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Mechanical behavior of tropical Glued Laminated Timber beams with fingers joints

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Abstract

This paper presents an experimental investigation on Glued Laminated Timber (GLT) beams made with two tropical woods species, for structural purposes. Two tropical wood species with different density and under-exploited were chosen. These are *Dacryodes buettneri* (Ozigo) and *Pterocarpus osun* (Padouk), Ozigo species was taken as a reference species. A Phenol Resorcinol Formaldehyde (PRF) adhesive resistant to harsh tropical environments was used for bonding. The static bending tests were conducted on beams compound of two and three lamellas with fingers joints. The aims of these tests were to determine the key mechanical parameters such as Module of Rupture (MOR) and the Module of Elasticity (MOE). Influence of the finger's joints on the bending strength of the GLT beams is also investigated in this work. The results show that the position of lamella and finger joint has an impact on the loss of bending strength of the specimens tested, but they have no influence on their stiffness properties.

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Keywords: Tropical wood species; Glued Laminated Timber; composite beams; Experimental characterization; Principle of sandwich beams.

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1. Introduction

Gabon forest covers about 85% of the territory and is considered as the second largest forest potential in the Central African region (Odounga et al, 2019). But unfortunately, because of the operating costs associated with first processing and drying, solid wood cut used in construction is still very expensive. An alternative could be to use Reconstituted Solid Wood (RB) and Glued Laminated Timber (GLT) from different species to minimize losses due to sawing and valorise certain species of wood little exploited or secondary species. Indeed, by assembling wood slats by gluing, we obtain a homogenization of the mechanical behaviour and a reduction of natural variability of the beams obtained (Kandler and Fussl, 2017). In addition, the combination by gluing of wood species of very different appearance, offers new perspectives to further integrate wood into high-end achievements. Currently, the evolution of bonding techniques has helped to optimize the use of tropical woods by recovering part of the production that is difficult to use in the state: secondary species, small diameter logs, decommissioned wood, sawmill waste (Gérard, 1999). Thus, the costs of GLT beams, whose prices are still high compared to the immense forest resources available to the country are controlled.

The advantage of GLT beams is therefore the possibility of manufacturing parts of large size or shape that could not have been obtained by the use of the solid wood without transformation. This is one of the reasons why, in recent times, their use has mainly increased in temperate countries in the construction of large structures [4]. This use has led to the establishment of current standards and the design of a manufacturing recommendation based on experimental testing for softwood species (Tran et al, 2016), (Kulasinski et al, 2015). Due to the lack of consistent experimental data for tropical wood species and also to African standardization. The standardization rules for the construction of GLT structures of tropical origin take into account European requirements as a normative basis (Gao et al, 2019). Studies conducted on GLT are almost non-existent, they are literally focused on the mechanical characterization of solid wood. Existing studies on the mechanical behaviour of tropical GLT is generally based on European standards. Nevertheless, some studies have focused on the bonding of different tropical wood species such as those of (Bourreau et al, 2013).

The main objective of this study is to propose a mechanical characterization of the combined GLT beams through four-point bending tests. But also, to study the overall mechanical behaviour of the beams according to the position of the lamella and the fingers joint. This study promotes wood species currently little exploited in the industry in order to participate in the protection of our environment but also to make accessible the use of wood in construction for local populations in particular.

2. Materials and methods

Given the wide variety of wood in Gabon, we based ourselves on four criteria for the choice of species, including (i) availability, (ii) log consumption, (iii) mechanical strength and (iv) work class. Two tropical wood species of different density, from the equatorial forest of Gabon, were combined to design combined BLC beams. These are the *Pterocarpus Osun* (Padouk) with a higher density and the *Buettneri Dacryodes* (Ozigo). These species, available in large quantities and underexploited, have a good bonding ability according to Tropix 7 (CIRAD ,2011). The bonding of the beams was done with a Phenol Resorcinol Formaldehyde (PRF) adhesive adapted to tropical climates. The beams were made within the company Ecowood SA partner of the study and specialized in tropical woods construction.

2.1. Preparation of specimens

Before the bonding process, the wooden planks were stabilized at a relative humidity of 12 %. The finger joints was profiled according to standard NF EN 408 (European standards, 2012) on the lamella intended for the design of combined GLT beams. Finger joints are machined according to the thickness of the lamella (Figure 1b) with a cutter to be embellished (Figure 1a). Then, a Prefere 6171 adhesive associated with a Prefere 6671 hardener is applied manually immediately on both surfaces of the finger joint (Figure 1c). After a pressure of 100 bar is applied for two seconds (Figure 1d) according to the recommendations of the manufacturer and the literature concerning hardwood (Tan, 2014). Finally, the lamella were planed 24 hours later to the desired dimensions (Figure 1e), notably 30 mm for the single lamella and the DUO (two lamella beam) and 20 mm for the TRIO (three lamella beam). After planing, the lamella (with and without finger joint) are manually spreaded on one side (Figure 1f) with a Phenol Resorcinol Formaldehyde (PRF) adhesive associated with an HRP 155 hardener manufactured by DYNEA (the PRF/hardener ratio is 100/33). The spreading time was 10 minutes, due to the high speed of polymerization under certain conditions. Then the lamellas are stacked according to the desired configurations and pressurized for 24 hours (Figure 1g).

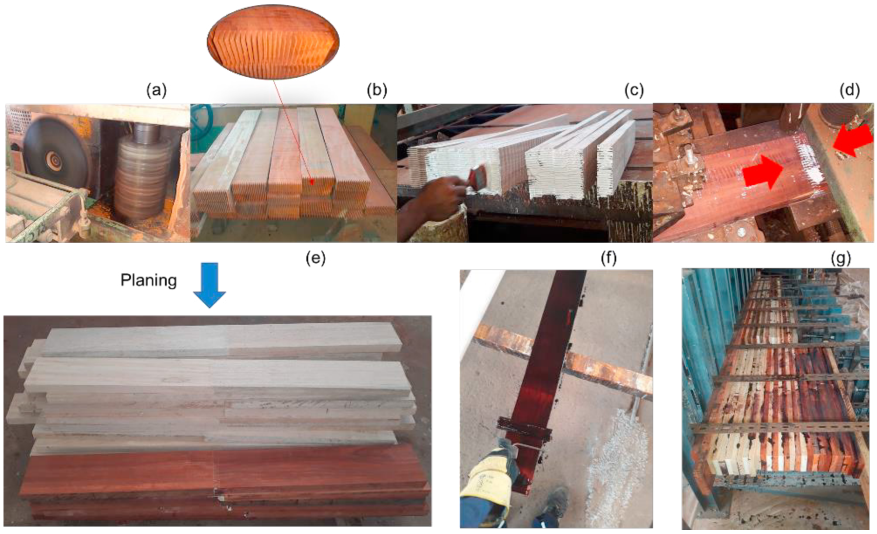

Fig 1: Gluing process, (a) Cutterheads ; (b) Finger jointed lamella; (c) Coating finger joints with Prefere adhesive; (d) Pressurize (2 s); (e) Lamellas with finger joint and planed, (e) Coating with PRF adhesive (g) Pressurize (24h);

2.2. Four points bending test

Figure 2 shows the mechanical principle of the 4-point bending test on specimens. For the single lamella, the finger joint is placed at mid-span (Figure 1a). For DUO two types of configuration have been made, including a configuration with the finger joint located on the upper lamella (A1 configuration) as shown in Figure 2b ; and one with the finger joint located on the lower lamella (A2 configuration) presented in Figure 2c. For TRIO, the finger joint is placed at the mid-span of the external lamella and on the middle lamella a double finger joints centered and a 360 mm apart (Figure 2d).

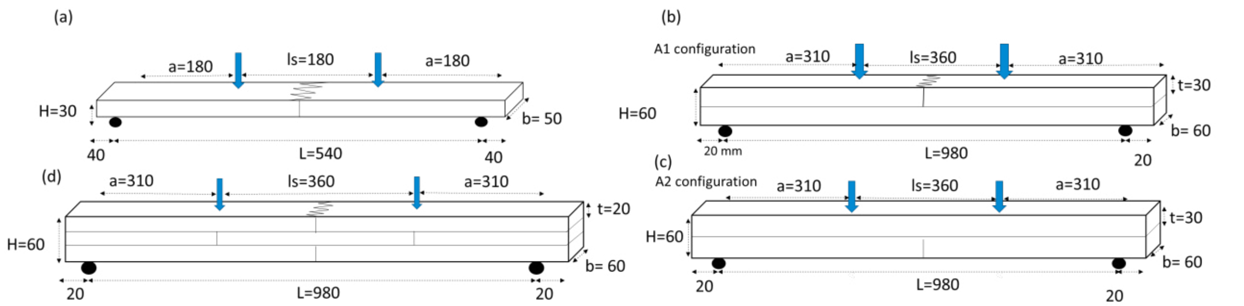

Fig 2: Mechanical principle of the 4-point bending test, (a) Single lamella with finger joint, (b) DUO in A1 configuration, (c) DUO in A2 configuration, (d) TRIO

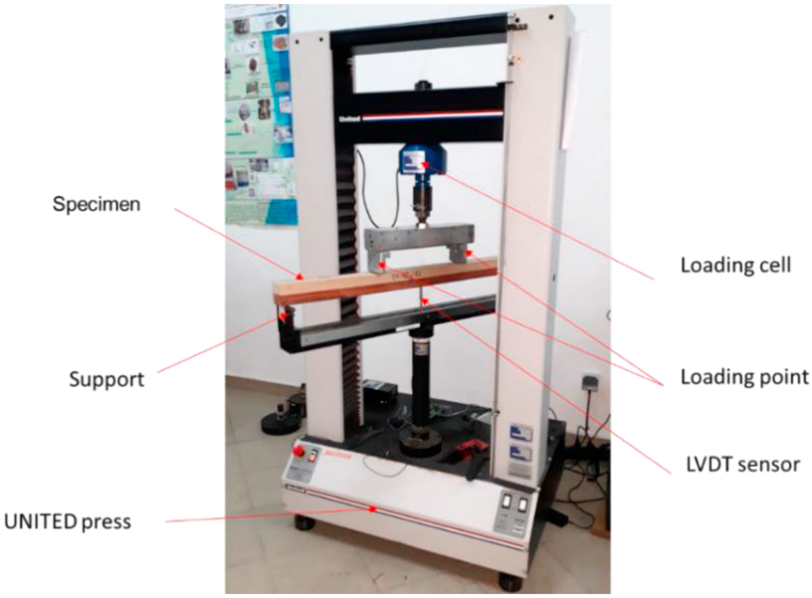

Fig 3: Experimental device

Figure 3 shows the experimental device, including a UNITED press with a maximum load cell of 100 kN.
These 4-point bending tests are carried out in order to determine the combinations of beams with the best mechanical characteristics according to the position of the lamella in the beam. The main characteristics of the beams are determined according NF EN 408 standard, this is the Modulue of Rupture (MOR) and Module of Elasticity (MOE).

The MOR is given by the equation:

$$MOR = (3*a*F_{max})/(b*H^2) \quad (1)$$

Where F_{max} is the maximal load in N, a the distance between a loading point and the nearest support in our a=310 mm, b the width of the specimen in mm and H the height of the specimen in mm.
The MOE is given by the equation:

$$MOE= (3*a*L* \Delta F)/(4*b*H3*\Delta w) \quad (2)$$

Where ΔF represents the increase in load (in N) on the regression line with a correlation coefficient of 0.99 ; Δw the increase in the displacement (in mm) corresponding to ΔF ; l_1 the base length to determine the modulus of elasticity (in mm) and $I=bH^3/12$ inertia of speciment (in mm^4).

3. Experimental results and discussion

3.1. Load displacement curves

Figure 4 shows the load displacement curves of the lamella with and without fingers joint, the objective is to evaluate the influence of finger on the mechanical properties.
In Figure 4a, there is an elasto-plastic behaviour followed by failure for the Ozigo specimens without finger joint and elastic behaviour followed by a sudden failure for the Ozigo specimens with finger joint. Figure 4b shows an elastic behaviour followed by a sudden failure for padouk with and without finger joint. Overall, we observe in lamella with finger a sudden failure, this instantaneous crack is due to the presence of the finger joint which can constitute a defect

on the lamella. It is also noted that the presence of finger joint has no influence on the stiffness of the lamella.

Figure 5 shows us the load displacement curves of the combined GLT beams, Figures 5a 5c show us an elasto-plastic behaviour, this is typical of that observed in Ozigo lamella. On the other hand, for the Combinations Pdk-Oz-A1, Pdk-Oz-A2 (Figure 5b) and Pdk-Oz-Pdk-A (Figure 5c) exhibit a behaviour similar to padouk lamella, including elastic behaviour until failure. It should be noted, however, that for DUO beams, the position of the lamella has no influence on the stiffness of the beams. While in TRIO beams, stiffness is greater on Pdk-Oz-Pdk-A combinations.

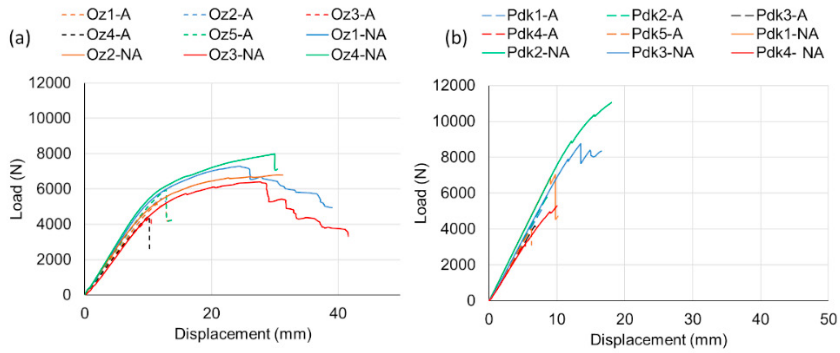

Fig 4:Load displacement curves of single lamella, (a) Oz-A Vs Oz-NA, (b) Pdk-A Vs Pdk-NA.

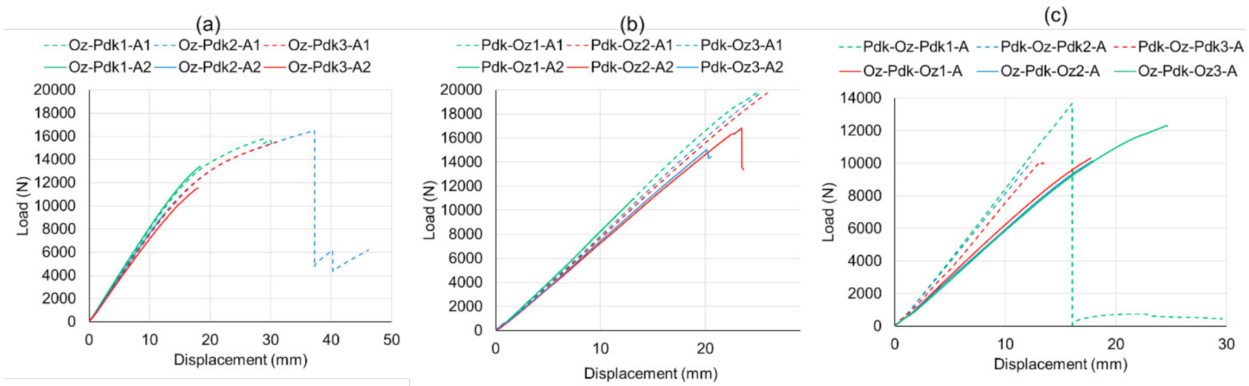

Fig 5:Load displacement curves of combined GLT beam, (a) Oz-Pdk-A1 Vs Oz-Pdk-A2, (b) Pdk-Oz-A1 Vs Pdk-Oz-A2, (c) Pdk-Oz-Pdk-A Vs Oz-Pdk-Oz-A

3.2. Mechanical's properties

Table 1 exhibits the gain (or loss) of the bending strength of the lamella and the beams combined compared to the massive lamella (without finger joint) of Ozigo and Padouk, respectively. But also, the mechanical properties, notably MOR and MOE of all specimens. It can be seen that for massive lamella, the finger joint creates a loss of strength, notably 22% for Ozigo and 42% for Padouk. For DUO, a decrease in strength is observed when the finger joint is placed on the lower lamella (configuration A2) than when it is placed on the upper lamella (configuration A1). Notably 29% and 27% respectively in the Oz-Pdk and Pdk-Oz combinations.

For combined TRIO beams, there is no significant difference in strength between the Pdk-Oz-Pdk-A and Oz-Pdk-Oz-A specimens. this is mainly due to the position of finger joint. Indeed, it appears that the presence of the finger joints on the lower lamella and their number constitute factors reducing the strength of the GLT beams.

Regarding the stiffness parameters, for the single lamella specimens, the presence of the finger joint has no influence on the module of elasticity. For the DUO beams it is noted that there is no significant difference in stiffness between the A1 and A2 configurations, the same observation is also made between Pdk-Oz-Pdk and Oz-Pdk-Oz combinations. This observation shows us that the position of the lamella and finger joint has no influence on the stiffness properties of the DUO and TRIO beams combined.

Table 1: Mechanical's properties of specimens

Specimens	Section aspect	MOR	MOE	Gain or loss	
		MPa	MPa	Oz-NA	Pdk-NA
Oz-NA		72	12938	/	
Pdk-NA		81	16963	/	/
Oz-A		56	12946	-22.22	/
Pdk-A		81	16963	/	-41.97
Oz-Pdk-A1		84	14172	+15.36	+3.21
Oz-Pdk-A2		60	14004	-17.01	-25.75
Pdk-Oz-A1		101	13980	**+39.01**	**+24.37**
Pdk-Oz-A2		74	13316	+1.77	-8.94
Oz-Pdk-Oz-A		62	12667	-14.02	-23.08
Pdk-Oz-Pdk		56	13063	-22.13	-30.33

Table 1 shows that the Pdk-Oz-A1 combination is better than the other combinations regarding the increase in strength compared to the lamella without finger joint. There is an increase of 39.01% and 24.37% respectively compared to the massive of of Ozigo and Padouk.

4. Conclusion

In this paper, an experimental study was carried out on DUO and TRIO beams combined with two tropical wood species for structural purposes, including *Pterocarpus Osun* (Padouk) and *Buettneri Dacryodes* (Ozigo). The objective was to determine the mechanical properties of 4-point bending tests on beams and to evaluate the influence of the finger joint on the strength of the beams. It appears that for lamella, the finger joints are a factor of loss of strength, on the other hand they have no influence on the properties of stiffness. For DUO beams, the results show that the position of the lamella and finger joint has an influence on the bending strength of the specimens, this is not the case for the module of elasticity. For TRIO beams, the Oz-Pdk-Oz and Pdk-Oz-Pdk combinations have similar mechanical behaviours, making the Oz-Pdk-Oz combination an advantage because it is less dense than the Pdk-Oz-Pdk combination. Overall, the module of elasticity of the combined GLT beams is between those of the constituent lamella.

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