Shrinkage and Swelling of Greek Chestnut Wood (Castanea Sativa Mill.) in Relation to Extractives Presence

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Abstract. The study of various woods shrinkage is of particular practical importance because the wood's property to shrink and swell with the adsorption or absorption of moisture from the atmosphere is a main cause of many defects that occur in wood and furniture during weather conditions changing. In the present study, measurements of the shrinkage of chestnut coppice wood samples were performed before and after extraction. The extraction was carried out with hot water for 6 and 12 days. Afterwards, the dry density, radial and tangential shrinkage were determined both in air-dry conditions and in absolute dry conditions. Moreover, the fiber saturation point was determined for the selected samples. The most significant result arrived from this study is that, now, in conjunction with the other researches have been made, there is enough evidence for chestnut wood from Mediterranean coppice forests, to claim that maximum radial shrinkage is about 3.83% (ranging from 3.40% - 4.12%) and maximum tangential shrinkage is about 6.58% (ranging from 6.21% - 8.20%).

1. Introduction

Chestnut (Castanea sativa Mill) is a precious forestry species of Greece, that occupies an area of 0.51% from the total Greek forest area and produces 8.58% of the total technical hardwood. In coppice forest (cutting age around 20-25 years) produces timber that is mainly used as construction wood and furniture. Shrinkage and swelling of wood are important properties, which affect its utilization. The effect might be a simple fluctuation of dimensions or an uneven shrinkage or swelling due to different humidity or density distribution. These results in various defects such as alteration of wooden objects shape, warping, opening or tightening of joints, change of cross-sectional shape, checking or even collapse of wood [1]. Among the factors influencing shrinkage (density, humidity, extractives), the influence of extractives [2] was studied in particular. Tangential wood shrinkage measurements, according to other studies [3-5] ranged from 2.8 to 10%, while in our study it ranged from 4 to 6.5%.

2. Materials and methods

Shrinkage was calculated in green wood specimens which came from logs cut from the base of five (5) chestnut coppice trees aged 25-27 years harvested in Arnaia (region of Halkidiki, Greece). Each log was cut to boards of 3 cm thick approximately. From every log one of the two central boards were
selected and used for the creation of shrinkage specimens. From each board (a, b, c, d, e and f) the shrinkage specimens were formed with successive tangential cuts from pith to bark and in the distance of 2-4 cm between them. Figure 1 shows the way of specimens’ formation from each log, their position related to pith, the direction of the annual rings and codes as well. In total, 198 samples were formed (Log A and B gave 36, Log C, D and E gave 42). The samples dimensions for the determination of shrinkage (radial, tangential) were measured successively from initial green condition, after air drying and then to absolute dry condition (kiln drying to 103 °C), with the aid of electronic micrometre. For the determination of humidity content of air-dried specimens their weight and their dry dimensions were measured at the same time.

![Logs A, B](image)

![Log C](image)

![Logs D, E](image)

**Figure 1.** Way of samples formation from each log and their codes (air dried)

The specimens volume used for the determination of dry density was calculated by their geometrical dimensions. The extractives effect was studied to specimens coded with a1, a2, a3, c7, c8, c9, b4, b5, b6 and d10, d11, d12, after the determination of shrinkage. Samples a and c were extracted with hot water for 6 days, when b and d for 12 days. The extractions were conducted to a Soxhlet device for 4 hours daily. The rest of the time wood samples were sunk into water.

3. Results and discussion

From the radial and tangential dimensions of the specimens (in wet, air-dry and at zero moisture content conditions), the shrinkage was determined based on the ratio (1):

\[
\beta(\%) = \frac{l_1 + l_2}{l_1} \times 100
\]

\(l_1\), initial green dimension (cm)

\(l_2\), final dry dimension (cm)

Swelling [1] can be determined by the relation (2):

\[
\alpha(\%) = 100 \times \frac{1}{1 - \beta}
\]

\(\alpha\), swelling (%)
Considering that the relationship between the changes in wood dimensions and the moisture content up to the fiber saturation point is rectilinear, the fiber saturation point was determined by the changes in the radial and tangential dimensions of the specimens (from the wet conditions to the air-dry and zero moisture content conditions) on the basis of the relation (3):

\[
\frac{\beta_1}{\beta_2} = \frac{f}{f - y}
\]

\(\beta_1\), maximum shrinkage (%)
\(\beta_2\), air-dry shrinkage (%)
\(f\), fiber saturation point (%)
\(y\), air-dry equivalent moisture content (%).

The determination of the samples dimensions was held with the use of a micrometer and repeated measurements until the stabilization of the dimensions. From each specimen seven smaller parts came out and were measured, after they were fully saturated. Dry density, radial and tangential shrinkage and fiber saturation point are shown in Table 1. As shown in Table 1, the mean maximum radial shrinkage of chestnut wood was 3.83% and ranged from 3.58% - 4.12%. Tangential shrinkage was 6.58% and ranged from 6.21% - 7.01%. The shrinkage values determined were comparatively similar to corresponding values in the literature [6-8], with the exception of the large tangential shrinkage value (10.0%) reported by Fioravanti [9]. There were no differences between the shrinkage values of the present study and the values from the literature. As shown in Table 1, the fiber saturation point calculated from changes in the tangential dimensions of the samples and their moisture content was found to be slightly higher in comparison to corresponding values determined by the changes in radial dimensions. This difference led to first changing the tangential dimensions of the wood and then the radial ones when reducing moisture content. This difference is very low and does not affect the commercial use of wood.

| Sample | Dry density (g/cm³) | Shrinkage (%) | FSP (%) |
|--------|---------------------|---------------|---------|
|        | Rad. | Tang. | Rad. | Tang. | Rad. | Tang. |
| A1-36  | 0.577 | 2.399 | 3.821 | 4.122 | 6.374 | 26.574 | 27.560 |
| B1-36  | 0.551 | 2.095 | 3.637 | 3.754 | 6.209 | 24.680 | 26.007 |
| C1-42  | 0.544 | 2.204 | 4.406 | 3.610 | 7.013 | 29.008 | 30.051 |
| D1-42  | 0.619 | 2.069 | 4.237 | 3.582 | 6.938 | 26.985 | 29.196 |
| E1-42  | 0.575 | 2.376 | 3.869 | 4.075 | 6.357 | 27.250 | 29.288 |
| Avg.   | 0.573 | 2.229 | 3.994 | 3.829 | 6.578 | 26.899 | 28.420 |

* Shrinkage from wet (green) to air-dry condition (moisture content 10.615% - 11.640%)
** Maximum Shrinkage from wet (green) to oven-dry condition (moisture content 0%)
*** Determination from dimensions changes (radial and tangential respectively) according to FSP (fiber saturation point)

The radial variation (from pith to bark) of the maximum shrinkage for each log is shown separately in Figure 2. As shown in Fig. 2 the radial shrinkage decreases from pith to bark (logs C, D and E). In the logs A and B, shrinkage seemed to either slight decrease or initially to increase and then decrease along with the radial direction from pith to bark. Tangential shrinkage was found to increase in the direction from pith to bark (logs A and E) or to decrease (logs B, C and D).
Figure 2a. Block A, distance from pith (cm). Upper tangentially and down radial

Figure 2b. Block B, distance from pith (cm). Upper tangentially and down radial

Figure 2c. Block C, distance from pith (cm). Upper tangentially and down radial

Figure 2d. Block D, distance from pith (cm). Upper tangentially and down radial

Figure 2e. Block E, distance from pith (cm). Upper tangentially and down radial

Figure 2. Maximum radial and tangential shrinkage changes along with the direction from pith to bark. Upper tangentially and down radial (air dried).
The effect of hot water extraction (6 and 12 days) on density, shrinkage and fiber saturation point is shown in Table 2 and Figure 3.

**Table 2.** Density, shrinkage and fiber saturation point (FSP) of chestnut wood before and after extraction (6 and 12 days) with hot water density, radial/tangential.

| Sample | Density, g/cm³ | Shrinkage (%)* | Shrinkage (%)** | FSP (%)*** |
|--------|----------------|----------------|-----------------|------------|
|        | Rad. | Tang. | Rad. | Tang. | Rad. | Tang. | Rad. | Tang. |
| Before hot water extraction | | | | | | | | |
| A_{1,1-3, 7-9} & 0.583 & 2.54 & 3.91 & 4.37 & 6.58 & 26.590 & 27.081 |
| B_{1,1-3, 7-9} & 0.548 & 2.22 & 3.75 & 3.76 & 6.27 & 26.171 & 26.637 |
| C_{1.4, 9-12} & 0.537 & 2.10 & 4.43 & 3.41 & 7.03 & 29.069 & 29.982 |
| D_{19.22, 27-30} & 0.626 & 2.21 & 4.45 & 3.73 & 7.26 & 27.984 & 29.118 |
| E_{19.22, 27-30} & 0.585 & 2.41 & 4.07 & 4.10 & 6.48 & 28.249 & 30.812 |
| Average & 0.576 & 2.30 & 4.12 & 3.87 & 6.72 & 27.613 & 28.726 |
| After 6 days hot water extraction | | | | | | | | |
| A_{1,1-3, 7-9} & 0.518 & 3.62 & 5.68 & 4.84 & 7.44 & 32.701 & 34.981 |
| B_{1,1-3, 7-9} & 0.502 & 3.10 & 5.69 & 4.28 & 7.49 & 29.206 & 33.453 |
| C_{1.4, 9-12} & 0.485 & 2.68 & 5.79 & 3.61 & 7.63 & 33.437 & 34.873 |
| D_{19.22, 27-30} & 0.516 & 3.21 & 6.46 & 4.34 & 8.25 & 31.140 & 39.021 |
| E_{19.22, 27-30} & 0.567 & 3.32 & 5.29 & 4.59 & 6.97 & 30.517 & 34.654 |
| Average & 0.518 & 3.19 & 5.78 & 4.33 & 7.56 & 31.400 & 35.396 |
| Before hot water extraction | | | | | | | | |
| A_{4,6-10, 12} & 0.584 & 2.60 & 4.01 & 4.41 & 6.53 & 26.762 & 28.728 |
| B_{4,6-10, 12} & 0.550 & 2.19 & 3.76 & 3.71 & 6.35 & 26.161 & 26.283 |
| C_{5,8, 13-16} & 0.540 & 2.04 & 4.43 & 3.37 & 6.87 & 28.478 & 31.302 |
| D_{23,26, 31-34} & 0.624 & 2.13 & 4.36 & 3.83 & 7.21 & 25.842 & 28.712 |
| E_{23,26, 31-34} & 0.579 & 2.45 & 3.96 & 4.19 & 6.44 & 27.921 & 29.730 |
| Average & 0.575 & 2.28 & 4.10 & 3.90 & 6.68 & 27.033 & 28.951 |
| After 12 days hot water extraction | | | | | | | | |
| A_{4,6-10, 12} & 0.496 & 5.96 & 8.20 & 7.12 & 10.02 & 47.830 & 42.413 |
| B_{4,6-10, 12} & 0.488 & 4.71 & 8.06 & 5.93 & 9.78 & 37.172 & 43.246 |
| C_{5,8, 13-16} & 0.472 & 4.47 & 8.62 & 5.51 & 10.10 & 41.345 & 72.895 |
| D_{23,26, 31-34} & 0.490 & 4.53 & 9.29 & 5.55 & 10.91 & 55.311 & 50.786 |
| E_{23,26, 31-34} & 0.538 & 3.14 & 8.81 & 4.33 & 10.65 & 28.498 & 45.332 |
| Average & 0.497 & 4.56 & 8.60 & 5.69 & 10.29 & 42.031 & 50.934 |

* Shrinkage from green (wet) to air-dry conditions
** Maximum shrinkage to oven-fry conditions (moisture content 0%)
*** Determination from corresponding dimensional changes (radially, tangentially)

The prolonged extraction duration of the samples led to an average extract of 10.5% and 17.20% for extraction 6 and 12 days, respectively, compared to an average of 19.22% extracts determined according to ASTM standards. Hot water extraction led to 10.07% and 13.57% decrease in density after extraction for 6 and 12 days, respectively. Air-dry shrinkage increased 38.70% radially and 40.29% tangentially after 6 days extraction. This increase was higher (almost double) after 12 days extraction (100% and 109.76% radial and tangential respectively). Maximum shrinkage increased 11.89% radially and 12.50% tangentially after 6 days extraction. This increase was, also, higher after 12 days extraction, radially (45.90%) and tangentially (54.04%). In all cases, fiber saturation point was increased after extraction. Higher increase was found after 12 days extraction. In those cases where lower shrinkage values were found around pith area, they could be attributed to the presence of "juvenile" wood, due to increase of microfibrils angle associated with the presence of such wood or to a higher content of extracts in heartwood region around pith.
Lower radial and tangential shrinkage values in "juvenile" wood (1.5% and 2.8% respectively) compared to corresponding "typical" wood (2.1% and 3.7%) are also reported by Militz et al. [10] for coppice chestnut wood.

![Figure 3: Radial and tangential chestnut wood shrinkage before and after extraction (6 and 12 days) with hot water. * Shrinkage from green (wet) to air-dry conditions ** Maximum shrinkage to oven-fry conditions (moisture content 0%).](image)

4. Conclusions
Mean maximum radial shrinkage of chestnut wood was 3.83% and ranged from 3.58% - 4.12%, while maximum tangential shrinkage was 6.58% and ranged from 6.21% -7.01%. These values, combined with the rest of literature, tend to precisely reflect the shrinkage of chestnut wood from Mediterranean coppice forests. Removal of water-soluble extracts results in an increase in radial and tangential shrinkage. From pith to bark direction, shrinkage seems to have some fluctuations (mainly reductive for radial shrinkage) but not to a large extent. Fiber saturation point calculated from changes in the tangential dimensions was found to be slightly higher than in radial dimensions. This difference led to first changing the tangential dimensions of the wood and then the radial ones, when reducing moisture content, but is, also, a very low difference and does not affect the commercial use of wood.

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