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Effects of long-term loading on Moabi wood beams in the tropical environment of Gabon: variability in properties and effects of exposure conditions on mechanical properties in 3-point bending tests

Valérie Nsouami [a], Nicaise Manfoumbi Boussougou [b], Emilio Bastidas-Arteaga [c], Rostand Moutou Pitti [d,e]

[a]*Ecole Normale Supérieure L'Enseignement Technique (ENSET), LaReVa Bois, Libreville, BP 3989, Gabon*
[b]*Ecole Polytechnique de Masuku, Université des Sciences et Techniques de Masuku, Franceville, BP 901, Gabon*
[c]*Laboratoire des Sciences de l'Ingénieur pour l'Environnement (LaSIE UMR CNRS 7356), La Rochelle Université, 17042 La Rochelle, France*
[d]*Université Clermont Auvergne, Clermont Auvergne INP, CNRS, Institut Pascal, BP 10448, 63000 Clermont-Ferrand, France;*
[e] *CENAREST, IRT, BP 14070 Libreville, Gabon*

Abstract

This work is devoted to 3-point bending tests performed on tropical specimens of Moabi (*Baillonella toxisperma*) from Gabon. The beams are formerly subjected to long-term loading in three media (air-conditioned, unsheltered and sheltered outdoor) in a tropical environment. The beams were sawn into nine 340 mm long sections and subdivided into three sections in the vertical direction (top section, middle section and bottom section). From each section, two specimens were extracted for the bending test, two for the tensile test and four for the compression test. In the present study, 81 bending specimens with a cross-section of 15 x 15 mm^2 and a length of 300 mm were used. The tests for the determination of the local modulus of elasticity and failure strength in bending were carried out according with NF EN 408. The results obtained show a strong influence of time and exposure environments on the mechanical parameters (bending strength and modulus of elasticity). There is also a strong variability of these mechanical parameters along the length of the beams with a clear correlation between the sampling areas and the level of exposure; this confirms quite well the level of complexity of the wood material.

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Keywords: *Moabi (Baillonella toxisperma); variability; Long-term-loading; Bending*

* Corresponding author. Tel.: +33 6 79 58 24 25; fax: +33473407494.
E-mail address: rostand.moutou_pitti@uca.fr

1. Introduction

The forests of the Congo Basin are located in Central Africa and covers the following countries : Cameroon, the Central African Republic, Republic Democratic of the Congo, the Congo, Equatorial Guinea and Gabon (De Wasseige et al. 2012). They have a forestry potential of about 70% of Africa's forests. On the 530 million hectares of the Congo Basin, 300 million are covered by the forest. The forest area is made up of more than 99% primary or naturally regenerated forests, as opposed to plantations, and 46% of dense lowland forests (World Bank 2012). The Gabonese forest represents nearly 85% of its territory with nearly 400 species of wood. It is rich in Okoumé, Ozigo and other woods called : "various woods" which are in greater number, these are Azobé, Bilinga, Moabi, Movingui, Padouk, Sapelli etc. (Manfoumbi 2012).

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Moabi wood has a density of 0.87 ± 0.07. It is classified as hardwood having a pinkish brown to reddish brown color. This species is very much adored by the quality of its wood for interior and exterior carpentry (doors, windows, parquet floors, stairs, various fittings, works in contact with the ground or with fresh water) and wood in permanent contact with seawater (pillars, pontoons, submerged timber), heavy framework, for veneer (furnishings and decoration), for marine construction, for cabinetmaking, slicing and sculpture (CIRAD 2011; Doucet et Kouadio 2007). The objective of this study is to evaluate the mechanical parameters of the specimens subjected to long-term loading (9 years) to ensure the reliability of the structure. In other words, studying the mechanical behavior of tropical woods, in the case of Gabonese species in their immediate environment, is crucial to control their lifetime and guide locals in their choice of construction materials (Odounga et al. 2017). The different specimens were kept in an air-conditioned room and the tests were carried out in this same room where the average temperature and relative humidity were respectively 24.3 ° C and 43.8%. The mechanical parameters were adjusted to a moisture content of 12% for comparison.

Nomenclature

ΔF	Force increment
Δw	Increase in the arrow
b	Thickness of the specimen
$Fmax$	Maximum force
FS	Failure stress
h	Length of the specimen
l	Length of the specimen
MOAC4B	Specimen 4 of Moabi in lower part in an air-conditioned environment
MOS4B	Specimen 4 of Moabi in lower part in a sheltered environment
MOU4B	Specimen 4 of Moabi in lower part in a sheltered environment
MOAC4H	Specimen 4 of Moabi in upper part in an air-conditioned environment
MOS4H	Specimen 4 of Moabi in upper part in a sheltered environment
MOU4H	Specimen 4 of Moabi in upper part in a sheltered environment
MOAC4M	Specimen 4 of Moabi in middel part in an air-conditioned environment
MOS4M	Specimen 4 of Moabi in middel part in a sheltered environment
MOU4M	Specimen 4 of Moabi in middel part in a sheltered environment

2. Materials and Methods

2.1. Materials

The Moabi (*Baillonella toxisperma*) specimens are debited from three beams (89 × 176 × 3090 mm^3) storage in three tropical environments (air-conditioned, unsheltered exterior and sheltered exterior), see figure 1. These beams had been loaded during 9 years (Manfoumbi, 2012). In addition, these beams were sawn into nine sections 340 mm long. Fig. 2.b and 2.c show the different specimens obtained in height (upper part, middle part and lower), see Fig. 2a. From each section, we shoot two bending specimens (81 samples of section 15 × 15 mm^2 and 300 mm long), two for traction and four for the compression tests (78 specimens of section 20 × 20 mm^2 for 120 mm long). Please note that only bending tests have been presented and discussed in this paper. Please note that the density is obtained by the classical weighing method.

Fig. 1. a) Air-conditioned environment. b) Unsheltered environment. c) Sheltered environment

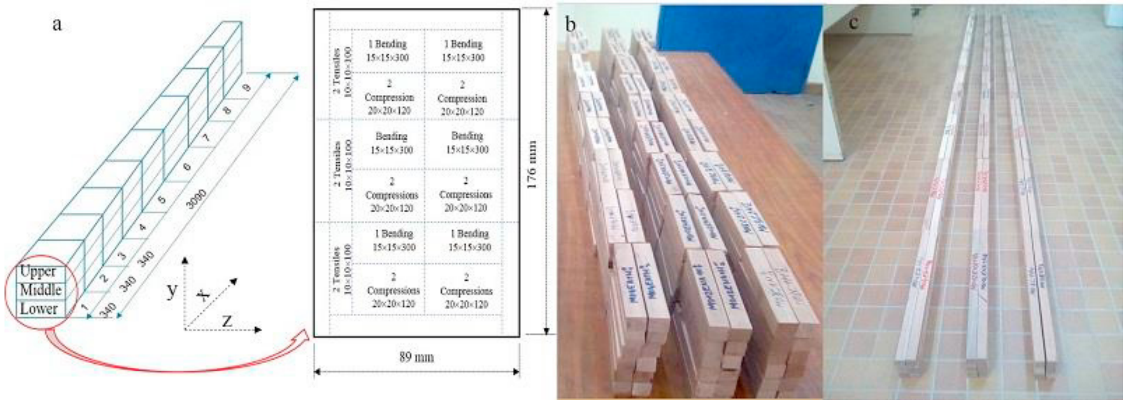

Fig. 2. Spatial representation of the beam. a) Beam cutting plane. b) Compression specimens. c) Bending specimens

2.2. Methods

2.2.1. Experimental Protocol

The experimental device used for the three point bending tests is an ‘United’ hydraulic press testing system machine of the series N ° 0314523 (Figure 3). The maximum load capacity is 100 kN. The device is connected to a data acquisition system managed by the Datum 5.0 software.

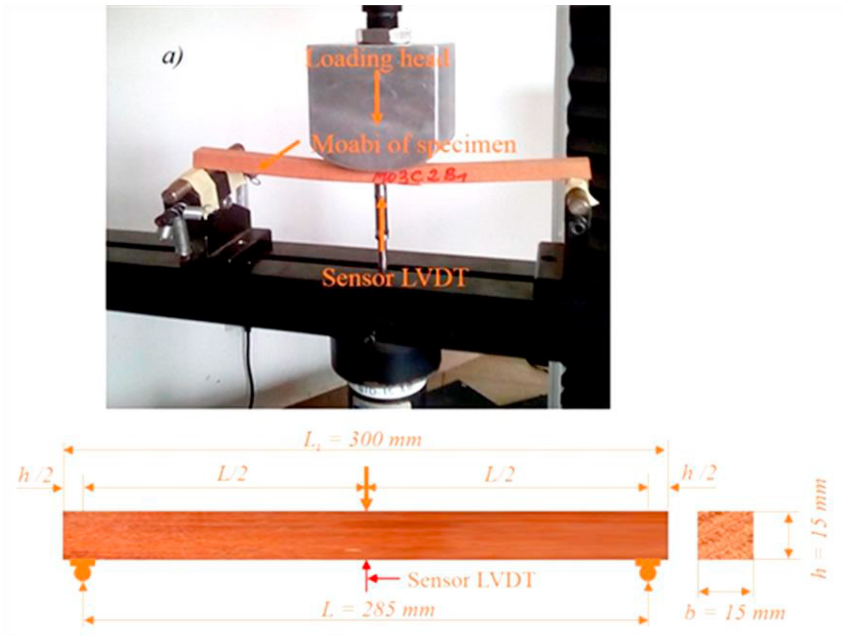

Fig. 3. Experimental devices. a) Three-point bending test

For the bending posted in Fig. 3, the determination of the elastic modulus (MOE) and of the failure stress (FS) introduced respectively by the Equation (1) and (2) in 3-point bending are done using the following equations (AFNOR, NF EN 408 2009) :

$$MOE = \frac{l^3 \times \Delta F}{4 \times \left(b \times h^3\right) \times \Delta w} \quad (1)$$

Where ΔF is a load variation on the rectilinear part of the load deformation curve (N), Δw is the corresponding deformation increment (mm), l is the reference length (mm), b is the thickness and h is the height of the specimen (Fig. 3b).

$$FS = \frac{4 \times F\max \times l}{2 \times \left(b \times h^2\right)} \quad (2)$$

Where *Fmax* is the maximum force applied during the bending test.

3. Results and discussion

3.1. Loads displacement curves

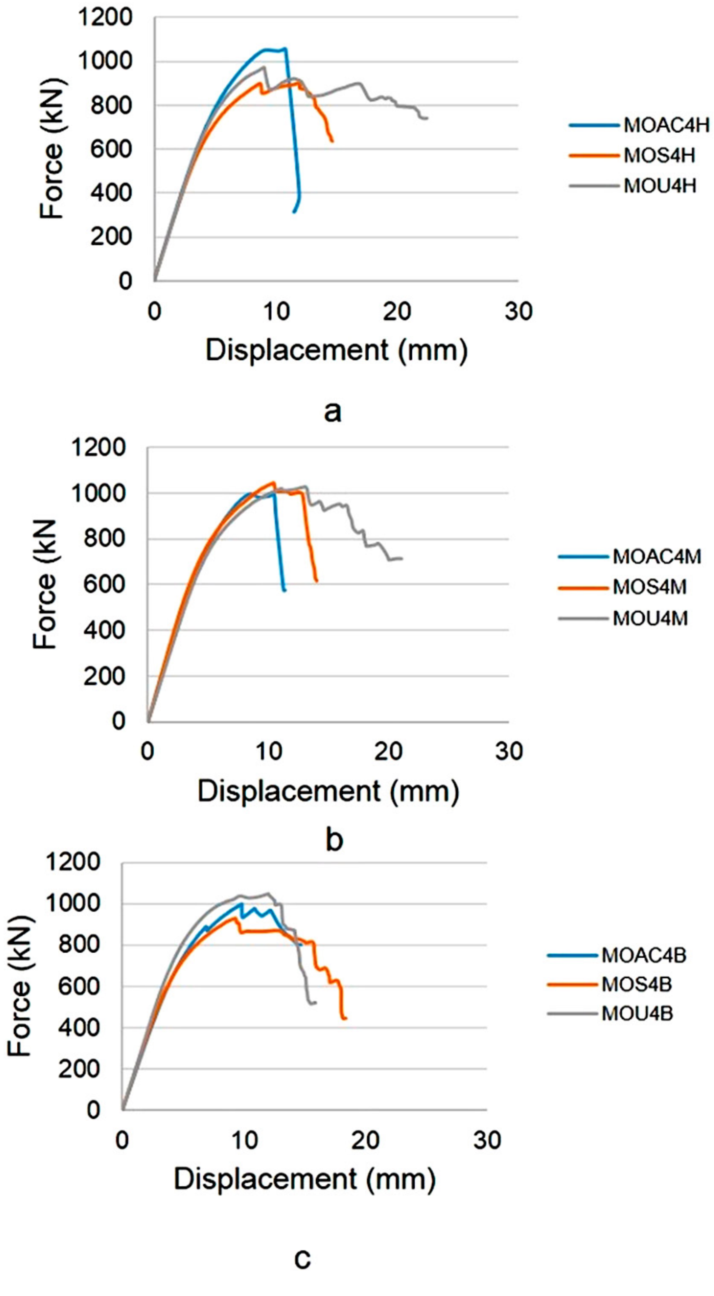

Figure 4. Force-displacement curves for the (a) upper (b) middle and (c) lower portions

Figure 4 presents the Force – displacement curves for the three environments posted in Fig 1. The considered specimens have defined in the nomenclature section and have been chosen in the same vertical zones (upper (a), middle (b) lower (c)), according to Fig 2 c. It is shown that in middle zone (or portion), the maximal forces are similar in the three environments. However, the maximal force is noted in Air-conditioned atmosphere for upper zones in compression. Simultaneously, the maximal force occurs in sheltered environment for lower zone in tensile.

3.2. Results of bending tests

The results of bending tests presented in Fig. 4 are discussed in this section in order to investigate the impact of physico-mechanical parameter. Table 1 summarizes the experimental results per zone and the mean value per beam. The coefficient of variation (Cov) concerns the beam and was estimated from 27 samples.

Table 1. Results of physico-mechanical bending parameters

Exposures	Parameters	Density (kg/m3)	MOE (MPa)	FS (MPa)
Air conditioned	Number of specimens		27	
	Average	756.16	14 871	122.33
	Standard deviation	24.57	1 131	11.04
	Coef of variation (%)	3.2	7.6	9.0
Unsheltered	Number of specimens		27	
	Average	732.07	14 180	99.84
	Standard deviation	32.64	1 519	11.61
	Coef of variation (%)	4.5	10.7	11.6
Sheltered	Number of specimens		27	
	Average	749.27	17 195	114.06
	Standard deviation	32.91	1 096	7.05
	Coef of variation (%)	4.4	6.4	6.2

In view of the results obtained in Table 1, the physio-mechanical parameters of the specimens from different environments clearly illustrate a real variability depending on the exposure medium. Although, we observe that the modulus of elasticity of the protected medium is higher than the other two. This can be explained, for example, by its larger density (Jodin 1994; Natterer, Sandoz, et Rey 2004) even though it is in a sheltered outdoor environment. Other parameters can also explain this phenomenon such as the humidity rate, temperature, etc.

In a sheltered and unsheltered outdoor environment, the strength and modulus of elasticity of the upper and middle specimens are greater than those calculated in the lower part. This observation is particularly pronounced for the unsheltered outdoor environment. This can be explained by the high exposure of the upper part of the beams to the weather compared to the lower part which is less exposed to run and solar radiation.

Concerning mean values of MOE, Manfoumbi (2012) reported the following values for this kind of timber: 17400 MPa (air-conditioned), 21400 MPa (unsheltered) and 24600 MPa (Sheltered). We found a decrease in beam stiffness for all environments varying from (14.5% to 33.7%). This loss in beam stiffness could be due to environmental effects, loading duration, material aging and wood density. Saifouni (2014) reported that the mechanical behavior is impacted by wood density. On the other hand, the coefficients of variation (Cov) vary between 0.01 and 0.10. The larger Cov correspond the unsheltered conditions where the environmental exposure could affect the microstructure of the timber increasing the variability of mechanical properties.

4. Conclusion

The 3-point bending tests applied on tropical specimens of Moabi (*Baillonella toxisperma*) have been investigated in the work. The specimen are debited on beams previously exposed in three different tropical environments (air-conditioned, unsheltered and sheltered). Based on the experimental results obtained, we observed that there is significant variability in all the mechanical parameters studied in relation to the values of the variation coefficients obtained. Comparing the experimental results with the initial values obtained by Manfoumbi (Manfoumbi 2012) during the mechanical loading, we observe a significant decrease for elastic modulus and strength in the different media studied. Indeed, we observe, for stiffness, a decrease of 14.53% in air-conditioned environment, 33.74% in exposed environment and 30.10% in protected environment. Similarly, for strength, we noted a decrease of 59.54% in air-conditioned environments, 64.28% in exposed environments and 56.01% in protected environments. We also noted that stiffness is more impacted for the unprotected environment compared to the protected environment and the conditioned environment.

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