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# EVALUATION OF GROWTH STRESSES IN LIVING TREES OF *Corymbia citriodora* Hill & Johnson (*Eucalyptus citriodora* Hook) USED FOR STRUCTURES BY DETERMINING THE LONGITUDINAL RESIDUAL STRAIN

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**ABSTRACT:** The equipment called extensometer is responsible for the measurement of longitudinal residual strain (LRS). The objective of this study was to measure the LRS in *Corymbia citriodora* Hill & Johnson, checking in four different positions in the tree and their correlation with diameter at breast height (DBH), height and thickness of the bark. Eight trees of *Corymbia citriodora* were chosen randomly. In each tree, the following measurements were taken: DBH, bark thickness, tree height and the LRS in four different positions. A low correlation between LRS and the variables DBH, height and thickness of the bark was found. It can be concluded that there is a need, for a more accurate evaluation, a large number of trees are evaluated to provide a better understanding of the correlates of longitudinal residual strain and other variables in the population evaluated.

**KEYWORDS:** structural wood quality, extensometer, longitudinal residual strain (LRS)

## 1 – INTRODUCTION

The wood has historically been used for various purposes. He has served for our predecessors such as housing, as a building material and the passage of time pillars and beams were discovered in prehistory in various civilizations, before the fire. Each civilization, climate, terrain, cataclysms that determined a different approach in the use of wood [1].

Worldwide, the timber is immensely used as a material for greater versatility of use in various sectors, such as construction, the furniture industry, window frames, floors, paper and cellulose and others.

Thus, the man saw the wood a range of opportunities for your use. Wood floats, therefore, boats were created. It is easy workability, new forms, furniture and objects emerged. Varying with locality and their types of trees, the wood was and is always present in human history and is used naturally or combined with some other element [1].

According to [2] wood choice of woody species for a particular job can only be done with economy and safety, with knowledge of the values that define their behaviour, both from the physical point of view of their resistance when subjected to mechanical stress. To obtain these values can be used for destructive sampling methods and non-destructive.

Methods or non-destructive tests are important tools for evaluating the properties of wood, as are techniques to qualify the material without compromising its future use.

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In countries where wood is found in abundance, in implanted plantations for certain pre-established uses, or wood is exploited from natural forests under forest management techniques, have a great variety of species and related characteristics to anatomical, physical, chemical, cosmetic, resistance and workability. We must increasingly understand and study this variability for understanding the quality of the wood produced by each species with timber potential and tailor your end use of these features.

In this sense, the possibility of evaluating, at least in part, properties of the timber non-destructively allow a large number of designs possible, research and previous evaluations of the quality of wood, without the need for complicated logistics, involving slaughter, cutting logs, making samples, material drying and evaluations of non-destructive equipment.

According to [3] methods or non-destructive tests are important tools for evaluating the properties of wood, as are techniques to qualify the material without compromising its future use. Thus, the methods provide a saving of time and costs in the preparation of the samples, unlike destructive sampling.

In the forestry area, more and more researchers have advanced in the generation of information that can be generated by methods and non-destructive trials.

Currently forest research organizations are used for non-destructive evaluations [4]. According to [5] the non-destructive evaluation can be defined as the science of identifying the physical and mechanical properties of a part of a material without affecting the usability end.

In addition to cost savings, the non-destructive tests also have great utility for species where vegetative propagation is unreliable [3].

[6] deals with that for anatomical analysis the selection of raw materials with minimal cellular variation is important for the quality control of wood products. However, the evaluation based on these characteristics is difficult because of the wide variation that occurs between and within species.

This variation can be divided into three aspects. The first is the variation between species. The second is the variation within the same species and the third is the variation found in relation to age. The size, proportion and arrangement of various forms of structural elements of wood make a species can be distinguished from other [6].

This variation of the anatomical elements directly affects the performance of the species when they are subjected to physical tests, thus defining potential as the commercial use [6].

According to [7] among the methods considered non-destructive or semi destructive for measuring deformations associated to the growth stresses are developed by the CIRAD-Forêt [8], which consists of measuring, with the aid of a dial indicator, the deformation experienced in the central area between two pins fixed to 45 mm apart along the grain, the surface of the trunk without bark.

The strain measurements are carried out by releasing tension and drive pins process. For this, it made a hole with a drill of 20 mm in diameter [7].

These stresses may vary in intensity and can be tensile or compressive depending on the location within the xylem and its direction of operation: longitudinal, tangential and radial [9].

The growth stresses represent a kind of tension which helps maintain the balance of the tree and this occur generated during the growth thereof and should not be confused with the resulting voltage of the tree canopy weight, the voltage of the sap, or even those resulting from the reaction timber and the drying tensions.

Growth stresses occur more effectively in more external layers of the trunk throughout the tree's growth. These tensions are generally greater in species with faster development in the field and generate tension in the wood from the formation of new cells in the outermost part and compression forces in the central part.

It is in the longitudinal direction the tensions have the most severe form, with a distribution that varies progressively in the shell cord direction, starting with traction on the periphery of the tree (bark), to maximum compression in the medulla [10].

Despite the growing tensions be present on the trunks of various tree species, its impact is much greater in hardwoods than in conifers, so are associated with a broadleaf tree’s species phenomenon [11].

Of the species planted in various parts of the world, eucalyptus stands out for its rapid growth, as in areas of

Brazil, and has increasingly been used as solid wood in addition to its traditional and enormous use as raw material for cellulose and paper. Thus, increasingly understanding the issue of the formation of growth tensions and developing tools to measure them, leads to the possibility of including variables like this in forest improvement programs.

Silvicultural character attributes usually go in the opposite direction in relation to the technological nature. It is common to a kind of high productive capacity is not suitable for any type of use or have limited usefulness. Still, the eucalyptus wood comes, day by day, gaining space in the lumber industry and wood-based products, diversifying their use until recently primarily intended for the pulp industry. Currently, it is already a reality the production of chipboard panels, fiberboard, plywood and sawn Eucalyptus wood. However, the use of eucalyptus lumber is limited by certain undesirable features such as the presence of growth stresses.

The selection of material with lower growth stress levels and the combination of these stresses easily measurable characteristics, should be prioritized in forest breeding programs. For this, there is the need to determine the levels of these voltages on the bark of trees still alive [12].

Generally, eucalyptus has high levels of growth stresses, but these tensions are not exclusive of eucalyptus, occurring in all hardwoods. However, some species, are more intense than others; clear signs of growth in mahogany tension were observed (*Swietenia machrophylla*), Jatoba (*Hymenaea* sp), Andiroba (*Carapa guianensis*), cedar (*Cedrela* sp) Tatajuba (*Bagassa guianensis*) and Cupiúba (*Goupia glabra*) and of course in *Eucalyptus* [13].

The effects of growth stresses can be observed in logs after felling the trees, and especially on the boards during the sawing operations in sawmill. The result of these tensions is reflected in the decline in yields in lumber, depending on its magnitude, can cause great losses during the stages of the production chain; this due to the release of these strains that cause defects such as cracks and warping. The same happens in the process of drying the boards, when an even greater loss of material. In certain circumstances, these defects can reach cripple solid wood entry eucalyptus in the lumber market [7].

A study carried out by [14] showed that 25% of sawn boards of *E. cloeziana* F. Muell, 32 years old, were disqualified as a result of bulges and twists, and other distortions. Different types of distortions in sawn wood pieces are shown in Figure 1.

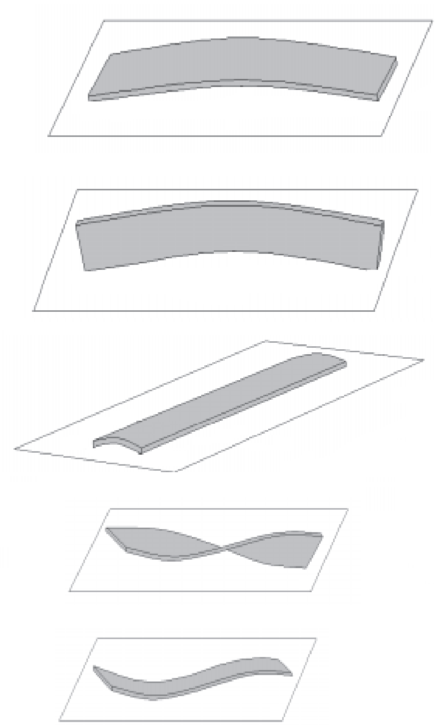

*Figure 1. Different types of distortions in sawn wood pieces.*

In young eucalyptus wood, growth stresses are more noticeable and also have, apparently, genetic factors that interfere with greater or lesser stresses in different trees and origins, which reinforces the importance of studies that evaluate the heritability of the presence of growth stresses in the formation of wood, which, if better understood, could be more widely used in forestry research.

There is a tendency to attribute the growth stresses and their consequences in eucalyptus, to large growth rates, however, it is not proven that growth higher rates induce higher growth stresses. It must be understood that growth stresses it is not growth velocity rate tension [13].

The intensity of the growth stress is highly variable among species, among trees of the same species and also in different locations within the tree. According to the stress distribution inside the trunk, pieces of wood removed from the periphery of the trunk tended to


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decrease its length in response to its drive state, since the removed parts close to the pith will tend to lengthen in response to its compression state [7] (Figure 2 and 3).

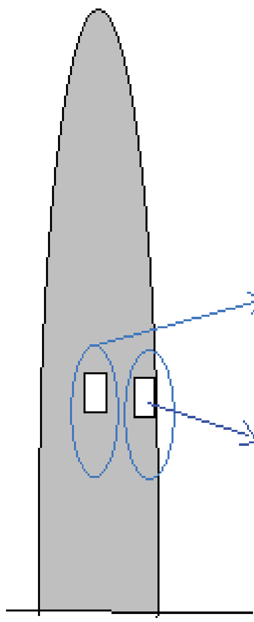

*Figure 2. Possible changes in the dimensions of sawn pieces of wood generated by different parts of the tree after the release of growth stresses.*

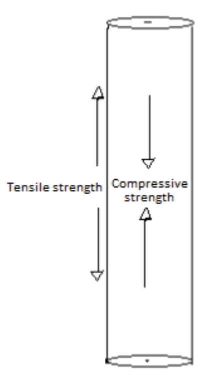


*Figure 3. Distribution of strengths within the trunk.*

Surveys have shown that there may still be a connection between the classes of diameter and height with the magnitude of the residual strain. The relationship of the diameter with the growth of tension level and noted that the peripheral tensile stress was the same for small and large diameter logs. The diameter only affects the slope of the tension gradient of the curve in the pith-bark. Therefore, the logs with smaller diameters are more susceptible to warping and cracking occurred for the release of growth stresses due to its lower section for redistribution of these tensions [10].

[15] in studies with *E. saligna* Smith, concluded that the size of the cracks in the boards increases with the reduction in the diameter of the logs, showing the highest level of growth stress.

According to some authors, the growth stresses still have high effects considering the bottom-up direction, and this fact influenced by the diameter [7], found that samples of the base and through the tree presented deformations between 6 and 8 mm, while the top of the samples showed values varying between 8 and 10 mm, thus confirming previous studies.

The growth tensions were studied previously, after the tree felling, being estimated from the change in measuring the lengths of pieces of wood, the size of cracks in both logs as on boards and arrow of warping [7].

According to [7], the growth stresses are naturally forces acting on the tissues of the trees to keep them whole and straight, providing resistance to mechanical breakage and bending the stem, causing resistance against impact of winds. These tensions in the outer parts of the bole play the role of a steel reinforcement in the concrete columns, the bases for the boles of the trees do not easily break when subjected to lateral forces.

The non-destructive technique of extensometer has the great advantage of the ease of use and speed of data collection in the field, as the assessment is made on the standing tree. This method is based on determining the LRS, measured by the extensometer (growth deformations measurer) at a fixed distance, which is directly proportional to the growth stress in the longitudinal direction.

According to [9] the usefulness of the non-destructive method is reflected both in wood science and technology and in the forest improvement. Its importance in wood technology area is characterized by the study of the distribution of forces along the stem and its relations with other wood characteristics. To improve the forest this method allows the selection of the genetic material with desirable characteristics, such as less prone to defects.

Some studies have been conducted in Brazil using the extensometer with satisfactory results, especially in the classification and selection of eucalyptus clones, among which are the [9]. The author had the common objective evaluation of LRS in eucalyptus in given age and location. The method for determining growth stresses developed by "CIRAD-Forêt" was pioneering and created ease and speed in field measurements. The method contributes to the choice and selection of trees for later cloning, for example, and to establish relationships with the diameter and height of the tree.

Measurements with extensometer provide digital data of longitudinal residual strain (LRS), which is directly related to longitudinal stress growth, this smaller shape is the value of the LRS, lower levels of internal stresses growth and wood most favourable to use as a solid product.

The objective of this study was to measure the longitudinal residual strain in *Corymbia citriodora* Hill & Johnson, checking in four different positions in the trunk and their correlation with diameter at breast height (DBH), height and thickness of the shell.

## 2 – MATERIAL AND METHODS

Eight trees of *Corymbia citriodora*, from the Campus of the Rio de Janeiro Rural Federal University (UFRRJ), Seropédica/RJ were chosen randomly.

In each sampled tree, the following measurements were taken: "diameter at breast height" (DBH, 1.30m from the base), bark thickness (Figure 4), tree height and the longitudinal residual strain (LRS) in four different positions around the trunk (north, south, east and west).


*Figure 4. Measurement of the thickness of the bark of the trunk.*

The quantification of the percentage of bark was carried out further form, as an additional purpose to work, depending on the portion of the shaft characterized as bark represent a material that generates a residual by-product of wood processing, and these results also serve to better characterization of the species and planting evaluated.

The LRS were measured in DBH with the aid of the extensometer. For install the extensometer is necessary to remove the bark forming a square of 15cm x 15cm on the tree trunk (Figure 5 and 6).

*Figure 5. Bark is removed from the bark to produce a window measuring approximately 15cm x 15cm in the tree trunk.*

*Figure 6. Window made in the tree for equipment fixing.*

From this, for performing each measurement, inside this panel are fixed two metal pins at a distance of 45mm from each other and with the aid of a hand drill a hole was made between the pins, thus the growth stresses were released, thus enabling the measurement of the strain gauge through the LRS (Figure 7 and 8).


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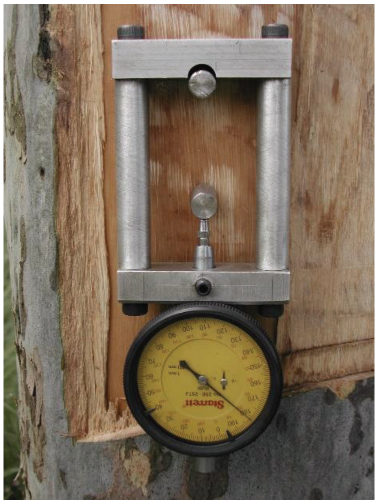

*Figure 7. Extensometer method detail.*

*Figure 8. Measurement of longitudinal residual strain.*

## 3 – RESULTS AND DISCUSSION

The following are the main results of this study, which is part of a line of research developed with non-destructive methods of evaluation of the wood quality, Timber Processing Laboratory, Department of Forest Products, the Forestry Institute, Federal Rural University of Rio de Janeiro.

Residual Longitudinal Deformation (LRS) average was observed at 0.081mm (Table 1). In the analysis of variance (ANOVA) had a p value of 0.2007, so the average between four LRS values (measured in directions north, south, east and west) are equivalent.

*Table 1: Results of longitudinal residual strain (LRS), diameter at breast height (DBH), height and thickness of the bark*

| Tree | DBH (cm) | Height (m) | Bark thickness (mm) | LRS 1 (mm) | LRS 2 (mm) | LRS 3 (mm) | LRS 4 (mm) | Average LRS |
|---|---|---|---|---|---|---|---|---|
| **1** | 35.97 | 18 | 4 | 0.051 | 0.033 | 0.015 | 0.037 | 0.034 |
| **2** | 69.71 | 21 | 11 | 0.060 | 0.068 | 0.045 | 0.048 | 0.055 |
| **3** | 61.43 | 20 | 12 | 0.120 | 0.190 | 0.155 | 0.070 | 0.134 |
| **4** | 35.33 | 15 | 5,5 | 0.139 | 0.136 | 0.164 | 0.094 | 0.133 |
| **5** | 19.42 | 13 | 4 | 0.024 | 0.033 | 0.044 | 0.013 | 0.028 |
| **6** | 26.10 | 12 | 6 | 0.090 | 0.129 | 0.118 | 0.101 | 0.110 |
| **7** | 36.29 | 20 | 3 | 0.084 | 0.149 | 0.138 | 0.033 | 0.101 |
| **8** | 53.32 | 23 | 5 | 0.047 | 0.096 | 0.039 | 0.022 | 0.051 |
| **Average** | 42.20 | 17.75 | 6.31 | 0.077 | 0.104 | 0.090 | 0.052 | 0.081 |
| **Standard derivation** | 17.52 | 3.99 | 3.35 | 0.039 | 0.057 | 0.060 | 0.033 | 0.044 |
| **Minimum** | 19.42 | 12.00 | 3.00 | 0.024 | 0.033 | 0.015 | 0.013 | 0.028 |
| **Maximum** | 69.71 | 23.00 | 12.00 | 0.139 | 0.190 | 0.164 | 0.101 | 0.134 |
| **CV (%)** | 41.53 | 22.48 | 53.04 | 50.75 | 54.71 | 66.90 | 62.84 | 54.05 |

[12] obtained in their research the average value of longitudinal residual strain (LRS) for *Eucalyptus citriodora* and *Eucalyptus urophylla*, respectively, 0.106 and 0.092 mm. Lima [7], in *Eucalyptus* spp clones. LRS observed an average of 0.079 mm and [9] al. (2006) of 0.093 mm in eucalyptus clones.

Therefore, the results of this study are within the range of values reported in the literature.

It is observed in Table 2 that most of the LRS values there is a negative correlation with variables DBH and height as the variable thickness of the bark has a low positive correlation to LRS.

*Table 2: Pearson correlation between the longitudinal residual train (LRS), diameter at breast height (DBH), height and bark thickness*

| | DBH (cm) | Height (m) | Bark thickness (mm) | LRS 1 (mm) | LRS 2 (mm) | LRS 3 (mm) | LRS 4 (mm) |
|---|---|---|---|---|---|---|---|
| DBH (cm) | 1 | 0.8086 | 0.7817 | 0.1527 | 0.2502 | -0.0368 | -0.0163 |
| Height (m) | | 1 | 0.3007 | -0.0899 | 0.1409 | -0.1922 | -0.4205 |
| Bark thickness (mm) | | | 1 | 0.3398 | 0.3570 | 0.1982 | 0.3425 |
| LRS 1 (mm) | | | | 1 | 0.8282 | 0.9048 | 0.8193 |
| LRS 2 (mm) | | | | | 1 | 0.90142 | 0.5768 |
| LRS 3 (mm) | | | | | | 1 | 0.6813 |
| LRS 4 (mm) | | | | | | | 1 |

[12] noted in his research a negative and significant correlation between LRS and height to *Eucalyptus urophylla*. According to [16], the longitudinal residual strains showed significant correlations with the bark thickness. According [14], there are significant positive correlations of LRS to the height and diameter of *Eucalyptus cloeziana* trees.

Thus, it is observed how distinct is the LRS interactions with the growth characteristics of one species to another.

## 4 – CONCLUSIONS

Through the interpretation of the results obtained in this study the following conclusions registration was possible:

- The longitudinal residual strain average observed was 0.081 mm;

- The longitudinal residual strain measured in the four directions (north, south, east and west) does not differ statistically;

- There is a negative correlation between height and LRS and a positive correlation between LRS and the bark thickness.

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## 7 – REFERENCES

[1] UFSC. Federal University of Santa Catarina, Brazil. "Wood history". http://www.arq.ufsc.br/arq56 61/ Madeiras/historia.html. Date accessed: June 16, 2014.

[2] A. B. Cunha. "Analysis of Physical Properties, Mechanical and Energy Air Party and Trunk of Algaroba (*Prosopis Juliflora*)". Monograph (Forest Engineer). 40p. 2012. Brasília University, Brazil.

[3] F. A. Pádua. "Amostragem para Avaliação da Densidade Básica da Madeira de um Híbrido de *Eucalyptus grandis* W.Hill ex Maiden x *Eucalyptus urophylla* S. T. Blake". 99p., 2009. Thesis (Doctor in Science and Wood Technology. Lavras Federal University – UFLA) Lavras, Brazil.

[4] C. P. Hansen. "Application of the pilodyn in forest tree improvement". Humlebaek: Danida Forest Seed Centre, 2000. 15 p. (Series of Technical Notes, TN55).

[5] A. M. Couto, "Modeling of basic density and chemical characterization of clones of *Eucalyptus urophylla* e *Eucalyptus grandis*". 2011. 71 p. Master's in science and Wood Technology. Lavras Federal University – UFLA) Lavras, Brazil.

[6] G. P. M. Palermo. "Properties and Wood Technological Behaviour of *Eucalyptus grandis* W. Hill ex-Maiden Aiming its Use in High Value Added Products". 2010. 249p. Thesis (Doctor in Environmental and Forest Sciences, 2010. Federal Rural University of Rio de Janeiro) Seropédica – RJ, Brazil.

[7] J. T. Lima, et al. "Longitudinal residual strains due to growth stresses in eucalypts and their association with other properties". Árvore Paper, v.28, n.1, p.107-116, 2004.

[8] H. Baillères, and P. Y. Durand. "Non -destructive techniques for wood quality assessment of plantation grown teak". Bois et Forest dês Tropiques, Montpellier, v. 54, n. 263, p. 17-20, 2000.

[9] P. F. Trugilho, et al. "Longitudinal residual strain (LRS) and tangential (TRS) in six clones of *Eucalyptus* spp". Cerne, Lavras, v. 12, no. 3, p. 279-286, July / Sep button. 2006.

[10] C. H. S. Del Menezzi. "Use of a processing and drying method for the production of sawn wood from *Eucalyptus grandis* Hill ex-Maiden and *Eucalyptus cloeziana* F.Muell". 1999. 85f. Dissertation (Master's in Wood Science and Technology). "Luiz de Queiroz" College of Agriculture, Piracicaba, 1999.

[11] J. V. F. Latorraca; C.E.C. Albuquerque. "Effect of rapid growth on wood properties". In: Forest and 7, n.1, p.279-291, 2000.

[12] M. P. Gonçalves. "Correlations of height and diameter growth stresses in *Eucalyptus citriodora* Hook and *Eucalyptus urophylla* S. T. Blake". Monograph. Rural Federal University of Rio de Janeiro/RJ. Seropédica, 2007.


https://doi.org/10.52202/080513-0693

[13] R. H. Ponce. “Eucalyptus lumber: challenges and perspectives”. In: Seminar on the Use of Eucalyptus Sawn Wood for Sawmills, São Paulo, 1995. Proceedings. Piracicaba: IPEF, 1995. p.50-58.

[14] A. Muneri, et al. “Relationships between surface longitudinal growth strain and tree size, wood properties and timber distorcion of 4 years old plantation grown *Eucalyptus cloeziana*”. In: IUFRO CONFERENCE – The Future of Eucalyptus for Wood Products, 2000, Lauceston, Australia, IUFRO. Proceedings… Launceston. 2000. p .292-300.

[15] M. J. A. C. Miranda and M. A. R. Nahuz. “Study of the influence of planting spacing of *Eucalyptus saligna* Smith on cracking rates after initial processing and after drying”. In: Scientia Forestalis, Piracicaba, n. 55, p. 107-116, 1999.

[16] R. Beltrame. “Determination of longitudinal residual strains arising from the growth stresses in *Eucalyptus* spp”. 2010. 81p. Dissertation. Santa Maria Federal University, Santa Maria, RS. 2010.