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Heartwood and Sapwood Properties of *Quercus castaneaefolia* in the Iranian Forests

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Abstract: This study examines to the physical and mechanical properties of heartwood and sapwood in *Quercus castaneaefolia* species. Ten normal trees for evaluation wood properties were selected in north of Iran. Disks and logs cut down at breast height. Samples for testing were prepared from Heartwood and sapwood. The results showed that there are significant differences between wood properties and heart-sapwood, so that the mean of wood density, volumetric shrinkage, volumetric swelling, modulus of rupture and compression parallel to the grain in heartwood are greater than sapwood. The relationship between the wood density and volumetric shrinkage was determined by regression analyses. It was found that there were positive relationships between wood density and shrinkage, but these correlations in heartwood are stronger than sapwood. The average modulus of rupture varied between the heartwood and sapwood from 88.67±24.02 to 71.43±25.12 MPa and the average of compression strength parallel to the grain varied between heartwood and sapwood from 74.63±10.90 to 59.19±11.32 Mpa.

Key words: *Quercus castaneaefolia* · Heart-sapwood · 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 from Astara in northwestern of Ciulan province to Golidagh in east of Golestan province. The length of these forests is 800 km and the width is 20 to 70 km. Three major provinces, Giulan, 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. The Hyrcanian forests comprise a little more than 2.1 million hectares of almost 100 percent hardwoods, primarily beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*). Other marketable species include maple (*Acer insigne*), oak (*Quercus castaneaefolia*), alder (*Alnus subcordata*), elm (*Ulmus glabra*), 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].

The xylem of most tree species two histologically similar but physiologically different zones: the sapwood and the heartwood. The sapwood, the outer zone, contains physiologically active living cells and reserve materials. The outer rings allow the transport of water and minerals from the roots to the cambium and leaves. The heartwood, the inner zone of the xylem, is physiologically inactive regarding water conduction. With tree ageing, the parenchyma cell die, lose their reserve material and the wood becomes impregnated with complex organic compounds. These are normally referred to as extractives and are responsible for the natural durability of this xylem zone and for its usually darker colour [2].

Heartwood and sapwood content vary between and within species and have been related to growth rates, stand and individual tree biometric features, site conditions and genetic control. Reviews on heartwood and sapwood formation and variation can be found in Bamber and Fukazawa (1985), Hillis (1987) and Taylor *et al*. (2002) [3-5]. Heartwood and sapwood have different properties and their proportion within the tree will have a significant impact on the utilization of wood. For 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 (panels and furniture).

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When there is a large colour difference between sapwood and heartwood, selection of wood components by colour also plays a significant role in some timber applications [2, 5].

Oak wood (*Quercus castaneaefolia*) is a native ring porous hardwood species in Caspian forests and grows in mixed stands with hornbeam and beech and with iron wood in some areas. Thus, the objectives of this study were to investigate the variation of wood density, volumetric shrinkage and volumetric swelling in the heartwood and sapwood of oak species in north of Iran. In addition, the relationship between wood density and volumetric shrinkage were examined by linear regression in heartwood and sapwood.

MATERIALS AND METHODS

This study was carried out on ten oak (*Quercus castaneaefolia C. A. M*) trees obtained from natural forests in Tonekabon- Mazandaran site in the north of Iran. Disks and logs from each sampled tree were cut at breast height. The age of trees was 75-78 years-old. The annual rainfall and annual average temperature (1960-2009) was 1232 mm and 16.2°C, respectively. 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. The altitude of this site was 350 m. These tree cut down in October 2009.

Determination of Physical Properties: A 5-cm-thick disc was collected from these logs for evaluation of physical properties such as oven-dry density, basic density, volumetric shrinkage and volumetric swelling. In order to determine the physical properties, testing samples with dimensions of 2 × 2 × 2 cm were prepared according to the ASTM-D143. Testing samples were prepared from heartwood and sapwood (Figure 1). Oven-dry measurements were taken after the specimens dimensions were measured in both green and dry conditions by a slide caliper and mass measured on an electric balance to an accuracy of 0.01g. Basic density was determined from green Volume (using the water displacement method) and oven-dry mass. Shrinkage and swelling was calculated using the dimensional change from the green (saturated) to oven-dry condition. Overall, the physical properties of the specimens were calculated by the following equations:

$D_{0} = P0 / V0$
$D_b = P0 / Vs$
$\beta v = (V_s - V_o) / V_s$
$\alpha_v = (V_s - V_0) / V_0$

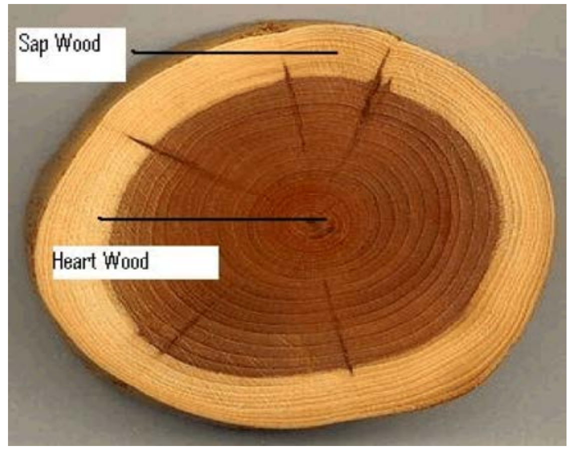

Fig. 1: Testing samples from the sapwood and heart wood

Where D_0 is oven dry density (g cm^{-3}), D_b is basic density (g cm^{-3}), βv is volumetric shrinkage (%), α_v is volumetric swelling (%), V_s is volume in state of saturate (cm^{-3}), V_o is volume in state of oven-dry (cm^{-3}), P_0 is weight in state of oven dry (g) and P_s is weight in state of saturate.

Determination of Mechanical Strength Properties: One 50 cm log and one 15 cm log was removed for evaluation of mechanical properties. The first log was used for the static bending tests (to calculate the modulus of rupture) and the other second log was use for the compressive strength parallel to the grain. The specimens were taken from heartwood and sapwood. According to the ASTM D143-94 standard (second method), the sample dimensions were 25 × 25 × 410 mm for modulus of rupture (MOR) and were 25 × 25 × 100 mm for compressive parallel to the grain. 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.

$$MOR = 3\ P_{max}\ l / 2\ b\ h^2,\ \sigma cpl = P_{max} / F$$

MOR = modulus of rupture (MPa), P_{max}= maximum load at break point (N), l = length of span (mm), b = width of specimen (mm), h = thickness of specimen (mm), σcpl = compressive strength (MPa), F = area of cross section of specimen on which force was applied (mm^2).

Statistical Analysis: The statistical analysis was conducted using SPSS programming method in conjunction with T- Test student techniques was used to test the statistical significance at 0.05 levels. In addition, the relationship between wood density and volumetric shrinkage was determined with using linear regression.

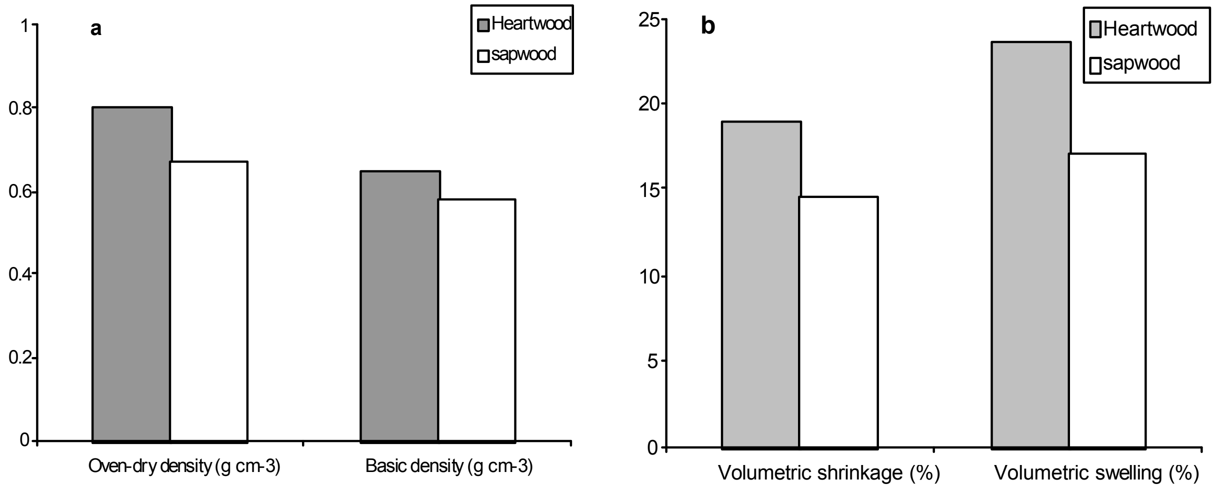

Fig. 2: Average of wood density (a), volumetric shrinkage and volumetric swelling (b) of oak wood in heartwood and sapwood

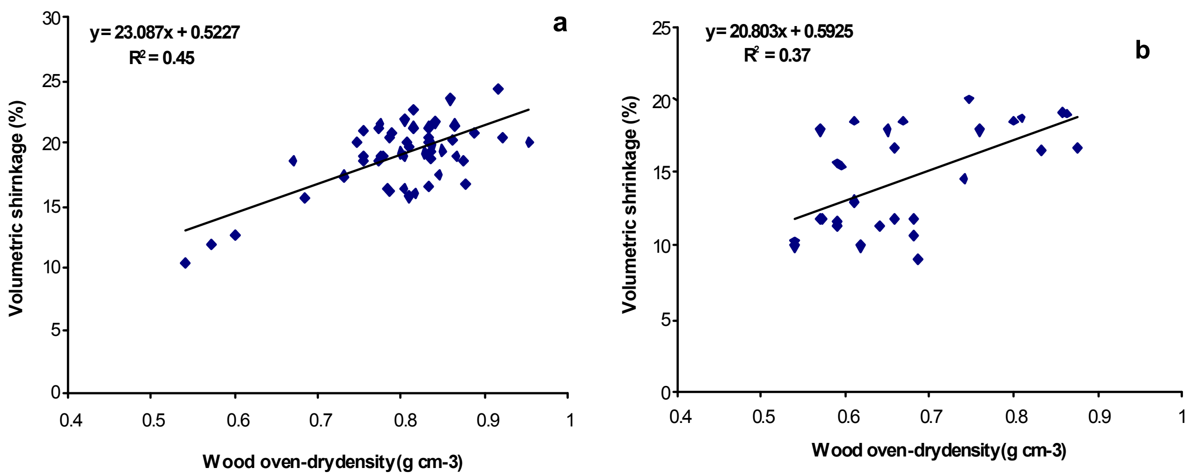

Fig. 3: The relationship between wood density and volumetric shrinkage in heartwood (a) and sapwood (b)

RESULTS

Physical Properties: The wood oven-dry density and basic density, volumetric shrinkage and volumetric swelling values of oak wood for heartwood and sapwood are shown in Figure 2. Results indicated that there are significant differences between above properties and heartwood-sapwood, so that the physical properties in heartwood are more than sapwood. The mean oven-dry density, basic density, volumetric shrinkage, volumetric swelling values were 0..799±0.07 g cm^{-3}, 0.65±0.05 g cm^{-3}, 18.97±2.74% and 23.55±4.06% in heartwood, respectively. These values in sapwood were 0.671±0.10 g cm^{-3}, 0.58±0.07 g cm^{-3}, 14.56±3.55% and 17.09±4.62%, respectively.

The relationships between wood oven-dry density and volumetric shrinkage in heartwood and sapwood are shown Figure 3. There are strong and positive correlation between above properties in heartwood and sapwood, but these coefficients correlation between wood density and volume shrinkage in heartwood (R^2 = 0.45) is more than sapwood (R^2 = 0.45).

Mechanical Strength Properties: The modulus of rupture (MOR) and compression parallel to the grain values of oak wood for heartwood and sapwood are shown in Figure 4. Results showed that there are significant differences between mechanical properties and heart-sapwood of oak wood, so that these values in heartwood are greater than sapwood. The modulus of rupture value was 88.67±24.02 MPa in heartwood and 71.43±25.12 MPa in sapwood. The compression parallel to the grain value was 74.63±10.90 MPa in heartwood and 59.19±11.32 MPa in sapwood.

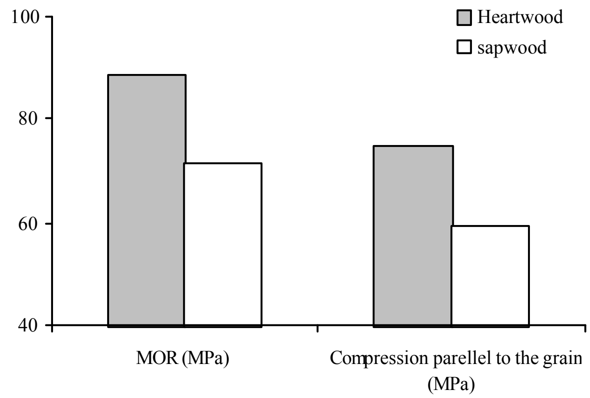

Fig. 4: Average mechanical properties of oak wood in heartwood and sapwood

DISCUSSION

This study examines the physical and mechanical properties of oak wood in heart-sapwood in north of Iran. The results indicated that the wood density and mechanical strength properties in heartwood is greater than sapwood. In addition, the mean of modulus of rupture in heartwood were 88.67 MPa and it is by 24% is more than modulus of rupture of sapwood. The compression parallel to the grain strength values in heartwood about 26% is higher than sapwood. These differences were due to the chemical structure in heartwood and sapwood. The amount of extractive component in the heartwood is higher than sapwood [6, 7]. The formation of heartwood is the main cause of variation in the type and quantity of extractives within the tree. Significant amounts of extractives are deposited in the heartwood, up to two to three times more than in sapwood. These will have an effect on wood reactivity or treatment processes, finishing, preservation, gluing and production of polymer/wood composites [2, 7].

Variation of shrinkage in different directions is due to the cellular structure and physical organization of cellulose chain molecules within the cell walls [8], the microfibril angle of the S_2 layer [9] and heartwood-sapwood ratio [10] are important factor. Yamamoto *et al*. (1992) reported that the presence of a gelatinous layer in fibers results in large shrinkage in the longitudinal direction [11]. The magnitude of shrinkage and swelling is affected by the amount of moisture gained or lost by wood when the moisture content fluctuates between zero and fiber saturation point [6]. Kollman and Cote (1968) explained that shrinkage differs in the three different directions due to the influence of wood rays and different arrangements of fibrils in the cell walls [12]. However, the most important parameter affecting wood shrinkage is the wood density [13]. In our study, the values of volumetric shrinkage and volumetric swelling in heartwood are more than sapwood. Also, there are a positive correlation between wood density and volumetric shrinkage of oak wood. This correlation between wood density and volumetric shrinkage in heartwood is more than sapwood, which these results reported by Pinto *et al*. [2].

CONCLUSIONS

Variations of the wood physical and mechanical properties between heart wood and sapwood were significant. The wood density, which is considered an important indicator of strength, was marginally higher in the heartwood. In addition, there is a positive relationship between wood density and shrinkage. But these correlations in heartwood are stronger than sapwood.

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