# EFFECT OF THE STRIPPING INTENSITY ON PHYSICAL AND MECHANICAL PROPERTIES OF CORK

A. EL Alami[1], A. Hakam[2], B. Kabouchi[3], A. Famiri[1], A. Bouchti[1] and M. Ziani[4]
[1]CRF Forest Research Center, PB Rabat, Morocco
[2]Equipe Science du bois, Faculty of Sciences of Rabat, Mohammed V University, P. B. R. P Rabat, Morocco
[3]Laboratoire de Matière Condensée et Sciences Interdisciplinaires (LaMCScI), Faculty of Sciences. P. B, Mohammed V University Rabat, Morocco
[4]National Institute of Archaeology and Patrimony Sciences, P. B, Hay Riad, Rabat Morocco
E-Mail: alami65ma@yahoo.fr

## ABSTRACT

The cork oak (*Quercus suber L.*) is an important Mediterranean species due to the economic value of the cork it produces. The effect of the stripping intensity on the characteristics of the cork was studied across the analysis of the physical and mechanical properties of cork samples from 31 trees of Sidi Yahia region in Morocco that underwent different stripping intensities ($K_1 = 1$, $K_2 = 1.5$, $K_3 = 2$ and $K_4 = 2.5$). The densities of the cork samples ranged from 0.123 to 0.255 $gcm^{-3}$. The compression was respectively 0.45 MPa, 0.47 MPa, 0.47 MPa and 0.43 MPa for the coefficients $K_1$, $K_2$, $K_3$ and $K_4$ while Young's Moduli was respectively 16.5 MPa, 16.9 MPa, 15.3 MPa and 16.4 MPa. The study showed a great variability of the physical and mechanical properties between the trees while the stripping intensity had no significant effect.

**Keywords:** cork, stripping intensity, physical and mechanical properties.

## INTRODUCTION

The cork oak (*Quercus suber* L.) is a Mediterranean species where it covers roughly 2.7 million hectares [1]. Morocco, with its 230 000 hectares of cork oak equivalent to 14 % of the world surfaces [2], has a long history in the cork harvest. However, Moroccan cork oak has suffered heavily, during last decades, from human interventions (overgrazing, pruning, cutting…) various parasitic attacks (*Lymantria dispar*, cork ants…) and negative impacts of unsustainable management leading to significant regression of their extent and stand density.

The cork oak has diverse products such as wood, cork, acorns, truffle and leaves. He has also an important environmental role by creating rich landscapes with habitats supporting a high diversity of flora and fauna and fixing the sand of the Mamora forest.

The cork, a material with exceptional properties, which distinguish it from other forest products, constitutes the main production of Cork oak often ending in high value products. This material is thus of great economic importance because of benefit and created jobs. The unique combination of properties presented by cork contributes to its use in a wide range of domain. Since the early twentieth century, cork had a massive expansion, mainly resulting from the development of cork-based agglomerates [3].

Morocco produces approximately 15000 tons/year of cork (6.7 % of the world production). Nevertheless, it is far from the level of other countries (Portugal reaches 150000 T/year) with a productivity of only 0.56 $m^3$/ha/year.

During the last 5 years, the annual average of harvested volume is 11000 tons/year. Regarding to its potentialities, the loss in production is around 20000 $m^3$ per rotation, a 17% decrease in production [2]. This variation is due to climatic conditions and cork oak degradation, which result largely from bad management practices and cork harvesting operation. Tree injuries and bad harvest have a direct impact on trees. These constraints reduce cork production and make it difficult to plan harvesting.

The produced cork is sold through a tendering procedure according to quality criteria with regards to thickness and defects.

Cork is harvested at a height equal to twice the circumference at 1.30 m for all stands, without regardless of the physiological state of trees. This practice often causes irreversible damage for trees.

Given these constraints that threaten this productive sector and the needs to ensure sustained and competitive production of cork as part of sustainable management of *Quercus suber*, this study aims to assess the effect of various stripping intensity of cork oak according to their vigour without altering the quality of their cork.

## MATERIAL AND METHODS

Cork is well known for its excellent physical and mechanical properties: elasticity, low density, impermeability, thermal and acoustic insulation, etc.

### Experimental study

The experimental device that served as the basis for this study was installed in 2008 in Sidi Yahia El Gharb, an occidental region of Morocco (Figure 1). This region, which is part of the Atlantic zone, has an important cork production. The soil consists of a layer of clay on which rests a layer of red sand. The bioclimate is warm sub-humid to temperate semi-arid. The average annual rainfall is around 480 mm and the mean summer temperature is around 23 °C. The chosen plot is a completely random device and four debarking coefficient have been applied. In addition to the usual intensity used by Moroccan foresters, which is twice the perimeter at breast height over cork and which is designated $K_3$, we have used three other debarking coefficients, respectively: ($K_{1}$=1), ($K_{2}$=1.5) and ($K_{4}$=2.5). The trees are numbered and located in the plot. The debarking coefficient is defined as the quotient between the debarking height and the perimeter at breast height over cork:

$$K = \frac{h}{C_{(1,30)}}$$

where K is debarking coefficient, h is debarking height and C is perimeter at breast height over cork


**Figure-1.** Location of the experimental plot.

The cork samples was collected in 2016, after nine years of growth, from 31 cork trees of about 70 years old, mature and healthy, with diameters at 1.30 m between 23 and 80 cm and tree heights between 7.5 and 17.5 m.

**Sampling and flow**

When cork is harvested, a location along the longitudinal (L), radial (R) and tangential (T) directions of the tree is carried out (Figure-2).

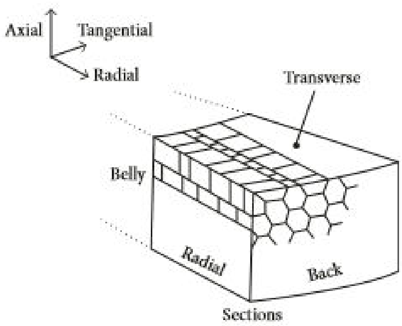


**Figure-2.** Diagram showing the different sections and directions of a piece of cork and the morphology of the cells of each section.

In order to determine the physical and mechanical properties, we cut cork planks into transverse plates of 25 mm thick from parallel sawn timber. These trays are then cut into bars of dimensions 2×2×6 $cm^3$. The bars obtained are then cut into test samples of 2×2×2 $cm^3$. The selected sampling or cutting plan allows us to preserve a test sample whose parallel faces are oriented along the longitudinal, radial and tangential directions of the cork.

To carry out this study, 372 samples were made at the Laboratory of Physical and Mechanical Tests of the Forest Research Center (CRF) in Rabat.

**Physical properties**

The water content, densities and dimensions are determined on cubic samples (2×2×2 $cm^3$) respectively according to the standards NF B 51004, NF B 51-005 and NF B 51-006. These samples are weighed by a 0.001 g precision resolution scale and the dimensions along the three reference directions are measured by a 0.001 mm resolution digital comparator.

The dimensional changes were determined for each sample of cork subjected to a boiling operation with water for one hour to make them more flexible. Boiling reduces the waviness of the cell walls, increase in cork volume, and become smoother [4]. The samples were dried in an oven at 100 °C until no change in weight. The humidity of the planks before boiling was on average 7%.

The linear dimensions (Ls), the volume (V), the mass (M) and the density were determined immediately after baking and compared with their initial values (before baking).

**Compression behaviour**

Compression is the most important mechanical test for characterizing a fragile material. Six cork samples per tree, of geometrical dimensions 2x2x6 cm3 made in the radial, tangential and axial directions respectively, making 186 samples. These specimens were subjected to a compression test using a Universal "Testwell" hydraulic press with a maximum load cell equal to 12 tonnes. This machine has been adjusted to a speed of about 8 mm / min in order to apply a progressive load to the specimens and obtain the values of the displacements and the appropriate breaking loads (Figure-3). The compression test is carried out in a period of between 1.5 and 2 minutes.

**Figure-3.** Testwell universal press.

The compression is given by the following formula:

$$\sigma\,(\mathrm{MPa}) = \frac{F\,(\mathrm{N})}{S\,(\mathrm{mm}^2)}$$

where F is maximum tensile strength and S is dimension of the cross-section of the sample.

The modulus of elasticity (Young's moduli) was determined from the mean slope of the stress-strain curve in the linear zone.

**Statistical analysis**

The results were statistically processed by analysis of variance using the effect of fixed variation as the exasperation coefficient. The effects were considered statistically significant when the p (probability) value was less than or equal to 0.05. All statistical analyses were performed using SPSS, Statistical Software (version 20.0, SPSS Inc., Chicago, IL).

## RESULTS AND DISCUSSIONS

Despite its various uses, cork does not benefit from a great scientific attention regarding his high qualities. Some recent studies [1, 5, 6, 7, 8, 9, 10], provided a better understanding but only of properties of this material.

In Tunisia the best thickness of cork is obtained after using the debarking coefficient K= 3. However, and in order to maintain trees in good condition, scientists suggest the coefficient K = 2.5 [11]. In Algeria, a study revealed weak correlations between sanitary status and the stripping intensity [12].

**Moisture before and after boiling**

At 100 °C, the moisture content increases from 7% (before boiling) to approximately 69% after 1 hour of boiling (Table-1). Water diffuses into cork through cell walls and lenticular canals causing an increase in volume [13]

**Table-1.** Moisture before and after boiling.

| Stripping intensity | Moisture before boiling | | | Moisture after boiling | | |
|---|---|---|---|---|---|---|
| | Average + sdv | Min | Max | Average + sdv | Min | Max |
| k1 | 8,811 ± 0,334 | 5,921 | 22,619 | 71,83 ± 2,721 | 38,0 | 104,0 |
| k2 | 9,020 ± 0,387 | 2,793 | 27,950 | 68,415 ± 1,758 | 41,0 | 161,0 |
| k3 | 7,536 ± 0,182 | 4,730 | 10,366 | 67,40 ± 1,786 | 44,0 | 93,0 |
| k4 | 7,620 ± 0,175 | 6,667 | 9,091 | 70,416 ± 5,117 | 54,0 | 119,0 |

Sdv: standard deviation, Min : Minimum, Max : Maximum

The statistical analysis of moisture uptake by the samples subjected to boiling did not show a significant difference between stripping intensities (F = 0.548 and p = 0.650).

**Density and expansion**

For each stripping intensity, the average density and expansion values of the tested samples were determined and shown in Table-2. The densities of the cork samples ranged from 0.123 to 0.255 gcm$^{-3}$. A great variability of density was observed between the trees of the same stand (F = 29.099 and p = 0.000) whereas the effect intensity has no significant effect on the density of the cork.

**Table-2.**Physical properties.

| Stripping intensity | Density (gcm$^{-3}$) | | | expansion (mm) | | |
|---|---|---|---|---|---|---|
| | Mean ± sdv | Min | Max | rad ± sdv | tg ± sdv | lg± sdv |
| **k1** | 0,178 ± 0,003 | 0,135 | 0,227 | 8,90 ± 0,53 | 0,81 ± 0,40 | 3,62 ± 0,23 |
| **k2** | 0,180 ± 0,002 | 0,123 | 0,255 | 12,66 ± 0,80 | 1,42 ± 0,32 | 3,63 ± 0,13 |
| **k3** | 0,165 ± 0,001 | 0,145 | 0,193 | 10,24 ± 1,25 | 3,65 ± 1,13 | 4,95 ± 1,02 |
| **k4** | 0,171 ± 0,002 | 0,147 | 0,187 | 5,51 ± 0,83 | 0,95 ± 0,53 | 3,16 ± 0,47 |

sdv: standard deviation, rad : radial, tg : tangential, lg: longitudinal

**Table-3.** Effects of boiling on the dimensional, volume and density changes of boiled cork after air-drying.

| Stripping intensity | l/l0 | | | v/v0± sdv | d/d0± sdv |
|---|---|---|---|---|---|
| | radial± sdv | tangential± sdv | longitudinal± sdv | | |
| **k1** | 1,036 ± 0,002 | 1,008 ± 0,004 | 1,089 ± 0,005 | 1,17 ± 0,009 | 0,94 ± 0,003 |
| **k2** | 1,036 ± 0,001 | 1,014 ± 0,003 | 1,126 ± 0,008 | 1,18 ± 0,013 | 0,91 ± 0,007 |
| **k3** | 1,049 ± 0,010 | 1,036 ± 0,011 | 1,102 ± 0,012 | 1,21 ± 0,015 | 0,94 ± 0,003 |
| **k4** | 1,031 ± 0,004 | 1,009 ± 0,005 | 1,055 ± 0,008 | 1,12 ± 0,008 | 0,95 ± 0,004 |

sdv: standard deviation, v : volume, d : density

Table-3 summarizes the results of changes in length, volume, and density after cork boiling at a temperature of 100 °C for the different stripping intensities. All changes are expressed as the ratio between the values after boiling and the initial values. Before boiling, the cork cells are compressed and irregularly shaped. Boiling causes expansion and changes in the cellular structure of cork, resulting in changes in physical and mechanical properties [14]. The results obtained show that the dimensional variations induced by boiling are anisotropic. The cork boiling resulted in a volume expansion of about 18% for the different stripping intensities (Table-4).

**Table-4.** Volume variation after boiling.

| Stripping Intensity | Volume variation after boiling in % | | |
|---|---|---|---|
| | Mean + sdv | Min | Max |
| k1 | 18± 0,935 | 2,25 | 28,56 |
| k2 | 19± 0,931 | 1,64 | 49,50 |
| k3 | 21± 1,550 | 3,55 | 56,45 |
| k4 | 14± 1,071 | 4,69 | 20,71 |

Radial expansion is much greater (≈ 11%) than that in the axial or tangential directions (≈ 4) for different intensities. Similar results are highlighted in literature [15]. The analysis of the results showed a strong variability of the different parameters with coefficients of variation above 20% for most cases. This variability between the samples of the different trees is superimposed on the variability between the different stripping intensities, which statistically does not show significant difference.

**Axial compression and Young's Moduli**

Cork is an elastic cellular material that combines an interesting set of mechanical properties. In the mechanical performance of cork, two characteristics have an important role: the capacity of cell walls to deform and collapse strongly without fracture and the presence of lenticular canals [1]. Cork allows large deformations under compression, with significant dimensional recovery when stress is relieved. The compression behaviour of cork has been described by various authors [1, 13, 16, 17, 8], explained in large part by cork cellular structure [5]. Figure-4 shows the compression behaviour of a cork sample in the axial direction.

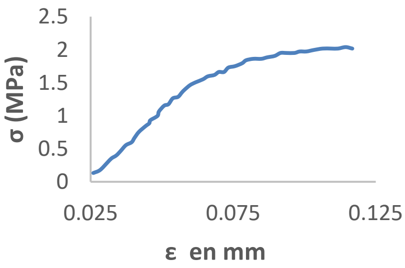


**Figure-4.**Stress-strain curve.

The compression behaviour of the different samples of the cork at axial compression is similar and has not been significantly influenced by the values of the different stripping intensities. Deformation stress curves followed the known pattern of an elastic zone followed by a plateau, caused by the gradual buckling of cell walls [9, 19, 20]. However, cork samples with a higher density show significant resistance to axial compression. Same results have been reported by other researchers [9, 10]. The average values obtained for the different stripping intensities for axial compressive strength and Young's modulus are given in Table-5.

**Table-5.** Axial compression and Young's moduli.

| Stripping Intensity | Axiale compression (σ)(MPa) | | | Young's moduli (E)(MPa) | | |
|---|---|---|---|---|---|---|
| | Mean ± sdv | Min | Max | Mean ± sdv | Min | Max |
| k1 | 0,45 ±0,194 | 0,29 | 0,71 | 16,577 ± 1,078 | 4,074 | 32,926 |
| k2 | 0,47 ±0,013 | 0,23 | 0,85 | 16,965 ± 0, 762 | 3,518 | 39,758 |
| k3 | 0,47 ±0,023 | 0,31 | 1,03 | 15,373 ± 0, 641 | 10,374 | 25,128 |
| k4 | 0,43 ±0,024 | 0,34 | 0,61 | 16,446 ± 0, 905 | 13,029 | 24,272 |

sdv: standard deviation ; MPa: MegaPascal

The mean values of the axial compression (σ) as well as Young's modulus (E), at any intensity, are respectively of 0.46 MPa and 16.55 MPa. A recent study reported an average value 16.9 MPa for Young's moduli [9] and 16.6 MPa to 18.5 MPa according to cork density [10].

The statistical analysis of the results showed that the stripping intensity did not have a significant effect on the mechanical behaviour of the cork and a great variability was observed between the trees of the same plot ($F = 17.78$, $p = 0.000$)

## CONCLUSIONS

The study of the effect of stripping intensity on physical and mechanical properties of the cork shows that the density of the cork varies within large limits (123-255 kg/m$^3$) and a great variability of density has been found between trees in the same stand, whereas the intensity effect has no significant effect on cork density.

The dimensional changes induced by boiling are anisotropic. The mean expansion volume is about 19%. The expansion in the radial direction is much greater than that in the axial or tangential directions for the different intensities.

The compression behaviour was similar for all samples and was not significantly influenced by the different stripping intensities. With an average compressive strength of 0.46 MPa and 16.55 MPa for Young's modulus. The variation in cork compression properties may be associated with differences in density. The results obtained showed a great variability between trees of the same stand in terms of density, dimensional change after boiling and modulus of elasticity. The variability encountered shows the preponderant effect of the tree as a source of variation.

## ACKNOWLEDGEMENTS

The authors wish to thank the Moroccan Department of Water and Forests and the Fight Against Desertification for its support.

## REFERENCES

[1] Pereira H. 2007. Cork: Biology, Production and Uses. Amsterdam : Elsevier,

[2] Ziad M. 2017. Etude sur la valorisation de la filiere du liege. projet europeaid/134637/c/ser/ma. Assistance technique au programme d'appui de l'union européenne à la politique forestière du maroc.

[3] Gil L. 2014. Cork: a strategic material. Front Chem. 2:16.

[4] Silva S. P, M. A. Sabino,. E. M Fernandes, V. M Correlo, L. F Boesel and R. L. Reis. 2005. Cork: properties, capabilities and applications,International Materials Reviews. 50(6): 345-365.

[5] Pereira H., M.E. Rosa, M.A. Fortes. 1987. The cellular structure of cork from Quercus suber L. IAWA Bulletin. 8(3):213-218.

[6] H. Pereira, J. Graça, C. Baptista. 1992. The effect of growth rate on the structure and compressive properties of cork. IAWA Bulletin 13(4): 389-396.

[7] Pereira H. 2013. Variability of chemical compposituion of cork. Buiressources. 8(2):2246-2256.

[8] Anjos O., H. Pereira, M.E Rosa. 2005. Variation of compression and tensile properties of cork. Suberwood – new challenges for integration of cork oak forests and products. Huelva 20 a 22 de Outubro, Espanha.

[9] Anjos O·, H. Pereira · M. E Rosa. 2008. Effect of quality, porosity and density on the compression properties of cork. Holz Roh Werkst. 66 : 295-301.

[10] Anjos O, C. Rodrigues, J. Morais et H. Pereira. 2014. Effect of densité on the compression behaviour of Cork," Material and design. 53(2014): 1089-1096.

[11] Garchi S. et T. Sghaier. 2008. Etude de l'effet du coefficient de démasclage et de la grosseur des tiges sur la croissance en épaisseur du liège. Geo-Eco-Trop. 32: 21 -28.

[12] Roula B. et M. Messaoudene. 2009. Etude de la qualité du liège de reproduction des subéraies de la région de Jijel. Les actes du Med Suber 1: 1ère Rencontre Méditerranéenne Chercheurs-Gestionnaires-Industriels sur la Gestion des Subéraies et la Qualité du liège. Université de Tlemcen.pp. 90-97.

[13] Rosa M. E., H. Pereira, M.A. Fortes. 1990. Effects of hot water treatment on structure and compressive properties of cork. Wood and Fiber Science. 22: 149-164.

[14] Rosa M. E., H. Pereira. 1994. Effects of long term treatment at 100ºC-150ºC on structure, chemical composition and compression behavior of cork. Holzforschung. 48: 226-232.

[15] Rosa M. E, M.A. Fortes, 1988a .Stress relaxation and creep of cork. J Mater Sci. 23:35-42.

[16] Rosa M.E., M. A. Fortes. 1988. Rate effects on the compression and recovery of dimensions of cork. J. Mater Sci. 23 (3) : 879-885.

[17] Gibson L.J., K.E. Easterling, M.F. Ashby. 1981. The structure and mechanics of cork. Proc. Roy. Soc. London A. 377: 99-117.

[18] Gil L. 1998. Cortiça: produção, tecnologia e aplicação.Lisbon, INETI.

[19] Rosa M. E and. Fortes M. 1991.A Deformation and fracture of cork in tension. J. Mater. Sci. 26, 341-348.