Madera y Bosques vol. 22, núm. 1: 169-175 Primavera 2016

Vertical variation of density, flexural strength and stiffness of Persian silk wood

Variación longitudinal en densidad, resistencia a flexión y rigidez de la madera 'de seda' persa

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Abstract

The aim of this research was to investigate the effects of longitudinal position (stem height) and heart-sapwood on density, modulus of elasticity (MOE) and modulus of rupture (MOR) in bending for Persian silk wood (*Albizzia julibrissin)*. Five normal trees were selected from the Guilan region, Iran. Samples for testing were prepared at four stem height levels (5%, 25%, 50% and 75% of total stem height) in both positions along radial direction (heartwood and sapwood). Analysis of variance results (Anova) indicated that the effects of longitudinal position (stem height) and heartwood-sapwood on the wood density, MOE and MOR were significant. The mean of wood density, MOE and MOR along longitudinal position from base to top decreased with height. The mean of wood density, MOR and MOE in sapwood are lower compared to the corresponding values for heartwood. The relationship between wood density and mechanical strength properties were analyzed by regression models. A positive correlation was found between wood density with MOE and MOR in both heartwood and sapwood.

Keywords: *Albizzia julibrissin*, modulus of elasticity, modulus of rupture, radial direction, stem height.

Resumen

El objeto de esta onvestigación fue estudiar los efectos de la posición en dirección longitudinal (altura del tronco) y del duramen y la albura sobre la densidad, el módulo de elasticidad (MOE) y el módulo de ruptura (MOR) en flexión para la madera de 'seda' persa (*Albizzia julibrissin)*. Se recolectaron cinco árboles representativos de la región de Guilan, Irán. Se elaboraron especímenes para prueba a cuatro niveles de la altura del árbol (5%, 25%, 50% y 75% de la altura total del tronco) en ambos tipos de madera en la dirección radial (duramen y albura). Los resultados de los análisis de varianza (Andeva) indicaron que los efectos de la ubicación longitudinal (altura del árbol) y duramen y albura sobre la densidad de la madera, el MOE y el MOR fueron significativos. Los valores promedio de la densidad, MOE y MOR a lo largo de la posición longitudinal de la base a la copa disminuyeron con la altura. Los valores promedio de la densidad, MOR y MOE en albura son menores comparados con los del duramen. La relación entre la densidad de la madera y las propiedades mecánicas se analizaron por medio de modelos de regresión. Se encontró una correlación positive entre la densidad de la madera con MOE y MOR tanto en duramen como en albura.

Palabras clave: *Albizzia julibrissin*, modulus of elasticity, modulus of rupture, dirección radial, altura del árbol.

Introduction

In the living tree, the sapwood, in contrast with heartwood, is physiologically active, conducting water and nutrients from roots to leaves (Bamber, 1985; Hillis, 1987) and storing food materials (Bamber, 1985). The transformation of sapwood into heartwood is characterized by the death of parenchyma cells (Hillis, 1987), development of tyloses in the vessels of many species (Bamber, 1976) and the biosynthesis of nonstructural compounds, leading to an important accumulation of extractives and to the differences in physical and chemical properties between sapwood and heartwood (Sellin, 1994). Heartwood and sapwood in a tree vary with a large number of factors, including species, age, climate, rate of growth, foliage area, site quality and tree vitality, and have been the subject of several reviews (Pinto *et al*., 2004; Climent *et al*., 2002).

Heartwood and sapwood have different properties and their proportion within the tree will have a significant impact on the utilization of wood (Climent *et al*., 2002). For pulping, heartwood is at a disadvantage as its extractives can affect the process and product properties. For solid wood applications the different properties of heartwood and sapwood influence drying, durability, and aesthetic values for the consumer (Pinto *et al*., 2004; Morais and Pereira, 2007). When there is a large colour difference between sapwood and heartwood, selection of wood components by color also plays a significant role in some timber application (Dzifa *et al*., 2004).

A study on the variation of wood properties of Kyere wood indicated that the wood density and mechanical properties decreased along longitudinal position from the bottom up the stem. Site also had significant impact on the wood properties. Wood samples collected from the site with the highest mean annual rainfall had the least density and strength properties (Ayarkwa, 1998).

Albizia julibrissin or Persian silk tree is legume specie in the genus *Albizia*. The global distribution of this species is in the North Anatolian, northern Iran, Caucasus, Sinai, Japan, Cyprus, Yugoslavia, Bulgaria, and probably planted in Australia (Mozaffarian, 2003). There are two tree species in this genus, *Albizia julibrissin* that grow in temperate and cool temperate northern forests of Iran, and *A. lebbeck* grows only in tropical regions of Iran (Sabeti, 1975; Mozaffarian 1996). This species is used for making soap, hair shampoo and UV protectors and probably other compounds (Nehdi, 2011; Panahian and Rahnama 2010).

The information about the effect of longitudinal position on the wood different properties is not available for *Albizzia julibrissin* (silk wood) in Iran. Therefore, to use this material properly and efficiently, it is a requisite to know its different properties.

Objectives

The objectives of this study were: (a) to examine the variations of wood density and mechanical strength properties (MOE and MOR) along longitudinal position, (b) to compare wood properties between heartwood and sapwood, and (c) to determine the relationship between wood density and mechanical properties in Persian silk wood (*Albizzia julibrissin)*.

Material and methods

Wood samples

Five silk trees (*Albizzia julibrissin)* from natural forests in the Guilan province in the north of Iran were sampled. Selected trees with straight trunks, normal branching and no disease or pest symptoms were felled. The age of silkwood trees was 36-42 years-old. The average air temperature is 11.6 °C and the total annual rainfall 700 mm/year in this region. The altitude of this region is 160 m asl.

Stem sectional discs were taken from each tree at different levels of total height (5%, 25%, 50% and 75%). The radial variation was studied by sampling in each wood disc at 2 positions (heartwood and sapwood). In this species, the heartwood shows a distinctive brown colour compared to the lighter coloured sapwood. The heartwood and sapwood area within the stem cross sectional area decreased with height. At the base height level, the heartwood area was generally higher than sapwood area and decreased afterwards until the top.

Wood density

Wood sampling method and the general requirements for physical tests were in accordance with the ISO standard 3129-E (1975). The ISO standard 3131-E (1975) was used to measure the wood density. The samples were oven-dried at 103 °C ± 2 °C to 0% moisture content for 24 h. After cooling in desiccators, the oven-dry weights of the specimens and theirs dimensions were measured. The values of the wood oven-dry density were calculated using the following equation (are oven-dry density (kg/m^3), dried weight and dried volume, respectively):

$$D_0 = \frac{p_0}{v_0}$$

Flexural strength properties

Static bending or flexural strength test were measured according to the ASTM–D143-94 standards. The dimensions of the samples were of 25 mm × 25 mm in cross-section and 410 mm in longitudinal direction. The length span was of 360 mm. Theprepared samples were then conditioned at the temperature of 20 °C ± 2 °C and at 65%±5% relative humidity until the specimens reached an equilibrium moisture content of about 12%. From the test results the modulus of elasticity (MOE) and modulus of rupture (MOR) were derived.

Statistics analysis

To determine the effects of longitudinal position and heartwood-sapwood on the wood density and mechanical properties analysis of variance (Anova) were conducted with the SPSS program. Also, a regression model was used to analyze the relationship between wood density and mechanical parameters (MOR and MOE) in heartwood and sapwood.

Results

Wood density

Average and standard deviation of wood density along longitudinal position in hartwood and sapwood are listed in table 1. The analysis of variance (Anova) indicated that the longitudinal position and heartwood-sapwood did affect significantly wood density. The interaction effects between longitudinal position and heartwood-sapwood were not significant on wood density (Table 2). The mean of wood density along longitudinal position from the base upward decreased in heartwood and sapwood. The relationship between longitudinal position and wood density in heartwood (R^2=0.459) is stronger than in sapwood (R^2= 0.431). The average of wood density in heartwood is higher compared to the sapwood (439 kg/m^3 *vs* 394 kg/m^3).

MOR

Average and standard deviation of MOR along longitudinal position in hartwood and sapwood are listed in table 1. The analysis of variance (Anova) indicated that the longitudinal position and heartwood-sapwood did affect significantly MOR. The interaction effects between longitudinal position and heartwood-sapwood were not significant on MOR (Table 2). The mean of MOR along longitudinal position from the base upward decreased in heartwood and sapwood. The relationship between longitudinal position and MOR in heartwood (R^2= 0.492) is weaker than in sapwood (R^2= 0.626). The average of MOR in heartwood is higher compared to the sapwood (54.78 MPa *vs* 50.12 MPa).

MOE

Average and standard deviation of MOE along longitudinal position in hartwood and sapwood are listed in table 1. The analysis of variance (Anova) indicated that the longitudinal position and heartwood-sapwood did affect significantly MOE. The interaction effects between longitudinal position and heartwood-sapwood were not significant on MOE (Table 2). The mean of MOE along longitudinal position from the base upward decreased in heartwood and sapwood. The relationship between longitudinal position and MOE in heartwood (R^2=0.403) is weaker than in sapwood (R^2= 0.468). The avaerage of MOE in heartwood is higher compared to the sapwood (5.53 GPa *vs* 4.80 GPa).

Relationship among wood properties

The dependence of static bending properties (MOE and MOR) on the oven-dry density was modeled using simple regression models (Figs. 1 and 2). These relationships in sapwood (R^2 density-MOR = 0.368, R^2 density-MOE = 0.174) are higher compared to the heartwood (R^2 density-MOR = 0.139, R^2 density-MOE = 0.138).

Discussion

The wood density, MOE and MOR in heartwood is higher compared to sapwood. These differences are related to the chemical properties in herawood and sapwood. Significant amount of extractives are deposited in the hearwood, up to two or three times more than in sapwood (Panshin and de Zeeuw, 1980). Our observation of silk-

Table 1. The variation of wood properties in different stem height levels for silk wood.

Wood	*Longitudinal position (%)*	*Density (kg/m³)*	*MOR (MPa)*	*MOE (GPa)*
Heartwood	5	494.4 (39.16)	60.08 (2.53)	6.14 (0.50)
	25	437.6 (40.13)	54.62 (3.61)	5.63 (0.54)
	50	425.2 (40.32)	53.20 (3.77)	5.41 (0.59)
	75	400.4 (29.64)	51.21 (3.46)	4.95 (0.36)
	Average	439.4 (50.68)^A	54.78 (4.69)^A	5.53 (0.67)^A
	R^2	0.459	0.492	0.403
Sapwood	5	440 (38.62)	54.86 (3.38)	5.36 (0.47)
	25	391.8 (37.17)	49.66 (1.24)	5.13 (0.60)
	50	375.5 (24.61)	48.73 (1.41)	4.54 (0.38)
	75	369.2 (26.03)	47.23 (2.15)	4.15 (0.57)
	Average	394.1 (42.23)^B	50.12 (3.61)^B	4.80 (0.70)^B
	R^2	0.431	0.626	0.468
Total	5	467.2 (47.29)^d	57.47 (3.96)^d	5.75 (0.64)^d
	25	414.7 (44.71)^c	52.14 (3.66)^c	5.38 (0.62)^c
	50	400.3 (41.49^b	50.97 (3.61)^b	4.97 (0.65)^b
	75	384.82 (31.78)^a	49.22 (3.49)^a	4.55 (0.62)^a

Uppercase and lowercase letters respectively show significant differences among longitudinal position and between heartwood-sapwood.

Table 2. F-value (in Anova results) for wood properties along longitudinal position

Variable	*Density*	*MOR*	*MOE*
Heart-sapwood (A)	83.343**	133.075**	100.088**
Longitudinal position (B)	52.165**	77.417**	49.634**
A × B	1.026^{ns}	0.465^{ns}	1.225^{ns}

wood behavior are in accodance with the studies of Panshin and de Zeeuw (1980) ("Type 4 woods: specific gravity of the wood exhibit a general decrease from pith to bark in the stem". Examples of North American hardwoods: *Fagus sylvatica*, *Liriodendrum tulipifera*, *Populus* spp., *Prunus serotina* and *Quercus falcata*), Morais and Pereira (2007; *Eucalyptus globulus* Labill.) and Pinto *et al*., (2004; a conifer, *Pinus pinaster* Ait). Panshin and de Zeeuw (1980) also point out that "among the hardwoods there is almost even division between reported increases and decreases in specific gravity from pith to bark".

Within-tree wood density and mechanical properties decreased along the stem, from the base upwards; however, wood density, MOE and MOR was the highest at 5% of total tree height. Similar patterns of wood density and mechanical properties variation in the longitudinal direction have also been reported by several researchers:

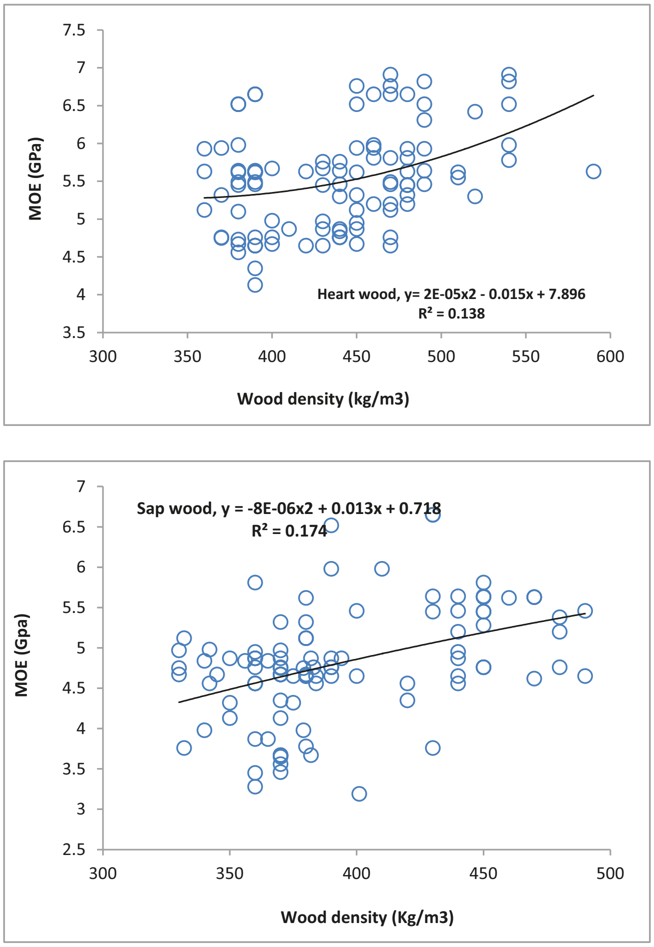

FIGURE 1. The relationship between wood density and modulus of elasticity (MOE) in heartwood and sapwood.

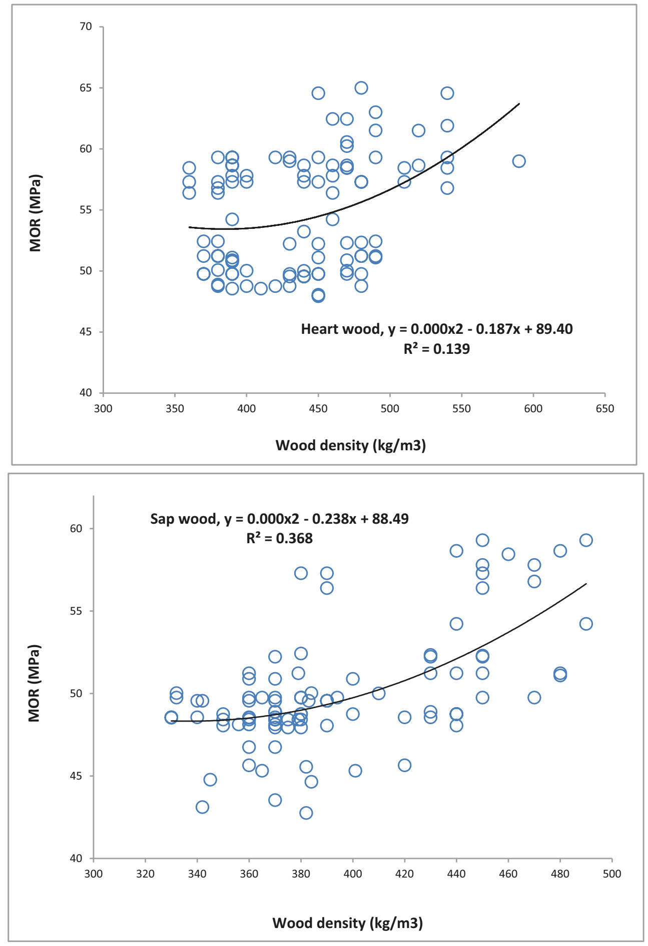

FIGURE 2. The relationship between wood density and modulus of rupture (MOR) in heart wood and sapwood

Panshin and de Zeeuw (1980. “Static bending properties… decrease upward in the stem for *Pinus resinosa* Ait. and *Shorea almon* Foxw.); Ayarkwa (1998; *Pterygota macrocarpa* K. schum); and Kord *et al.*, (2010; *Populus euramericana*). This may be due to the fact that butt log of the same tree has more mature wood than the top log which consists mainly of juvenile wood (Panshin and de Zeeuw, 1980). Juvenile wood is explained by Kolzlowski (1971) and Larson (1969) as being the results of the relative abundance of growth regulators and carbohydrates in the cambial zone near the crown. Juvenile wood density and mechanical properties were lower than that of mature wood. The lower density and strength properties of the wood near the top may be due to the thin walls of the cells of the wood, the lower cellulose content and crystallinity of the wood compared with that of the matured wood in the log at the butt (Zobel and Sprague, 1998).

Positive relationship was found between wood density and mechanical strength properties in heartwood and sapwood. Also, the relationship between wood density and MOE is weaker than the relationship between wood density and MOR in heartwood and sapwood. A similar trend has also been reported by several researchers for various species (Zhang, 1997; Zobel and Van Buijtenen, 1989). Wood density had important role on the variation of mechanical properties.

Conclusions

In the present research, the wood density and mechanical properties of heartwood and sapwood in silkwood were determined. The following conclusions were drawn from the study:

1. The analysis of variance (ANOVA) indicated that the longitudinal position and heartwood-sapwood did affect significantly wood density, MOR and MOE.
2. The interaction effects between longitudinal position and heartwood-sapwood were not significant on wood density, MOR and MOE.
3. The average of wood density, modulus of elasticity (MOE) and modulus of rupture (MOR) along longitudinal position from base to the top were decreased. The mean of wood density, MOE and MOR in heartwood is higher than sapwood for Silk wood.
4. There are positive relationship between wood density and mechanical properties (MOE and MOR) in heartwood and sapwood.

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Manuscrito recibido el 7 de agosto de 2014.
Aceptado el 19 de noviembre de 2015.

Este documento se debe citar como:
Kiaei, M. and M. Farsi. 2016. Vertical variation of density, flexural strength and stiffness of Persian silk wood. *Madera y Bosques* 22(1):169-175.