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USE OF *Eucalyptus grandis* CLONES TREATED WITH A WATER REPELLENT TO IMPROVE THE DIMENSIONAL STABILITY OF UTILITY POLES

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ABSTRACT

Wood is a common construction material used in most environments. However, its sensibility to abiotic agents, in particular those that affect the dimensional stability, limits the durability of the material and decreases its properties. In this work, the efficiency of a paraffin-emulsion-based product as a water repellent, combined with the selection of *Eucalyptus grandis* clones with a low cracking index, was tested for its use in utility poles in order to improve the woods dimensional stability. Four selected *Eucalyptus grandis* clones were treated with the product mixed with Chromated Copper Arsenate - the most commonly used wood protector - in a single stage by the Bethell method at two retention levels. The dimensional stability of the treated samples was studied through the determination of anti-shrink efficiency. Test samples were also exposed to accelerated weathering processes for 200 h, and later analyzed by SEM microscopy. Results showed a significant improvement in the dimensional stability of treated wood when compared to samples without the water repellent, with variable efficacy depending on the clone used. Despite the weathering process slightly affected the appearance of the wood surface, the product is suitable for exterior use.

Keywords: Anti-shrink efficiency, dimensional stability, *Eucalyptus grandis*, shrinking-swelling, water repellent, wood poles.

INTRODUCTION

Commonly used in civil construction among other outdoor applications, wood is highly sensitive to abiotic agents such as water, humidity, wind, oxygen, pollutants, or radiation. Such agents, alone or in combination with biotic agents, limit their durability and decrease their properties. For example, when untreated wood is used in a humid environment, it swells, as it absorbs water from the environment between the microfibrils and tends to separate them. Likewise, when the environment is dry, wood loses water and the forces of cohesion in hollow spaces tend to bring its microfibrils closer, contracting the wood (Oliveira *et al*. 2010). This dimensional instability that occurs below the fiber saturation point, is due to the hygroscopicity of the material, influenced by the chemical composition of the wood. This phenomenon does not include changes in the shape of the wooden pieces due to internal stresses (Sargent 2019). Another example is solar radiation, an abiotic agent that deteriorates wood exposed to the elements. Although its action

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is at a superficial level, producing a negative effect in the coloring of the wood that does not compromise its structure; nevertheless, it causes microfissures that deepen over time, even if the wood was treated. When this microfissures are combined with dimensional variations due to the effect of ambient humidity, entrance doors for biotic agents are created, rapidly decreasing the useful life of the wood product in service.

Frequently, on top of the effects, the aforementioned abiotic agents have on the wood is the fact that many wood species present growth stresses in their trunks, which are released when the tree is felled. These stresses are generated during the growth and maturation of cells in the youngest rings of the tree, which tend to expand laterally and contract longitudinally, while there is resistance in older tissues. This leads to a high degree of stress by having tension on the surface of the trunk and compression in the center (Richter 2015, França *et al*. 2020). While the tree is standing, the stresses are balanced across the trunk; when dislodged, the tissues under tension tend to contract longitudinally (periphery of the trunk) and those under compression (center of the trunk) tend to expand longitudinally (Oliveira *et al*. 2010). This causes cracks at the ends of the logs and subsequently, various types of warp (bends, arches, etc.) in the sawn pieces. Likewise, if the wood dries below the fiber saturation point, the so-called “seasoning cracks” are produced, which generates new radial cracks on the surface (Richter 2015). These phenomena are very common in different species of the *Eucalyptus* genus.

Argentina (northern region of Entre Rios and southern Corrientes) and Uruguay (northern and western region of the country) present 1,2 million and 1,1 million planted ha respectively, of which between 70 and 80% are *Eucalyptus*. Both countries use significant volumes of *Eucalyptus grandis* in house construction (structural parts and door and window frames), civil construction, furniture, decks and utility poles. The growth site has a positive effect on the quality of the *Eucalyptus grandis* wood; this species is fast growing, and has good mechanical properties for specific uses. One of the biggest problems for solid use is its great growth stresses; these are generally quantified through the log cracking index, by either direct measurements or indirect measurements with the applied mathematical models (Hernández *et al*. 2014). This characteristic has a high genetic control (López *et al.* 2018*)*.

In some applications, this phenomenon is a problem that shortens the wood life span. As *Eucalyptus grandis* utility poles, used in Argentina and Uruguay, have a maximum of 2 cm of sapwood that can be protected by impregnation, the cracks in its surface ultimately lead to fungal damage. Strategies have been implemented to mitigate these effects. One of them is the use of clones which allows to choice and use of a unique genotype of the low cracking index, selected among many other individuals. Other properties of interest are growing homogeneity, stem shape, quality of the wood and tolerance to biotic or abiotic factors (Freitas *et al*. 2016).

Impregnation of wood with acidic or alkaline salts would be expected to improve its dimensional stability by decreasing the availability of OH groups of the wood constituent polymers; however, Arantes *et al*. (2017) demonstrate that CCA (Chromated Copper Arsenate) does not improve either the dimensional stability or the coefficient of wood anisotropy of *Eucalyptus urophylla x E. grandis*. The addition of a water repellent - linseed oil, waxes, silane, methyl methacrylate, polyethylene glycol (PEG), aqueous solutions of phenol-formaldehyde resin-forming compounds, styrene or methyl methacrylate (Chau *et al*. 2015) - can improve all the aforementioned effects.

The present work studies the improvement of the useful life of *E. grandis* utility poles by decreasing superficial damage induced by weathering or humidity -which leads to biotic damage. Two strategies are combined: the selection of low cracking index *E. grandis* clones, and the application of a water repellent -in development by Argentinian industry - capable of being applied in a single stage mixed with CCA.

MATERIALS AND METHODS

For this study, four *Eucalyptus grandis* clones of the low cracking index (116, 2155, 102, and 130) from south Corrientes, Argentina, were used. Five individuals of each clone were chosen due to their growth characteristics (diameter, total height, trunk straightness, and average annual growth), to be debarked. They were then treated by the Bethell method- 30 minutes vacuum, 60 minutes at 18 kg/m^2 pressure, 30 minutes final vacuum- with a CCA-WR (water repellent) mixture at three concentrations (0

%; 0,45 % and 4,0 % of water repellent in water). A double door industrial autoclave of 22,50 m (length) x 1,94 m (diameter) with a total charge volume of 66 m^3 was used in República Argentina. The water repellent used is an aqueous paraffin-based emulsion, which is able to stay emulsified for more than 4 hours without stirring. It does not foam and is compatible with preservatives such as CCA (Chromated Copper Arsenate). It tolerates pH between 1,6 and 3,2 so it can be applied in a single stage, mixed with the preservative. It prevents water absorption, cracking, and swelling.

Once impregnated with the mixture and past its fixation period, ten (10,0 long x 10,0 tang x 3,0 rad) cm sapwood samples were cut from each of the individuals. The samples were then taken to the Forest Laboratory of Sede Tacuarembó of the Universidad de la República, Uruguay for the subsequent tests. There, the Anti-Shrink Efficiency (ASE), as a measurement of the dimensional stability of the wood, was determined along with the anisotropic coefficient.

Dimensional stability assessment

Five (3,0 rad x 4,0 tang x 2,0 long) ± 0,1 cm wood specimens were cut from each of the sapwood samples. The commonly used *Eucalyptus grandis poles*-treated only with CCA at a 12 kg/m^3 retention, were taken as reference.

Untreated, reference and treated wood specimens were immersed in water at room temperature for 10 days, almost reaching saturation. Past this period, they were weighed, and their length, width and thickness (longitudinal, tangential, and radial direction respectively) were measured with a digital caliper with a 0,01 mm accuracy, at previously marked points. The wood specimens were put in an oven at 40 °C overnight, then dried at 103 °C until constant weight, and finally measured and weighed again. This cycle was repeated three times (Rowell and Youngs 1981).

The moisture content of the treated samples was determined and the Anti-Shrink Efficiency, ASE (Rowell and Youngs 1981, Skaar 1988, Sargent *et al*, 2015) was calculated according to the following Equation 1:

$$ASE(\%) = \frac{\left[\left(\frac{vr_{WS} - vr_{OD}}{vr_{OD}}\right) - \left(\frac{vt_{WS} - vt_{OD}}{vt_{OD}}\right)\right]}{\left(\frac{vr_{WS} - vr_{OD}}{vr_{OD}}\right)} \; x\ 100 \qquad (1)$$

Where: vr_{ws}- volume of the reference samples after water soaking (mm^3); vr_{OD}- volume of the reference samples after oven drying (mm^3); vt_{ws}- volume of the treated samples after water soaking (mm^3); vt_{OD}- volume of the treated samples after oven drying (mm^3).

The wood specimens were later conditioned in a conditioning chamber at 22°C and 85 % relative humidity for 20 days until equilibrium humidity moisture content was reached. They were then weighed, and their dimensions were measured again with the digital caliper at the same previously marked points. Subsequently, they were oven dried at 103 ± 2 ºC, until constant weight, in order to determine dry mass and dimensions.

Finally, the anisotropy coefficient of all specimens was determined by the following Equation 2:

$$CA = \beta \frac{t}{\beta r} \qquad (2)$$

Where: CA: anisotropy coefficient (dimensionless); βt: maximum tangential shrinkage (%) and βr: maximum radial shrinkage (%).

Maximum tangential and radial shrinkage were determined from the saturated and oven dry dimensions of the wood specimens according to Equation 3:

$$\beta(r,t) = \left(\frac{d_v - d_s}{d_s} \right) x\ 100 \quad (3)$$

Where: β (r,t): maximum shrinkage (%); d_v: saturated dimension (mm); and d_s: dry dimension (mm), in a given structural direction.

Artificial weathering test

All samples, including controls, were subjected to an artificial weathering test, exposing one side of each specimen to a UVA 340 fluorescent lamp at an irradiance of 0,98 W/m^2 in a custom solar chamber for a total of 200 hours (Nagarajappa and Pandey 2016). Every 5 hours, the specimens were moistened in order to maintain 70% RH.

Superficial damage caused by radiation was quantified using a 0-5 scale, where 0 is extreme damage and 5 no damage (Michelman 2009). Microscopical analysis was performed with a JCM 6000 Plus (JEOL Ltd, Tokyo, JP) scanning electronic microscope (SEM) in high vacuum conditions, operating at 10KV in SED mode (Secondary Electron Detector).

Finally, wood specimens were put in the weathering chamber at 22 °C and 85 % relative humidity for 10 days. Tangential shrinkage of wood specimens of all clones was compared before and after weathering according to the following Equation 4:

$$\beta(t) = \left(\frac{d_h - d_a}{d_h} \right) x\ 100 \quad (4)$$

Where: β (t): shrinkage at H humidity content in tangential direction (%); d_h: tangential dimension at H humidity content (mm); d_a: tangential dimension at anhydrous condition(mm).

Statistical analysis

A variance analysis model of one way (ANOVA, oneway) was applied to the results for a p value=0,05. Means were compared by the Tukey test.

RESULTS AND DISCUSSION

Dimensional stability evaluation

Since there are no standardized methods to determine the dimensional stability of the wood (Sargent 2019), water soaking test was chosen, as it emulates the humidity conditions of wood in service; utility poles not only withstand the variability of external environmental conditions but are sometimes in contact with liquid water.

Figure 1 shows the ASE values (%) of the sapwood samples treated with the CCA-water repellent mixture at two concentrations (0,45 and 4%), for the four *E. grandis* clones tested. ASE values were calculated from the averages of the 5 measurements of the wood specimens of each clone. *E. grandis* wood commonly used in utility poles (not from the selected clones) -treated with CCA by the Bethell method at retention of 12 kg/m^3- was taken as reference. Figure 1 shows that only clone 2155 presented significant differences; the effectiveness of the water repellent is conditioned by the clone; for example, the anti-shrink efficiency barely exceeds 20 % for clone 116, while for clone 2155 it reaches 90 %. This dependence on the clone could be explained by the fact that the water repellent is applied in a pressure process, which involves the deep penetration of the product into the wood. This process lines the interior of the individual cellular cavities, so its distribution depends on the characteristics of wood, such as its permeability and interfacial surface tension (Skaar 1988). Although the *E.grandis* clones tested were chosen for their low cracking index, they have different characteristics - such as density (López *et al*. 2018, Arango and Tamayo 2008) - among them, which can create microenvironments inside the wood with their own characteristics, which behave differently against water repellent.

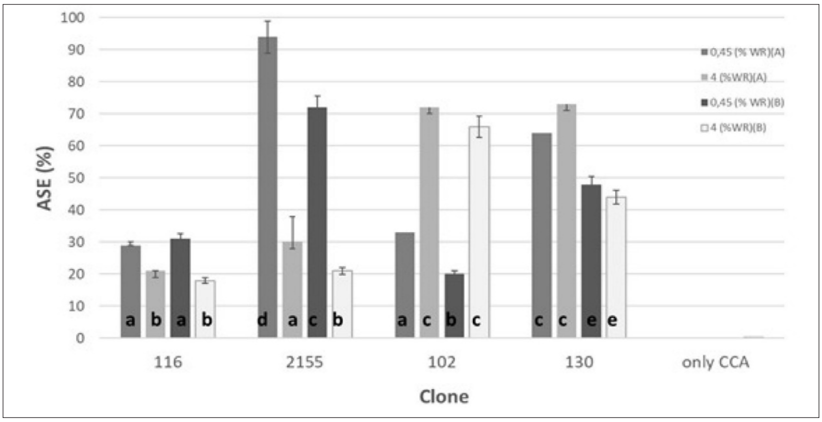

Figure 1: ASE values graph of each *E. grandis* clones tested at two water repellent (WR) concentrations (0,45 % WR and 4 % WR)
Conditions for ASE calculation: A - anhydrous and saturated; B - anhydrous and RH equilibrium at 22 °C and 85 % RH. Equal letters indicate no significant differences between treatments, according to the Tukey test.

In order to approximate the test conditions to the ones of the wood in service, the ASE (%) was determined on the equilibrium moisture content at 22 °C and 85 % RH. The results maintain the tendency shown by the previous test (on anhydrous and saturated conditions Figure 1). Under these conditions, none of the clones reaches a moisture content above 17 %. This can be due to both the water repellent presence and the fact that wood loses hygroscopicity after oven dried at 103 °C and an RH under 96 % (Hoffmeyer *et al*. 2011).

It can also be observed in Figure 1 that there is no correlation between the water repellent concentration and its effectiveness; only for clone 102 the effectiveness increases with the concentration. For this test, the water repellent had a higher effectiveness when applied to clone 2155 at a lower concentration.

The equilibrium moisture content of the different clones treated with CCA-water repellent mixture at each stage of the test was also analyzed, as well as the anisotropy coefficient of each one of them; Figure 2 shows the results.

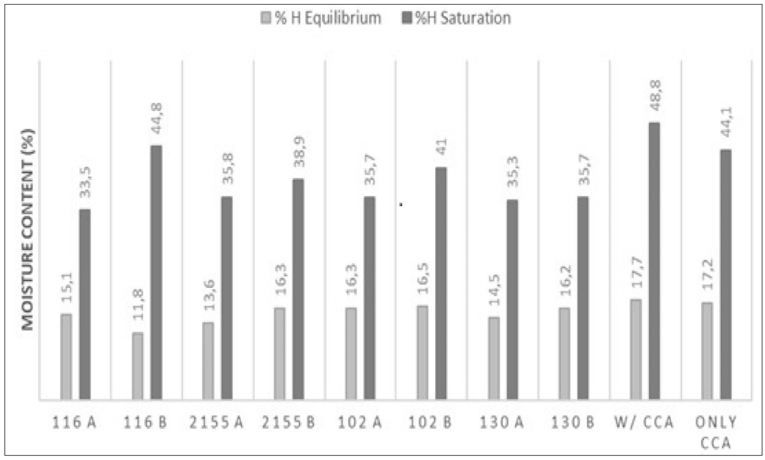

Figure 2: Moisture content reached by the four clones under study as well as the control and untreated wood specimens. A = 0,45 % WR; B = 4 % WR (WR water repellent)

For the most extreme condition of the test – saturation – untreated *E. grandis* wood reached a moisture content of 48,8 %; when treated with CCA alone, it decreases to 44 %. Clones 116 (0,45 % WR), 2155 (0,45 % WR),102 (0,45 % WR) and clone 130 (at both concentrations) achieve the lowest equilibrium moisture content values (<40 %) under these conditions. As mentioned above, this could be explained by the anatomical and chemical differences (quantity and type of extractives) between the clones, which may create different microenvironments inside the wood, which in turn affect the effectiveness of the water repellent.

Since the anisotropy coefficient depends on the dimensional variation, it is an indicator of potential defects such as deformations and cracks. As reported by Coronel (1994), woods with coefficient values between 1,2 and 1,5 can be considered excellent, while between 1,6 and 1,9 are classified as normal; those with values over 2,0 present difficulties for certain uses. As shown in Table 1, according to this parameter, WR treated clones 2155 (0,45 % WR) and 130 (4 % WR) classify as excellent; all clones classify as normal for both WR concentrations, with the exception of clones l02 and 130 at a WR concentration of 4 %.

Table 1: Anisotropy coefficient for the four clones under study as well as the control and untreated wood specimens.

	Anisotropy coefficient (%)	
Clon	0,45 % WR	4 % WR
116	1,6	1,9
2155	1	2
102	1,9	2,1
130	1,8	1,4
without CCA	2,2	
only CCA	2,2	

WR: water repellent

Artificial weathering test

According to Cogulet *et al*. (2018), the term weathering describes any surface degradation of the wood resulting from a wide range of environmental factors. Therefore, the scale used to quantify the superficial damage takes into account microcracks, roughness, fibrous areas and color changes. Figure 3 shows the variation in the surface appearance of the different clones according to the exposure time. A faster and greater deterioration can be observed in the samples without treatment or treated only with CCA. This indicates that the water repellent resists degradation in a humid environments after 200 hours of radiation, but does not implicate that the water repellent provides any protection against radiation.

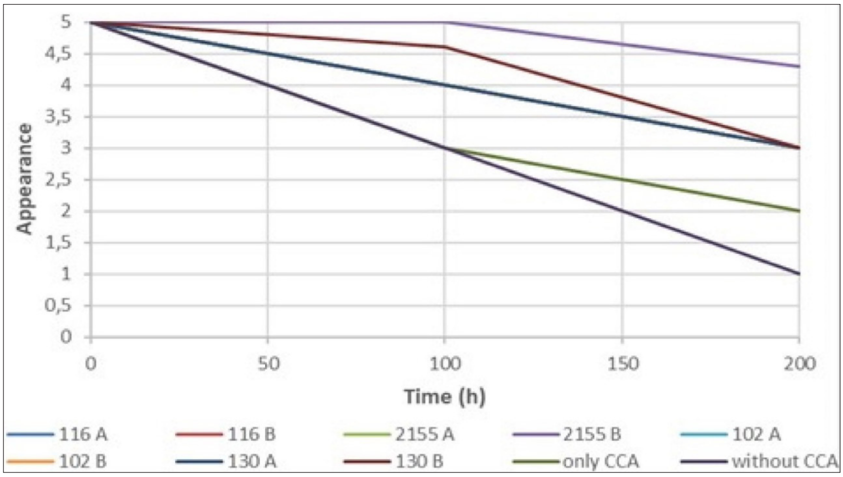

Figure 3: Appearance of artificial weathering exposure.
A = 0,45 % WR; B = 4% WR (WR water repellent)

As shown in Figure 4, when comparing before and after weathering the maximum tangential shrinkage coefficient (%) – considering saturated and oven dry dimensions - increases, with the untreated and the only - CCA treated specimens having significantly higher values.

Figure 4: Coefficients of maximum tangential shrinkage β (%) before and after weathering.
A: 0.45 % water repellent, B: 4 % water repellent.

Microscopic analysis of the specimens shows that the surface of clones 2155 (0,45 % WR), 102 (4 % WR) and 130 (0,45 % WR) show less deterioration after weathering, when compared to other clones. Figure 5 compares two of these clones with untreated wood; it can be observed that the untreated wood tends to shred as a result of radiation, while treated clones show much less damage regardless of the WR concentration.

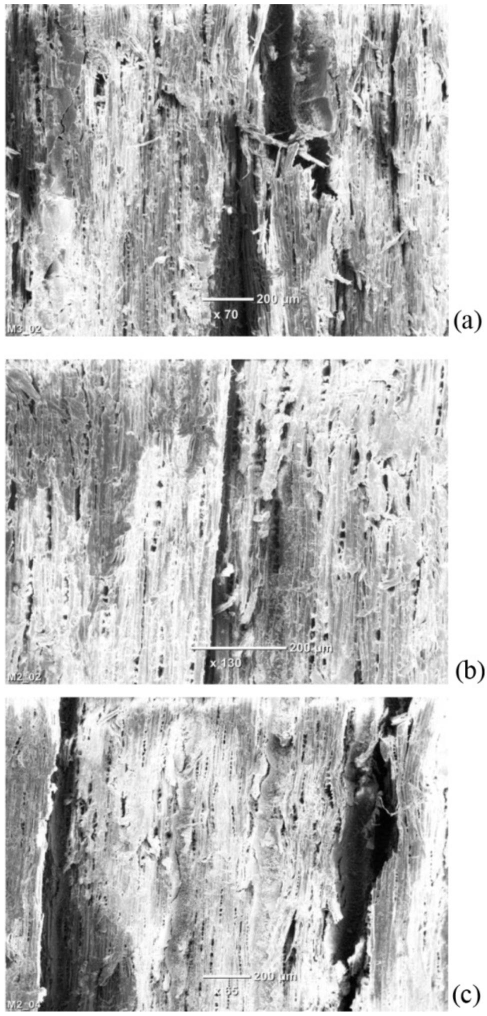

Figure 5: SEM images of the surface of three samples after the weathering test, all at 200µm: (a) samples without CCA or WR; (b) 130 (0,45% WR) and (c) 102 (4% WR).

Finally, it can be observed that clone 130 does not change its behaviour, regardless of the concentration of the water repellent; meanwhile, clone 2155 is the most dimensionally stable at a WR concentration of 0,45 %.

The WR lowers the equilibrium moisture content of the wood. It had the best performance when applied to clone 2155 at the lower concentration. Based on the number of samples tested, the link between WR concentration and efficacy can't be conclusively asserted.

The combined strategy of selecting *E. grandis* clones with a low cracking index and applying an aqueous paraffin-based emulsion as a water repellent to increase the useful life of utility poles shows promising results. The paraffin reduces water absorption, increasing dimensional stability even when the wood is exposed to humid conditions. After exposure to accelerated weathering tests, the surface of the wood was slightly affected, with minimal cracks and roughness, indicating that the water repellent can change as a result of radiation, or can slightly degrade. There is always a certain dimensional stability loss after weathering, but the control specimens (neither selected clones nor treated with the WR) show significantly higher values. It should be noted the main advantage of the WR is that it can be applied in a single stage mixed with the preservative, since it does not require other inputs such as solvents (Can and Sivrikaya 2016) or temperature (as in the application of zinc chloride-silicone oil) (He *et al*. 2019).

CONCLUSIONS

The selection of suitable clones and the application of the WR synergize, improving their effectiveness on dimensional stability, reducing superficial damage and preventing the entrance of biotic agents.

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