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Cork oak (*Quercus suber* L.) wood hygroscopic properties and dimensional stability

S. Leal, V. B. Sousa and H. Pereira*

Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade Técnica de Lisboa,
Tapada da Ajuda, 1349-017 Lisboa, Portugal

Abstract

Cork oak (*Quercus suber* L.) wood has a potential for high value uses because of its strength and aesthetic properties but one obstacle is the lack of knowledge of the wood-water relations. Variations in wood equilibrium moisture content, density and dimensions were studied at air temperatures of 22°C and 27°C (representing acclimatized homes and summer non-acclimatized homes, respectively) varying from 80% to 30% of relative humidity.

For indoor uses (22-27°C, 50-65% of relative humidity), the wood equilibrium moisture content ranged 12-17% and these values are recommended for the final commercial drying of cork oak wood. The fibre saturation point averaged 27%. Total volumetric shrinkage at 22°C-27°C averaged 12%, the linear shrinkage 8.1-8.5% and 3.6-3.6%, respectively in tangential and radial directions. Anisotropy averaged 2.3. Wood density at 12% moisture content ranged 0.63 to 0.67 g/cm^3. The higroscopicity obtained was 0.003. The average tangential differential shrinkage was 0.32 for both temperatures and the average radial differential shrinkage was 0.14 and 0.15, at 22°C and 27°C respectively. The shrinkage factor was 0.90 cm^3/g and 0.82 cm^3/g, at 22°C and 27°C respectively. Differences between temperatures were only statistically significant at 80-70% of relative humidity.

Key words: Cork oak; moisture content; hygroscopicity; *Quercus suber*; shrinkage.

Resumen

Propiedades higroscópicas y de estabilidad dimensional de madera de alcornoque (*Quercus suber* L.)

La madera de alcornoque tiene potencial para usos de alto valor debido a su resistencia y propiedades estéticas, pero presenta un obstáculo como es la falta de conocimiento de las relaciones agua-madera. Se han estudiado las variaciones en el contenido de humedad de equilibrio de la madera, la densidad y las dimensiones a temperaturas del aire de 22°C y 27°C (que representa casas climatizadas y casas de verano no aclimatadas, respectivamente) variando entre 80% a 30% de humedad relativa. Para usos interiores (22-27° C, 50-65% de humedad relativa), el equilibrio de humedad de la madera osciló entre el 12-17% y se recomiendan estos valores para el secado final de la madera comercial de alcornoque. El punto de saturación de la fibra promedio es del 27%. La contracción volumétrica total a 22°C-27°C en promedio es de un 12%, la contracción lineal varía entre 8.1-8.5% y 3.6-3.6%, respectivamente en direcciones tangenciales y radiales. La anisotropía promedio fue de 2,3. La densidad de la madera con un contenido de humedad del 12% varió entre 0,63 a 0,67 g/cm^3. La higroscopicidad obtenida fue de 0,003. La contracción diferencial tangencial promedio fue de 0,32 para ambas temperaturas y la contracción radial diferencial promedio fue de 0,14 y 0,15, a 22°C y 27°C respectivamente. El factor de contracción fue de 0,90 cm^3/g y 0,82 cm^3/g, a 22°C y 27°C respectivamente. Las diferencias entre las temperaturas fueron estadísticamente significativas sólo al 80-70% de humedad relativa.

Palabras clave: alcornoque, contenido de humedad, higroscopicidad, *Quercus suber,* contracción.

Introduction

Cork oak (*Quercus suber* L.) is an important tree species well known because of producing cork, a material used worldwide for several industrial purposes, but mainly for producing cork stoppers for wine bottling (Fortes *et al*., 2004; Pereira, 2007).

The cork oak is an evergreen oak, native to the countries of Europe and North Africa that surround the western Mediterranean basin, at present occupying an

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* Corresponding author: hpereira@isa.utl.pt

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area of over two million ha, mostly in Portugal and Spain (Pereira and Tomé, 2004). The cork oak stands are presently managed for cork production with little attention given to the wood component of the tree. However the economic sustainability of the cork oak system is fragile because of depending on one product, the cork stoppers, especially when alternative closures are introduced into the wine bottling market. Therefore it is strategic to explore complementary and economically viable uses for the cork oak tree, such as high value wood products, and to incorporate them on the management of the system.

It is not surprising that little research has been assigned to the cork oak wood since most scientific literature on the species is related to cork characterisation (e.g. Pereira *et al*., 1996) and production (e.g. Vázquez and Pereira, 2005). A few recent studies focused on the factors affecting wood growth (Costa *et al*., 2001; 2002; Leal *et al*., 2008), anatomy (Leal *et al*., 2006; 2007) and density (Knapic *et al*., 2007).

Cork oak wood was one of the most valuable woods in the 16th-17th centuries, when it was extensively used for naval construction due to its high resistance to compression and impact, as well as durability. Like other oaks, this wood has also a strong aesthetical character, resulting from its particular anatomical features, and is appropriate for several end-uses in spite of problems during sawing and drying, such as cracks and collapse (e.g. Zobel and van Buijtenen, 1989). However, most problems result from inadequate wood processing due to lack of knowledge concerning the wood properties and specific processing demands, namely regarding moisture content and dimensional variations in various conditions.

Wood is a hygroscopic material, i.e. its moisture content varies depending on wood-environment water exchanges. Inside the wood, water may be kept as bound water in cell walls and as free water in cell cavities, and the point at which cell walls are saturated and cell cavities are empty is called fibre saturation point, FSP (Tsoumis, 1991). Wood swells or shrinks as a result of adsorption or desorption of moisture in the cell walls below FSP according to the classical definition, or starting already above FSP (e.g. Almeida Hernández, 2006). These properties are important in wood processing, since most of the drying defects can be avoided if the process is performed according to the specific wood-water relations and the weather conditions it will be exposed to while in service (Joly and More-Chevalier, 1980).

Here we present the results on the variation of cork oak wood stability, moisture content, dimensions and density with changing air conditions, covering a broad range of air relative humidities and two air temperatures representing house interior situations: for an acclimatized home (22°C), and summer conditions in a non-acclimatized home (27°C). The between-tree and within-stem axial and radial variations were also studied to address the issue of the wood supply homogeneity.

Material and methods

The cork oak samples used in the study were collected from five mature and healthy cork oak (*Quercus suber* L.) trees under cork production, approximately 120-yr old and with diameters at 1.30 m of tree height ranging between 38 and 67 cm. The trees were harvested at Herdade dos Albardeiros (Alvito, Beja district, Alentejo region, Portugal; 38°15'N, 7°59'W). The site is a private property containing an area of cork oak stands where 12 ha were legally harvested because of cultural substitution with vineyard.

Wood discs were collected from each tree at three stem height levels: at 0.5 m (Bottom), at 1.30 m (Breast height), and below the stem bifurcation at 2.1 m (Bifurcation). The wood discs were stored indoors in well ventilated conditions during one year prior to further sampling. Three radial strips (extending from pith to bark) equally spaced and free of defects were randomly selected from each disc. The test pieces were cut at three radial positions along the wood radial strips (Fig. 1): at 10% (Inner heartwood), 50% (Outer heartwood) and 90% (Sapwood) of distance from pith.

At each sampling point, two types of test pieces were cut (Fig. 1): $2 \times 2 \times 2$ cm^3 cubes (type A) and pieces with a transversal section of 5×5 cm^2 and 1 cm of thickness (type B). A total of 90 sample pieces per type were prepared and 30 samples (one per each combination of tree, tree height and test piece type) were chosen

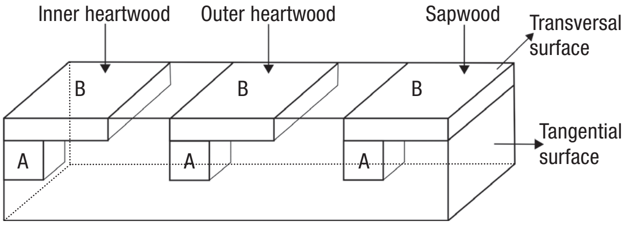

Figure 1. Schematic representation of the positioning of the test pieces on the wood strips (extending radially along the direction of growth). A and B represent the different types of test pieces (see text for description).

for measurement of dimensional variations based on accuracy of dimensions and absence of defects. The air-dried test specimens had an average moisture content of 12%. The methodology was based on the Portuguese standards NP-614 for moisture content determination, NP-615 for shrinkage determination and NP-616 for density determination.

The entire set of test pieces was soaked in water for several weeks for re-wetting over fiber saturation point, and after that their mass was determined using a 0.1 mg precision balance and the dimensions measured twice in the three directions (radial, tangential and axial) with a digimatic calliper with 0.01 mm of precision.

The re-wetted (hereafter referred to as saturated) pieces were placed inside a climatic cabinet (KBWF climatic cabinet, from WTB Binder, with ± 2% RH) regulated to 22°C of air temperature and 80% of air relative humidity (RH). When constant mass was achieved the test samples were weighted and measured. The cabinet was then regulated for 70% of air relative humidity, maintaining the temperature, and the test pieces reintroduced. The new mass after stabilization was registered and the procedure repeated, reducing each time another 10% in humidity, until 30% of air relative humidity.

The test pieces were again soaked in water for a second desorption test, and the whole procedure was repeated at an air temperature of 27°C. At the end of the experiment the test pieces were dried at 103 ± 2°C until constant mass in order to obtain the oven dried mass and dimensions.

Wood moisture content for the different conditions was calculated, using the data for the type A test pieces as

$$H = \frac{m_1 - m_2}{m_2} \times 100$$

where m_1 is the mass at H moisture content (g) and m_2 the oven dried mass (g).

The linear (radial and tangential) shrinkage (ε) was calculated using for measurement the radial and tangential directions of type B test pieces, as

$$\varepsilon = \frac{l_1 - l_2}{l_1} \times 100\,,$$

where l_1 is the average saturated length (mm), over a certain direction (radial, tangential) of the test piece and l_2 is the average length (mm), over the same direction, at a given moisture content.

The volumetric shrinkage (ε_v) was calculated with the measurements taken in the type A test pieces as

$$\varepsilon_v = \frac{v_1 - v_2}{v_1} \times 100\,,$$

where v_1 is the average saturated volume (cm^3) and v_2 is the average volume (cm^3) at a given moisture content.

The linear and volumetric shrinkages were calculated, according to ISO 4469 and ISO 4858 respectively, for the several wood moisture contents achieved during the drying process at each combination of air humidity and temperature. Total linear and volumetric shrinkages were calculated using the dimensional variation between the maximum wood saturation and oven dried states.

The differential shrinkage q (ratio of shrinkage) proposed by Noack *et al*. (1973) was followed to quantify the dimensional stability of the wood i.e. tangential and radial dimensions changes by 1% of moisture content variation as

$$q(H_1 - H_2) = \frac{\varepsilon_{v1} - \varepsilon_{v2}}{H_2 - H_1}$$

where ε_{v1} is the radial or tangential shrinkage at H_1 and ε_{v2} is the radial or tangential shrinkage at H_2. These dimensional changes were studied in the following hygroscopic ranges 80-70%, 70-50% and 50%-30% for 22°C and 27°C air temperature.

The variation in the external volume of wood during shrinkage with the variation in the weight of an equivalent volume of water represents the shrinkage factor R proposed by Chafe (1987) as:

$$R(H_1 - H_2) = \frac{q_1 - q_2}{H_1 - H_2} = \frac{\Delta V}{\Delta M_{water}}$$

where: q_1 is the volumetric differential shrinkage at H1 and q_2 is the volumetric shrinkage at H_2; ΔV is the volumetric variation between the volumetric dimension (cm^3) at H_1 and H_2 and ΔM_{water} is the weight of water (g) variation between H_1 and H_2.

Analysis of variance was performed using a factorial analysis with tree height, humidity ranges and tree as factors of variation.

Wood density (ρ_H) was calculated from measurements of type A test pieces as

$$\rho_H = \frac{m_H}{v_H}$$

with m_H as the mass (g) and v_H as the volume (cm^3) at H% moisture content.

Several of the B test pieces became excessively warped during the course of the experience, due to large or angled growth rings, and were excluded from the dimensional calculations.

Results

Variation in wood moisture content

On average the cork oak wood samples had 88.1% moisture content after soaking in water. This initial maximum moisture content decreased along the radial direction from the inner heartwood to the sapwood from an average of 106.4 ± 10.5% to 86.5 ± 20.1% and to 71.5 ± 13.1% (Figure 2).

Figure 3 shows the desorption isotherms for 22°C and 27°C. With decreasing air humidity (from 80 to 30%), wood moisture decreased reaching on average 9.7 ± 0.6% and 7.8 ± 0.2% at 30% air humidity at 22°C and 27°C air temperature, respectively. At 27°C, the moisture content was lower, at the successive air humidity conditions. The differences in moisture, compared with 22°C, amounted to a maximum of 3.8%, at 80% air humidity, and a minimum of 1.5%, at 50% air humidity.

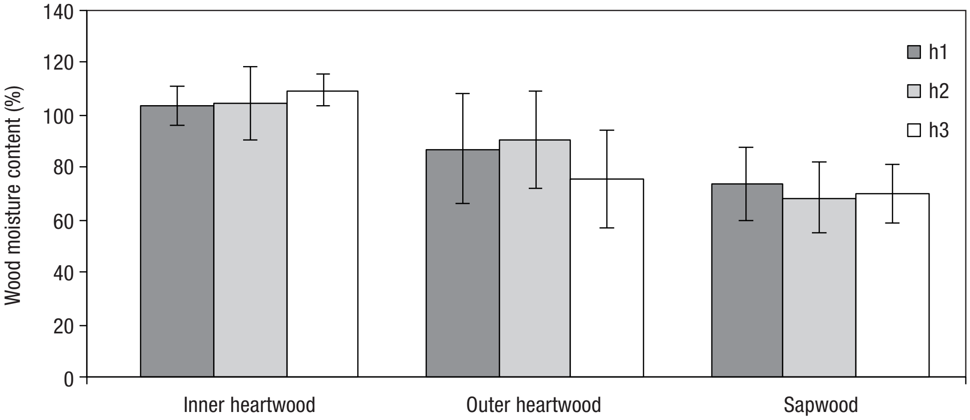

Figure 2. Wood moisture content, after soaking in water, for the several radial positions and tree height levels (h1 = bottom; h2 = breast height; h3 = bifurcation) with error bars representing standard deviations.

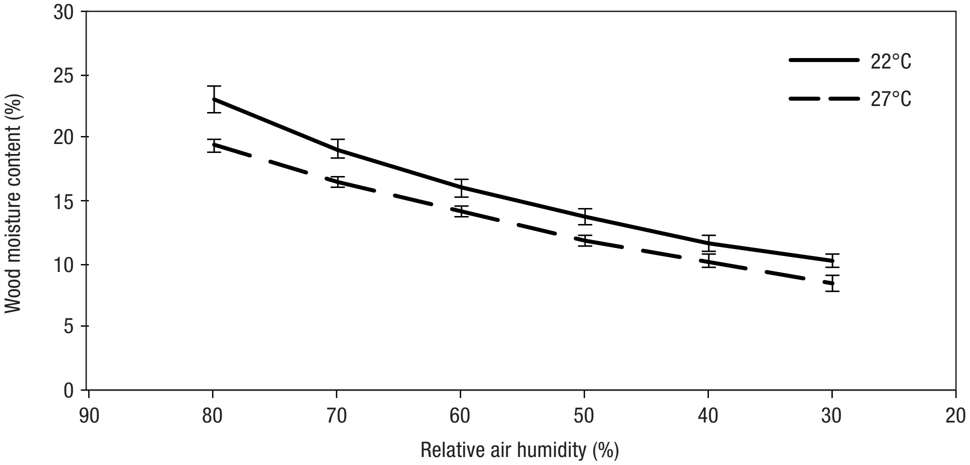

Figure 3. Evolution of wood equilibrium moisture content with decreasing air humidity, at two different air temperatures with error bars representing standard deviations.

Variation in wood dimensions

Figure 4 shows the variation in radial, tangential and volumetric shrinkage with changing moisture content. The cork oak wood behaved similarly under the two tested air temperatures. Shrinkage was noticeable below the FSP following an approximate linear relationship with wood moisture content. According to the shrinkage intersection point method the FSP was estimated with ± 2% accuracy (Walker, 2006), corresponding to 27.4% at 27°C and 27.2% at 22°C.

The volumetric shrinkage was 12.0 ± 1.2% and 12.6 ± 1.7% respectively at 27°C and 22°C (slightly different, t-test, $P < 0.05$), the tangential shrinkage, respectively, 8.5 ± 0.9 and 8.1 ± 0.9% (significantly different, t-test, $P < 0.01$), and the radial shrinkage 3.7 ± 0.4 – 3.6 ± 0.3. The tangential shrinkage was about two times the radial shrinkage, and the anisotropy ratio was 2.3 ± 0.3.

Table 1 shows the differential tangential and radial shrinkage at three RH ranges (80-70%, 70-50% and 50-30%) for 22°C and 27°C. The variation of differential shrinkage between different RH stages was not significant at 27°C and significant ($P < 0.01$) at 22°C. The average radial differential shrinkage was 0.14 and 0.15 at respectively 22°C and 27°C; the average tangential differential shrinkage was 0.32 for both temperatures.

The shrinkage factor was 0.82 cm^3/g (CV of 11.6%) and 0.90 cm^3/g (CV of 14.1%), at 27°C and 22°C respectively (Table 2). Differences between temperatures were statistically significant ($P < 0.01$) for the 80-70% RH variation but no differences were found between 70-50% or 50-30% of relative humidity ranges. Between-height variation was not significant for all cases. The average shrinkage factor for desorption between 50-30% of relative humidity was 0.94 cm^3/g and 0.95 cm^3/g at 22°C and 27°C, respectively. The shrinkage factor was in general less than the unity showing that cell cavity shrinks (Skaar, 1988).

Variation in wood density

The variation in wood density with changing moisture content are shown in Figure 5. Cork oak wood initial density was 1.12 g/cm^3 after soaking in water, and on average 0.69 g/cm^3 at FSP. From this point on, decreases in moisture content resulted in less pronounced decreases in density. The wood density was on average 0.65 g/cm^3 at 12% moisture content, reaching a minimum average of 0.62 g/cm^3 at the oven dried state.

Wood density decreased with tree height, and differed 0.04 g/cm^3 between the bottom and breast height levels, and 0.04 g/cm^3 between breast height and bifurcation levels. Hygroscopicity, i.e. the variation in density when moisture varies 1%, ranged between 0.0015 and 0.0053.

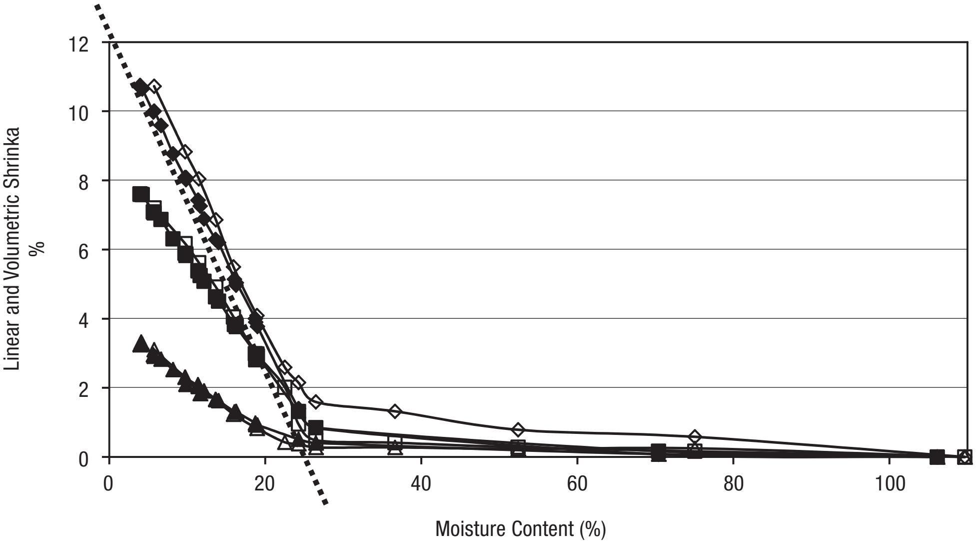

Figure 4. Wood dimensional variation (volumetric, tangential and radial) with changing wood moisture content. The approximate locations of the fibre saturation point (FSP) according to the intersection point method (dashed line). The volumetric, tangential and radial variation is represented by lozenge, square and triangle, respectively. The unfilled symbols represent 22°C and the dark ones 27°C.

Table 1. Differential shrinkage (q) values at three ranges of relative humidity for the two temperatures studied. T is the tangential differential shrinkage and R the radial differential shrinkage; values in parentheses represent the coefficient of variation (%) of 5 samples

Temp	Height level		80-70% RH		70-50% RH		50-30% RH	
22°C	Bottom	T	0.25	(34.0)	0.36	(18.0)	0.33	(13.1)
	Breast height		0.27	(9.0)	0.38	(15.8)	0.32	(15.1)
	Bifurcation		0.23	(30.6)	0.38	(4.0)	0.35	(24.3)
	Bottom	R	0.09	(20.0)	0.15	(21.8)	0.18	(12.2)
	Breast height		0.12	(24.6)	0.16	(12.1)	0.17	(10.7)
	Bifurcation		0.11	(27.5)	0.16	(20.3)	0.15	(15.6)
27°C	Bottom	T	0.32	(24.1)	0.32	(15.4)	0.32	(21.7)
	Breast height		0.30	(11.3)	0.34	(11.2)	0.31	(10.5)
	Bifurcation		0.32	(9.3)	0.34	(8.0)	0.31	(9.4)
	Bottom	R	0.13	(9.7)	0.16	(8.7)	0.16	(10.0)
	Breast height		0.11	(15.4)	0.16	(11.7)	0.17	(7.6)
	Bifurcation		0.13	(12.2)	0.15	(11.7)	0.15	(9.1)

Table 2. Shrinkage factors (R) at three ranges of relative humidity for the two temperatures studied. Values in parentheses represent the coefficient of variation (%) of 5 samples

Temp	Height level	80-70 % RH		70-50 % RH		50-30% RH	
22°C	Bottom	0.71	(35.9)	1.01	(9.84)	0.90	(7.42)
	Breast height	0.84	(13.7)	0.92	(10.65)	0.91	(19.66)
	Bifurcation	0.79	(6.6)	1.01	(14.27)	1.00	(8.94)
27°C	Bottom	0.65	(6.9)	0.89	(7.55)	0.92	(10.82)
	Breast height	0.55	(13.6)	0.90	(8.80)	0.97	(14.23)
	Bifurcation	0.62	(23.0)	0.92	(12.14)	0.97	(7.05)

Discussion and conclusions

Wood moisture content

The wood equilibrium moisture content levels at the successive stages of air relative humidity were higher than those reported for *Quercus pyrenaica* at 25°C (García-Esteban *et al.*, 2005) and *Quercus robur* at 22°C (Popper *et al.*, 2005). At 22°C, wood moisture content varied between the same interval of values for *Q. suber* and *Q. robur* (Popper *et al.*, 2005); it increased, respectively, from 6.4 and 4.5%, at 10% air humidity, to 26.5 and 27.0%, in saturated air. However, in the case of *Q. suber* this increase progressed linearly while in *Q. robur* (Popper *et al.*, 2005) it followed a sigmoidal path, i.e. the increase was less pronounced under lower hygrometric states (from 4.5 to 10.5% at 60% air humidity versus an increase from 6.4 to 16.0% in the case of *Q. suber*) and more pronounced under higher hygrometric states (from 10.5 to 27.0% versus an increase from 16.0 to 26.5% in the case of *Q. suber*). One reason for the difference could be the fact that in those studies the equilibrium moisture content report to wood adsorption while in the present study the wood was measured under desorption, which results into higher equilibrium moisture contents (Tsoumis 1991; Simpson and TenWolde 1999).

In commercial wood drying, the targeted final moisture content corresponds to the equilibrium the wood will have at the end use situation (air humidity and temperature conditions). As a general guideline, hardwood to be used indoors (e.g. flooring, furniture, inte-

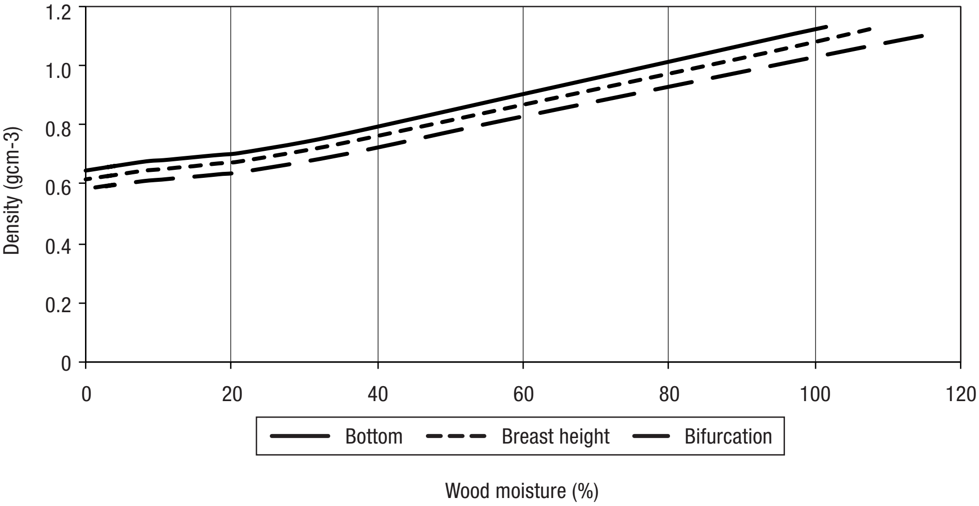

Figure 5. Variations in wood density with changing wood moisture content, at different tree height levels.

rior panelling) should be dried to a moisture content of 6-8% (Tsoumis, 1991) or 8-12% (Joly and More-Chevalier, 1980; Carvalho, 1996). Air humidity inside houses will tend to vary between 50% and 65% because of permanent or occasional heating (Joly and More-Chevalier, 1980). Considering this range of air humidities and the temperatures of 22°C and 27°C (chosen as representative of average conditions inside acclimatized homes and non-acclimatized homes in summer, respectively), cork oak wood equilibrium moisture content will fall in the range 12-15% at 27°C, and 14-17% at 22°C (Fig. 3). Therefore, the general recommendation for wood drying is not appropriate for cork oak wood for indoor uses; were the guidelines followed, the wood would be too dry and would gain water while in service, resulting in undesired warping.

Wood dimensional stability

The differential shrinkage q showed wood stability within the range of 80-70%, 70-50% and 50-30% air humidity. Similar results were found for birch and beech (Almeida, 2006). According to the classification of Noack *et al.* (1973), the tangential differential shrinkage may be considered as normal (between 0.3 and 0.4). The shrinkage factor showed more constancy between 50-30% of relative humidity for both temperatures. Cork oak wood FSP (27%) is similar to other oak species, such as *Q. robur* (Kolin and Janezic, 1996), *Q. pyrenaica*, *Q. rotundifolia*, *Q. rubra*, *Q. faginea* (Carvalho, 1997), and red oak (Wang and Wang, 1999), and to the general average wood FSP of about 30% moisture content (Simpson and TenWolde, 1999). However the precise determination of the fibre saturation point is difficult and rather a FSP region corresponding to a range of values should be considered (Tsoumis, 1991). This determination varies according to whether the values refer to measurement on the original green wood or on rewetted samples which always show somewhat smaller values (Walker, 2006). To avoid under estimations, Almeida and Hernández (2006) used only volumetric shrinkage values obtained between 33% and 76% of relative humidity to estimate FSP by the intersection method. It should also be pointed out that the obtained results are only representative of in-use conditions and the situation may be different under kiln-drying since the FSP decreases with increasing temperature (from 20°C to 80°C) according to Kolin and Janezic (1996).

A dimensional stable wood remains relatively constant in size when changes in moisture occur. Thus, a given wood can have a high total shrinkage (from green to oven-dry conditions), and yet the dimensional change between two hygrothermal conditions may be relatively small and therefore exhibit high dimensional stability (Hernández, 2007). The wood dimensional variations were similar for both tested air temperatures (Fig. 4). However, studying a broader range of temperatures, Svensson (1996) found that shrinkage depends strongly on temperature and tends to decrease at higher temperatures.

Cork oak wood total volumetric shrinkage (on average 12%) is characteristic of oak species (Carvalho, 1996). The values are similar to several American and European oak species, with shrinkages between 12-19% (Tsoumis, 1991; Carvalho, 1997; Simpson and TenWolde 1999), and lower than *Quercus spinata*, a tropical oak species from Indonesia (Choong and Achmadi, 1991). The second desorption showed 5.0% lower values agreeing with the decrease described in the literature.

Cork oak total radial (3.6-3.7%) and tangential (8.1-8.5%) shrinkages are lower than several American and European oak species, whose radial and tangential shrinkages vary between 4.0-6.6 and 8.6-13.0% respectively (Tsoumis, 1991; Carvalho, 1997; Simpson and TenWolde 1999). However, the anisotropy of shrinkage is medium to high (2.3), comparable to other European oak species (Carvalho, 1996; 1997) and similar or lower than other Mexican oak species (Cruz de Leon, 1994). Differences between the first (22°C) and the second (27°C) desorption were about 2.8% for the radial dimensions and 4.9% for tangential dimensions.

High values of anisotropy indicate a tendency for wood splitting and warping because it will undergo a non-uniform dimensional change when loosing water (Tsoumis, 1991; Svensson, 1996). The reasons for the difference between radial and tangential shrinkages are still not well known although it may be related to the presence of rays and their restrictive effect to radial retraction due to their radial orientation (Badel and Perré, 2007). The rays in oak woods are important features for determining the wood pattern, and they are very characteristic and appreciated by the consumer. Cork oak wood has an especially large proportion of rays and a ray pattern with enough variation for visual appreciation while ensuring within and between tree uniformity (Leal *et al.*, 2006). However, the present study shows that this dominant presence of rays does not result in an enhanced anisotropy of shrinkage, in comparison with other oaks.

Wood density and hygroscopicity

Cork oak wood is classified as moderately dense and its density (0.65 g/cm^3 at 12% moisture content) is within the range for American oaks (Tsoumis, 1991; Simpson and TenWolde 1999). European oaks tend to be heavier with densities between 0.69-0.90 g/cm^3 (Tsoumis, 1991; Carvalho, 1997). However, the results are below the average 0.89 g/cm^3 found with microdensitometric studies (Knapic *et al.*, 2007; 2008).

The rewetted wood conditions and the successive desorption cycles might explain the obtained lower density values since the large vessels that are one characteristic cork oak wood anatomical feature have limited sorption predisposition.

Cork oak wood density increased 0.08 g/cm^3 from the base of the tree to the top of the stem (Fig. 5). Although most diffuse-porous hardwoods show little variation in density from the base to the top, some have the highest density at the base and the lowest at the top (Zobel and Buijtenen, 1989).

The average hygroscopicity of 0.003 places cork oak wood in a medium class, as other oaks (Carvalho, 1996).

In summary, cork oak wood physical properties are within the range of most oak woods. The wood offers a considerable regularity, since it did not show large variations within and between trees. Since cork oak wood tends to achieve higher equilibrium moisture content than other woods under similar temperature and air humidity conditions, for indoor uses it should be dried until a moisture content of 12-17%, instead of the usually recommended 8-12%. The differential shrinkage and the shrinkage factor showed moderate stability with higher constancy under lower moisture contents. The results showed that cork oak wood has more or less standard shrinkage values for oaks, but this could be tempered by the frequency of warping related to grain irregularities and curvature of growth rings which advises to use rather short and thick boards. Further studies should explore temperatures approaching situations of kiln drying, and analyse the influence of drying time which is a variable of high economical importance.

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