

## Research Article

# Experimental Study of the Mechanical Behavior of Local Wood *Terminalia Superba* (Fraké) by Glued Wood Assembly According to the Beveled Configuration

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The design of structural elements, the design of connections and supports, and damage have a significant influence on the technical characteristics of wood construction projects. An innovative experimental study was carried on locally obtained glulam beams. This study aimed to evaluate the load-bearing capacity of a finger-jointed *Terminalia Superba* (fraké) lamellae during routine use of an adhesive in the local area and to improve the connections in glulam structures. The achievement of this objective will allow to determine the influence of the technical characteristics of finger-jointing on the mechanical resistance, to maximize the mechanical resistance of the reconstituted beams, and eventually to minimize the losses due to sawing. All this will have a considerable impact on the technical and economic aspects of a wood construction project. The physical aspect of the species was studied and properties found. The influence of variation in density, the bonding surface, and joint efficiency on the bending strength (MOR) of *Terminalia Superba* (fraké) was studied. Mechanical properties were found and related to the optimum joint angle  $\alpha$ , and the breaking point reads 0.20 mm. For the angular range of  $[0^\circ-30^\circ]$ , adhesive failures are witnessed, and beyond this range, the failures are mixed. The  $45^\circ$  finger-jointing angle appeared to be better in the axial traction mode of rupture.

## 1. Introduction

Wood is a sustainable and renewable construction material; it is a versatile raw material.

The *Terminalia Superba* wood, which is the object of our study, is a tropical and local material now a day found in

several fields of use. It is used, for example, as the sides of trucks in the automobile and the carriages, the frames, and the bridges in construction. The use of wood species currently cut by mixing those of lesser quality in the structure of laminated wood is one of the techniques to minimize losses due to sawing. The cost of wood construction is still

expensive in relation to forest resources in our environment. These techniques participate in the recovery of forest residues and protection of our environment. The local companies in sub-Saharan countries are interested in the exploitation and the techniques of finger-jointing of a wood species called *Terminalia Superba* (Fraké). However, the data concerning the finger-jointing of local woods still need to be completed and improved. Only few authors in the literature have addressed the issues related to finger-jointing with wood. In particular, information on the beveled and glued joints. Local Cameroonian wood in quality and quantity remains unexplored, such as *Terminalia Superba* (Fraké) used in this study. It is therefore relevant to understand the behavior of beveled joints when subjected to different stresses.

In the manufacture of finger-jointed engineered wood products, [1] outlines the steps involved. The bevel configuration was developed given the low strength of butt jointing and was improved to provide a bonding surface nearly parallel to the wood grain. The fracture process of finger joints is often caused by a combination of both modes in a mixed mode behavior according to [2]. Previous work has shown that sample geometry, joint configurations, and end pressures influence the strength of finger-jointed wood pieces [2–5]. The results obtained from these tests allowed numerical calculations or modeling that could evaluate the stresses in the glue joints. However, the problem encountered concerns the bonding pressure, the dimensions of the adhesive joint (bonding surface), and also the fit between the adhesive and the substrate. [6] investigates the finger joints of different types of hardwoods. He states that bonding-related factors such as adhesive application, pressing time, and applied pressure depend on joint strength. The strength and integration of glue joints in glulam materials, implement a prerequisite requirement for the structural implementation of these elements [7]. A study conducted by [8] on the strength and stiffness of 15 and 25 mm long finger joints for eight Malaysian tropical kinds of wood concluded that they were suitable for use in glulam production. The influence of geometric and material parameters, joint pressure, and failure modes on the bending strength of finger-jointed finger-jointing of “Eucalyptus” wood species were presented by [9]. [10] did experimental studies on the tensile testing of finger joints on “beech” specimens. They use a melamine-type adhesive to test the finger joints. Due to the use of mainly softwood species in the construction industry, research on hardwood is also lacking in European countries [10]. [11] obtained finger-jointing efficiency values of 55%, 65%, and 77% with species called “Dark red meranti” of 11, 12, and 13 mm finger length specimens, respectively, and defined finger-jointing efficiency as the ratio of the modulus of rupture (MOR) of finger-jointed specimens to the MOR of solid samples expressed as a percentage.

It emerges from the analysis made on the experimental approach of the mechanical behavior of the assembly of the identified wood that many ways of research remain unexplored, those having to do with the improvement of the performance of beveled assemblies of the structural elements in glued laminated wood in constructions. This is reflected in a certain lack of knowledge of their behavior, particularly about the presence of damage that can lead to the

degradation of their mechanical properties. In our study, we are going to determine the mechanical properties in bending and tension and also the influence on the mechanical resistance resulting from the beveled assembly from local Cameroonian wood species and then make a comparison of these mechanical properties with those of the local Malaysian wood called Dark red meranti (*Shorea* spp.) and spruce commonly used in the assembly by jointing.

## 2. Materials and Experimental Methods

**2.1. Preparation of Samples and Methodology.** The choice of material was simple. The local species was chosen based on a multi-criteria analysis, such as straightness, buttress, grooves, bumps or knots, splits, and log section. The *Terminalia superba* is called in Cameroon (AKOM). Trees were chosen in the South region of Cameroon, Dja and Lobo Division, Zoétélé subdivision, geographically located in the large forest of the “Messock” village; between 6°30' and 6°45' latitude and between 5°52' and 6°12' longitude. The sampling was done on 2 trees aged 32 years each (identified by ring count) with the following log dimensions: bole length from 15 to 22 m and diameter from 25 to 42 cm at the small end, then from 50 to 70 cm at the large end. *Terminalia Superba* is a very slender tree whose bole can measure more than 30 m high. Its bole is generally cylindrical and its very thin bark of gray color often cracked in length and can be able to detach in broad plates. It has a large footprint rising to several meters from the base and is triangular in shape. It is a fairly homogeneous straw-yellow wood with a light counter grain [12]. The boards were stored (stacked on sticks) as shown in Figure 1 in the Laboratory of Mechanics, Materials and Photonics at the University of Ngaoundere, to improve air drying. This wood sometimes has a soft heart, the drying of this species is fast, without risk of deformation and splitting. *Terminalia Superba* is often used for carpentry, framing, fiberboard or particleboard, joinery, seats, slatted panels, and furniture [13]. The samples for the production of the test specimens were taken from the base of the tree trunk (Figure 2). Beams were reconstructed in 3 lamellae by gluing by varying the angle of abutment of the central lamella, and each lamella had a thickness of 15 mm. The specimens were directly extracted on these beams and reported to normal dimensions. The Physical properties considered in this study are size and shape. Three linear dimensions were measured, that is length, width, and thickness using a Vernier caliper (ROCH-France) reading to 0.02 mm and the meter. The specimens were made in a carpentry company and reduced to normal dimensions for moisture tests. In our test campaign, bending and tensile tests were carried out. The main purpose of bending tests is to determine the mechanical characteristics of material in various assembly configurations (modulus of elasticity and breaking stress) and that of tensile test is to determine the failure modes and the strength of the glue joint.

**2.2. Study of the Dispersion of the Humidity Rate.** The determination of the moisture content of the wood will be defined according to the NF B 51-004 standard [14]. The mass of each test piece was determined by means of an

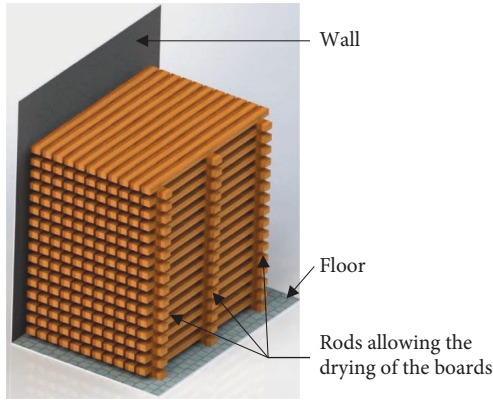


FIGURE 1: Plank storage and drying plan.

FIGURE 2: Base of the tree trunk *Terminalia Superba*.

electronic balance (KERN 440-45N) with a precision of 0.1 g. The measurements were repeated 20 times each. The value of the moisture content is obtained by

$$H = \frac{M_H - M_0}{M_0} \times 100, \quad (1)$$

where  $H$  is the moisture content or Humidity of wood;  $M_H$  is the initial mass of the specimen before drying; and  $M_0$  is the mass of the anhydrous specimen.

The specimens were taken from parallelepiped samples with a volume of  $72 \times 24 \times 24$  mm on a single 2400 m board as shown in Figure 3. This sampling will show us if there is a dispersion of moisture content on the same board.

**2.3. Determination of Wood Density.** The Humidity and density of wood are two of the parameters that affect its mechanical properties [15]. The bonding capacity of wood is related to its density and moisture content. The densities of the respective samples were determined using

$$\rho_{V_e} = \frac{m_e}{V_e}, \quad (2)$$

$$d = \frac{\rho_{V_e}}{\rho_e}, \quad (3)$$

where  $\rho_{V_e}$  is the density of the specimen;  $m_e$  is the mass of the specimen;  $V_e$  is the volume of the specimen;  $\rho_e$  is the density of the water; and  $d$  is the relative density.

#### 2.4. Test Equipment and Methodology

**2.4.1. Four-Point Bending Test.** The specimens were reconstituted by eliminating the singularities, then a passage of these samples to the machine for the planning in order to obtain the samples intended for the test bending 4 points (simple beam on two supports with concentrated loads  $F_C$  and  $F_D$ ) for the unjointed and jointed specimens. We chose this type of configuration because it is considered better according to [16, 17] and that in local area, some wood industries are not equipped with splitters. The different configurations of finger-jointed laminations according to the variation of angles ( $0^\circ$ ,  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$ , and  $75^\circ$ ) are shown in Figure 4. We used a Phenol-Resorcinol-Formaldehyde (PRF) type adhesive combined with a HRP-155 hardener. The same bonding principle was reported for the flexural specimens with a clamping pressure of 100 bar. For the end angles  $\alpha$   $15^\circ$  and  $30^\circ$ , the application of the bonding pressure is following the axis of the specimens for vertical bonding mounting. For the end angles  $\alpha$   $45^\circ$ ,  $60^\circ$ , and  $75^\circ$ , the application of the bonding pressure is perpendicular to the axis of the specimens for horizontal mounting. The specimens were made and sized ( $950 \times 70 \times 45$  mm<sup>3</sup>) according to [18], for the bending test. Figure 5 shows the principle of the 4-point bending test allowing to characterize the wood and to measure the mechanical strength of the specimen by the bending moment.

The four-point bending tests were performed using LDW1 test equipment (equipped with a 50 kN capacity load section) as shown in the setup presented in Figure 6. This bending test was done in order to establish a relationship between breaking mode of the specimens and the beveled configuration by varying the angles and were repeated on 12 specimens on each configuration. For the different butt-jointed samples and solid wood, the loading speed is 4 and 5 mm/min, respectively. The need for these test campaigns was to determine the longitudinal modulus of elasticity (MOE) and the modulus of rupture (MOR) resulting from various assembly configurations.

**2.4.2. Tensile Test.** Tensile specimens were made by giving a parallelepiped shape and then reducing its section and making rounded shapes from a machine router. Then, we used the different angle jigs manufactured to cut the manufactured specimens with the saw while eliminating singularity defects in some specimens before gluing them back together. According to the NF EN 301 standard [19], the glue chosen must be adapted to the wood used and produce durable and reliable connections during the life of the structure. In order to comply with the European standards, for the realization of the specimens according to the bevel configuration (Figure 4), we used a Phenol-Resorcinol-Formaldehyde (PRF) type adhesive combined with a HRP-155 hardener. For the tensile specimens, the clamping

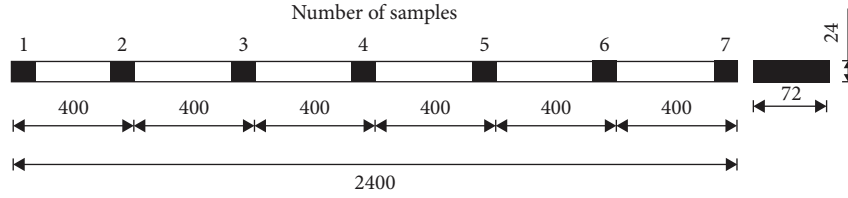


FIGURE 3: Sample collection.

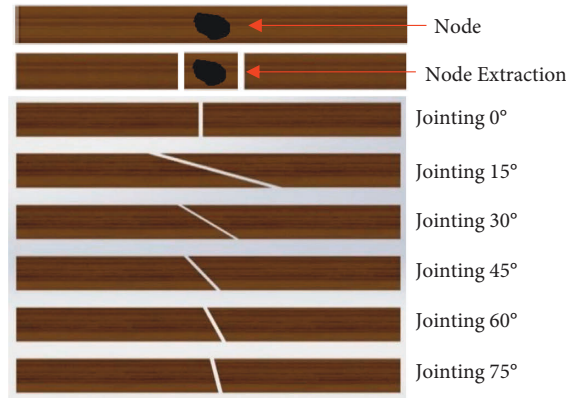


FIGURE 4: Various configurations of the slats butted by beveling manufactured by removing the singularities.

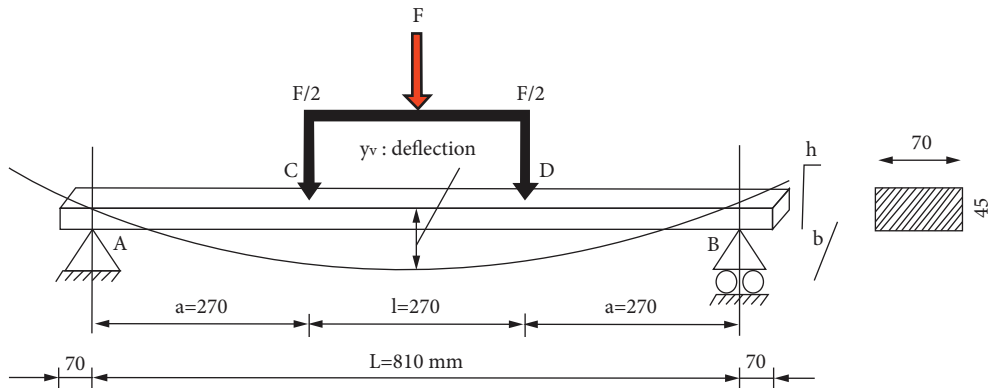


FIGURE 5: Schematic illustration of the flat 4-point bend test.

pressure was constant (10 bar) and a stabilization of 24 hours before loosening [20] and a wait of one week for curing of the assembled specimen. Figure 7 shows the geometry and dimensions (in mm) of the specimen used in axial tension. The principle was as follows: on each clamping jaw was fixed one end of the specimen by ensuring the perfect alignment of the whole (jaw-test-specimen-jaw). Our tests were controlled on a speed of 0.5 mm/min and according to the test of Kufner and Kollmann [21, 22] and were repeated on 12 specimens in each configuration.

**2.4.3. Determination of the Longitudinal Modulus of Elasticity or Longitudinal Young's Modulus ( $E_L$ ).** In the elastic domain, what interests us is the longitudinal modulus of elasticity ( $E_L$ ) and the maximum stress in bending ( $\sigma_{\max}$ ), because among the three directions of wood (longitudinal,

radial, and tangential), it is the longitudinal direction that has great importance in the use of structural elements. From the experimental load conditions, the relationship between the Young's modulus and the loads can be obtained by

$$E_{L,\text{global}} = \frac{3aL^2 - 4a^3}{2bh^3(2f_2 - f_1/F_2 - F_1 - 6a/5Gb)}, \quad (4)$$

where  $G$  is the shear modulus. If it is not known, it can be taken equal to infinity. Equation (4) then becomes

$$E_{L,\text{global}} = \frac{3aL^2 - 4a^3}{2bh^3(2f_2 - f_1/F_2 - F_1)}, \quad (5)$$

$$E_{L,\text{global}} = \frac{3aL^2 - 4a^3}{4bh^3} \times \frac{F_2 - F_1}{f_2 - f_1}.$$

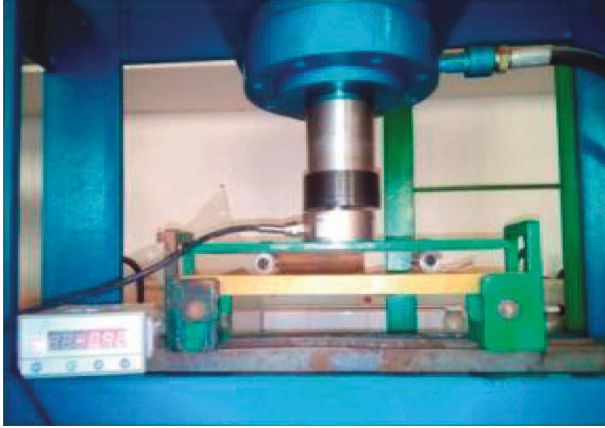


FIGURE 6: Four point bending test device.

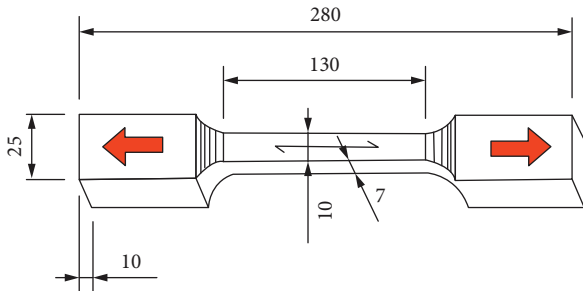


FIGURE 7: Schematic illustration of the axial tensile test specimen.

But for

$$\alpha = \frac{F_2 - F_1}{f_2 - f_1}, \quad (6)$$

then

$$E_{L,global} = \frac{3aL^2 - 4a^3}{4bh^3} \alpha. \quad (7)$$

$\alpha$  is obtained by linear regression on the experimental points;  $b$  and  $h$  are the dimensions of the specimen in (mm) (Figure 5);  $L$  (mm) is the length of the specimen between the supports;  $a$  (mm) is the distance in between a loading point and the nearest support;  $(f_2 - f_1)$ , in (mm), is the variation of the following deflection  $(F_2 - F_1)$ ;  $(F_2 - F_1)$ , in (N), is the variation of the force obtained on the linear regression line on the experimental points.

**2.4.4. Determination of the Bending Strength or Maximum Stress ( $\sigma_{max}$ ).** The modulus of rupture in bending is obtained according to the formula given by

$$\sigma_{max} = \frac{F_{max}/2a}{bh^3/12} \times \frac{h}{2} = \frac{3F_{max}a}{bh^2}, \quad (8)$$

where  $F_{max}$  is the maximum force in (N) applied to the specimen.

The local modulus of elasticity will be determined using equation (7) according to the standard NF EN 384 [23].

$$E_{L,local} = (E_{L,global} \times 1,3) - 2690. \quad (9)$$

The Standard NF EN 384 recommends that for thicknesses  $h < 150$  mm, the mechanical strength of the species should be reduced to a reference thickness of 150 mm using a correction coefficient defined as given by

$$k_{ref} = \left(\frac{150}{h}\right)^{0.2}. \quad (10)$$

**2.5. Estimation of the Load Applied for Abutted Angles.** The required area of the specimens is defined by the width and thickness.

$$P = \frac{F}{S_C}. \quad (11)$$

with  $P$  as the bonding pressure,  $F$  the load normal to the bonding surface,  $S_C$  the bonding surface,  $S_i$  the initial surface of the specimen,  $N$  the vertical load, and  $\alpha$  the butting angle (Figure 8(a)).

$$S_C = \frac{S_i}{\cos(\alpha)}, \quad (12)$$

$$S_C = \frac{h}{\cos(\alpha)} \times b, \quad (13)$$

$$F = P \times \frac{h}{\cos(\alpha)} \times b, \quad (14)$$

$$N = \frac{F}{\cos(\alpha)}. \quad (15)$$

**2.6. Studies of Stresses and Displacements in an Inclined Section (Law of Projections).** The stresses exerted in an inclined section of angle  $\alpha$  are the normal stresses ( $\sigma_\alpha$ ) to the cutoff and tangential ( $\tau_\alpha$ ) apartment to the plane (Figure 8(c)). We will apply the equations of resistance of materials for the determination of  $\sigma_\alpha$  and  $\tau_\alpha$ .

**2.6.1. Normal Stress at the Cutoff ( $\sigma_\alpha$ ) along the y Direction.** The normal stress at the glue joint in a section inclined by angle  $\alpha$  represented by projection onto  $\vec{Y}$  (normal to the cutoff) and  $\vec{X}$  belonging to the plane is obtained using equation (18).

$$\sigma_\alpha = \frac{F}{S_C}. \quad (16)$$

Let us use the equations (12) and (15) in equation (17) which gives us

$$\sigma_\alpha = \frac{F}{S_i} \cos \alpha = \frac{N \cos \alpha}{S_i} \cos \alpha = \frac{N}{S_i} \cos^2 \alpha. \quad (17)$$

So

$$\sigma_\alpha = \sigma \cos^2 \alpha. \quad (18)$$



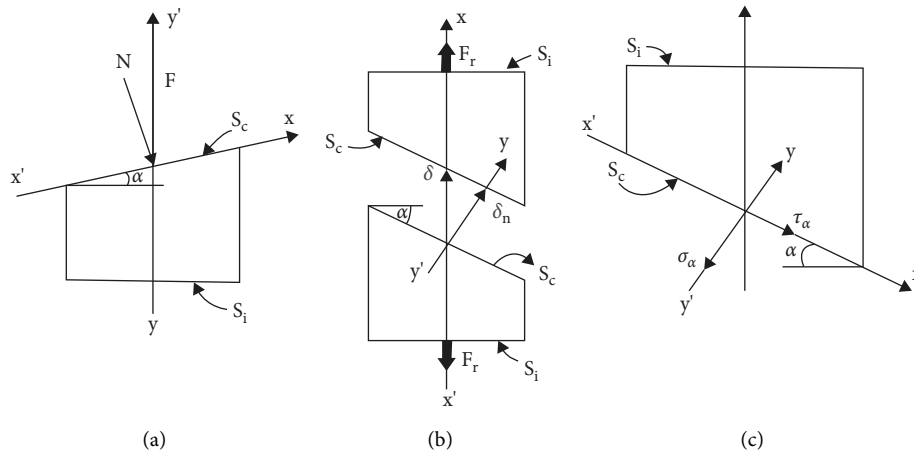


FIGURE 8: Illustration of the butting angle: (a) applied load, (b) different surfaces and displacement, and (c) normal stress at the cut and tangential.

2.6.2. *Tangential Stress at the Cutoff ( $\tau_\alpha$ ) along the  $x$  Direction.* The theoretical calculation of the tangential stress in a section inclined by angle  $\alpha$  is expressed according to formula given by

$$\tau_\alpha = \frac{T_\alpha}{S_C} = \frac{F \sin \alpha \cos \alpha}{S_i}, \quad (19)$$

$$\tau_\alpha = \sigma \sin \alpha \cos \alpha. \quad (20)$$

2.6.3. *Displacements ( $\delta_n$ ) as a Function of the Force along the  $y$  Direction.* The displacement  $\delta$  along the  $y$  direction is determined theoretically. This displacement is also the direction normal to the bonding surface  $S_C$  (glue joint plane) (Figure 8(b)). The displacement  $\delta$  is found experimentally when the specimen breaks in the axial direction.

$$\delta_n = \delta \cos \alpha. \quad (21)$$

### 3. Results and Discussion

3.1. *Physical Properties of the Local Species.* The humidity during drying shows a slight variation characterized by the position of the sample in a board. There is no regularity in moisture loss on the sample shown in Figure 9. A rapid decrease in the mass of the sample in the interval [0–8 h] hours and finally a regularity of the water loss which shows that there is little water left in the sample. Whether a specimen is taken from the ends or the middle of the board (Figure 3), there is no major difference in humidity due to the arrangement of the board storage (Figure 1) and to the thickness of the board.

The test campaigns for the determination of the average moisture content of wood by placing the samples in an oven at a temperature of 105°C for 24 hours. The moisture content and density were determined from equations (1) and (2), respectively. Table 1 shows us the summary obtained on the specimens. In our test campaigns, the average

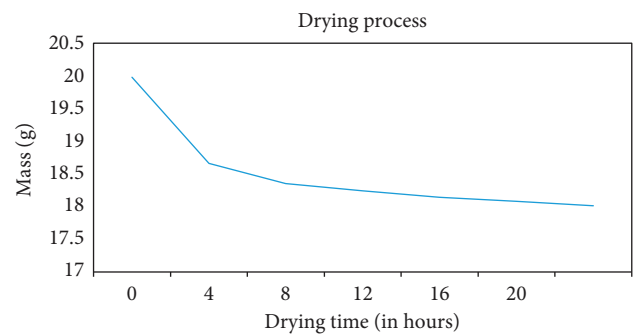


FIGURE 9: Specimen drying process.

value of moisture content was 11.79%. The average value of the solid specimen of Dark red meranti and Spruce according to [24] was 11.5% and 12.4%, respectively. The average density value of Terminalia Superba obtained was 537 kg/m<sup>3</sup>. For Dark red meranti and Spruce specimen according to [24], the average density value was 564 and 497 kg/m<sup>3</sup>, respectively. The physical properties of our wood obtained during our testing campaigns seem to be similar to those reported by [24]. In this study, the density of the Terminalia Superba sample obtained is comparable to the average value of 540 kg/m<sup>3</sup> for the same species reported by [13].

#### 3.2. Bending Properties

3.2.1. *Modulus of Elasticity and Bending Strength of Solid and Assembled by Various Configurations Specimens.* The average values of mechanical properties such as the global and local longitudinal modulus of elasticity of solid wood and for the different beveling configurations obtained using equations (7) and (9), respectively. A variation of the longitudinal Young's modulus of solid wood and finger-jointed wood is observed. The variation of the longitudinal modulus of elasticity of the solid lamella compared to the average value of the longitudinal modulus of elasticity of the finger-jointed

TABLE 1: Summary of the physical properties of the local wood *Terminalia Superba* (Fraké).

	Dimensions (mm)			Volume $V$ (mm <sup>3</sup> )	Initial mass (g)	Anhydrous mass (g)	Humidity $H$ (%)	Density $d$ (kg/m <sup>3</sup> )
	Length $L$	Width $b$	Thickness $h$					
Max. value	23.3	72.2	22.6	38019.08	26.82	24.55	12.24	700.57
Min. value	22.8	71.8	22.3	36505.99	18.86	16.84	10.71	437.36
Extent	0.5	0.4	0.3	1513.09	7.96	7.71	1.53	263.22
Mean value	23.1	72	22.5	37425	24.84	22.69	11.79	537.20
Standard deviation	0.15	0.26	0.21	4164.23	0.27	0.25	0.63	88.31
CV (%)	0.65	0.36	0.93	11.13	1.33	1.4	5.38	16.44

lamellae is small, of the order of less than 10% for the finger-jointing at 15° (Figure 10). The results of the ANOVA test show that there is no significant difference ( $P \geq 0.05$ ) between the MOE means of the solid and 15° finger-jointed specimens. To obtain the strength values as a function of the reference height, we weighted our results using a corrective coefficient  $k_{ref}$ . The average values of the bending strength were obtained using equations (9) and (11). We note the variability of the flexural mechanical strengths of the finger-jointed specimens (Figure 11). The variability may be due to a bonding defect or a crack on the bonding surface of one of the laminae. The 15° bevel configuration appears to have better strength compared to the other configurations (30°, 45°, 60°, and 75°).

The average values presented in Table 2 are the results of the bending strength of solid wood samples and various connection configurations as a function of angle in comparison with other species. Equations (13) and (14) allowed us to determine the bond area and the load normal to the bond area. It is not surprising that the mean value of the modulus of rupture (MOR) of the massive specimens of *Terminalia Superba* (Fraké), Spruce specimen, and Dark red meranti (*Shorea* spp.) are higher than that of the specimens obtained by bevel configuration and by finger-jointing. Statistical analysis (Table 2) showed no significant difference between the mean values MOR of massive *Terminalia Superba*, Dark red meranti, and spruce specimens at the 95% confidence level. Dark red meranti specimens have a modulus of rupture about 9% higher than *Terminalia Superba* and the latter has a value about 4% higher than Spruce.

The joint efficiency of the adhesive was obtained by calculating the ratio between the modulus of rupture of the solid specimens and the modulus of rupture of the finger-jointed specimens of the same species. The joint efficiency values of the specimens made by beveling using a Phenol Resorcinol-Formaldehyde (PRF) adhesive combined with HRP-155 hardener were 83%, 76%, 64%, 56%, and 50%, respectively, 15°, 30°, 45°, 60°, and 75°. In this study, the joint efficiency of *Terminalia Superba* obtained samples is comparable with Dark red meranti made with Phenol Resorcinol-Formaldehyde (PRF) adhesive and Spruce samples depending on the types of joint configuration and also with the types of joint compared with that of solid wood [17]. A correlation between density and bending strength of solid wood of *Terminalia Superba* is presented in Figure 12.

**3.2.2. Factors Influencing the Bending Properties.** The 15° butted specimens were compared with the 30° butted specimens because of the effectiveness of the glue joint. The objective was to find out whether the bonding surface influenced the bending strength. Statistical analysis revealed a significant difference between the modulus of rupture of the 15° and 30° butt joint at the 95% confidence level. This shows that the bonding surface of each specimen influences the flexural strength. A study by [25] shows that the variation of the configurations and the effect of the length of the specimen influence the mechanical properties in bending of the wood. In this study, the angles vary, the thickness and width of the specimen remain constant. The angle factor influences the modulus of rupture of *Terminalia Superba* in bending. It can be concluded that hardwood species, such as *Terminalia Superba* in this study, may require variable bonding surfaces to produce joints of adequate strength compared to softwood species. The bending strength as a function of the density of the abutted specimens (15° and 30°) is presented in Figure 13.

### 3.3. Tensile Properties

**3.3.1. Variation of the Splice Angle as a Function of the Bonding Pressure in Axial Tension.** As the angle  $\alpha$  increases, the bonding area varies and the vertical force to be applied to a specimen becomes significant as a function of the bonding pressure obtained for our tests (Figure 14). A load applied progressively on the specimen until it breaks presents us with the behavior of a force-displacement curve.

Table 3 summarizes the parameters calculated using the equations obtained by the law of projections. To determine these parameters, we used equations (13)–(15). We have illustrated more clearly the curves showing the evolution of the load as a function of the variation of the angles at a constant bonding pressure. Table 3 also shows the evolution of the failure stress as a function of the joint angle. The average values obtained in our experimental tests show that the fracture stress, the fracture force, and the adhesive joint area increase with the joint angle.

**3.3.2. Study of Displacement ( $\delta$ ), Normal, and Tangential Stresses.** The normal and tangential stresses meet at 45°, so the finger-jointing angle between [0° and 45°] presents us

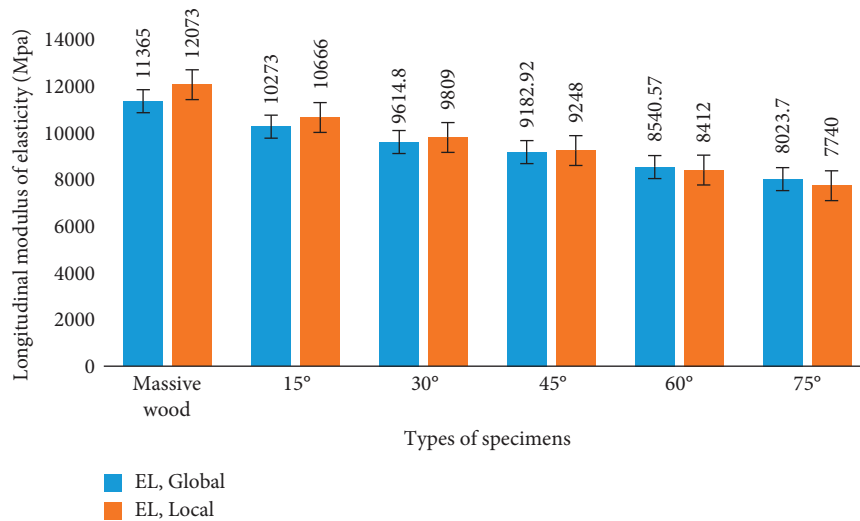


FIGURE 10: Comparison of longitudinal modulus of elasticity of solid and finger-jointed timber.

TABLE 2: Bending mechanical properties resulting from various assembly configurations in comparison with other species.

Specimen	Number of specimens	MOR $\sigma_{\max}$ (N/mm <sup>2</sup> )	MOE $E_{L,G}$ (N/mm <sup>2</sup> )	Initial surface $S_i$ (mm <sup>2</sup> )	Bonding surface $S_c$ (mm <sup>2</sup> )	Pressure (N/mm <sup>2</sup> )	Load normal to the bond area $F$ (N)
<i>Terminalia Superba (Fraké)</i>							
Massive specimen	12	85.04	11365	2940	—	—	—
15°	12	70.3	10273	2940	3261.12	10	30430.1
30°	12	64.35	9614.8	2940	3637.31	10	33948.2
45°	12	54.28	9182.92	2940	4454.77	10	41577.9
60°	12	47.89	8540.57	2940	6300	10	58800
75°	12	42.82	8023.7	2940	12170.66	10	113592.9
<i>Dark red meranti (Shorea spp.) [24]</i>							
Solid D	10	93.1	16000			—	
FJ4	12	59.4	17000			10	
FJ1	10	71.9	15500			12.5	
<i>Spruce specimen</i>							
Solid S	12	81.8	16900			—	
FJS	13	52.9	16100			12.5	

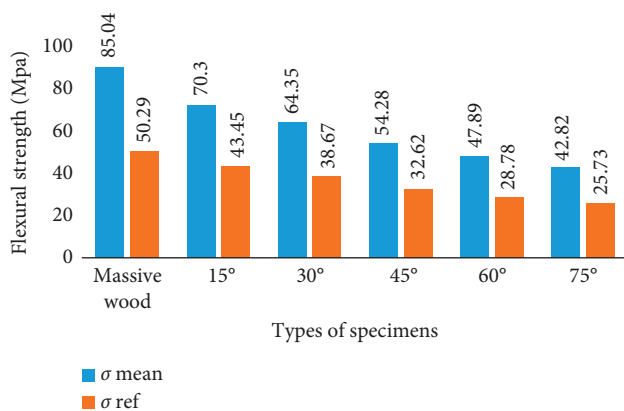


FIGURE 11: Comparison of bending strengths of solid and finger-jointed timber.

with a rupture in traction (Figure 15). The rupture occurring on the specimen at more than 45° is combined (traction-shear). Whatever the breaking force, the axial or normal displacement is constant (Figure 16). At the 45° finger-jointing angle, the specimen ruptures completely when the normal displacement reaches 0.20 mm. Therefore, it is very possible that any beam will rupture from a displacement of 0.20 mm without taking into account the finger-jointed configuration at the 0° angle, because it has a very small displacement. The average values such as normal displacement ( $\delta_n$ ), normal ( $\sigma_\alpha$ ), and tangential ( $\tau_\alpha$ ) stresses as a function of angle  $\alpha$  were determined from equations (18), (20), and (21) (Table 4). The normal and axial displacement at the bonding surface remains relatively constant whatever the breaking load.



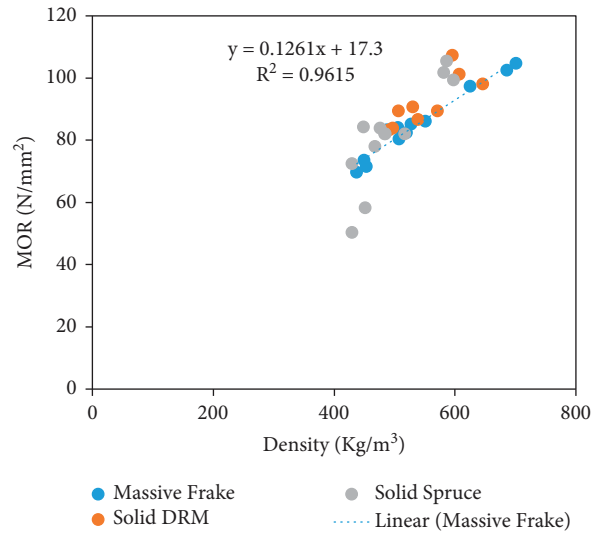


FIGURE 12: Bending strength as a function of density for massive *Terminalia Superba* (Fraké), *Spruce*, and *Dark red meranti* (*Shorea spp.*) specimen.

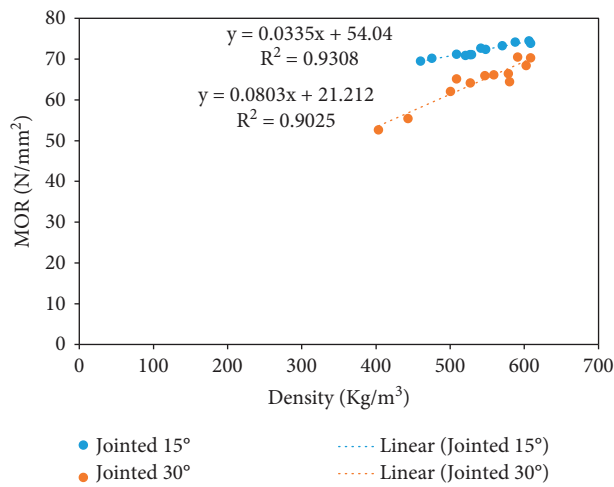


FIGURE 13: Bending strength as a function of density for jointing 15° and jointing 30° specimens.

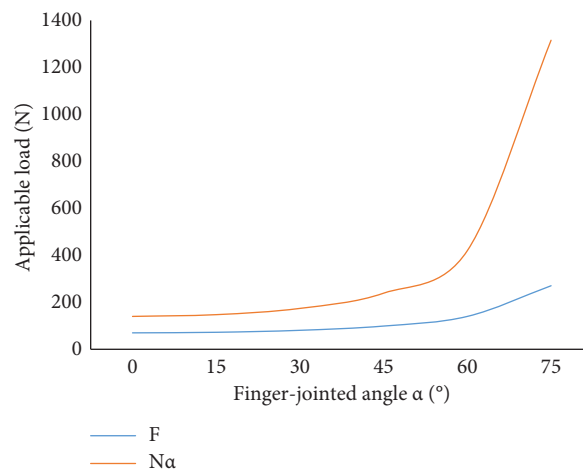


FIGURE 14: Evolution curve of the loads to be applied as a function of the angle  $\alpha$ .

TABLE 3: Normal and vertical loads of the specimen ( $P=1 \text{ N/mm}^2$ ) and synthesis of experimental tests in axial traction by angle variation  $\alpha$ .

Angle $\alpha$ ( $^\circ$ )	Initial surface, $S_i$ ( $\text{mm}^2$ )	Bonding surface $S_c$ ( $\text{mm}^2$ )	Load normal $F$ (N)	Vertical force $N_\alpha$ (N)	Breaking force $F_r$ (N)	Breaking stress $\sigma$ ( $\text{N/mm}^2$ )	Axial displacement $\delta$ (mm)
Massive specimen	70	—	—	—	8239.50	117.69	1.46
0	70	70	70	70	660	9.40	0.08
15	70	72.46	72.46	75.02	950.50	13.14	0.17
30	70	80.83	80.83	93.33	1155.60	14.33	0.22
45	70	98.99	98.99	140	1536.70	15.52	0.28
60	70	140	140	280	2315.20	16.55	0.44
75	70	270.46	270.46	1044.97	5163.30	19.03	1.02

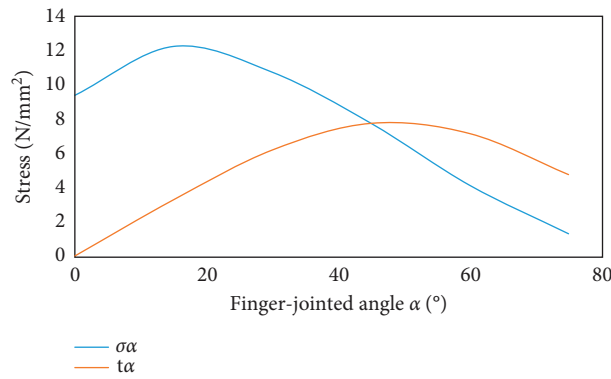
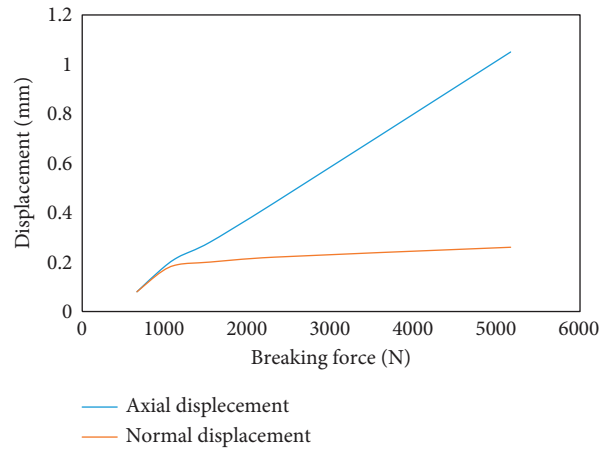
FIGURE 15: Normal ( $\sigma_\alpha$ ) and tangential ( $\tau_\alpha$ ) stresses as a function of the angle  $\alpha$ .

FIGURE 16: Axial and normal displacements as a function of breaking force.

TABLE 4: Displacements ( $\delta_n$ ), normal ( $\sigma_\alpha$ ), and tangential ( $\tau_\alpha$ ) stresses as a function of the angle  $\alpha$ .

Angle $\alpha$ ( $^\circ$ )	Breaking force $F_r$ (N)	Breaking stress $\sigma$ ( $\text{N/mm}^2$ )	Axial displacement $\delta$ (mm)	Normal stress $\sigma_\alpha$ ( $\text{N/mm}^2$ )	Tangential stress $\tau_\alpha$ ( $\text{N/mm}^2$ )	Normal displacement $\delta_n$ (mm)
Massive specimen	8239.50	117.69	1.46	—	—	—
0	659.90	9.40	0.08	9.40	0.00	0.08
15	950.50	13.14	0.17	12.26	3.29	0.16
30	1155.60	14.33	0.22	10.75	6.2	0.19
45	1536.70	15.52	0.28	7.76	7.76	0.20
60	2315.20	16.55	0.44	4.13	7.16	0.22
75	5163.30	19.03	1.02	1.3	4.76	0.26

TABLE 5: Characteristics of the break as a function of the butting angle  $\alpha$ .

Butting angle $\alpha$ (°)	Rupture of specimens bonded with adhesive (PRF)	Observation
Massive specimen	Wood breaking	Reduced part of the specimen
15°	Adhesive failure	Total failure of the abutment (adhesive)
30°	Adhesive failure	Failure of the abutment with little wood detached from the section
45°	Adhesive/mixed failure	
60°	Adhesive/mixed failure	Breakage with detachment of small pieces of wood
75°	Adhesive/mixed failure	Significant breakage of wood fibers

3.3.3. *Characteristic Study of the Failure of the Specimen.* The determination of the type of failure was done qualitatively. In a first step, we considered that the breakage occurs in the glue joint if only in the interval [0%–20%] of the glue cross section is located in the wood. In a second step, the failure occurs if 80% of the glued section is in the wood. If these parameters are not met, the other failures are considered mixed. During the test campaign, the observations will be mentioned in Table 5 below. During our test campaigns, all failures took place at the glue joint.

#### 4. Conclusion

The main objective of this study was to determine the mechanical properties resulting from various assembly configurations to enhance the use of a local species. A test campaign was conducted and the results of these tests were analyzed using ANOVA statistical analysis. This work has made it possible to study experimentally the mechanical behavior of beams of a local species in solid wood and in wood butted by the bevel configuration and also to determine the mechanism of failure of a beveled wood-wood assembly.

The test campaigns carried out on *Terminalia superba* (Fraké) from the natural forest give encouraging results, on the one hand for the longitudinal modulus of elasticity and on the other hand for its mechanical resistance in bending. Specimens of *Terminalia superba* (Fraké) showed higher flexural strength than spruce specimens and inferior to Dark red meranti (*Shorea* spp.). In terms of resistance, the butting of the lamellae seems to be a reducing factor in comparison with solid wood. *Terminalia superba* (Fraké) abutting specimens in particular at 15°, 30°, and 45° offered better joining efficiency than Dark red meranti (*Shorea* spp.) FJ4 specimens at a pressure of 10 N/mm<sup>2</sup> and also those spruce FJS specimens. In the event of butting, we recommend the use of test specimens assembled in a bevel with an angle  $\alpha$  equal to 15° butted at 15° with the use of an adhesive of the Phenol-Resorcinol-Formaldehyde (PRF) type combined with a hardener HRP-155 because the variation of the bonding surface influences the bending resistance. There was no similarity between the MOE values of the solid specimens and those of the abutting specimens of *Terminalia superba* (Fraké), which shows an influence of beveled joints on the bending stiffness. In this study, the MOR of massive specimens of *Terminalia superba*, dark red meranti, and spruce appeared to correlate with the density of the specimens.

The tensile tests carried out made it possible to determine the failure mechanism. In axial traction, the mode of rupture changes depending on the butting angle  $\alpha$ . The finger-jointing angle  $\alpha$  equal to 45° appears to be better following the breaking mode in axial traction. The results obtained in this study constitute a step toward the development and valorization of local species.

#### Data Availability

All data generated or used during this study are included in this article.

#### Conflicts of Interest

The authors declare that they have no conflicts of interest.

#### Authors' Contributions

All authors have read and approved the final manuscript.

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