International Journal of Current Research and Applied Studies, (IJCRAS)

ISSN: 2583-6781

available at https://ijcras.com/

Volume 2 Issue 6 Nov-Dec 2023

Page 11-25

PRESERVATION IMPACT: CHROMATED COPPER ARSENATE TREATMENT AND ITS INFLUENCE ON FLEXURAL AND SHEAR PROPERTIES OF GLUE LAMINATED EUCALYPTUS GRANDIS

Ahamada Zziwa[1]*, Allen Kyolaba Nabacwa[2], Simon Kizito[2] and Agatha Syofuna[2]

[1]Department of Agricultural and Biosystems Engineering, College of Agricultural and Environmental Sciences, Makerere University, P.O Box 7062, Kampala (Uganda)
[2]Department of Forestry, Biodiversity and Tourism, College of Agricultural and Environmental Sciences, Makerere University, P.O Box 7062, Kampala (Uganda)

*Corresponding Author: engzziwa@gmail.com and ahamada.zziwa@mak.ac.ug
Orcid https://orcid.org/0000-0002-7258-2156

ABSTRACT

This study examined the impact of Chromated Copper Arsenate (CCA) preservative treatment on specific mechanical properties of glue-laminated Eucalyptus grandis wood. Prior to glulam specimen preparation, wood with moisture content (MC) below fibre saturation (25±5%) underwent CCA pressure impregnation using the full Cell method. During impregnation, timber ends were sealed with PVC gel to restrict end penetration. Post-treatment, timbers were air-dried for a week, then kiln-dried to 10±3% MC, yielding an average preservative penetration and retention of 17.5±2 mm (62%-78%) and 181±11 kgm-3, respectively. Test specimens were prepared and evaluated for Modulus of Elasticity [MOE], Modulus of Rupture [MOR], and shear strength following ASTM D198 and BS373 using a Universal Testing Machine at the Department of Forestry Biodiversity and Tourism Wood Testing laboratory. Delamination percentage was assessed using the soaking delamination test. Each test employed 20 replicates, with untreated samples serving as controls. Levene's test was used to analyze flexural properties (MOE and MOR), and one-way ANOVA was used to assess shear properties at a 95% significance level. Results indicated a 19.1% and 13.3% decrease in MOE and MOR, respectively, for treated glulam samples. Shear strength properties also declined by 3.3%. However, no delamination occurred in any glulams. Treated wood glulams exhibited lower MOE, MOR, and shear strength compared to untreated glulams, with no significant differences in strength properties observed. It is recommended that glulams from CCA-treated Eucalyptus grandis be avoided for high structural applications but could be suitable for lightweight construction projects.

Keywords: *Eucalyptus Grandis*, CCA preservation, Glulams, strength properties, MOE, MOR, Shear strength

1. INTRODUCTION

Previously in Uganda, until early 2000s, tropical hard wood species were preferred in construction for furniture; batten bodies and other high value wood composites due to their authentic appearance and natural durability (Coulson, 2011). However, at present there is a reduction in exploitation of hardwoods species to allow for regeneration of the natural forests that were heavily degraded due to excessive extraction of hard woods (Zziwa et al., 2009). To cover the supply deficit, the demand for timber and other value-added wood panel products has shifted to plantation species namely Eucalyptus, Cypress and Pinus sp (Wessels et al. 2014; Zziwa, et al., 2020). In fact, plantation grown Eucalyptus is currently the top of the previously lesser utilised species preferred for manufacturing a variety of products such as furniture, wood cabinets and house roofing. It has a high biomass accumulation rate resulting into a maturity span between 6-12 years depending on the end-use however, the average harvesting time for most construction works is 10 years (Sseremba et al., 2016).

Despite the fact that lesser utilized specialized species such eucalyptus are taking center stage to cover the wood supply gap, there are still setbacks on their wide scale utilization. For instance, compared to other substitute materials for construction, wood is more susceptible to deterioration from several environmental factors which include insect attacks and moisture variations (Temiz et al., 2010). When it occurs, the deterioration drastically decreases the strength properties of wood, which adversely affects the useful life of wood derived products (Isaksson et al., 2013; Brischke & Meyer-Veltrup, 2016). To extend the service life of eucalyptus derived wood products, several chemical treatment preservation methods are employed. The treatment involves use of either water-soluble preservatives like Ammoniacal Copper Quaternary (ACQ), Ammoniacal Copper Zinc Arsenate (ACZA) and Chromated Copper Arsenate (CCA), or oil-based preservatives such as Creosote (Yang et al., 2008). However, from recent research reports water-soluble preservatives are the most used and make wood more resistant to a wide range of xylophagous organisms (Boschetti et al., 2016). In Uganda, pressure impregnation with either Creosote or CCA is the two most commonly used wood preservation methods (Ssemaganda et al., 2011). However, concerning wood panel products, not much research has been done on the effect of CCA preservation on the mechanical behaviour of Eucalyptus wood especially in glue-laminated products a.k.a Glulam. Glulam products have been successfully applied in construction as building materials (Raftery & Whelan, 2014) because with application of Glulam technology timbers with low density can be improved to a higher grade (Mohamad et al., 2016; Mohamad et al., 2014). Nonetheless, because they are derived from wood, they need chemical pretreatment to protect them from biological degradation (Wang et al., 2018).

This study focused on evaluating the effect of CCA preservative treatment on delamination ratio, shear, and flexural properties of Eucalyptus. The study was based on the premise that understanding the effect of CCA as a wood preservative on the mechanical properties of glue laminated eucalyptus will contribute to reduced wood wastage since glue laminated timber makes use of smaller and less desirable dimensions of timber engineered to be stronger and larger than the similar sized timbers made of solid wood. The study findings are envisaged to provide information to manufacturers and local artisans to improve their production processes.

2. MATERIALS AND METHODS

2.1 Materials

The wood samples were of Eucalyptus grandis species and these were obtained from a pure stand aged 10 years privately owned forest owned by Namwasa Sawmilling Company in Mubende District (0° 33' 14.0436" N and 31° 23' 18.4848" E.). Within the plantation plots of 3 plots of 10 m*10 m were made from an area of 100 m *100 m and from 3 plots 10 trees per plot (straight with no observable defects) were randomly selected, felled and crosscut using a power saw. After crosscutting, the harvested boles (top diameter of 25-35 cm and bottom diameter of 20-30 cm and length of 4 m) taken from bottom and middle parts of the tree were quarter sawn into timber of standard length (4 inches*2 inches *4 m using a portable wood-mizer sawmill. The sawn timber was stacked in a shelter and allowed to air dry to below fibre saturation moisture content (~28%).

2.2 Sample preparation for preservative treatment

From the initial sawn timber volume, the best 20 pieces were purposively selected based on visual grade i.e. no drying (splits, bends, warpage, and other serious defects) and growth defects (knots, collapsed wood etc) from which a total of 300 samples specimens with dimensions of 300 mm × 25mm × 25mm (L*W*H, see Figure 1) were obtained for use in the CCA treatment and subquently the Glulam production. The moisture content of all pieces was conditioned to 12±2% (BS EN 408) prior treatment using an electric timber kiln. For CCA treatment 150 specimens were used based on the full-cell CCA pressure impregnation method. The treatment procedure was done as follows; firstly, the wood specimens were placed into an impregnation vessel and preliminary vacuum was applied for 60 min (Francis and Zaidah, 2018), which removed some air from the wood to increase uptake and penetration of the preservatives into the wood. Treatment solutions were prepared from CCA-C wood preservative commercial formulation K-33TM (C-60), manufactured by Timber Specialties Ltd., containing 29.50% chromic acid, 20.00% arsenic pentoxide, and 10.50% copper oxide The concentration of the final preservative solution was 1.6% (active ingredients (AI) of CCA) and this was poured into the vessel from a storage tank and pressure applied for 2hrs at a pressure of 1.38N/mm2 (Francis and Zaidah, 2018). A final vacuum was applied for 15 min, to remove excess preservatives from the wood following the treatment as per the AITC 109.1 (2007) standards for preservative treatment of Structural Glued-Laminated Timber. The quality of the preservative treatment was evaluated via penetration and retention tests.

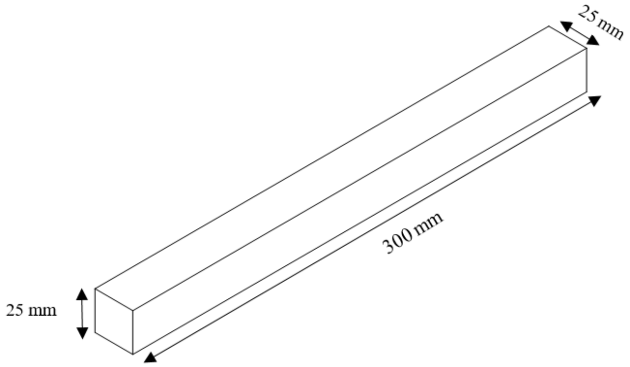

Figure 1: Specimen geometry of the lamella before gluing

2.2.1 Determination of CCA penetration

Peripheral partial penetration and total penetration evaluation was considered (Brito et al., 2020). Three wood borings per sample were extracted 100 mm from the butt end (Theoretical Ground Line), at mid-length (200 mm and 300 mm) from the top end using a wood borer. The borer was drilled 20,4mm (0.82 inches) deep into the wood thickness. The borings were spread on a graduated plate where the dark part covered by CCA was observed and its length measured (Mugabi and Thembo, 2018).

2.2.2 Determination of CCA retention

Using the same borings that were used to determine CCA penetration 6,5 mm (0,25 inch) part of the boring was cut and discarded. The remaining 13.9 mm (0,547 inch) of the boring was weighed and recorded. Triplicate samples of approximately 2 g of treated borings were placed in a syphon-type extraction cup held in the neck of a flask and extracted using……. The CCA concentration was determined UV-Vis spectrophotometry following the procedure detailed by Suzana Radivojevic and Paul A. Cooper (2007). Conversions of treatment retentions to standard units (kg/m3) were based on basic relative densities (ASTM D 2395-93).

2.3 Manufacture of Glulams

Prior to glulam production the previously pretreated and untreated samples were condition to moisture content of 10±2%. The dried wood was then made into the glulam laminates of two pieces of timber with lamella size of 20 mm × 40 mm × 300 mm in length using Urea–formaldehyde (UF). The UF was applied as supplied without any dilution and according the manufacture specification the pH value, density and gelation time were; 7.0, 1.1g/cm3 30 mins. During gluing the UF was clearly smeared onto the wood lamellae to achieve a spread of 0.26kg/m2 which is recommended for use at these standard conditions (Henkel, 2015 and Pröller, 2017). After gluing and perfect alignment, the specimens were pressurized and cured for 48 h using pressing clamps (Fig 2). After forming a tight bond, the final dimensions of the glulam were 40 mm in thickness, 20 mm in width and 300 mm in length in accordance to ANSI/AITC standard A190.1 for structural glue laminated timber.

Figure 2: Fabrication of the glulam

2.4 Laboratory tests

2.4.1 Bending test

The specimen for the bending test was 40 mm in thickness, 20 mm in width and 300 mm in length in accordance to ASTM D3737(2007) and a total sample of 60 pieces (30 treated and 30 untreated) were tested

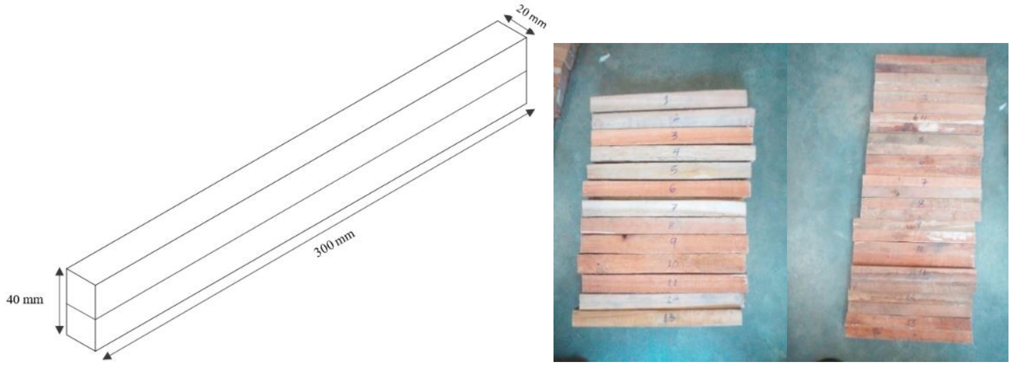

Figure 3: Specimen size for bending test

The bending test was carried out using the Universal Testing Machine by three-point loading method at a loading rate of 6mm/min as per ASTM D198 (2003). The Modulus of Elasticity and Modulus of Rapture were calculated using equations (1) and (2) respectively: -

$$MOE = \frac{\Delta PL^3}{4\Delta ybh^3} \tag{1}$$

$$MOR = \frac{3PL}{2bh^2} \tag{2}$$

where ΔP is the difference between the upper and lower loading limits in the proportional limit(N), Δy is the deflection with respect to ΔP (mm), L is the span (mm), b the width of the glulam (mm), h is the thickness of the glulam (mm) and P the maximum loading (N).

Figure 4: Test process for the flexural properties of Eucalyptus glulam

2.4.2 Shear test

A sample of size 60 pieces (30 treated and 30 untreated) was evaluated for the shear test. Shear test parallel to the grain was measured and the specimen was cut to 20mm × 20mm × 20 mm according to EN 386:2001(2001), which states that bonding strength of bond-lines shall be assessed as bond-line integrity test.

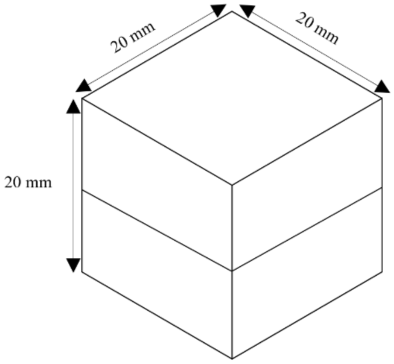

Figure 1: Specimen size for shear test

The average loading speed was 0.4mm/min. The shear strength was calculated as follows;

$$\sigma = \frac{P}{A} \tag{3}$$

Where P (N) is the rupture load and A (mm^2) is the area of the bonding layer.

2.4.3 Soaking Delamination

A sample of size 60 pieces (30 treated and 30 untreated) was evaluated for the shear test. The soaking delamination test specimen was cut from both ends of each sample glulam, with the original cross sections 50mm×25mm and a length of 75mm.

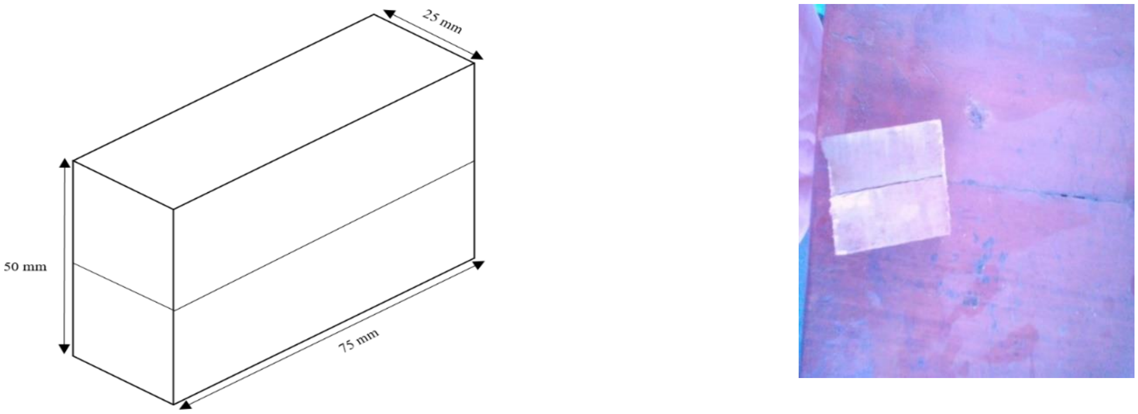

Figure 2: Specimen size for testing the delamination ratio

The specimen was immersed in water at room temperature for 24hrs and then placed in the oven at 70°C to dry for 24hrs. The process was repeated twice and the delamination ratio was calculated in accordance with Vella *et al*., (2019) using equation (4):

$$DR = \frac{l_d}{l_g} \times 100 \tag{4}$$

Where, DR = Delamination ratio, l_d= length at which delamination will occur (mm), l_g = Total length of the glue line (mm).

2.4 Data Analysis

Descriptive statistical procedures were used to obtain means and standard deviations for all test properties using SPSS software version 40.0. A one sample t- test was used to compare the mean parameters for the two groups (untreated and treated eucalyptus glulams). In order to accommodate the influence of any sources of variation during the experiment, percentiles were used to generate a tolerance interval within which 95% of the measured properties of a given specimen are likely to fall at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 CCA penetration and Retention

The penetration was in range 17.5±2 mm (62% -78%) with a mean of 16.4 ± 1.3 mm), while the average retention was calculated to be in range of 173-192 kg/m^3 with a mean of 181±11 kgm^{-3}. Both the retention and penetration satisfied the minimum standard which is 6.5-10 kg/m^3 and 40-60% of CCA per treated wood (Mugabi and Thembo, 2018).

3.2 Flexural Properties

The mean values of the flexural properties for both treated and untreated wood are summarized in Table 1.

Table 1: Descriptive statistics for flexural properties (N=60)

Property	Variable	Mean	Std. Error
Shear (MPa)	Treated	6.6034	0.45688
	Untreated	6.8340	0.53446
MOE (MPa)	Treated	12464.39	1113.89
	Untreated	14370.06	1340.67
	Face to face bonding	17677.56	570.67
	Edge to edge bonding	4896.56	174.49
MOR (MPa)	Treated	155.22	11.07
	Untreated	191.80	13.03
	Face to face bonding	210.62	8.02
	Edge to edge bonding	99.28	4.74
Maximum Load (N) at point load	Treated	7109.29	318.32
	Untreated	8630.32	294.31
	Face to face bonding	8023.96	305.87
	Edge to edge bonding	7561.49	360.63

Figures 7 to 9 show the mean MOE, MOR and maximum Load at point load for the untreated and treated when glued face to face and edge to edge gluing.

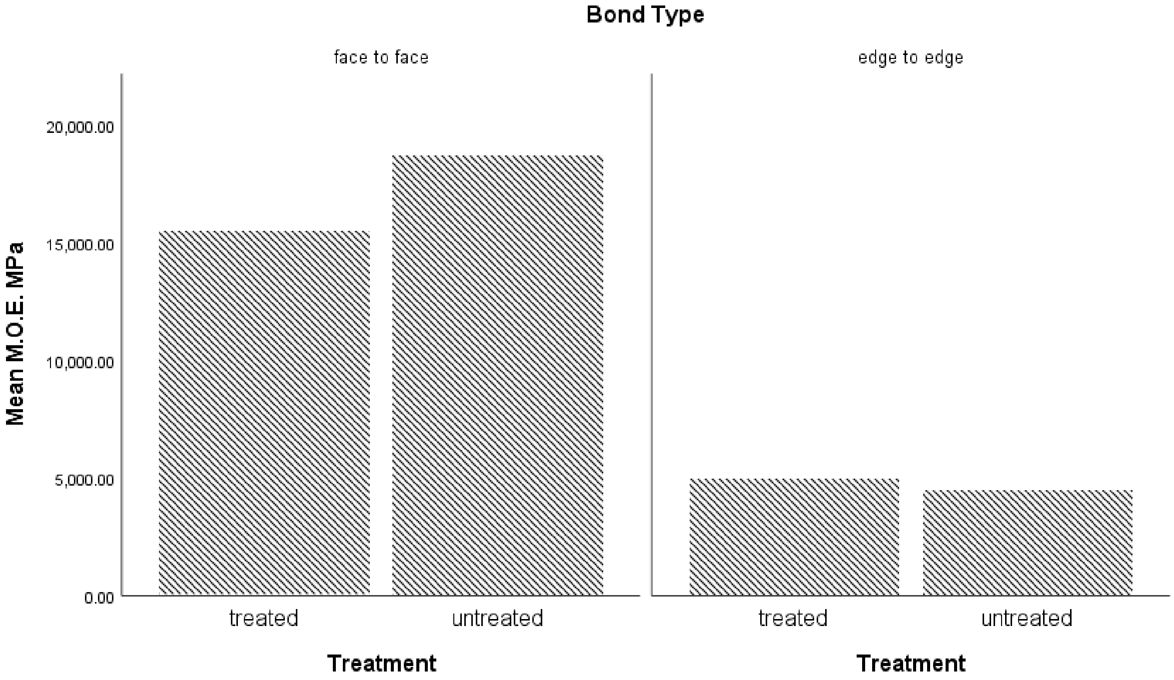

Figure 3: Mean MOE for untreated and CCA treated Eucalyptus samples

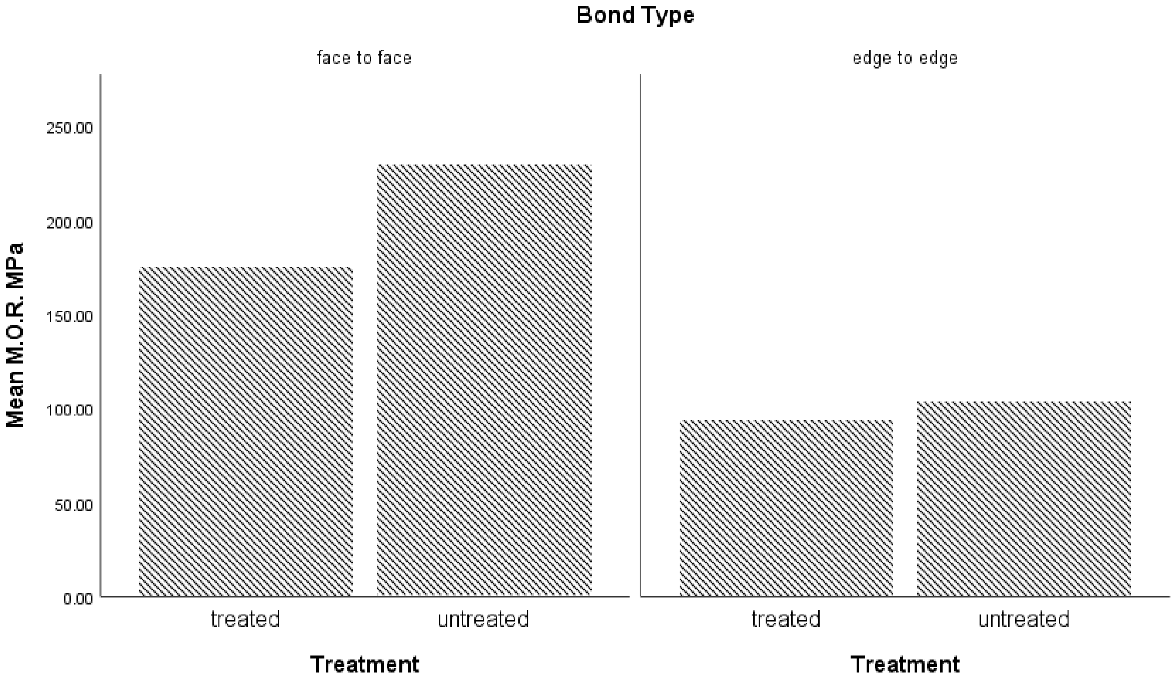

Figure 4: Mean MOR for untreated and CCA treated eucalyptus samples

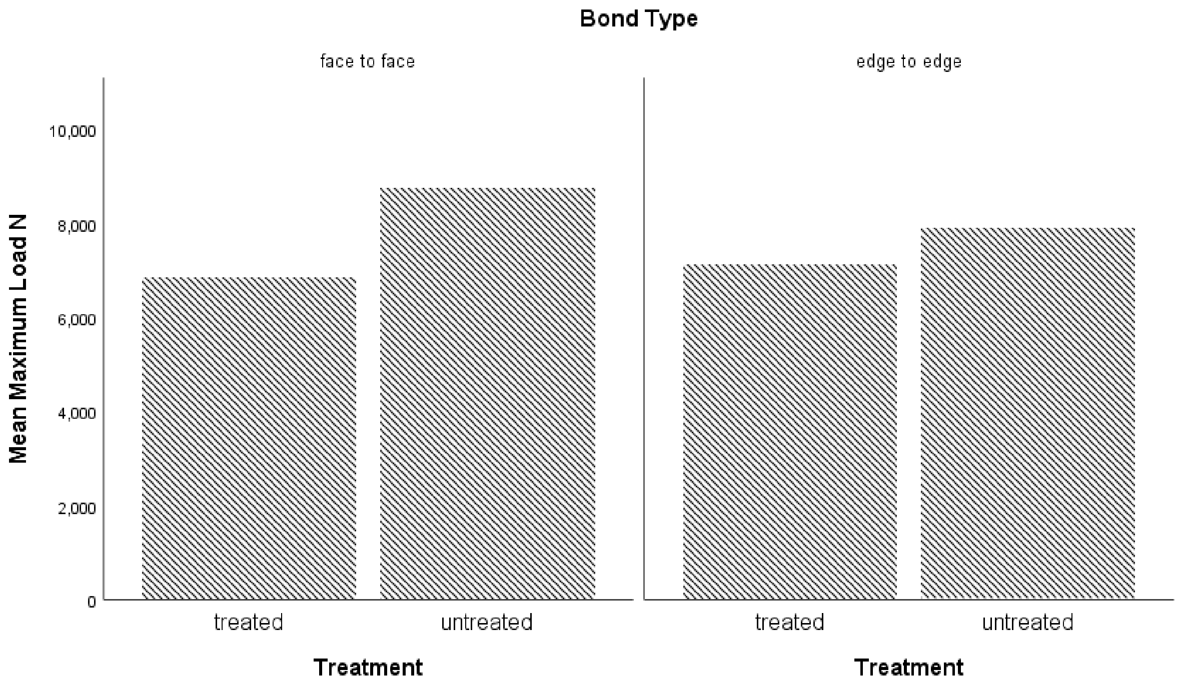

Figure 5: Mean Maximum Load at point for untreated and CCA treated Eucalyptus samples

The MOR and MOE of the treated wood were lower than that of the untreated wood (Figures 7 to 9) clearly showing the effect caused by CCA treatment. In particular, the MOR was reduced by 19.1% and the MOE by 13.3% in the treated specimens as compared to the untreated samples (Table 1). Statistical analysis showed that there was no significant difference in the MOE and MOR between the treated and untreated wood samples. In face-to-face bonding, the MOE of the treated wood samples was lower than that of untreated wood samples and the MOE of edge-bonded glulams was slightly higher in the treated wood as compared to that of the untreated wood. Particularly the MOE decreased by 71.93% in the edge bonded glulams less than that of the face-to-face bonded samples. Figure 8 showed that the MOR decreased by 52.86% in face to face as compared to that of edge-to-edge bonding as shown in table 1. Statistical analysis showed that there was no significant difference (P>0.001) between the MOE and MOR values obtained under edge-to-edge bonding and face to face bonding. To determine the effect of CCA preservative on the flexural properties of glue laminated eucalyptus, an independent sample t-test was performed and homogeneity of groups determined. With regard to the MOE and MOR values, there was no significant difference (P>0.05) between the untreated and CCA treated groups. Similar results were reported by Yildiz *et al*., (2004) regarding the effects of wood preservatives on the mechanical properties of scots pine (*Pinus sylvestris*). It was pointed out by Yildiz *et al*., (2004) that there are no significant differences in MOE between the untreated and treated glulam. This is due to the depolymerization of wood caused by excess ethanolamine. Humar *et al*.; (2007) reported that the functional group in wood which can react with the copper or ethanolamine complex was limited. In addition during reaction of the ethanolamine with in wood or its components, free radicals were formed which causes the depolymerization of lignin (Humar *et al.;* 2003). Further research by Humar *et al*.; (2008) also indicated that ethanolamine in copper-based wood preservatives enables copper fixation, which causes degradation of lignin or other wood components hence changing the mechanical properties.

Table 1 shows that the MOR decreased by 19.1% for the treated wood samples which explains that CCA preservative has a significant effect on the strength and stiffness performance of glulam. Following the Levene's for equality of variances on the MOR values, there was no significant difference among the untreated and the CCA treated wood samples. Previous investigation of the mechanical properties of preservative treated wood showed that preservative treatment with CCA did not cause significant reductions in wood bending properties (Winandy, 1987; Gasper *et al*., 2010). Other studies showed that values of MOE and the MOR values decreased from 0% to 20% for the treated glulams depending on the severity of the redrying temperature employed (Yang *et al*., 2012). The treatment process relies on chemical reactions to bind the chemicals in wood (Hingston *et al*; 2001). Water-borne preservative treatments generally reduced the mechanical properties of the wood as noted by Barnes and Lindsey (2009). The strength loss caused by water borne preservative directly relates to its chemistry and the severity of its fixation reaction where the metal is reduced to less soluble forms by oxidizing the wood cell-wall components (Yang *et al*., 2012). Winandy (1995) contented that these effects on the mechanical properties appear to be directly related to several key wood material factors and pretreatment, treatment and post-treatment processing factors. The addition of heat during and after treatment potentially accelerates the hydrolytic reactions magnifying strength reduction. Strength loss as a result of exposure to elevated temperatures is also magnified by high moisture content induced by the water solvent in the wood

3.2 Shear Strength

The mean values of the glue-line shear strength test for both the treated and untreated eucalyptus samples are summarized in Table 2. The results suggested that the bond-line integrity was higher in the untreated eucalyptus samples. The mean shear strength of the treated eucalyptus glulam was 3.37% lower than the mean shear strength of the untreated glulam as shown in figure 10. With the F-value (0.108), there was no significant difference in the bond line integrity of both the treated and untreated glulam specimens. The mean shear strength of the treated eucalyptus glulam was 3.37% lower than the mean shear strength of the untreated glulam. Addition of CCA shows negative effect on the bending strength of glue joints and this is due to influential factors such as variability in wood properties for shear strength of wood joints. (Hass, *et al*.; 2009; Uysal, 2010). For good bonding, the bond needed to have good shear strength and the failure should occur in timber rather than in the glue line.

Table 2: Descriptive statistics for shear strength test (N= 60)

Treatment	Mean [MPa]	Std. Error of Mean
Treated	6.6034	0.45688
Untreated	6.8340	0.53446

3.3 Soaking Delamination

Visual verification of the state of the glue lines showed that that the specimens had no delamination slits; and it was verified that the percentage of delamination was equal to zero in both the treated and untreated eucalyptus glulams. Regarding the delamination test of the glued laminated specimens, it was observed, through the visual verification of the state of the glue lines, that the specimens had no delamination slits. A similar result was observed by Yang *et al*., (2012), who obtained 0% delamination for pieces of glued laminated wood produced with polyurethane adhesive. The percentage of delamination observed in this study was lower than the maximum of 10% stipulated by European Standard EN 386 (2001) and lower than the maximum allowed by Standard JAS 234 (2003) which is 5%. The moisture content of 11.29 % provided good adhesion between the laminations, avoiding the delamination process.

4. CONCLUSIONS

In conclusion, treatment of glulam with CCA does not significantly weaken the flexural and shear properties of the glulam. No delamination was found in all glulam specimens. However, untreated wood samples show higher bonding properties and flexural properties and therefore can be used as high structural members. Further research on the potential effect of various adhesives available on market and machining properties should be done to widen the scope of understanding of the effects of preservative treatment on the structural strength quality of timbers on the market. Further research should be carried out to ascertain the effect of temperature and moisture on the bond integrity of glue laminated timber.

Conflict of interest

The authors collectively declare and assert no conflicts of interest, confirming the absence of financial or personal connections that could bias their work. They state no known conflicts and have not received any significant financial support influencing this publication.

REFERENCES

American Society for Testing Materials, 1992. ASTM D3737 Standard Method For Establishing Stresses for Structural Glue Laminated Timber. ASTM West Conshohocken, Pennsylvania

American Institute of Timber Construction, 1992. ANSI/AITC A190.1 American National Standard for wood products-Structural Glued-laminated Timber. AITC. Englewood, Colorado.

American Institute of Timber Construction. 1990. AITC 110 Standard for Preservative Treatment of Structural Glued-Laminated Timber. AITC, Englewood, Colorado.

Ahmad Y. (2010). Bending Behaviour of Timber Beams Strengthened Using Fibre Reinforced Polymer Bars and Plates. Johor. Malaysia. Universiti Teknologi Malaysia. Johor. Malaysia.

Barnes HM, Lindsey GB (2009) Bending properties of wood treated with a new organic wood preservative system. Bioresour Technol 100:778–781

Boschetti, W. T. N., Vieira, D. M., Moulin, J. C., Lopes, D. J. V., Paes, J. B., and Carvalho, A. M. M. L. (2016).” Preservative treatment of fence posts evaluation through photocolorimetry segmentation performance”. *Árvore* 40(4), 731-739.

Brischke, C., & Meyer-Veltrup, L. (2016). Modelling timber decay caused by brown rot fungi. *Materials* *and Structures/Materiaux et Constructions*. https://doi.org/10.1617/s11527-015-0719-y

British Standard BS EN 408, "Timber structures – structural timber and glued laminated timber," Determination of some physical and mechanical properties, 2003.

Crafford, P.L., and Wessels, B.C. (2016). "The potential of young, green finger-jointed *Eucalyptus grandis* lumber for roof truss manufacturing." *South. For*.78(1), 61-71.

Coulson, J. (2011). *Wood in construction: How to avoid costly mistakes*. John Wiley & Sons.

Dadzie, P. K., Amoah, M., Frimpong-Mensah, K., & Oheneba-Kwarteng, F. (2016). Some physical, mechanical and anatomical characteristics of stemwood and branchwood of two hardwood species used for structural applications. *Materials and Structures/Materiaux et Constructions*. https://doi.org/10.1617/s11527-016-0835-3

de Almeida, T. H., de Sousa, A. M., Martins, A. S. M., Christoforo, A. L., de Almeida, D. H., & Lahr, F. A. R. (2018). Efeito da temperatura de serviço na resistência ao cisalhamento de madeiras de Pinus para estruturas de cobertura. *Acta Scientiarum - Technology*, *40*(January). https://doi.org/10.4025/actascitechnol.v40i1.30913

Francis, L., & Zaidah, S. (2018). *Effects of CCA and LOSP Preservative Treatments on the Bending Performance of Glulam Timber Beam*. *118*(24), 1–14.

H'ng, P. S., Paridah, M. T., & Chin, K. L. (2010). Bending properties of laminated veneer lumber produced from keruing (Dipterocarpus sp.) reinforced with low density wood species. *Asian Journal of Scientific Research*, *3*(2), 118–125. https://doi.org/10.3923/ajsr.2010.118.125

Isaksson, T., Brischke, C., & Thelandersson, S. (2013). Development of decay performance models for outdoor timber structures. *Materials and Structures/Materiaux et Constructions*. https://doi.org/10.1617/s11527-012-9965-4

Jankowska, A., Drożdżek, M., Sarnowski, P., & Horodeński, J. (2016). Effect of Extractives on the Equilibrium Moisture Content and Shrinkage of Selected Tropical Wood Species. *BioResources*, *12*(1). https://doi.org/10.15376/biores.12.1.597-607

Lopes, D. J. V., Paes, J. B., Jankowsky, I. P., Segundinho, P. G. de A., & Vidaurre, G. B. (2017). Influências do Diâmetro e Umidade da Madeira na Qualidade do Tratamento Preservativo. *Floresta e Ambiente*, *24*(0), 1–10. https://doi.org/10.1590/2179-8087.020716

Mohamad, N. B., Ahmad, Z., Abu Bakar, A., & Md. Tahir, P. (2016). Assessment in bending and shear strength of glued laminated timber using selected malaysian tropical hardwood as alternative to timber railway sleepers. *Jurnal Teknologi*, *78*(5–5), 111–117.

Mohamad, W., Wan, H., Ahmad, Z., & Abd. Jalil, A. (2014). Bending strength of glulam from selected malaysian hardwood timber. *Advanced Materials Research*, *879*(November 2018), 237–244.

Moody, R. C., & Hernandez, R. (1997). Glued-Laminated Timber. In *Engineered Wood Products: A Guide for Specifiers, Designers & Users*.

Mugabi, P., Rypstra, T., Vermaas, H.F., and Nel, D.G.2010). "Relationships between drying defect parameters and some growth characteristics in kiln dried South African grown *Eucaalyptus grandis* poles," *Eur.J.Wood prod.* 68(3), 329-340.

Mugabi, P., Rypstra, T., Vermaas, H.F., and Nel, D.G.2010). "Effect of kiln drying schedules on the quality of South African grown *Eucaalyptus grandis* poles," *Eur.J.Wood prod.* 69(1), 19-26.

Paul Mugabi and James Thembo (2014). Effect of pole size on preservative penetration and retention in air-dried ugandan grown eucalypt utility poles. Maderas, Cienc. tecnol. vol.20 no.1 Concepción 2018 http://dx.doi.org/10.4067/S0718-221X2018005001701

Osuji, S. O., & Nwankwo, E. (2017). Investigation into the Physical and Mechanical Properties of Structural Wood Commonly Used in Nigeria: A Case Study of Benin City. *Journal of Civil Engineering Research*.

Perkins, R. A. (2010). *Alaska Department of Transportation & Public Facilities Creosote Treated Timber in the Alaskan Marine Environment Volume I Prepared By :I.*

Pröller, M. (2017). *An investigation into the edge gluing of green Eucalyptus grandis lumber using a one-component polyurethane adhesive*. *March*, 71.

Sseremba, O. E., Mugabi, P., & Banana, A. Y. (2016). Within-tree and tree-age variation of selected anatomical properties of the wood of Ugandan-grown Eucalyptus grandis. *Forest Products Journal*, *66*(7-8), 433-442.

Ssemaganda, I. E., Mugabi, P., & Tumwebaze, S. B. (2011). Effectiveness of selected preservatives in protecting ugandan grown Eucalyptus grandis wood against termite attack. *Maderas. Ciencia y tecnología*, *13*(2), 135-142.

Steiger, R., & Richter, K. (2009). Glued laminated timber — Shear test of glue lines. *Wood Adhesives*, *1995*(Astm 2003), 389–398.

Suzana Radivojevic and Paul A. Cooper (2007). The effects of wood species andtreatmentretention on kinetics of CCA-C fixation reactions. Wood Science and Technology 44(2):269-28. DOI:10.1007/s00226-009-0277-y

Temiz, A., Alma, M. H., Terziev, N., Palanti, S., & Feci, E. (2010). *Efficiency of Bio-Oil Against Wood Destroying Organisms Efficiency of Bio-Oil Against Wood Destroying Organisms*. *January 2014*. https://doi.org/10.1166/jbmb.2010.1092

Vella, R., Heitzmann, M. T., Redman, A., & Bailleres, H. (2019). Comparison of test methods for the determination of delamination in glued laminated timber. *BioResources*, *14*(4), 7920–7934. https://doi.org/10.15376/biores.14.4.7920-7934

Wessels, C. B., Dowse, G. P., and Smit, H. C. (2011). “The flexural properties of young *Pinus elliottii* × *P. caribaea* var. *hondurensis* timber from the Southern Cape and their prediction from acoustic measurements,” *South. For.* 73(3-4), 137-147.

Wessels, C. B., Malan, F. S., Nel, D. G., and Rypstra, T. (2014). “Variation in strength, stiffness and related wood properties in young South African-grown *Pinus patula*,” *South. For.* 76(1), 37-46.

Winandy, J.E. (1987). Effects of treatment and redrying on mechanical properties of wood. *Proceedings of Wood Protection Techniques and the Use of Treated Wood in Construction*, *54*, 54–62.

Winandy, Jerrold E. (1995). Effects of Waterborne Preservative Treatment on Mechanical Properties: A Review. *Proceedings 91st Annual Meeting of the American Wood-Preservers' Association*, 17–34.

Yang, J. L. (2005). “The impact of log-end splits and spring on sawn recovery of 32-year-old plantation

Eucalyptus globulus Labill," *Holz Roh Werkst.* 63(1), 442-448.

Yang, T. H., Lin, C. H., Wang, S. Y., & Lin, F. C. (2012). Effects of ACQ preservative treatment on the mechanical properties of hardwood glulam. *European Journal of Wood and Wood Products*, *70*(5), 557–564.

Zziwa, A., Ziraba, Y. N., & Mwakali, J. A. (2009). Timber use practices in Uganda's building construction industry: current situation and future prospects. *Journal of the Institute of Wood Science*, *19*(1), 48-53.

Zziwa, A., Ziraba, Y. N., & Mwakali, J. A. (2016). Inferring Strength of Structural Timbers From small clear Specimen Strength Test Data. *International Jouenal of Research in Engineering & Advanced Technology*, *3*(6), 142–152.

Zziwa, A., Mukasa, J. and Kizito, S. (2020). Structural suitability of 10-year old Pinus caribaea timber with a forest fire history in farm buildings. *AgricEngInt*: CIGR Journal Open access at http://www.cigrjournal.org Vol. 22, No. 2