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The physical and mechanical properties of Eucalyptus hybrid E. camaldulensis x E. grandis: Comparison with its parental species

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ABSTRACT - *Thanks to their plasticity and their capacity of rapid growth, the Eucalypti take an important part in the forestry economics. They thus have good mechanical qualities and can be used as building material. Considering the potentialities of the Eucalypti grandis and camaldulensis, highlighted by the plots located in different Moroccan arboretums, and the various observations including the level of technological quality, forest research led to study the genetic variability within the species by setting up opportunities for vegetative multiplication by hybridization and cloning.*

The objective of this work being to study the physical and mechanical properties of three clones resulting from a cross between Eucalyptus grandis and Eucalyptus camaldulensis, and to compare them with those of the parental species. The wood of this hybrid E. camaldulensis X E. grandis has a rather important density classifying it among the mid-heavy wood, with strong withdrawal and has interesting mechanical properties.

Keywords – *Eucalyptus hybrid, Mechanical properties, Moisture, Sub-density, Withdrawal.*

I. INTRODUCTION

The cloned plantations of eucalyptus were introduced in Morocco for some decade, this way of accelerated production of wood destined for various industrial applications. This orientation may be unproductive if the stands are not driven optimally. Indeed, the studies conducted by the Forestry Office of Water and Forests and the Fight against Desertification (HCEFLD) on genetic variability within the most widespread species of the eucalypti in Morocco, whose almost totality of their wood products is intended for the production of pulp (40%) in the wood of service (25%) (Greenhouse, frame ...); to the combustion and firewood for the rest, have shown that there's the possibility of establishing a vegetative multiplication by cloning between the Eucalyptus *camaldulensis* (♂) (very nervous Species) and Eucalyptus *grandis* (♀) (Species of good dimensional stability) **[1]**. For a better valorization of Eucalyptus wood which presents internal defects 'growth stresses, coupled with sensitivity to the parasitic attacks **[2].**

The objective of this study is to compare the different physical characteristics of the wood of the three Eucalypt species, E. *camaldulensis*, E. *grandis* and E. hybrid E. *camaldulensis* X E. *grandis*, in order to predict the physical and mechanical behavior of wood of this derived clone.

Thus the analysis of the of moisture and infra-density distributions on discs cutting from the first ridges of the three trees of each one of these species, allowed us to understand the behavior of youthful and adult wood versus the adsorption of water.

II. MATERIALS AND METHODS

The vegetable matter used for this study consists of 9 trees, 3 trees per species, coming from the forest Mâamora. The circumferences of these trees are between 40 and 60cm and their heights are different because they aren't the same age. The choice of these trees was carried out on several criteria, knowing; the homogeneity along the trunk, the absence of defects (parasitical attacks, fungus, rot, hollow…), the quite slender trunk and has no distortions, the presence of a minimum branches to reduce nodes and the total height is important.

At the time of cutting down, the wood may contains more water than matter-wood; sometimes twice more in certain poplars. Moisture is then higher than 100%.

After cutting down and slicing trees, we collected two discs per tree, which were preserved in the greaseproof paper and settings at the freezer to keep them in their green state although before taking measurements. Sawing stud, according to the direction of the greatest value of growth stress indicators (GSI) was performed on the ridges.

On the boards obtained from logs of each strand, we measured dimensions (widths, lengths and thicknesses), moisture, slots and deformations in order to determine the sawing output and the burst index of the slits on boards.

We selected pieces of wood on the side of butt end of each board, and then stacked up under shelter, to monitor the reduction of moisture content versus time.

2.1 Determination of physical properties

We prepared the standard specimens from the diametrical broad of the first log of each strand of dimension 20X20X20 mm^3, for determining the physical properties of wood; we took 30 samples of each tree, according to the sampling method of Angeli (1975) with a fixed margin of error to 5% and a confidence level of 95%.
The characterization of the physical properties, in particular the densities and the withdrawals, is carried out on cubic specimens of 20mm along edge cut according to the three privileged directions of wood (Radial, Tangential and Longitudinal), and in compliance with French standards. The measurements of edges and masses of specimens were undertaken respectively thanks to the Mitutoyo comparator with a sensitivity of 10^{-3}mm and the Sartorus balance with a sensitivity of 0.001g.

Thus, we proceeded to the determination of anhydrous density (D_0), basal density or sub-density (D_b), fiber saturation point (PSF), linear and volumetric withdrawals and anisotropy.

2.2 Determination of mechanical properties

For the determination of the mechanical properties, we made specimens of dimensions 20x20x60mm^3 and others of 20x20x360mm^3 (cut according to the Radial, Tangential and Longitudinal directions) that we employed for the characterization of the axial compression stress, and the dynamic modulus of elasticity by vibratory method BING respectively.

The test of axial compression is performed according to standard NF B 51-007. The specimens have a right prism shape with square section of 2cm on side and a length parallel to the grain of the wood of 6cm. For each specimen, we measured transverse dimensions at mid-length by the Mitutoyo comparator. The apparatus used for the purpose of this test is a Testwel machine of 12 tons capacity, which enables us to exert the effort continuously and at constant speed of 5mm/min to reach the rupture.
The axial compression stress C_a of each specimen at moisture of H=14% is given by the following equation (1):

$$c_a = \frac{P}{a \times b} \qquad (1)$$

Where:
P: is the maximum load in Newton,
a and b: are the dimensions in mm of the cross section of the specimen,
C_a is expressed in MPa.

The measurement of the dynamic modulus of elasticity is obtained using the method B.I.N.G. (Beam Identification by Non-destructive Grading). This technique developed in recent years and used by the Forest Research Center of Rabat, has allowed us to determine the physic-mechanical characteristics of beams (bending and compression modulus of elasticity, density, shear modulus) by simple vibratory excitation.
As a first step, placing a wooden specimen on two elastic supports (synthetic foam, tended rubber bands…), then a shock is formed on one of the ends of the sample. The latter begins to vibrate in all its natural modes **[3]**. The BING applies the installation of several elements. A microphone then recovers the acoustic information and transforms it into an electrical signal. Firstly, this signal is amplified and then filtered by an apparatus eliminating unwanted noise, fig.1.

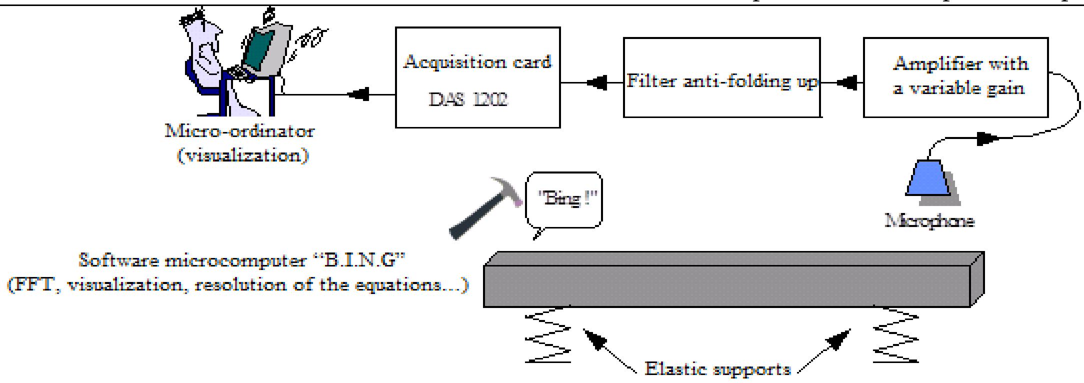

Fig.1: Protocol of BING test.

We check the display quality of the spectrum and the peaks of frequencies obtained. These must be sufficiently clear and distinctive.

At least two peaks are selected for the measurement of longitudinal elastic modulus and transverse shear modulus by their assigning a sequence number increasing with the frequency level. We repeat the measurement several times to check the value of elastic modulus obtained **[4]**.

III. RESULTS AND DISCUSSIONS

3.1 Physical properties

In table 1, we present the mean values and the standard deviations of the wooden physical properties of the three species, such as the anhydrous density (D_0), the sub-density (D_b), the various withdrawals (R_v (%), R_t (%), R_r (%)), and the anisotropy (A)) taken on a lot of 30 specimens per tree.

Table1: *Physical properties of wood of E. Camaldulensis, E. grandis and E. hybrid.*

	E. *grandis*		**E. *camaldulensis***		**E. *hybrid***	
	Mean	**Std variation**	**Mean**	**Std variation**	**Mean**	**Std variation**
D_0	0,53	0,11	0,9	0,13	0,56	0,05
D_b (g/cm^3)	0,46	0,08	0,78	0,08	0,47	0,03
R_r (%)	5,9	1,34	8,41	1,55	6,81	2,37
R_t (%)	8,95	1,53	12,64	1,36	10,74	3,6
R_v (%)	15,54	2,61	22,4	2,19	19,25	6,25
A	0,67	0,15	0,7	0,12	0,66	0,2

R_r, R_v, R_t are respectively radial, volumetric and tangential withdrawal

The examination of table 1 shows that the wood of Eucalyptus *camaldulensis* is dense with an average anhydrous density of 0,90, nervous with an average anisotropic coefficient of about 0,70 **[5]**, whereas the wood of Eucalypts *grandis* has a lower average density at the anhydrous state (D_0) than that of the E. *camaldulensis*. It is likely that this lower value is the consequence of the anatomical features of wood **[6]**, **[7]**. The mean values of the indexed densities of the wood of Eucalypts *grandis* vary from 0,45 to 0,60 which means that it is a mid-heavy wood.

The E. *grandis* has a better dimensional stability with a lower total volumetric withdrawal 23% than that of E. *camaldulensis*. The anisotropy (A) depends more on the radial withdrawal than that the tangential withdrawal. These two leaved trees are strongly anisotropic; this is explained by their nervousness. Considering the degree of nervousness of E. *camaldulensis* is greater than that of E. *grandis*.
The hybrid Eucalyptus wood E. *camaldulensis* X E. *grandis* is mid-dense with an average anhydrous density of 0,56, light heavy with a sub-density of 0,47 g/cm3, and its dimensional stability is affected by an average volumetric retractibility coefficient of about 19,25%, and an average anisotropic of about 0,66 (according to standard NF B 51-005 and 006).

This study allowed us to see that the values found by A. Daya **[8]** on the E. *grandis* represented on table 1, are mostly similar to those obtained by our recent study on the E. hybrid E. *camaldulensis* X E. *grandis*, which implies that the physical behavior of the two species is analogue.

In this section we will study the distribution of the moisture and the sub-density of the two species of similar physical characteristics to determine their profiles as a function of radial growth of the tree. Starting from the diametrical plate of the discs oriented in the North-South direction (fig.2), the radial bars were made of dimension 20 X 20 X 20 mm^3 to determine the radial evolution of moisture and sub-density
The radial variations can be slow and reflect the effect of the passage of youthful wood (≈15 years) to mature wood. The transition from youthful wood to adult wood (≈ 30 years) is the phenomenon which affects more the technological quality of wood.

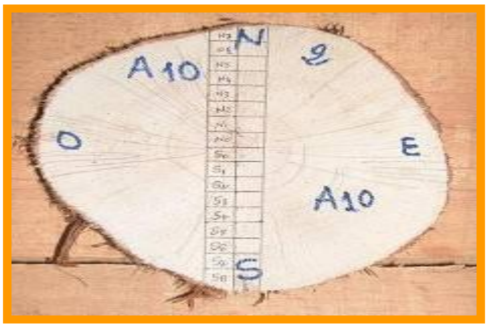

Fig.2: Bars of the diametrical plate to determine moisture and sub-density profiles

3.1.1 The moisture profile

The moisture profiles of the woods of Eucalyptus *grandis* (Fig.3a) and Eucalyptus hybrid are analogue (Fig.3b). The variation of moisture between the wood of core (youthful wood and adult wood) and the periphery is important for the Eucalyptus hybrid, as much as for the Eucalyptus *grandis*. This is explained by the average diameter of the studied trees which is approximately 130 mm satisfying the requirements of the sectors of the first transformation and by the age which is approximately 17 years for the E. hybrid and 45 years for the E. *grandis*.

Moisture is almost constant in the youthful wood while it increases in adult wood. The fall of moisture to the periphery is allotted to the drying surfaces.
We end up below the hygroscopic field at the periphery of the wooden discs of these two leaved trees, which favours cracking due to the drying stresses.

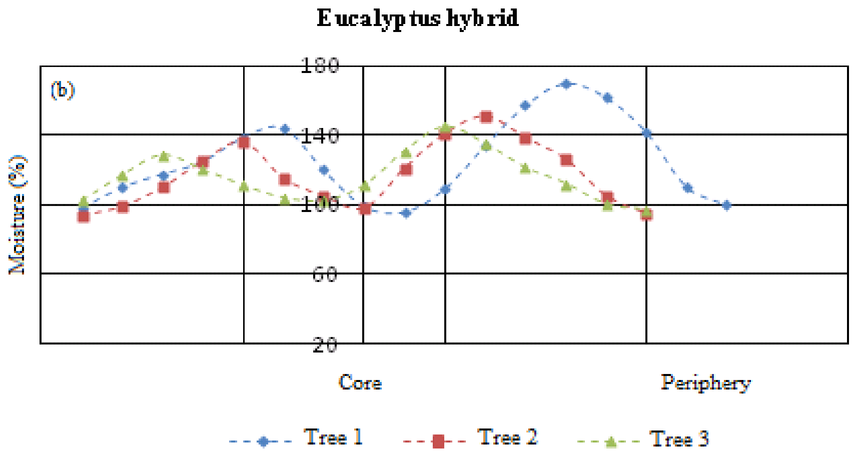

Fig.3: Moisture profiles of wooden discs of Eucalyptus grandis and Eucalyptus hybrid

3.1.2 Sub-density profile

The evolution of the sub-density of the woods of E. *grandis* (Fig.4a) and E. hybrid follows the same pace (Fig.4b).

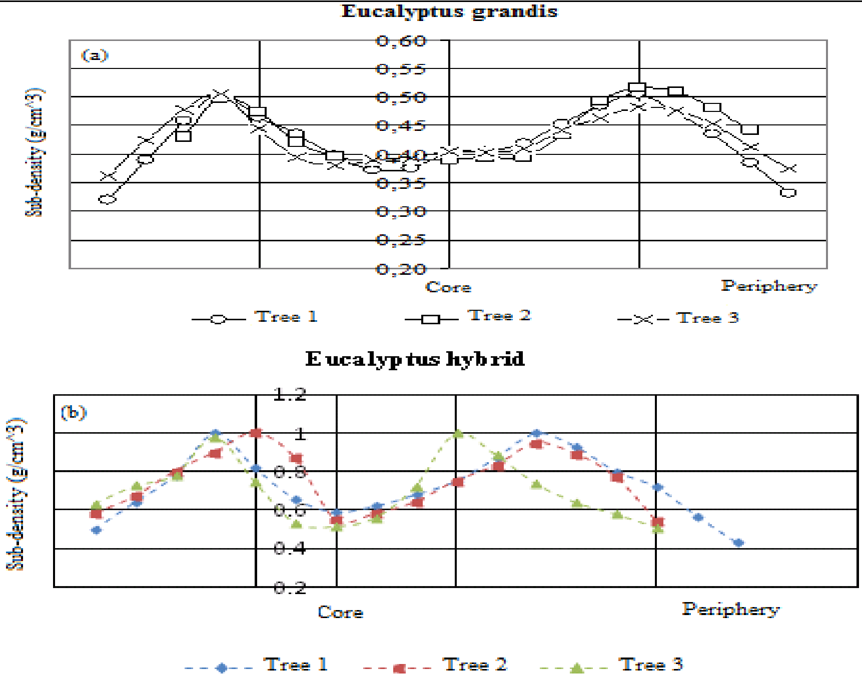

Fig.4: Sub-density profile of wooden discs of Eucalyptus grandis and Eucalyptus hybrid

The variation of the sub-density of Eucalypts *grandis* from the wood of core to the periphery is very weak about 0,40 in a youthful wood to 0,55 in an adult wood, but it is of 0,55 in a youthful wood to 1 in an adult wood for the Eucalyptus hybrid, which can be explained by the influence of the same parameters as the variation of moisture.

The sub-density is practically constant in youthful wood whereas it increases in adult wood. The fall of the sub-density on the periphery is due to the release of the wood extractives.
Youthful wood is distinguished from adult wood by its weak density because of quasi-absence of cells crushed on the thick walls.

The peaks of moisture and sub-density profiles of Eucalypti *grandis* and Eucalyptus hybrid woods could be explained by the gradual transition from youthful wood to mature wood whose properties vary because of the aging of the lateral meristems, as the length of fibers and the diameter of the vessels increase of the core to the bark.

3.2 Mechanical properties

Mean values and standard deviations of the basic mechanical properties of the wood of the three species E. *grandis*, E. *camaldulensis* and E. hybrid E. *camaldulensis* X E. *grandis* such as the bending dynamic moduli of elasticity (modulus of elasticity of Timoshenko E_t, and shear modulus of Timoshenko G_t) of the samples studied by vibratory method BING, and the strength to the axial compression C_a (Kg/cm^2), are gathered on table 2.

Table 2: Mechanical characteristics of specimens of E. grandis, E. camaldulensis and E. hybrid woods

	E. *grandis*		**E. *camaldulensis***		**E. *hybrid***	
	Mean	**Std variation**	**Mean**	**Std variation**	**Mean**	**Std variation**
E_t (Mpa)	14488	2509	18266	2663	18219	2151
G_t (Mpa)	654	168	1580	439	2434	1853
C_a (Kg/cm^2)	472	68	575	63	518	55

The values indicated correspond to the means obtained and their standard deviations on 30 specimens tested at a moisture of 14%.
Knowing that wood is a material of biological origin, heterogeneous and anisotropic, its physical and mechanical properties vary with the direction considered: axial, radial or tangential.

The values of the dynamic moduli of elasticity show that the wood of E. *camaldulensis* is a rigid material, and that it is able to absorb the vibrations induced by a non-destructive shock in flexion mode. Its strength axial compression is 575 Kg/cm² which expresses the hardness of its fibers and pushes us to exploit it for timber.

The E. *grandis* has an average rigidity according to the values of dynamic bending moduli of elasticity much less than those of E. *camaldulensis*. That is similarly for the strength axial compression. According to standards NF B51-007 and 008, the hybrid material has a hard behavior under axial compression, rigid according to the values of the dynamic moduli of elasticity. This would entrust it a good use in pieces of small sizes, like the parquet floor much more profitable in terms of stress resistance.

3.3 Correlation between mechanical and physical properties of the wood of E. hybrid E. camaldulensis X E. grandis

The elastic properties of wood are sensitive to the variations of the physical state of materials considered **[9]**. Among the physical parameters whose influence is certain we retained the sub-density, the density and the volumetric withdrawal.

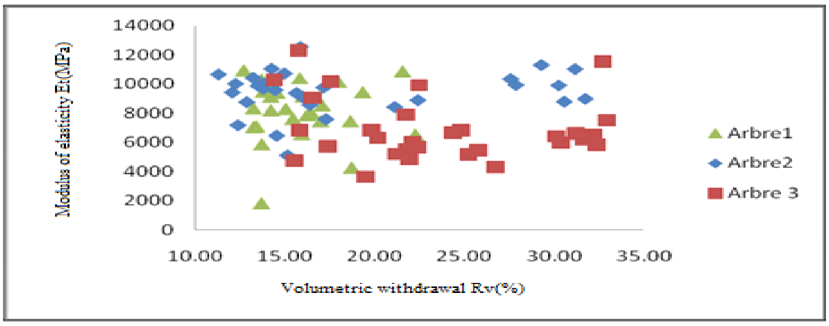

Fig.5: Relationship between modulus of elasticity E_t and volumetric withdrawal R_v of E. hybrid

According to the fig.5, we observe that the modulus of elasticity of Timoshenko E_t varies in a significant way as a function of the volumetric withdrawal for the samples of the three studied trees, which implies that the withdrawal is an important influencing parameter at the mechanical characteristics. However other parameters like the age, the speed of growth and the chemical composition can be employed in order to explain these noted variations.

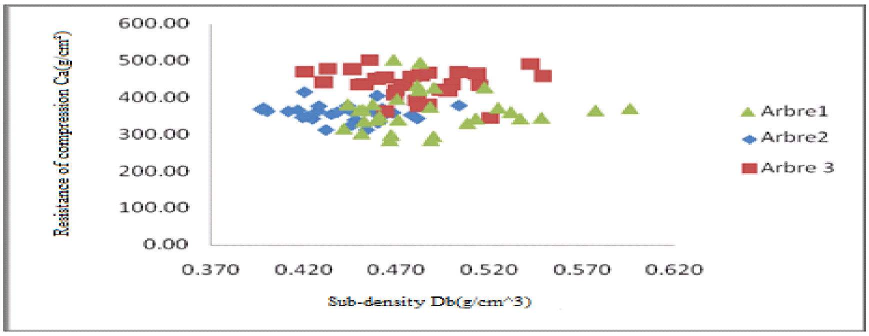

Fig.6: relationship between resistance of compression C_a sub-density D_b of E. hybrid

The examination of specimens subjected to axial compression test, showed that almost the totality of the specimens were broken at the ends, this may be due to the inhomogeneity of the specimens of wood (youthful wood and adult wood). According to the fig.6, the sub-density informs us about the degree of rigidity of wood of Eucalyptus hybrid E. camaldulensis X E. grandis, which is quite significant compared to the stress axial compression.

IV. Conclusion

The three species of Eucalypti studied in this article present a high nervousness. This disadvantage finds its origin in the form of the base of the trunk which leads to an eccentricity of the core and the wood tension formation. This nervousness is an argument often advanced by the processing industry to ignore wood of Eucalypti *grandis* and *camaldulensis*.

Wood has extremely heterogeneous features, not only between species but also between individuals and within an individual.

Factors such as the youthful proportion of wood or nodes strongly exploit the mechanical characteristics of a piece of wood.

The exact role of moisture for wood is just like the minimal level necessary to guarantee a quality of cut, and the outstanding degradation of quality is explained by the much accentuated difference in green wood moisture between sapwood and duramen **[10]**.

Knowing that the retractability is directly proportional to the content cellulose, of which density, to 15% of moisture, is of 1,55. Woods studied have a density quite lower than this value; they are the densest wood and containing consequently the most cellulose which presents the most retractability.

As the wood of the hybrid Eucalyptus contains more cellulose and this is why its use is intended for the field of the paper mill.

The estimations of the physical and mechanical correlations, obtained in this study indicate that the hybrid wood of Eucalyptus E. *camaldulensis* X E. *grandis* is denser, and tends to have a great linear and volumetric withdrawal.

These correlations pose a challenge with ameliorative which want at the same time to increase volume and density and to reduce withdrawal of wood

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