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PARTIAL SHRINKAGE AND PROPORTION OF CRACKS IN JUVENILE AND ADULT WOOD OF *Eucalyptus grandis* W. Hill ex Maiden

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Abstract: Drying defects which modify the structure and dimensions of wood are extremely harmful, causing limitations of use. It is known that the anatomical structure of wood has direct influence on the drying quality, in which weaker tissues lead to higher incidence of defects. As the wood drying process advances, it leads to the removal of bound water and, consequently, to the shrinkage of cell walls, which makes wood shorten its dimensions, causing defects related to this phenomenon, such as end and surface checks. The aim of this work was to evaluate the difference in partial shrinkage and proportion of cracks in *Eucalyptus grandis* juvenile (with pith) and adult wood (without pith) during natural air drying. The proportion of cracks was measured according to Brazilian Standard NBR 9487: Grading of hardwood lumber, and the partial shrinkage was obtained by direct measurement method. There was not a statistically significant difference of partial shrinkage between juvenile and adult wood. Lumber from juvenile wood presented worse quality in natural air drying than adult wood. The influence of wood position (juvenile or adult) in log exerted higher influence on drying quality than shrinkage.

Keywords: natural air drying; drying defects; wood quality; physical properties of wood.

CONTRAÇÃO PARCIAL E NÍVEL DE RACHADURAS EM MADEIRA JUVENIL E ADULTA DE *Eucalyptus grandis* W. Hill ex Maiden

Resumo: Defeitos de secagem que modificam a estrutura e as dimensões da madeira são extremamente prejudiciais, causando perdas e limitações de uso. É conhecido que a estrutura anatômica da madeira exerce influência direta na qualidade de secagem, em que tecidos mais

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frágeis tendem a apresentar mais defeitos. Conforme o processo de secagem avança, a madeira começa a contrair por causa da remoção da água higroscópica e, consequentemente, as paredes celulares começam a contrair, reduzindo as dimensões da madeira, levando a defeitos associados com o fenômeno de contração, tais como as rachaduras de topo e de superfície. O objetivo do trabalho foi avaliar a diferença na contração parcial e no nível de rachaduras de madeira juvenil (com medula) e adulta (sem medula) de *Eucalyptus grandis* durante a secagem natural. O índice de rachaduras foi medido de acordo com a norma NBR 9487: Classificação de madeira serrada de folhosas, e a contração parcial foi obtida pelo método da medição direta. Não houve diferença estatisticamente significativa de contração parcial entre madeira adulta e juvenil. A madeira juvenil apresentou pior qualidade na secagem natural do que a adulta. A influência da posição da madeira (lenho juvenil ou adulto) na tora exerceu maior influência na qualidade da secagem do que a contração.

Palavras-chave: secagem natural; defeitos de secagem; qualidade da madeira; propriedades físicas da madeira.

1 INTRODUCTION

In Brazil, eucalypt wood plays an important role in the supply chain of timber industry. It is used in a large variety of products, from firewood, pulp and paper to furniture and flooring.

According to the ABRAF – Associação Brasileira dos Produtores de Florestas Plantadas (ABRAF, 2013), the Brazilian area of eucalypt planted forests reached 5.1 million hectares in 2012, and this area has been enlarged year after year. Among many eucalypt species, *Eucalyptus grandis* is the most planted in Brazil, followed by *Eucalyptus urophylla*, *Eucalyptus saligna* and *Eucalyptus dunnii.*

Eucalyptus grandis is known as a very dimensionally instable wood, because of its high growing stresses and high shrinkage anisotropy. According to the IPT – Instituto de Pesquisas Tecnológicas de São Paulo (IPT, 2012), *Eucalyptus grandis* wood presents radial, tangential and volumetric shrinkage (from saturated to oven dry condition) of 5.3, 8.7 and 15.7%, respectively.

The shrinkage of wood is affected by many factors, such as moisture, density, anatomical structure, extractives, chemical composition and mechanical stresses (TSOUMIS, 1991). Regarding anatomical features, juvenile and adult woods are very important on the understanding of wood quality, especially on shrinkage anisotropy and mechanical properties.

Juvenile wood is the one comprising the growth rings that are near to the pith. This tissue is characterized by less pronounced latewood, shorter cells, larger microfibril angles, and lower crystallinity and cellulose content, in comparison to adult wood that is produced later (TSOUMIS, 1991).

The pith is at the very center of the trunk and is the remnant of the early growth of the tree, before wood is formed (WIEDENHOEFT, 2010), and depending on the kind of breakdown pattern used, this tissue will be present in lumber. According to Burger; Richter (1991), pith tissue is made of parenchyma cells, and its role is especially important in juvenile plants, taking part on food storage and sap ascension.

The existing differences in anatomical structure have adverse effects on juvenile wood properties, such as high longitudinal shrinkage and lower strength, and therefore affect the quality of products. Greater longitudinal shrinkage causes distortions, checks and splits in lumber and other products; shorter fibers and usually lower density reduce not only the strength of wood but also certain mechanical properties, as well as the yield of pulp (TSOUMIS, 1991).

Most drying defects or problems that develop in wood products during drying can be classified as fracture or distortion, warp, or discoloration. Defects in any of these categories are caused by an interaction of wood properties with processing factors. Wood shrinkage is mainly responsible for wood ruptures and distortion of shape. Cell structure and chemical extractives in wood contribute to defects associated with uneven moisture content, undesirable color, and undesirable surface texture (BERGMAN, 2010).

A check is a split parallel to the grain, normally a few centimeters long. Surface checking occurs during the early stages of drying when wood is exposed to severe conditions of temperature and low relative humidity (LANGRISH; WALKER, 2006). Surface checks occur early in drying when the shell of a board is stressed in tension enough to fracture the wood. These checks occur most often on the face of flat sawn boards (BERGMAN, 2010).

Checks develop at points of weakness, for example, along rays and other parenchyma tissues. Hence, flat sawn boards face-check, and quarter sawn boards edge-check. Very rapid end drying also cause the ends of boards to shrink ahead of the rest of the board and so end-check (LANGRISH; WALKER, 2006). End checks are similar to surface checks, but appear on the ends of the boards and logs. These checks occur because the rapid longitudinal movement of moisture causes the end to dry very quickly and develop high stresses, therefore fracturing (BERGMAN, 2010).

The aim of this work was to evaluate the difference of partial shrinkage and the proportion of checks in *Eucalyptus grandis* juvenile wood and adult wood during natural air drying.

2 METHODOLOGY

2.1 Sampling

The wood used in this research was from an *Eucalyptus grandis* W. Hill ex Maiden stand, 34 years old, planted in “Fazenda Paraíso”, 20° 32’ 44.36” S and 41° 49’ 30.03” W, Minas Gerais state, Brazil. The city’s climate is tropical of altitude, with warm summer and cold winter, with temperatures varying between 25.3°C (mean maximum) and 12.8°C (mean minimum), and a total rainfall average of 1,595 mm. Climatic data were obtained from the station located on the farm where the work was performed.

Two trees were felled with a chainsaw and were cut into 2,000 mm length logs. After that, the logs were also broken down with chainsaw, producing lumber of 70 to 80 mm thickness and 130 to 260 mm width (Figure 1).

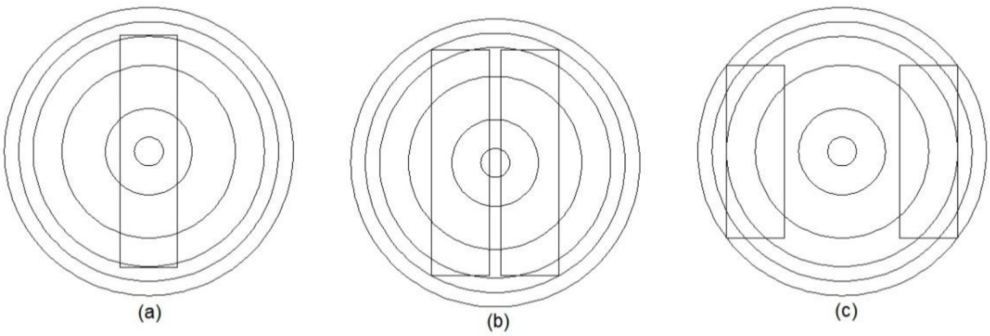

Figure 1. Cutting diagrams.

Figura 1. Modelos de corte.

According to Figure 1, planks were obtained and named juvenile wood, with pith (“a” and “b”), and adult wood, without pith (“c”). The planks from “a” were obtained from smaller diameter logs than those of “b” and “c”, being this the reason for only one plank by log.

After breakdown, 36 planks were randomly sampled, 18 from each group of juvenile and adult wood. These planks were directly measured in thickness, width and length in order to obtain their initial volume.

Then, the lumber was stacked and naturally air dried in the same farm where the trees were felled. The initial moisture content (determined gravimetrically from drying samples) was 61.34%, and the lumber achieved 17.67% after 270 days of drying.

2.2 Determination of partial shrinkage and the proportion of cracks

At the end of the drying period, the 36 planks had their volumes measured again, in order to determine its partial (from saturated to 17.67% moisture content) volumetric, radial and tangential shrinkages, according to Equation 1.

$$\beta = \frac{D_i - D_0}{D_i} \times 100 \qquad \text{(Equation 1)}$$

In which β: partial shrinkage (%); D_i: initial saturated dimension (radial, tangential or volumetric) (mm); D_0: final dried dimension (radial, tangential or volumetric) (mm).

At the same time, the proportion of cracks of each plank was measured, according to the NBR 9487 of Associação Brasileira de Normas Técnicas (ABNT, 1986), using Equation 2.

$$PC = \frac{\sum_1^n (c_1 + \ldots + c_n)}{L} \times 100 \qquad \text{(Equation 2)}$$

In which PC: proportion of cracks (%); n: number of cracks; c_1: length of the first longitudinal crack (mm); c_n: length of the last longitudinal crack (mm); L: total length of the plank (mm).

2.2 Statistical analysis

All tests were performed with a 95% confidence level. The effect of the sampling position of wood (juvenile and adult) was checked by applying the analysis of variance (ANOVA), with Bartlett's test used for its validation, which verifies a basic premise for the realization of ANOVA, the homogeneity of variances among treatments (RIBEIRO JUNIOR, 2001).

If the variances were not statistically equal, Kruskal-Wallis H-test – which provides a non-parametric method for ANOVA – was applied for the classification of a criterion or experiments with one factor, allowing generalizations (SPIEGEL, 1994). In this test, the original data of both treatments are increasingly ordered and receive scores, giving a mean score by treatment instead of an overall mean. If the medians were not statistically equal, the Box-and-Whisker Plot graph was used to identify them.

3 RESULTS AND DISCUSSION

3.1 Partial shrinkage

In Table 1 the means and other statistics of partial volumetric (βv), radial (βr) and tangential (βt) shrinkages are presented.

Bartlett's test verifies the null hypothesis that the variances of the shrinkage data of each treatment are the same. Bartlett's test revealed that there was not a statistically significant difference amongst the variances at 95% confidence level. So, it was possible to apply the ANOVA.

Table 1. Statistics of partial shrinkage of *Eucalyptus grandis* wood by treatment.
Tabela 1. Estatísticas da contração parcial da madeira de *Eucalyptus grandis* por tratamento.

Treatment	βv (%)	βr (%)	βt (%)
Juvenile wood	10.94 (9.61)*	3.37 (21.75)	7.36 (11.72)
Adult wood	11.60 (12.57)	3.78 (27.71)	7.55 (18.63)
Bartlett's test	1.05^{ns}	1.06^{ns}	1.12^{ns}
F-ratio	2.49^{ns}	1.93^{ns}	0.14^{ns}
P-value	0.1236	0.1741	0.7108

*Numbers in brackets correspond to the coefficient of variation; ns: not statistically significant (95% confidence level).

In absolute terms, the shrinkage of adult wood was higher than that of juvenile wood. However, the F-ratio of the Analysis of Variance showed that there was not a statistically significant difference (95% confidence level) between the means of volumetric, radial and tangential partial shrinkages of the treatments.

It was an interesting result, because according to Silva et al. (2006) adult wood of *Eucalyptus grandis* has higher shrinkage than juvenile wood, which was not observed. It was expected the adult wood would to more due to its higher density (TSOUMIS, 1991), which is directly related to dimensional instability. On the other hand, it is also known that juvenile wood presents higher shrinkage than adult wood because of the higher microfibrils angle.

Thus, it is believed that such factors acted synergistically, and one counterbalanced the other, resulting in non different means of shrinkage between juvenile and adult woods. Such a result is believed to have been found because the pieces were very thick (70 to 80 mm), so those samples which composed the juvenile wood treatment might have presented a part of adult wood too. Thus, the union of all these factors led the treatments not to show different statistical shrinkage differences.

The results presented in Table 1 correspond to partial shrinkage, because mean final moisture content was 17.67%. In general, researchers present total shrinkage when they are assessing wood, that is, shrinkage from saturated to oven dry moisture content. So, the theoretical total shrinkage for each treatment was calculated, and it is presented in Table 2. The fiber saturation point of 28% was considered as the moisture content in which wood starts shrinking with moisture loss.

Table 2. Calculated total shrinkage of *Eucalyptus grandis* by treatment.
Tabela 2. Contração total calculada da madeira de *Eucalyptus grandis* por tratamento.

Treatment	βv (%)	βr (%)	βt (%)
Juvenile wood	24.84	7.65	16.71
Adult wood	26.34	8.58	17.15

As it can be seen in Table 2, *Eucalyptus grandis* is a very instable wood. Comparing the shrinkage presented to other results for *Eucalyptus grandis* in literature, it can be seen that the wood of this work was more dimensionally instable.

For example, Lopes (2007) found mean volumetric shrinkage of 15.99% for wood from trees of 18 years old. Silva et al. (2006) found mean volumetric shrinkage of 22.30%. Both works considered adult wood, which means the most external and closest to bark. In both works the authors obtained the highest values of shrinkage for adult wood.

3.2 Proportion of cracks

While statistically significant difference was not observed between the shrinkage means of the treatments, the same cannot be pointed about the results for proportion of cracks. In Table 3 the results for proportion of cracks by treatment and some other statistics are presented.

Table 3. Proportion of cracks of *Eucalyptus grandis* wood by treatment.
Tabela 3. Nível de rachaduras da madeira de *Eucalyptus grandis* por tratamento.

Treatment	Proportion of cracks (%)	Coefficient of variation (%)	Average rank (%)
Juvenile wood	60.6	36.07	26.94
Adult wood	17.8	54.65	10.06
Bartlett's test	1.35*	-	-
Kruskal-Wallis test	23.13**	-	-

* Statistically significant at the 95% confidence level; **Statistically significant at the 99% confidence level.

As for the statistical analysis of shrinkage, Bartlett's test was performed for the proportion of cracks. However, the test revealed that there was a statistically significant difference between the variances of the treatments at 95% confidence level. This violated one of the important assumptions underlying the ANOVA.

Therefore, Kruskal-Wallis test, which tests the null hypothesis that the medians (instead of the means) of the treatments are the same, was applied. First, data were combined and ranked from smallest to largest. The average rank was then computed for the data at each level, and this is presented in Table 3. According to Kruskal-Wallis test, it was showed that there was a statistically significant difference between the proportion of cracks of the treatments, at 99% confidence level. The same result can be seen in the Box-and-whisker plot (Figure 2).

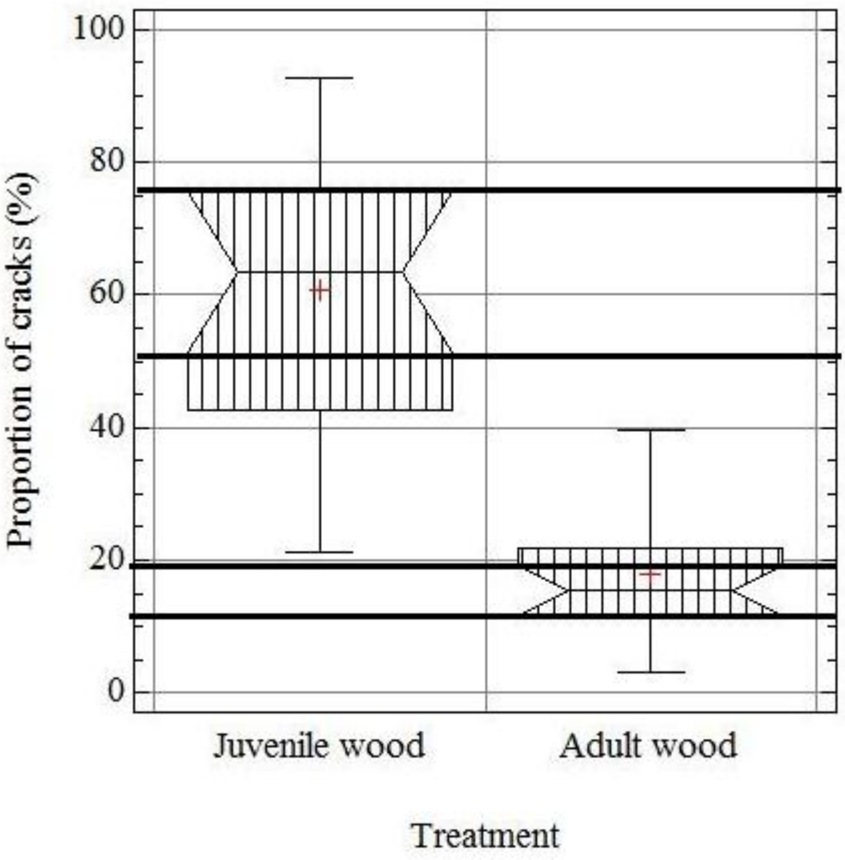

Figure 2. Box-and-whisker plot of the proportion of cracks of *Eucalyptus grandis* wood by treatment.
Figura 2. Gráfico de caixas do nível de rachaduras da madeira de *Eucalyptus grandis* por tratamento.

Since the parallel lines (which demark the notches of each box) do not overlap, it also means that there is a statistically significant difference between the medians of the proportion of cracks of juvenile and adult woods. These results are in agreement with the literature, which states that juvenile wood tissue is weaker than adult wood and, consequently, more susceptible to drying defects than the latter, which is more resistant.

In Figures 3 and 4 juvenile wood planks of *Eucalyptus grandis* are presented, evidencing the severity of enormous cracks, originated from the anisotropy shrinkage of wood and the low resistance of pith tissue.

Figure 3. Juvenile wood plank of *Eucalyptus grandis* presenting end and surface checking.
Figura 3. Madeira juvenil de *Eucalyptus grandis* com rachaduras de topo e longitudinal.

Figure 4. Juvenile wood plank of *Eucalyptus grandis* presenting a very long, deep and severe surface check.
Figura 4. Madeira juvenil de *Eucalyptus grandis* com rachadura longitudinal longa, profunda e severa.

The checks were so severe that the plank was almost split into two, and the fracture line coincides with pith tissue, which is the weakest one in wood.

According to the Brazilian Standard NBR 9487 (ABNT, 1986), taking into account the "classification for general market", which considers the evaluation of the worst face of the pieces, the average proportion of cracks presented by adult wood treatment classifies its wood as "fourth class" (the worst one). Similarly, juvenile wood is completely unclassified according to the same standard.

In order to achieve a better yield of wood, some recommendations can be pointed out. First, the very ends of the pieces must be sealed with some waterproof product, reducing the rapid longitudinal moisture flow which leads to high shrinkage stresses and cracks. This first recommendation is imperative and must be followed, independently of the further recommendations.

Second, if the dimensions of the pieces cannot be reduced (for some particular use), it is suggested that they be air dried under less severe conditions – for example, under coverage. This way, temperature will be lower and humidity will be higher, reducing the drying rate and, consequently, increasing the final quality of wood.

Of course, drying time will be severely enlarged under this situation. If a shorter period of drying, with higher final quality, is intended, the third recommendation is air drying wood under coverage and, after that, kiln drying with a proper schedule. However, it is necessary to evaluate the availability of such technology and its economic viability.

If lumber of smaller dimensions is intended, the fourth recommendation lies on the fact of rethinking the different lumber which can be sawn from the logs. Different breakdown patterns, which separate juvenile wood (and pith) from adult wood, could be proposed. This way, the resulting lumber would be more homogenous (regarding tissues and technological properties, including shrinkage), thus reducing the cracks.

Another indirect advantage of lumber of smaller dimensions, in relation to larger ones, is that the first dries faster and presents lower absolute shrinkage, reducing cracks and other defects associated to dimensional instability.

Anyway, wood must be rationally handled, resulting in high quality products, because it is a very valuable raw material which takes too long to be produced (in this case, 34 years).

4 CONCLUSIONS

There was not statistically significant difference between partial shrinkage of juvenile and adult wood.

Lumber from juvenile wood presented worse quality in natural air drying than adult wood.

The influence of wood position (juvenile or adult) in log exerted higher influence on the drying quality than shrinkage.

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