volume}$$

Statistics analysis

To determine the effect of planting condition (natural grown and plantation grown trees) and radial direction on the static bending properties, statistical analysis was conducted using the SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. A linear regression models was used to analyze the relationship among the various properties of the wood.

RESULTS AND DISCUSSION

Wood density

Radial variation of wood density for plantation and natural forests are shown in Fig. 1. The analysis of variance (ANOVA) indicated that planting conditions (F = 0.169, sig = 0.685), and the interaction between planting conditions and radial position (F = 4.253, sig = 0.026, $P<0.05$) did not affect significantly wood density. There were significant differences in wood density among radial samples (F = 0.488, sig = 0.620). The average of wood density in the plantation forest was slightly higher than that in the natural alder forest. Wood density increased along radial direction from the pith to the bark for both planting conditions. The average of wood density in plantation and natural alder trees was determined as 0.396 and 0.391 g cm^{-3}, respectively.

Modulus of elasticity (MOE)

Radial variation of modulus of elasticity (MOE) for plantation and natural forest trees is shown in Fig. 2. The analysis of variance (ANOVA) indicated that the effects of planting conditions (F = 0.911, sig = 0.349), radial position (2.528, sig = 0.101) and of the interaction between planting conditions and radial position (F = 0.343, sig = 0.713) on MOE were not significant. The average of MOE in plantation forest was slightly higher than that of natural alder forest. The average of MOE varied from the pith to the bark from 5 to 7 GPa for naturally grown alder stems and from 6 to 7 GPa for plantation alder stems.

Modulus of rupture (MOR)

Radial variation of modulus of rupture (MOR) for plantation and natural forests is shown in Fig. 3. The analysis of variance (ANOVA) indicated that planting conditions (F = 1.974, sig = 0.173), radial position (F =2.511, sig = 0.102) and the interaction between planting conditions and radial position (F = 0.388, sig = 0.683) did not have a significant effect on MOR. The average of MOR in plantation forest trees was slightly higher than that of natural alder forest trees. For natural alder stems, the increment of MOR from the pith towards the bark ranged, on average, from 42 to 47 MPa, and for plantation alder stems, from 44 to 54 MPa.

Fiber stress at elastic limit

Radial variation of fiber stress at elastic limit for plantation and natural forests is shown in Fig. 4. The analysis of variance (ANOVA) indicated that the effects of planting conditions (F = 2.854, sig = 0.104), radial position (F = 1.614, sig = 0.220) and of the interaction between planting conditions and radial position (F = 0.879, sig = 0.428) on the fiber stress at elastic limit were not significant. The fiber stress at elastic limit averaged 16.91 MPa in the pith (10% of radius), 18.25 MPa in the middle (50% of radius), and 17.64 MPa in the bark (90% of radius), for natural alder stems and, respectively, 17.70, 19.02 and 21.31 MPa for plantation alder stems.

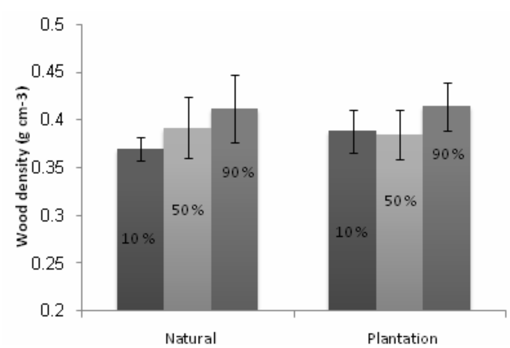

Figure 1: Average of wood density in natural and plantation alder forest trees

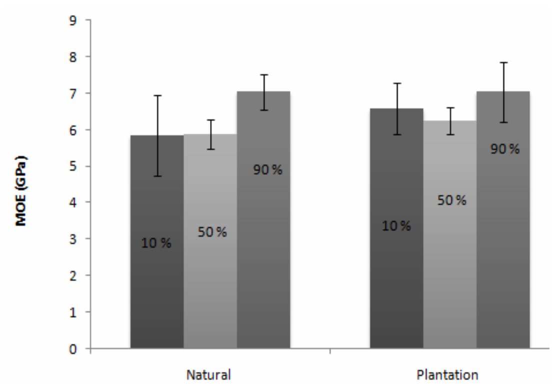

Figure 2: Average of modulus of elasticity (MOE) in natural and plantation alder forest trees

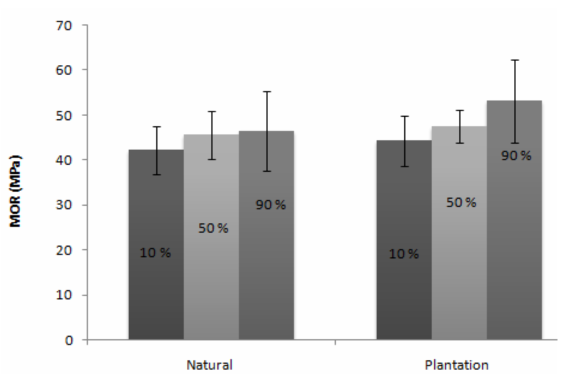

Figure 3: Average of modulus of rupture (MOR) in natural and plantation alder forest trees

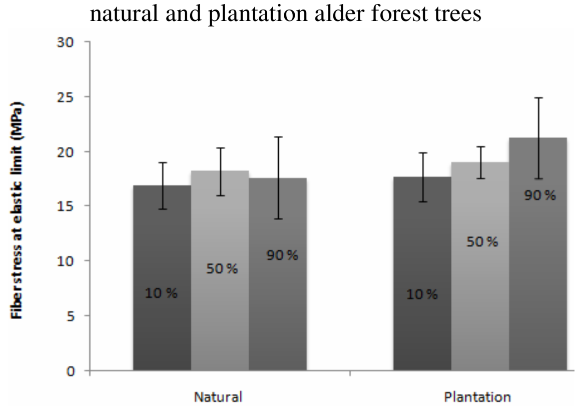

Figure 4: Average of fiber stress at elastic limit in natural and plantation alder forest trees

Relationship among wood properties

The dependence of static bending properties on the oven-dry density was modeled using simple regression equations (Fig. 5). The correlation coefficient between wood density and MOE, MOR, and stress at elastic limit in plantation alder wood was higher compared to that in natural alder wood. Furthermore, the correlation between wood density and MOE was considerably higher than that between wood density and MOR and between wood density and fiber stress at elastic limit. Overall, positive relationships were found between wood density and different mechanical strength properties for both planting conditions.

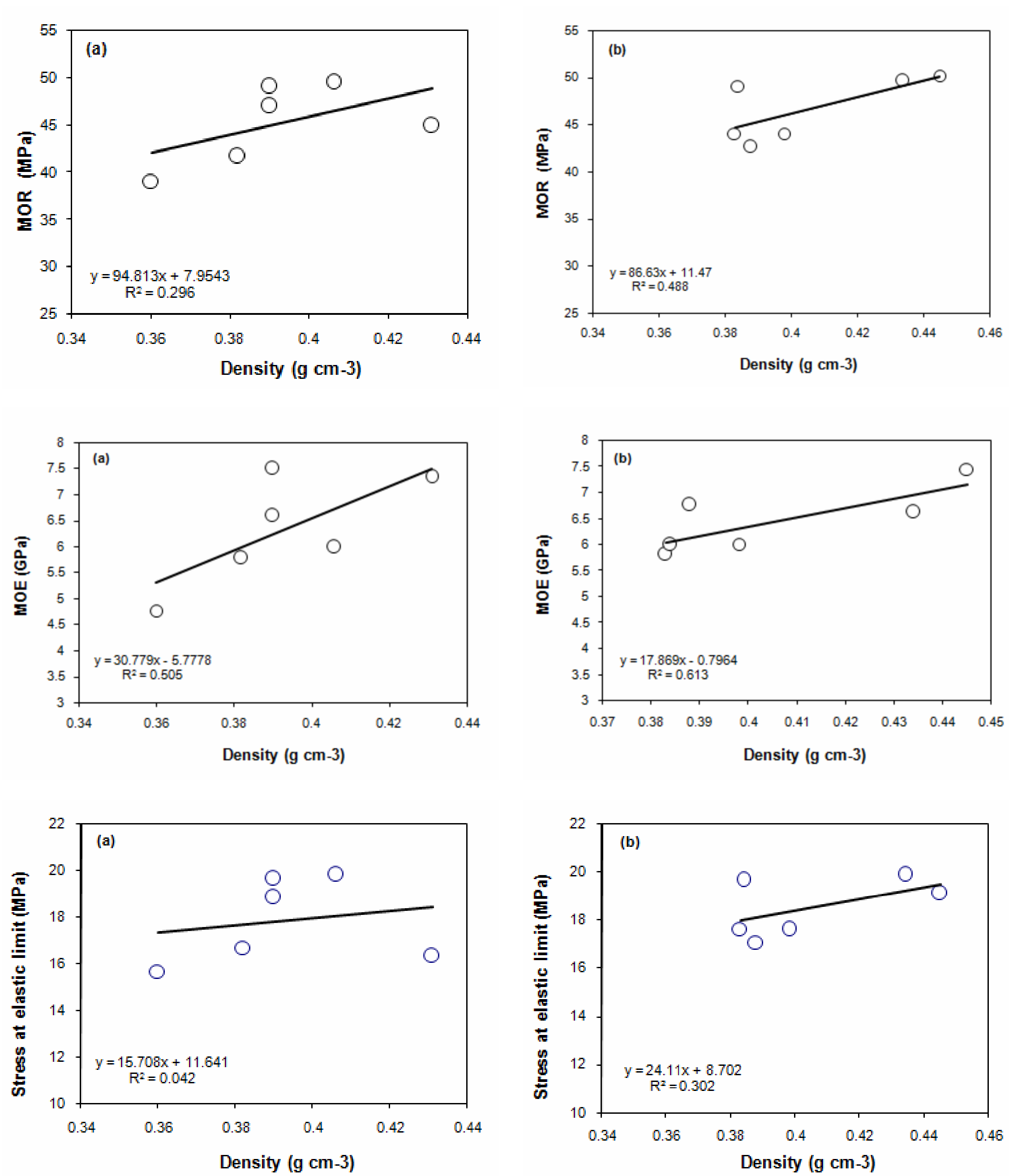

Figure 5: Relationship between wood density and mechanical strength properties for both planting conditions in alder stem: (a) naturally grown trees, and (b) plantation grown trees

Table 1
The linear relationship between wood density and mechanical strength properties along radial direction

Properties	Pith	Middle	Bark
Density – MOE	0.752	0.178	0.02
Density – MOR	0.844	0.311	0.448
Density – Stress at elastic limit	0.752	0.177	0.05

The relationships between wood density and static bending (MOE, MOR and stress at elastic limit) were determined along radial direction in the pith, middle and bark for alder wood by linear regression (Table 1). The results indicated that these relationships reduced along radial position from the pith to the bark.

Many researchers suggest that trees growing in plantation forests produce wood with lower wood properties, such as specific gravity and other wood property variables.[9] For example, *Terminalia amazonia* trees from natural forests in Panama,[10] Nicaragua,[11] Bolivia, Venezuela and Colombia,[12] and Honduras,[13] among others, were reported to have superior mechanical properties to those from the forest plantations evaluated by Moya and Munoz.[14] Another example, *Swietenia macrophylia* trees from natural forests had higher mechanical strength properties, compared to plantation mahogany trees.[6] *Alnus glutinosa* trees from natural forests in Turkey[7,14] were reported to have superior mechanical strength properties to those from forest plantations and to the naturally grown trees evaluated in the present study. The wood density of Turkish natural alder wood (0.454 g cm^{-3}) is higher than those of Iranian natural (0.391 g cm^{-3}) and plantation (0.396 g cm^{-3}) alder forest trees. This trend was found for modulus of rupture and modulus of elasticity of alder wood in Turkey and in the present study. The mentioned properties had values of 77.53 MPa and 8.61 GPa for Turkish alder stems.[7,14] In addition, the wood mechanical properties of Iranian *Alnus glutinosa* were found to be lower than those of *Alnus acuminata* in Costa Rica.[15] These divergent results suggest a probable influence of site and environmental conditions on wood quality. Zobel and Van Buijtenen suggest that large structure variations are produced by changes in climate, site and management characteristics as a product of these extrinsic factors influencing various activities.[16] Our study indicated that there were no significant differences between natural and plantation forest trees in wood density and static bending properties. The wood density, modulus of rupture, modulus of elasticity and stress at elastic limit were slightly higher in plantation alder wood, compared to natural alder wood, of about 1.2, 7.6, 21.2 and 9.3%, respectively.

Some researchers have reported that different properties of wood increase with age or distance from the pith, which is also supported by the fact that juvenile wood is usually known to be of a lower density than mature wood.[16-18] Our study indicated that radial direction had no significant effect on static bending for natural and plantation alder stems. This phenomenon may be related to the fact that the trees under study did not undergo the transition stage from juvenile to mature wood because of low tree age.

A positive correlation between wood density and static bending (MOE, MOR and stress at elastic limit) was found for both planting conditions. A similar trend has also been reported by several researchers for various species.[18-20] The correlation coefficients between wood density and different mechanical strength properties were stronger in plantation, compared to naturally grown alder wood.

CONCLUSION

In the present research, the static bending properties of natural and plantation alder stems from trees grown in Savadkouh, Mazandaran region, were determined. The following conclusions were drawn from the study:

1- There are no significant differences between planting conditions (natural and plantation alder stems) in wood density, MOE, MOR and stress at elastic limit;
2- Radial variation of wood strength indicated that MOE, MOR and stress at elastic limit increased with increasing cambial age for both planting conditions, while differences were not significant. The effect of radial variation on wood density was significant;
3- The interaction effects between radial direction and planting conditions were not significant on

wood density, MOE, MOR, and fiber stress at elastic limit;

4- A positive relationship between wood density and mechanical properties was found in natural and plantation alder stems. This relationship was stronger in plantation alder wood, compared to natural alder wood, according to correlation coefficients;

5- Wood density is an important key for wood quality. Wood quality in plantation trees was found similar to that of naturally grown alder trees. Given the similar properties of plantation alder wood and natural alder wood, plantation alder trees may benefit Iranian forests, and could be used, just like natural alder trees, in different wood industries.

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