Relationship between Density and Anatomical Structure of Different Species of *Eucalyptus* and Identification of Preservatives

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The species and density of *Eucalyptus* wood poles installed in the electrical network are useful parameters which must be considered when it is necessary to establish the service life of these structures. In this work, eucalyptus poles samples were collected and analyzed by scanning electron microscopy and energy dispersive spectroscopy (SEM/EDS). SEM image analysis showed that the lumen diameter average of fiber substantially is variable between the three species studied, in line with the wood density obtained in laboratory, for poles with several years in service in the electricity network, as well as for not used poles. In addition, EDS microanalysis was utilized for identify the presence of chemical preservatives employed in the conservation these poles. The analysis method proposed proved effective for characterization for this timber.

Keywords: *CCA, density, lumen, scanning electron microscopy, treated wood*

1. Introduction

In Brazil, particularly in the southern states, *Eucalyptus* poles account for 79% of the utility poles in service within the electricity distribution network[1]. These structures are manufactured from planted forests containing a wide variety of *Eucalyptus* species, also used for other purposes. *Eucalyptus* poles generally exhibit outstanding tensile strength, low density and reduced manufacturing costs when compared with their steel and concrete counterparts.

However, wood in service or storage is subject to deterioration by fungi and insects, even when treated with chemical preservatives. Chemical compounds such as CCA (chromated copper arsenate), a water soluble preservative, are used to treat *Eucalyptus* poles. CCA is an excellent fungicide and insecticide due to the presence of copper and arsenic, respectively, while the chromium acts as a fixing agent binding the other two elements to the wood. After impregnation, the chemical components of the CCA solution react amongst themselves and with those of the wood, binding together to form water-insoluble compounds[2,3].

The use of creosote, an important development in the history of wood preservation, with wood treated by large-scale pressure impregnation, has been widely employed as a preservative in wood structures for a variety of uses[4]. Prior to being banned in Brazil in 1998, it was the preferred treatment method, giving the wood a dark coloration and proving highly effective[5].

Vidor et al. report an accelerated decline in the state of conservation of certain *Eucalyptus* species as a result of negligence in manufacturing processes and species selection[6]. Boron and fluorine-based curative treatments

have proven effective when applied directly to the areas most exposed to microorganisms during routine inspections[7].

In light of growing concern over the disposal of treated wood waste, a number of methods have been studied to screen toxic elements harmful to the environment. Companies are increasingly concerned about the disposal or decontamination of waste from treated poles, particularly in the case of CCA, due to the presence of chromium and arsenic[8].

Several methods can be used to identify and quantify the elements present in treated waste wood. Williams reports that conventional analytical methods are generally lengthy and complex when compared to EDS microanalysis used by Helsen and Hacala[9,10]. Pedersen and Ottosen applied SEM/EDS to evaluate changes in the chemical composition of ash from burning CCA-treated wood, before and after the extraction process[11]. In addition to identification, morphological characterization of different species of *Eucalyptus* can be performed by electron microscopy.

Chinga-Carrasco, Johnsen and Oyaas applied field emission SEM and computerized image analysis to quantify the cell wall characteristics of mechanically, chemically and enzymatically altered cellulose fibers[12].

In order to achieve greater efficiency when using wood in engineering applications, its characteristics or physical properties should be considered[13]. According to Lobão et al., one of the most important parameters when classifying wood is density, since it is directly related to the mechanical properties of each *Eucalyptus* species[14].

Dutt and Tyagi morphologically compared fibers from two species of *Eucalyptus*, *E. grandis* and *E. tereticornis*,

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with respect to strength and flexibility with morphologic properties determined by a binocular microscope. Fibers with thinner walls and wider lumens showed less strength and greater flexibility, while those with thicker walls and narrower lumens were harder and less flexible[15]. Shimoyama reports that the density of *Eucalyptus* wood is a highly complex property since, in addition to involving a combination of anatomical elements, it also depends on the chemical compounds present[16]. Thus, if the use of wood for a specific application depends on its density and mechanical properties, which in turn can be influenced by its anatomical structure, it follows that density is related to the latter.

Relating the physical properties of wood to its anatomy is simple in new wood, but far more complex in wood with several years of service, as in poles from the electricity network due to its greater deterioration and absence of information.

The objective of the present study was to determine the relationship between the basic and apparent density of *Eucalyptus* wood and its anatomical structure in different species, using electron microscopy to estimate density. Moreover, we sought to validate the use of EDS to identify the presence of CCA components and fluorine in wood structures.

2. Material and Methods

For purposes of analysis, wood samples were collected from six new poles and thirty-three utility poles within the electricity distribution network, with varying service times. Of the six new poles analyzed, three were CCA-treated and three had not undergone chemical treatment. Among the thirty-three poles removed from the electricity network, twenty-six had been treated with CCA preservative and seven with creosote. Of the twenty-six CCA-treated poles, two received boron and fluorine-based curative treatment and one underwent CCA extraction. The species *Eucalyptus grandis*, *Eucalyptus saligna* and *Eucalyptus citriodora (Corymbia)*, the most widely used in the manufacture of utility poles in South Brazil, were selected for new poles untreated in order to relate fiber morphology with density. Decommissioned poles were randomly chosen from a batch of more than 10 000 structures, whose species were unknown, as are those of the three new and chemically treated poles.

Sections approximately 0.50 m long were cut just above where the pole most likely meets the ground, and used to prepare test specimens (TS) measuring $150 \times 50 \times 50$ mm. These were submitted to density determination using the stereometric method, in accordance with NBR 7190[17] guidelines. The density at 0% (ρ_0) moisture of the specimens was determined by dividing the weight of the specimen dried in stove by nine hours the volume obtained by the dimensions of the specimens. Using Equation 1 proposed by Rezende, Escobedo and Ferraz[18], was obtained value of the basic density (ρ_b) for each specimen analyzed. The apparent density (ρ_{ap}) was determined by dividing the weight of the specimen (wet) by volume obtained by the dimensions of the specimens.

$$\rho_b = (\rho_0 - 0,28\rho_0^2) \tag{1}$$

Samples of around 5 mm were taken from the center of the pith, the sapwood and heartwood of new poles were packaged under vacuum, fixed on the metallic support and then submitted to metallization process with Au and Pd performed to increase the conduction electric sample were subsequently analyzed in a scanning electron microscope coupled to a Philips XL 30 energy dispersive spectrometer (EDS). Cuts were made in two directions: parallel to the stem axis, for treatment identification, and perpendicular to the stem axis, for morphological assessment. The images were processed using ImageJ® software to obtain average lumen diameter. The degree of association between basic and apparent density and lumen diameter was determined by Pearson's correlation coefficient, with a *p-value* of 0.05.

To determine the initial concentration of Cu, Cr and As, all wood samples with particle size ≤ 425 µm were decomposed in a microwave. For this purpose the samples was added a mixture of HNO_3 and H_2O_2 after the mixture was submitted to a heating program. Thereafter, the resulting solutions were transferred to polypropylene vials and the volume adjusted with deionized water. ICP-MS Elan Model 6000 (Perkin-Elmer) was used to determine the concentrations of the samples.

In the CCA extraction procedure, described by Ferrarini[19], samples with particle size $\leq 9,5$ mm and extractor (H_2SO_4) were placed in contact in a glass-reactor attached a condenser which is used to avoid losses of elements by volatilization and minimized the reactor pressure. Then the reactor was put to a shaker operated at about 500 rpm and after was heated in a heating mantle. The extraction was performed in three cycles in two hours followed by three washing steps one hour each. After the extraction the wood samples were submitted to the decomposition process cited earlier, to determine the final amount decontaminated. Fluorine analysis was performed using an ion-selective electrode[20]. Findings were compared with the EDS spectra obtained.

Table 1. Mean values for density and lumen diameter of wood fibers from different species of eucalyptus new untreated.

Species	Average Lumen Diameter (µm)	Nº of Measurements	Mean ρ_b (Laboratory) (kg/m³)	Mean ρ_{ap} (Laboratory) (kg/m³)	ρ_{ap} NBR 7190/97[17] (kg/m³)
E. citriodora	2.34±1,38	95	697±15.3	979±29,1	999
E. saligna	4.87±1,68	175	589±15.3	781±23,3	731
E. grandis	7.95±2,33	150	440±26.4	563±41,1	640

±Standard deviation.

3. Results and Discussion

3.1. *Correlation between timber density and morphology*

Microscopic analyses of cross-sections taken at random points of the pith, heartwood and sapwood were used as a parameters to relate fiber density with morphology for the species *Eucalyptus citriodora (Corymbia), Eucalyptus saligna* and *Eucalyptus grandis.* Figure 1 (from a to c) shows images of *Eucalyptus grandis* wood, indicating substantial uniformity in lumen diameter for the three regions evaluated. Similar results were found for the other species studied in new poles and those removed from the network. Average lumen diameter considering all three regions (sapwood, heartwood and pith) was used to correlate timber morphology with density.

Oliveira, Hellmeister and Tomazello observed a tendency of various species of the genus eucalyptus wood basic density increased from pith to bark and each species shows a different profile of varying density in both longitudinal and cross-sections, with the species *E. citriodora (Corymbia)* the most uniform[21].

Table 1 shows the average lumen diameter of fibers for samples from untreated new poles, compared to the density value established in laboratory. Data obtained for each of the species studied was consistent with the relationship observed by Poubel et al.[22], who found a strong relationship between the density of some *Eucalyptus* species and the average lumen diameter of fibers determined using a binocular microscope from a sample pretreated. Significant differences in lumen diameter between the *Eucalyptus* species shown in Figure 2 were also recorded by Shimoyama, where the largest diameter was found in less dense timber such as *E. grandis*[16].

Given that the lumen diameter of fibers demonstrated a relationship with the density of the new poles evaluated, we extended the analysis to include those removed from service in order to confirm this correlation between the two variables. Images of samples removed from four such utility poles are shown in Figure 2 from a to d. The samples were collected from the healthy portion of the sapwood, which exhibited similar characteristics to the other regions.

Randomly selecting thirty poles withdrawn from the electricity network favored the occurrence of poles with varying service times and different treatments among the samples. Table 2 shows data obtained for pole number 6, 7 and 27, all CCA-treated and with different service times, and pole number 4, treated with creosote. Treatments using CCA, Creosote and CCA + Boron-Fluorine did not alter lumen diameter and variations in wood density were negligible. Service time within the electricity network also did not influence the data analyzed, likely because samples were taken from healthy areas of wood. Therefore, the data presented confirm that denser species exhibit smaller lumen diameter, regardless of the existence or type of treatment.

Figure 3 demonstrates the behavior of basic and apparent density, measured in laboratory, with the lumen diameter of fibers for the thirty poles removed from service. A negative correlation was found between these two variables, evidenced by the strong Pearson correlations observed. Basic density displayed more significant correlations (0.84) and *p-value* (9.27×10^{-9}) with lumen diameter when compared to apparent density (0.81 and 4.90×10^{-8}), with a significance level less than 5% in both cases. It is important to underscore that moisture is a factor that may interfere in correlations with respect to apparent/bulk density, since the latter considers damp wood, and microscope analyses were performed on dry wood.

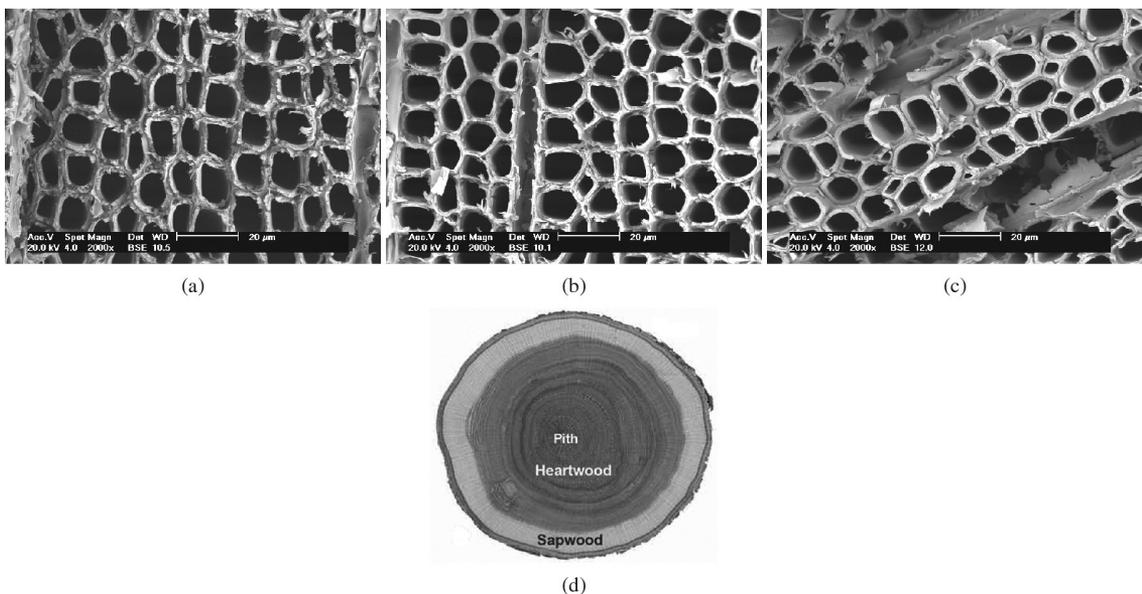(a)   (b)   (c)

(d)

Figure 1. SEM images of *Eucalyptus grandis* samples without chemical treatment. In (a) Sapwood, (b) Heartwood, (c) Pith and (d) Typical cross-section of a trunk (Adapted from the USDA)[13].

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As with the present study, Zbonak et al. analyzed variations in the morphological structure by fluorescence microscopy and density of wood among different *Eucalyptus* species and found that fiber properties significantly influenced wood density, making timber from trees with wider lumens significantly lighter[23].

There is the importance of this method of analysis, non-destructive, rapid identification for wood density,
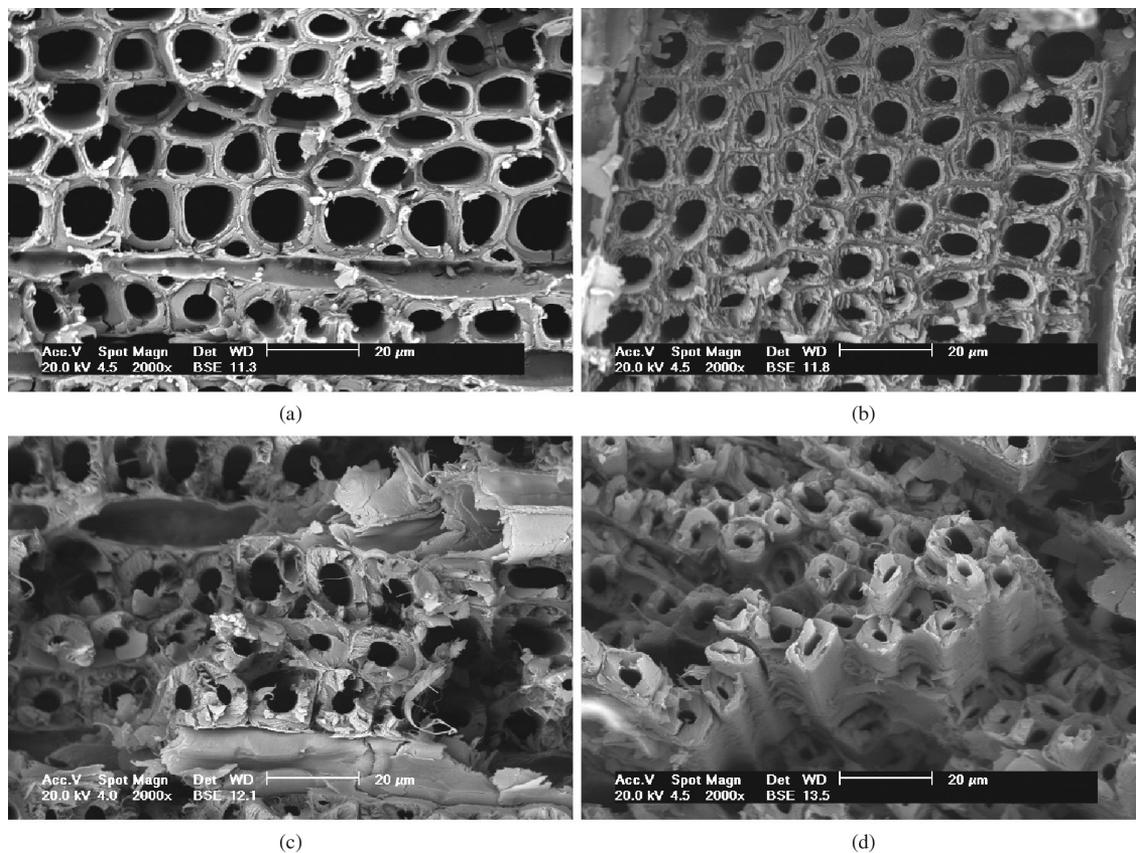

Figure 2. SEM images in cross-sections of sapwood. In (a) Pole 7, (b) Pole 6, (c) Pole 4 and (d) Pole 27.

Table 2. Average lumen diameter of fibers and wood density for decommissioned poles.

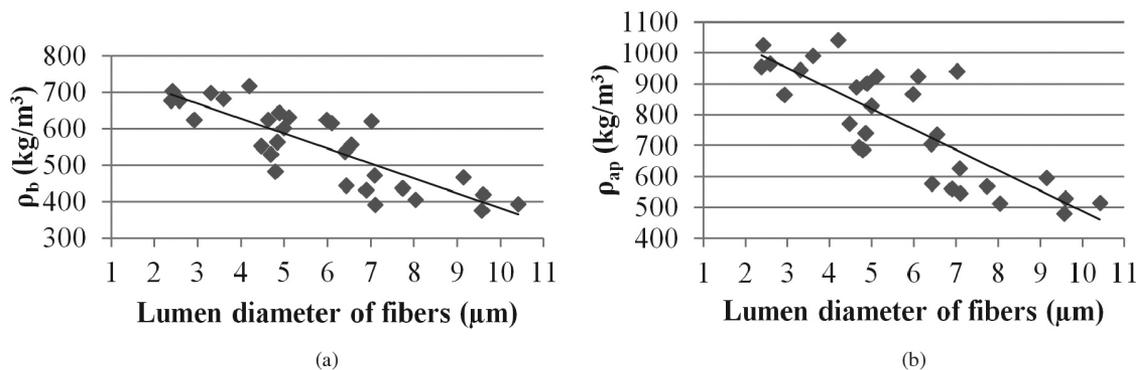| Sample	Preservative	Manufactured	w_{Lumen} (µm)	ρ_{ap} (kg/m³)	ρ_b (kg/m³)
7	CCA	2003	8.03	516	445
6	CCA	2004	6.43	580	407
27	CCA	1995	2.92	867	625
4	Creosote	-	2.38	959	678

Figure 3. Density variation with the lumen diameter of fibers. (a) Basic density and (b) Apparent density.

correlating this with the lumen diameter of the fibers, even in *Eucalyptus* wood with long time use. The species and density of *Eucalyptus* wood poles installed in the electrical network can not be easily identified by conventional methods. On the other hand, the density and the species is useful parameters which must be considered when it is necessary to establish the service life of these poles in the electrical network, that is in the determination of the actual condition of those structures[24].

3.2. *Identification of preservatives using tangential sections*

In order to locate elements of CCA in new and decommissioned poles, wood samples taken from three new poles treated with CCA and thirty poles removed from the electricity network were submitted to EDS analysis. Table 3 shows the concentrations of chromium, copper and arsenic present in the three new poles and three of those removed from service. EDS analyses conducted on three samples taken from the sapwood, heartwood and pith of a new pole (2) treated with CCA are shown in Figure 4.

EDS analyses revealed significant occurrence of chromium, copper and arsenic in only the sapwood samples for tests performed over the total area of the image, corresponding to 10 mm^2, and on specific regions of approximately 2 µm^2 over precipitates, light-colored areas and clusters. In the heartwood and pith, this technique identified none of the three CCA components. Similarly,

Santos reported that conventional analytical methods found no CCA metals in the pith, and concentrations of chromium, copper and arsenic recorded in sapwood were greater in samples taken near the trunk surface, decreasing toward the pith[20].

Figure 4a shows rounded precipitates, indicating a cluster associated to components of the preservative. Pedersen and Ottosen observed that mineral particles of chemical elements in the wood matrix may be associated or not to preservative components. Aluminum silicates and phosphates are not correlated to constituents of the preservative. Moreover, arsenic in association with calcium may form Ca-arsenate. The authors also report that a

Table 3. Total retention values for Copper, Chromium and Arsenic for samples from new poles and those removed from service preserved with CCA.

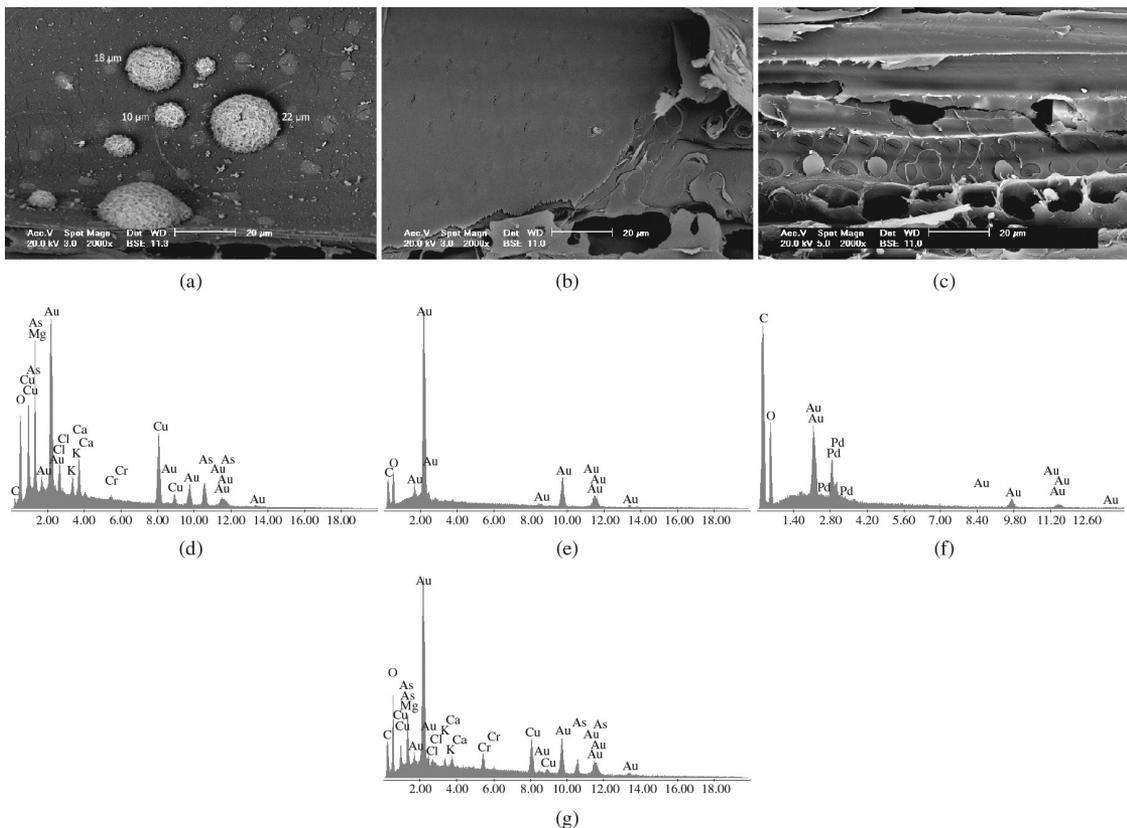| Pole	Retention (mg/kg)		
	Cu	**Cr**	**As**
New (1)	2457	3547	2834
New (2)	1778	2509	2193
New (3)	2484	3299	2762
25	847	1733	1458
27	588	781	707
28	2037	4152	1694

Source: Adapted from de Santos[20].

Figure 4. SEM images of a new pole (2) with CCA. In (a), (b) and (c) sapwood, heartwood and pith respectively. In (d), (e) and (f) EDS analysis of the total area in each of the images. In (g) EDS analysis of precipitate 1.

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substantial portion of the chromium in the preservative can be found as Cr-arsenate ($CrAsO_4$), either fixed onto the lignin or in the form of precipitates. Copper is present precipitated on the surface together with mineral inclusions and as $CuCrO_4$. In addition, arsenic may be associated with calcium, which is found in the porous regions of the timber[11]. Although EDS microanalysis only identifies the elements present in the area of the electron beam, the spectrum
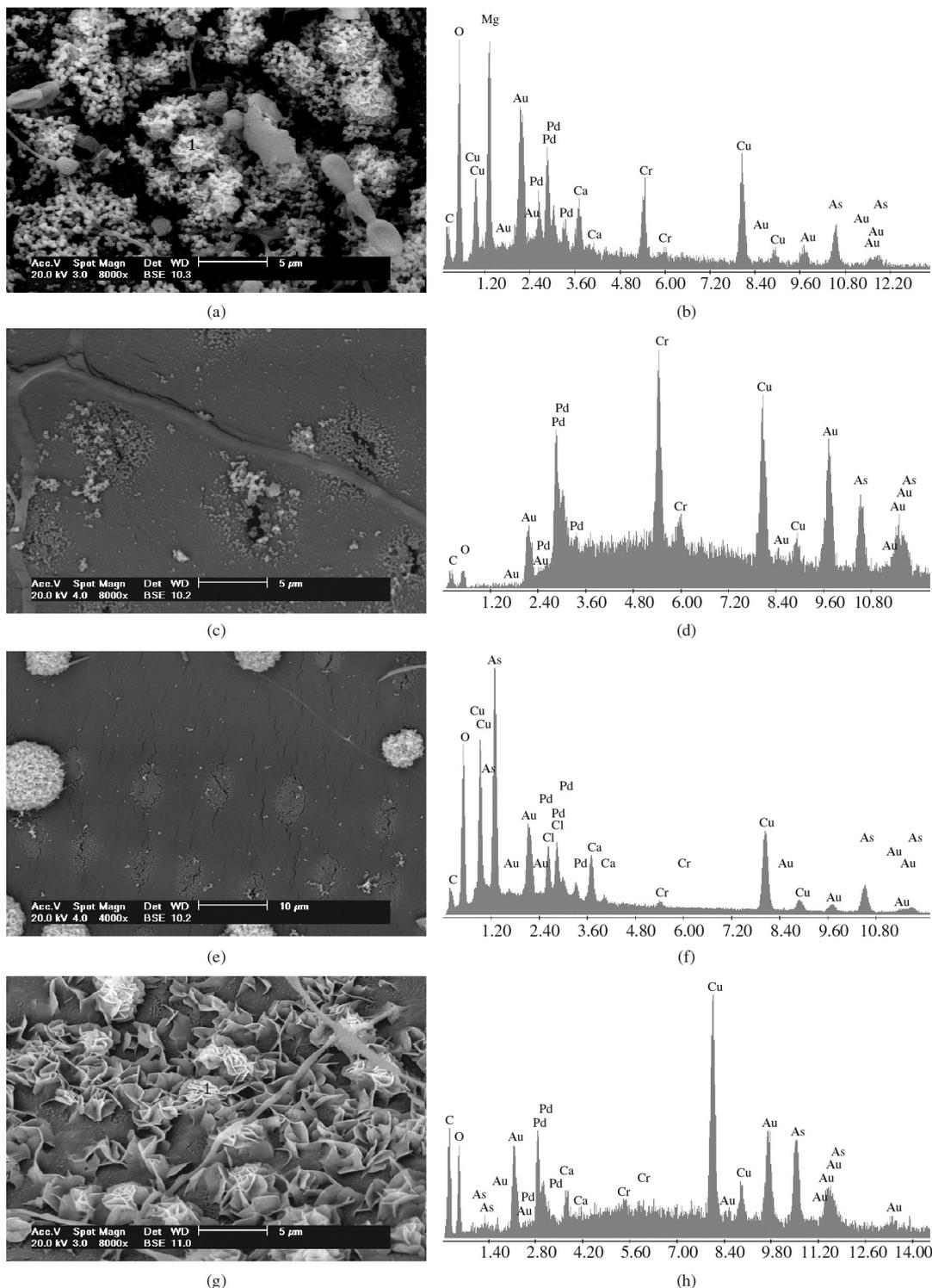

Figure 5. SEM images of the sapwood region with CCA. In (a) sample from pole (12), (b) EDS analysis of the precipitate in region 1. In (c) sample from pole (15), (d) EDS analysis of region 1. In (e) sample from pole (16), (f) EDS analysis of the total area of the image. In (g) sample from pole (27) and h) EDS analysis of the light-colored area (1).

in Figure 4g shows peaks corresponding to magnesium, potassium, chloride and calcium, suggesting that elements of the preservative are associated with wood components in the form of precipitates.

The methodology used in combining EDS analyses with scanning electron microscopy proved adequate in identifying CCA components in new poles and as such, was also applied to test poles removed from service. In both the new and decommissioned poles, chromium, copper and arsenic were detected only in sapwood samples, even for poles with several years of service. This confirms the effectiveness of chromium as a fixing agent for the fungicides copper and arsenic as reported by Van den Broeck[8], partially preventing their diffusion and dispersion, since evidence of these elements was not found in the heartwood and pith, because in the heartwood according Costa[5] formation occurs in the vessel tiles will providing a very low permeability. The sapwood exhibited several formations of preservative associated with wood components in the form of individual precipitates of varying sizes, clusters, in light-colored areas or impregnated in the timber, as shown in Figure 5.

The Figure 5 depicts a sample from the pole (12) subjected to EDS testing (Figure 5b) on a group of precipitates, in region 1. Peaks are evident corresponding to the three components of the preservative (copper, chromium and arsenic), though more intense for copper as well as magnesium and calcium peaks, predominant elements in wood.

Elements found in clusters of the pole sample (15), Figure 5c, in region 1, are also representative of the three

CCA components, as shown by the EDS spectrum in Figure 5d; however, in this case the chrome peak is more intense than the other elements in the sample. The rounded precipitates observed in the new poles treated with CCA were also present in samples of pole (16), as per Figure 5e. EDS analysis of the precipitate in Figure 5f demonstrates that, in addition to chromium, copper and arsenic, chloride and calcium are also present.

Figure 5g corresponds to the sample from pole (27), showing rosettes formed by small panels. EDS analyses of the rosettes in region 1 show greater intensity for copper peaks, followed by chromium and arsenic. A small amount of calcium, a characteristic element in wood, was also detected. Thus, there was a predominant presence of preservative in all the samples tested, irrespective of the service life of the pole. Of the twenty-three poles treated with CCA, only one did not exhibit the simultaneous occurrence of all three preservative components, with only arsenic and chromium identified in both the matrix and precipitates.

Furthermore, we observed that copper aggregated more than the other components, given that more intense copper signals were always recorded in the clusters, and not the matrix, for most samples tested.

Helsen and Hacala studied precipitates of preservative components in timber samples analyzed after burning and found precipitates of minerals associated with preservative components, whose composition and size were highly varied and different from those observed in the present study[10].

In the sapwood samples of the seven poles treated with creosote and submitted to EDS testing, only precipitates of
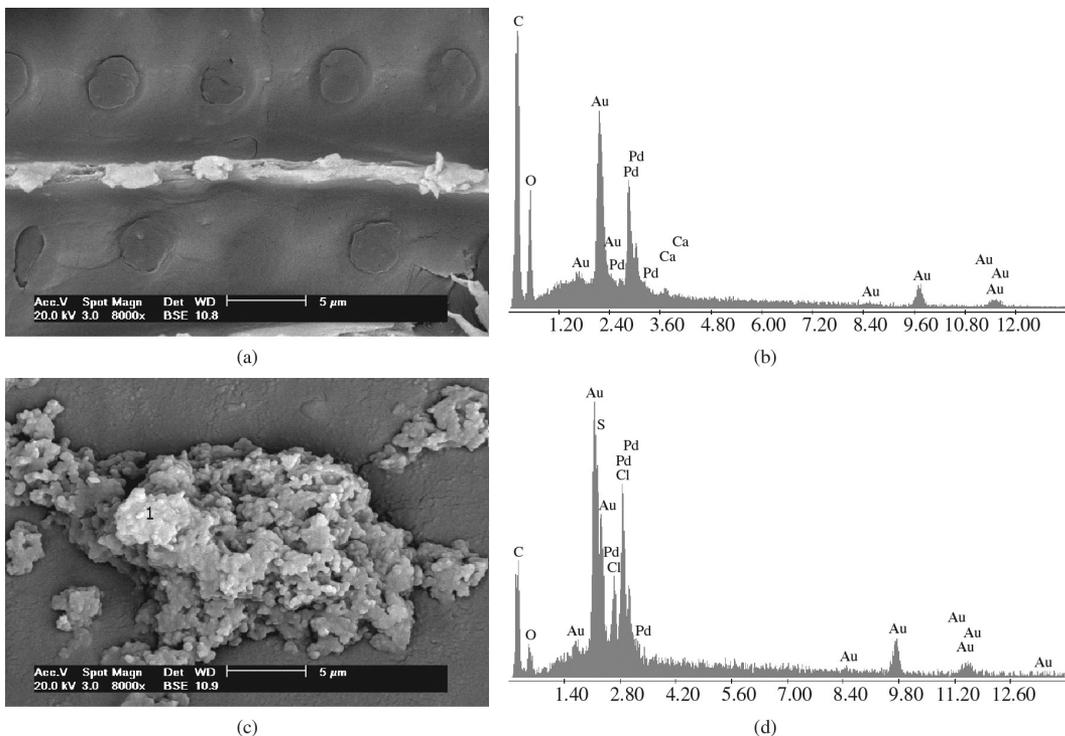

Figure 6. SEM images of the sapwood region with Creosote. In (a) SEM image of sample 4, (b) EDS on the total area for the image of sample 4, (c) SEM image of sample 29 and (d) EDS performed on the precipitate (region 1) sample 29.

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calcium, chloride and sulfur were observed, as per Figure 6. Although calcium is a characteristic element of wood, sulfur is not, and has been used in conjunction with chloride to fortify phenolic substances, increasing the toxicity of creosote, which could be an indication of the presence of this preservative in wood.

In samples of the two wood poles treated with CCA and retreated using Boron-Fluorine preservative, EDS only detected significant amounts of fluorine. Samples from new poles containing 82.0 mg/kg of fluorine showed no peaks related to fluorine or boron; however, fluorine peaks were observed in EDS spectra for samples with 362.4 mg/kg of fluorine.

Wood samples from poles treated with CCA submitted to extraction were analyzed by EDS before and after this process. Testing conducted after extraction showed a significant reduction in chromium peaks and no arsenic or copper peaks, even in samples that exhibited high concentrations of these elements prior to extraction. This decline in concentration was also observed in chemical analysis, with the resulting concentrations presented in Table 4. EDS analysis identified very low chromium content (482 mg/kg), but did not detect the presence of As (41 mg/kg) or Cu (63 mg/kg) in decontaminated wood.

In microscopes containing conventional EDS spectrometers, the established detection limit is from boron (Z=5) to uranium (Z=92); however, for safety reasons some manufacturers recommend considering sodium (Z=11) as the lower limit of detection due to the physical limitations of the technique for elements with a low atomic number. On the other hand, the minimum detectable concentration for light elements is 1.2 wt% and 1.0 wt% for heavier elements. For any result lower than these weights the element should be considered as merely "present"[25]. This is the case for boron, which has a low atomic number, and may be the case of fluorine (Z=9), however this is not true for the copper (Z=29) and arsenic (Z=33) found in the samples analyzed. Therefore, it can be established that amounts of boron were below the detection limits of the EDS equipment for wood samples submitted to extraction.

This method of analysis is important in identifying the density which may ultimately contribute to the determination of the species of wood in new poles and those in service, as well as rapidly detecting the presence of chemical treatments in timber. The identification of CCA and Creosote in decommissioned poles is significant due to the high toxicity of these preservatives, since once they are discarded and subject to weathering it is often impossible to determine whether the timber has been treated or not. It is important to note that Scanning Electron Microscopy and Energy Dispersive Spectrometry are non-destructive techniques used for compositional analysis or to define probable density among known wood species, given that samples required for analysis are very small in relation to the size of utility poles.

4. Conclusions

The lumen diameter of *Eucalyptus* wood observed by scanning electron microscopy showed no significant differences between the three regions studied within a same species (heartwood, sapwood and pith).

The average lumen diameter of fibers varied between the *Eucalyptus* species studied, resulting in substantial differences in density. The analysis method proposed proved effective for rapid and approximate determination of density for this timber.

SEM/EDS analysis was efficient in detecting the presence of CCA components, regardless of their concentration in the treated wood, enabling quick identification and helping to better distribute residues of this material, even after the extraction process. The technique was also effective in detecting high concentrations of fluorine in the wood.

Acknowledgements

Table 4. Concentrations of copper, chromium and arsenic in a decommissioned pole (33) before and after decontamination by acid extraction, and Fluorine content of poles submitted to preventive (CCA and Creosote) and curative treatment (Boron/Fluorine).

Pole	Concentration (mg/kg)			
	Cu	Cr	As	F⁻
33 – Before extraction	2063	3285	2757	-
33 – After Extraction	63	482	41	-
31	-	-	-	82.0
32	-	-	-	362.4

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Relationship between Density and Anatomical Structure of Different Species
of *Eucalyptus* and Identification of Preservatives

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Appendix - Supplementary Materials

Table S1. Results of measurements for density and lumen width of fibers for all the samples.

| | Characteristics | | | | | Density | | | | | | | | | | Lumen | | | |
Sample	Year	Length (m)	Class Inspection	Preservative	ρ_{ap} (kg/m³)	SD	SD (%)	ρ_b (kg/m³)	SD	SD (%)	ρ_0 (kg/m³)	SD	SD (%)	Class NBR 8456	A_w (µm)	SD	SD (%)	Nº Measurements
1	1991	11	2	CCA	968	30.8	3	678	18.3	3	910	37.1	4	6D	2.58	1.36	53	20
2	1994	9	3	CCA	994	15.2	2	682	8.4	1	918	17.5	2	6D	3.6	1.2	33	29
3		9	3	CCA	1028	28.2	3	704	7.8	1	965	17	2	7D	2.42	0.99	41	48
4		9	4	CRE	959	23.4	2	678	4.2	1	910	8.6	1	6D	2.38	0.6	25	21
5	2005	9	1	CCA	548	15.3	3	393	35.6	9	450	18.1	4	-	7.1	2.43	34	47
6	2004	11	1	CCA	580	33.5	6	445	32	7	522	45.3	9	1D	6.43	2.39	37	60
7	2003	9	2	CCA	516	19.9	4	407	11.5	3	468	15.6	3	1D	8.03	2.48	31	60
8	1999	9	2	CCA	630	15	2	472	12.1	3	560	17.6	3	2D	7.08	2.91	41	50
9	1998	9	2	CCA	570	10.9	2	437	2.2	0	510	3	1	1D	7.73	2.4	31	35
10	1992	9	2	CCA	482	4.1	1	376	6	2	427	7.9	2	-	9.56	3.28	34	36
11	2002	11	3	CCA	597	11.4	2	467	77.7	2	553	11.1	2	2D	9.14	3.42	37	49
12	1994	9	3	CCA	532	40.6	8	420	28.7	7	487	40	8	1D	9.6	4.51	47	33
13		9	3	CCA	563	44.1	8	433	33.7	8	504	47	9	1D	6.89	2.12	31	55
14	2000	9	4	CCA	518	8.2	2	394	8.4	2	450	11.3	3	-	10.41	2.23	21	39
15	1991	11	1	CCA	697	20.9	3	530	12.1	2	648	18.9	3	3D	4.69	1.82	39	41
16	1997	9	1	CCA	689	15.6	2	484	26.3	5	577	39	7	2D	4.79	1.68	35	38
17	1991	10	2	CCA	738	20.5	3	556	12	2	689	19.6	3	4D	6.55	2.73	42	60
18		9	3	CRE	773	35.9	5	554	29.3	5	685	47.5	7	4D	4.47	2.21	49	41
19	1985	11	4	CCA	707	57.9	8	537	37.3	7	659	58.7	9	3D	6.41	2.54	40	34
20		11	4	CCA	742	44.6	6	564	26.2	5	702	42.8	6	4D	4.84	1.82	38	46
21	1986	9	1	CRE	944	19.5	2	621	10.1	2	821	18.6	2	5D	7.01	2.69	38	33

Class Inspection: Class of deterioration of the pole, determined in the field, with 1 being the most sound pole and 4 post more deteriorated; Class NBR 8456: There are 9 classes of basic density ranging from 400 to 800 kg.m⁻³ according to the classification of the proposed revision of NBR 8456[26]; A_w: Average lumen width of fibers;SD: Standard Deviation.

Table S1. Continuation...

| | | | | | Characteristics | | | Density | | | | | | Class | Lumen | | | |
| | | | | | ρ_{ap} | | | ρ_b | | | ρ_o | | | | A_w | | | |
Sample	Year	Length (m)	Class Inspection	Preservative	(kg/m³)	SD	SD (%)	(kg/m³)	SD	SD (%)	(kg/m³)	SD	SD (%)	NBR 8456	(μm)	SD	SD (%)	N° Measurements
22		9	1	CRE	928	47	5	617	23.2	4	794	41	5	5D	6.09	2.91	48	40
23		9	1	CCA	904	12.1	1	644	11.5	2	844	21.9	3	5D	4.88	2.23	46	67
24		9	1	CRE	892	23.7	3	625	10.6	2	808	19.4	2	5D	4.63	3.98	86	36
25	2004	9	2	CCA	831	14.9	2	602	7.3	1	766	12.8	2	5D	4.98	2.61	52	34
26	1995	10	2	CCA	948	19.4	2	699	10.6	2	892	21.2	2	6D	3.3	0.84	26	26
27	1995	9	2	CCA	867	18.1	2	625	7.6	1	808	13.8	2	5D	2.92	1.2	41	39
28	1992	9	3	CCA	869	85.8	10	625	46.3	7	810	83.7	10	5D	5.97	1.71	29	29
29		9	4	CCA	928	50.8	5	632	7.2	1	821	13.3	2	5D	5.1	2.52	49	44
30		9	2	CRE	1044	13	1	717	15.5	2	994	35	4	7D	4.19	1.67	40	31
31	2005	11	2	CCA														
32	-	9	2	CRE														
33	1994	9	3	CCA														
C. citriodora	2009	9	New	SEM	979	29.1	3	697	15.3	2	951	32.5	3	6D	2.51	1.38	59	95
E. saligna	2009	9	New	SEM	781	23.3	3	589	15.5	3	744	26.4	4	4D	5	1.68	34	175
E. grandis	2009	9	New	SEM	563	41.1	7	440	26.4	6	515	37.4	7	1D	7.94	2.33	29	150
New (1)	2009	9	New	CCA	649	51.8	8	440	18.5	4	514	26	5	1D				
New (2)	2009	10	New	CCA	536	10.4	2	398	5.4	2	456	7.2	2	-				
New (3)	2009	11	New	CCA	658	91.6	14	425	30.4	7	493	41.6	8	1D				

Class Inspection: Class of deterioration of the pole, determined in the field, with 1 being the most sound pole and 4 post more deteriorated; Class NBR 8456: There are 9 classes of basic density ranging from 400 to 800 kg.m⁻³ according to the classification of the proposed revision of NBR 8456[26]; A_w: Average lumen width of fibers;SD: Standard Deviation.