

# Anatomical properties of *Eucalyptus grandis* wood and transition age between the juvenile and mature woods

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**Abstract** The present study is aimed at evaluating the anatomical characteristics of *Eucalyptus grandis* wood and the transition age between the juvenile and mature woods. Four trees of 23-year-old *E. grandis* were used. The juvenile, transition and mature wood zones were found by fiber length measurement from the pith to the bark. Samples were taken from juvenile wood, transition wood and mature wood and the anatomical properties of the wood were determined. The results showed that: (1) the fiber length, cell wall thickness, slenderness ratio, cell wall fraction and tangential vessel diameter increase from pith to bark; (2) fibers, axial parenchyma, ray parenchyma cells and vessels are equally distributed from pith to bark; (3) the transition zone between juvenile and mature wood occurs between the age of 8 and 13 years.

## 1 Introduction

In general, the heterogeneity of wood causes a large deal of inconvenience to the fabrication and processing industries that employ the wood. According to Cruz et al. (2003), knowledge of the various types of wood within a log may allow obtaining more uniform lots to meet more specific needs.

The material's chemical and physical–mechanical discontinuity occurs owing to several factors, such as species, silviculture, and particularly the wood anatomy. Juvenile wood can be defined as being close to the pith and, technologically, it differs from mature wood on account of several properties (Bao et al. 2001; Bendtsen 1978; Calonego et al. 2005; Ferreira et al. 2011; Palermo et al. 2011, 2013; Zobel and Van Buijtenen 1989; Zobel and Sprague 1998).

There are numerous hypotheses about the cause of juvenile wood. It is controlled by production of auxin in the tree crown and results from close proximity to the foliage. Thus, the most accepted concept is that it is directly related to the age of the cambium that determines whether juvenile, transition or mature wood is formed (Zobel and Van Buijtenen 1989; Zobel and Sprague 1998).

The length and wall thickness of fibers in juvenile wood obtained from 26-year-old *Corymbia citriodora* were 0.995 mm and 3.59  $\mu\text{m}$ , whereas in mature wood, they were 1.224 mm and 3.73  $\mu\text{m}$ , respectively (Bao et al. 2001). Calonego et al. (2005) demonstrated that 32-year-old trees of the above-mentioned species produce juvenile and mature wood with respective fiber lengths of 0.943–1.140 mm and 1.186–1.350 mm. The juvenile wood of 28-year-old *E. grandis* has 1.009 mm, whereas the mature wood has 1.145 mm (Leonello et al. 2008).

Brasil and Ferreira (1972) concluded that the juvenile wood of 16-year-old *E. grandis* trees has 0.836 mm, 17.00, 9.75, 3.88  $\mu\text{m}$ , 0.435  $\text{g}/\text{cm}^3$  and 325.6  $\mu\text{m}$  of fiber length, fiber diameter, lumen diameter, cell wall thickness, basic density and vessel length, whereas the mature wood has 1.276 mm, 17.25, 7.75, 5.00  $\mu\text{m}$ , 0.574  $\text{g}/\text{cm}^3$  and 400.4  $\mu\text{m}$ , respectively.

Even so, the juvenile and mature wood regions were determined according to several authors by the

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densitometric profile, microfibrillar angles and fiber lengths (Calonego et al. 2005; Leonello et al. 2008; Palermo et al. 2011, 2013; Taylor 1979; Zobel and Van Buijtenen 1989).

Calonego et al. (2005) showed that the juvenile wood of *C. citriodora* occurs between 40 and 55 mm from the pith. Leonello et al. (2008) concluded that the juvenile wood of *E. grandis* is confined up to 150 mm from the pith. Moreover, these authors did not perform studies to determine the transitional age of these types of wood. Nevertheless, Ramos et al. (2011) showed that the transition zone between juvenile and mature wood of *E. grandis* occurs between the 5th and 11th year.

The anatomical characterization of *Pinus elliottii* var. *elliottii* showed that the juvenile wood is confined between 145 and 185 mm from the pith that corresponds to formed wood of up to 21-year-old (Palermo et al. 2011).

Although several studies have been carried out on the juvenile and mature wood of softwoods, there is little knowledge of hardwoods (Evans et al. 2000; Bao et al. 2001; Calonego et al. 2005), and few comparisons have been made among the properties from the pith up to bark of the *eucalyptus*.

Therefore, the present study is aimed at evaluating anatomical characteristics of *E. grandis* wood and the transition age between the juvenile and mature woods.

## 2 Materials and methods

### 2.1 Collection of material

This study used the wood of four trees of 23-year-old *E. grandis* Hill ex Maiden from the Quinvale Company located in Barra do Piraí (22°43'23" south latitude and 44°08'08" west longitude), Rio de Janeiro, Brazil.

The trees were felled and disks with a thickness of 100-mm were sectioned in the stem at breast height (1.30 m). Samples measuring  $10 \times 10 \times 100 \text{ mm}^3$  in

length  $\times$  width  $\times$  height were taken from the pith to the bark, as shown in Fig. 1.

Half of each sample was used to produce macerated sections and the other half was used to obtain histological sections. The boundaries of the juvenile and mature wood regions were determined through visual analysis of graphs obtained from the fiber length average by standards of the International Association of Wood Anatomists Committee (1989), and as performed by Zobel and Van Buijtenen (1989), Calonego et al. (2005) and Ferreira et al. (2011). Thus, these samples were separated into three regions: juvenile, transition and mature wood.

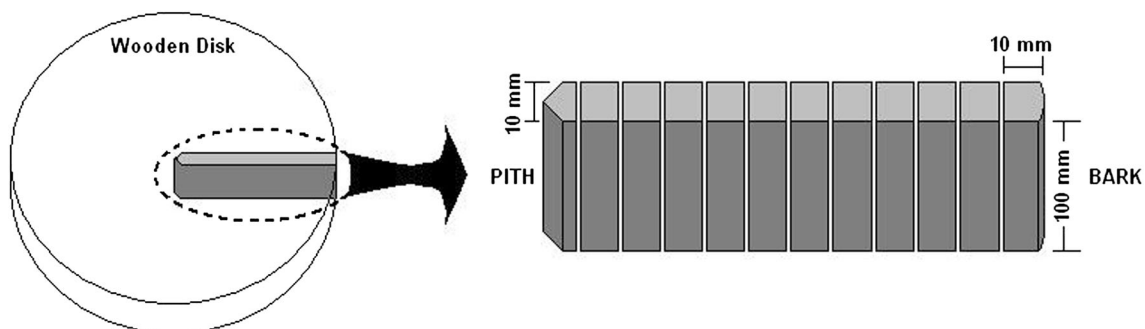
Later, the anatomical characteristics were dissociated by the method of Franklin (Sass 1951), and histology slides were produced on glass slides with glycerine and safranin (1 %) according to the procedure used by several authors (e.g., Leonello et al. 2008 and Palermo et al. 2013).

### 2.2 Anatomical analysis of *E. grandis* wood

Measurements of anatomical characteristics were made in the Laboratory of Anatomy and Quality of Wood at the Federal Rural University of Rio de Janeiro, RJ, Brazil, following the standard presented by IAWA Committee (1989) and recommendations of Foelkel and Barrichello (1975).

The following anatomical characteristics of each sample were measured by “Cell F” software: vessels (tangential diameter and length), fibers (length, diameter, lumen diameter, cell wall thickness, cell wall fraction and slenderness ratio). The number of replications used to determine the dimensions of each anatomical characteristic is shown in Table 1. The percentage of each anatomical characteristic in the wood (fiber, vessel, and axial and ray parenchyma cells) was also determined.

For the evaluation of anatomical properties, an analysis of variance with 95 % probability taking into account the type of wood and the Tukey test at 5 % significance for the comparison of the means were made.



**Fig. 1** Scheme for preparing the wood samples

**Table 1** Parameters used in the anatomical properties tests of *E. grandis* wood

Parameters	Units	Measuring site	Number of replications by type of wood
Fiber length (L)	mm	Macerated	25
Fiber diameter or fiber width (D or W)	μm	Macerated	25
Fiber lumen diameter (d)	μm	Macerated	25
Fiber wall thickness (e)	μm	Macerated	25
Wall fraction (D – d/D)	Dimensionless	Macerated	25
Fiber slenderness ratio (L/D)	Dimensionless	Macerated	25
Vessel length	μm	Macerated	25
Vessel tangential diameter	μm	Transverse sections	25
Fiber percentage	%	Transverse sections	1
Axial parenchyma percentage	%	Transverse sections	1
Ray percentage	%	Transverse sections	1
Vessel percentage	%	Transverse sections	1

### 2.3 Determination of age transition from juvenile wood to mature wood

The relationship between fiber length and radial distance was evaluated using polynomial regression, by taking into account the observed tendency of data. The models of the regression curves with 95 % probability were adjusted.

The boundaries of the juvenile, transition and mature wood regions were determined from the behavior of the fibers length at pith to bark direction, as recommended by Zobel and Van Buijtenen (1989), Calonego et al. (2005), Ferreira et al. (2011) and Palermo et al. (2011, 2013).

The age of transition between juvenile and mature wood was determined through measurements of growth rings by X-ray microdensitometry technique, according to Oliveira et al. (2012). An annual growth ring is regarded as the period for the formation of two consecutive peaks of high density, as shown by Ferraz (1983). Thus, by both demarcation of annual ring as well as annual growth increment the exact position of each sample in radial section was identified and consequently the year of their formation.

## 3 Results and discussion

### 3.1 Anatomical characterization of *E. grandis* wood

The parameters that characterize the anatomical properties of *E. grandis* wood are shown in Table 2.

It can be seen that there was a significant difference in the fiber length, cell wall thickness, cell wall fraction, fiber slenderness ratio and the vessel tangential diameter between the juvenile and mature wood regions of the stem.

These results are similar to those cited by Bao et al. (2001), who characterized the anatomical properties of *C. citriodora*, as well as those reported by Brasil and Ferreira (1972). In addition, these behaviors were similar to those presented by Calonego et al. (2005), Leonello et al. (2008), Ferreira et al. (2011) and Palermo et al. (2011, 2013).

Even according to Zobel and Sprague (1998) and Zobel and Van Buijtenen (1989), the fiber length, cell diameter and wall thickness of diffuse-porous species, among them the *eucalyptus*, are low at the pith, increase outward and tend to plateau in the mature wood. According to Zobel and Van Buijtenen (1989), the cambial initial cells increase in size with age of the secondary meristem and become more stable with the maturity of cambium.

Moreover, Table 2 shows that the percentage of each anatomical characteristic in the wood (fiber, vessel, and axial and ray parenchyma cells) did not reveal significant differences from the pith up to the bark of the *E. grandis* stem.

The fiber, vessels, and axial and ray parenchyma percentage of juvenile wood from *E. grandis* were 54.4, 17.2, 14.4, and 14.0 %, respectively. In the transition wood, these anatomical elements were 58.7, 15.4, 13.4, and 12.4 %, whereas the mature wood presents 51.8, 15.8, 15.6, and 16.8 %, in the respective characteristics. These behaviors are similar to those reported by Bao et al. (2001).

In addition, these results are similar to those found by Queiroz (2002), where the wood of smaller density *E. grandis* × *urophylla* showed fibers, vessels and parenchyma percentage of 69.3, 13.6 and 17.1 %, whereas in the wood of higher density clone, it was 66.5, 19.2, and 14.3 %, respectively.

The dimension of the fibers, the tissue composition of wood by fibers, vessels, radial and axial parenchyma can predict a specific property of the wood. For example,

**Table 2** Anatomical characteristics from the pith up to bark of *E. grandis* stem

Anatomical characteristics	Type of wood		
	Juvenile	Transition	Mature
Fiber length (L) (mm)	0.986 <sup>a</sup> (0.125)	1.088 <sup>b</sup> (0.0613)	1.110 <sup>b</sup> (0.0982)
Fiber diameter or fiber width (D or W) (μm)	21.04 <sup>a</sup> (2.235)	21.57 <sup>a</sup> (2.357)	22.05 <sup>a</sup> (2.772)
Fiber lumen diameter (d) (μm)	14.01 <sup>a</sup> (2.199)	14.29 <sup>a</sup> (2.087)	14.14 <sup>a</sup> (3.395)
Fiber wall thickness (e) (μm)	3.51 <sup>a</sup> (0.818)	3.62 <sup>ab</sup> (0.519)	3.93 <sup>b</sup> (0.664)
Wall fraction (D – d/D) (dimensionless)	0.445 <sup>a</sup> (0.230)	0.438 <sup>ab</sup> (0.211)	0.579 <sup>b</sup> (0.227)
Fiber slenderness ratio (L/D) (dimensionless)	47.10 <sup>a</sup> (5.609)	50.96 <sup>a</sup> (5.438)	51.24 <sup>b</sup> (8.656)
Vessel length (μm)	436.67 <sup>a</sup> (94.200)	429.18 <sup>a</sup> (67.420)	480.43 <sup>a</sup> (88.643)
Vessel tangential diameter (μm)	124.08 <sup>a</sup> (30.644)	134.77 <sup>ab</sup> (29.527)	140.53 <sup>b</sup> (22.524)
Fiber percentage	54.4 <sup>a</sup> (14.907)	58.7 <sup>a</sup> (15.263)	51.8 <sup>a</sup> (15.126)
Axial parenchyma percentage	14.4 <sup>a</sup> (7.445)	13.4 <sup>a</sup> (6.211)	15.6 <sup>a</sup> (7.239)
Ray percentage	14.0 <sup>a</sup> (5.526)	12.4 <sup>a</sup> (7.225)	16.8 <sup>a</sup> (8.536)
Vessel percentage	17.2 <sup>a</sup> (9.579)	15.4 <sup>a</sup> (5.739)	15.8 <sup>a</sup> (5.806)

Number in brackets—standard deviation; different letters—significant difference by Tukey test at probability 95 %; same letters—non-significant difference

increasing the density of the wood depends on the increase in cell wall thickness of fibers or an increase in the proportion of fibers at the proportion of vessels.

As shown in Table 2, the wall thickness, fraction and wall slenderness ratio increased from pith to bark.

This behavior was similar to that found by several authors, among them Brasil and Ferreira (1972) and Sette Junior et al. (2009). It is noted that the increase of this parameter increases the resistance of wood to friction during cutting or thinning and improves the quality of the machined surface in this region, which is advantageous if this timber is used for the production of higher value added.

### 3.2 Age transition from juvenile wood to mature wood

Figure 2 shows the variation of fiber length from the pith to bark of *E. grandis* stem and the delimitation of juvenile and mature wood zones.

The resulting curves from the average fiber length, measured in “mm”, in the radial direction, for each tree can be seen. For the studied trees, the fiber length showed a high, nearly linear increase until 60–70 mm after the pith, according to linear regression curves.

From the radial distance of 100–110 mm to the periphery of the stem, the increase rate in fiber length decreased, tending to be more stable and almost a constant value. This behavior is similar to the one described and observed by several authors, such as Calonego et al. (2005), Leonello et al. (2008), Ferreira et al. (2011), Palermo et al. (2011, 2013), Zobel and Van Buijtenen (1989) and Zobel and Sprague (1998). However, these

authors did not perform studies to determine the transitional age of these types of wood.

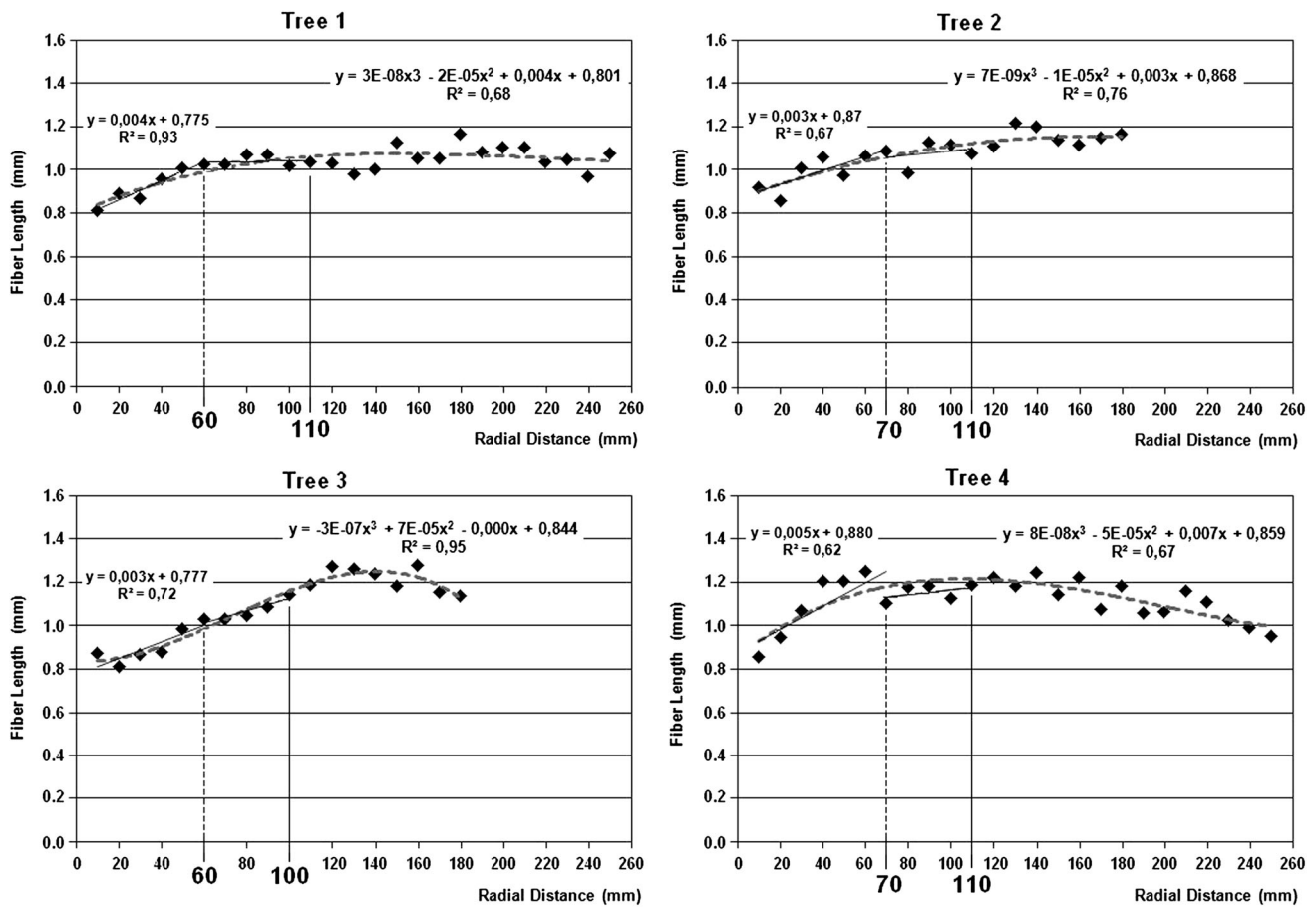
Moreover, based on the radial density analysis by X-ray densitometry, the transition age between juvenile and mature wood of *E. grandis* is shown in Table 3. The transition zone between juvenile and mature wood occurs between the 8th and 13th year.

These results are consistent with the literature, showing that this tendency is a characteristic of juvenile wood formation in the tree’s early years (Brasil and Ferreira 1972; Calonego et al. 2005; Leonello et al. 2008; Ferreira et al. 2011; Palermo et al. 2011, 2013; Zobel and Van Buijtenen 1989).

These results were not equal to those shown by Ramos et al. (2011) who studied *E. grandis* and concluded that the transition zone between juvenile and mature wood occurs between the 5th and 11th year. Furthermore, other factors may influence this variation in the transition age from juvenile and mature woods. Some authors (Bendtsen 1978, Zobel and Sprague 1998 and Loo et al. 1985) reported that the age of transition from juvenile to mature wood varies considerably among trees, region of forest stands, seed provenance, local environmental conditions, as well as genetic factors. It can also differ due to the property of the wood used to delimit the transition zone between the types of wood.

## 4 Conclusion

According to the results presented for *E. grandis*, it is possible to conclude that: (a) the fiber length, cell wall thickness, slenderness ratio, cell wall fraction, and



**Fig. 2** Demarcation of juvenile wood (up to the dashed line), transition wood (between dashed and solid lines) and mature wood (as from the solid line) from *E. grandis*

**Table 3** Transition age from juvenile wood to mature wood of *E. grandis*

Tree	Juvenile wood (mm)	Age (years)	Transition wood (mm)	Age (years)	Mature wood (mm)	Age (years)
1	0–60	7	60–110	8–11	110–250	11
2	0–70	10	70–110	10–16	110–180	16
3	0–60	7	60–100	7–12	100–180	12
4	0–70	9	70–110	9–13	110–290	13
Average		8.25 years-old or 8 years and 3 months old				13 years-old
Standard deviation		1.5				2.2

tangential vessel diameter increase from pith to bark; (b) fibers, axial parenchyma, ray parenchyma cells, and vessels are equally distributed from pith to bark; (c) the transition zone between juvenile and mature wood occurs between the 8th and 13th year.

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