Young's modulus measurement of wood and CFRP

Viet Anh Nguyen, Robert Le Roy, Jean-François Caron

1. Objectives

The objective is to carry out bending test on two wood-composite beams and a wooden beam to estimate the wood and CFRP (denoted as "carbon" hereafter for the sake of simplicity) elastic properties values, i.e. the Young's modulus ***E*** , and the shear modulus ***G***.
A direct tension experiment is also conducted on a small carbon coupon taken from one of the wood – composite beam.

Three and four point-bending tests were realized on different beams. Measurements of strain and displacement were realized by gauges and sensors placed in positions such as there is no border effect (wood knot). The capacity of the machine is 100 kN. The load applied varies between 5 to 18 kN for the bending tests.

2. Bending test device

2.1. Four point bending test

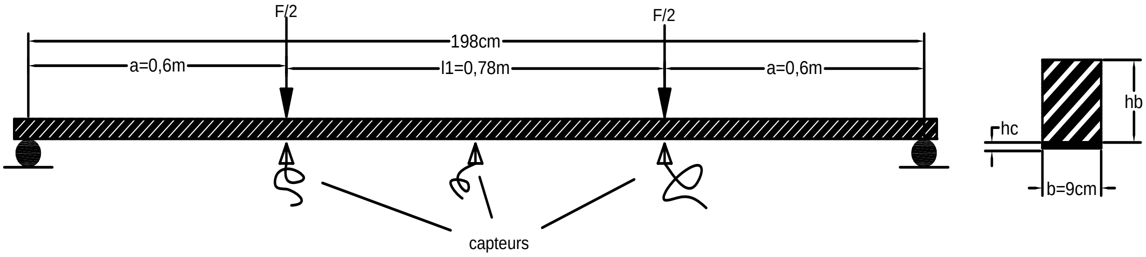


Figure 1. Four point bending test : dimensions

2.2. Three point bending test

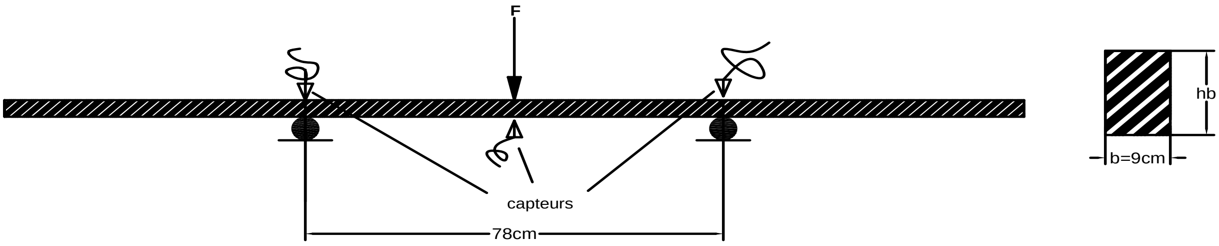


Figure 2. Three point bending test : dimensions

3. Analysis of results.

Maximum applied load is equal to approximately 40% of the ultimate load, so that the material is kept in the elastic range. Each loading consists of 4 cycles. The Young's modulus ***E*** and the shear modulus ***G*** of materials are deduced.

3.1 Determination of wood's Young modulus *E* by pure bending tests.

For the 4 point bending tests of a wood glulam (GL) beam, the following method described in the standard NF-408 is detailed below :

$$\frac{1}{R} = \frac{E_{m,l}.I}{M}$$

$$E_{m,l} = \frac{M}{R.I}$$

$$E_{m,l} = \frac{P.a}{2.I}\left(\frac{l_1^2}{8.w} + \frac{w}{2}\right) = \frac{P.a}{2.I}\left(\frac{l_1^2}{8.w} + 0\right)$$

$$E_{m,l} = \frac{P.a}{16.I}\frac{l_1^2}{w}$$

where $E_{m,l}$, I, M, R are, respectively, the local average modulus, inertia of section, bending moment and radius of curvature. The measures are taken in the central zone, where the bending moment remains constant. The dimensions are given on the figure 1:

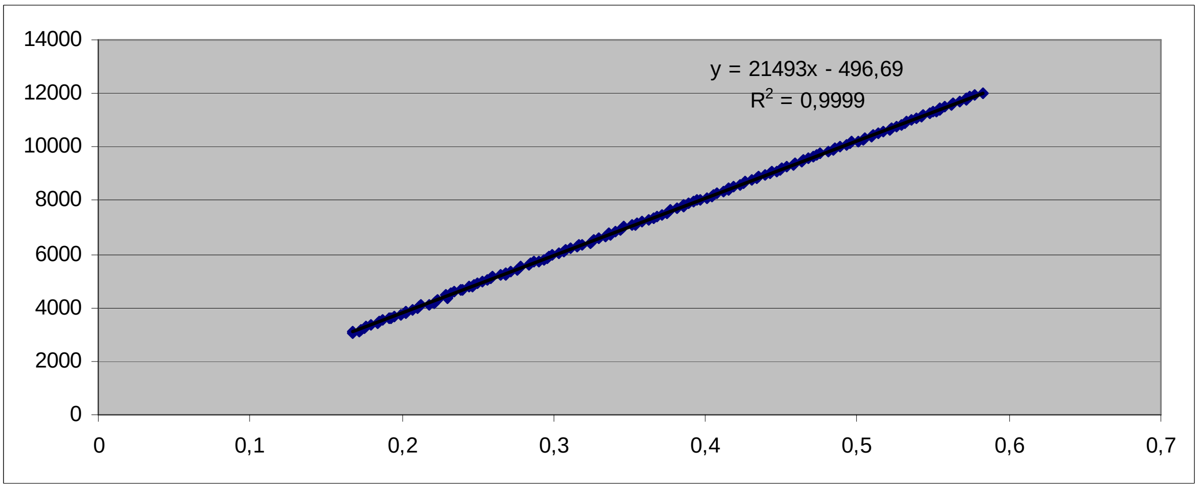


Figure 3. Force (N) versus relative deflection (mm) –
4points bending test of wooden beams, section 18x9cm ²

Three successive tests were carried out on the same beam for loads varying from 300 to 14000N. The Young's modulus $E_{m,l}$ of wood was found between 10.22 to 11.21 GPa. The calculation is detailed in Table 1.

3.2 Determination of wood shear modulus.

Then a 3 point-bending test was conducted on the wooden beam of § 3.1. The part of the deflection generated by the shear force is the difference between the total deflection and the deflection generated by pure bending moment. Thus:

$$\frac{F.l}{4.G.S^d} = \frac{F.l^3}{48.E_{m,app}.I} - \frac{F.l^3}{48.E_{m,l}.I}$$

$$\frac{k_G}{4.G.b.h} = \frac{l^2}{4.E_{m,app}.b.h^3} - \frac{l^2}{4.E_{m,l}.b.h^3}$$

$$\frac{k_G}{G} = \frac{l^2}{E_{m,app}.h^2} - \frac{l^2}{E_{m,l}.h^2}$$

finally,

$$G = \frac{k_G.h^2}{l_1^2.(\frac{1}{E_{m,app}} - \frac{1}{E_{m,l}})}$$

$E_{m,app}$ may be obtained by the following formula :

$$E_{m,app} = \frac{l_1^3(F_2 - F_1)}{48.I.(w_2 - w_1)}$$

where k_G the section factor, $k_G = 1,2$ for rectangular sections.

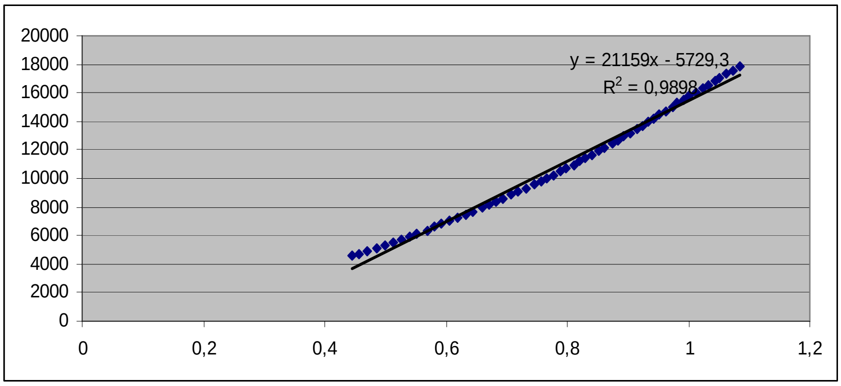


Figure 4. Force (N) versus relative deflection (mm) -
3 points bending test of wooden beams, section 18 x 9cm ²

In this test, the wood shear modulus was measured between 575 MPa and 533 MPa when the modulus $E_{m,l}$ varies respectively from 10.22 to 11.21 GPa. The results are detailed in Table 1.

3.3 Determination of CFRP's Young modulus, layered on the intrados of the wood beam

We have done two 4 point-bending tests on two wood-composite beams, one reinforced with 10 layers of unidirectional CFRP, the other with 12 layers. To simplify the analysis, equivalent dimensions were classically introduced (see figure below).

Equivalent width :

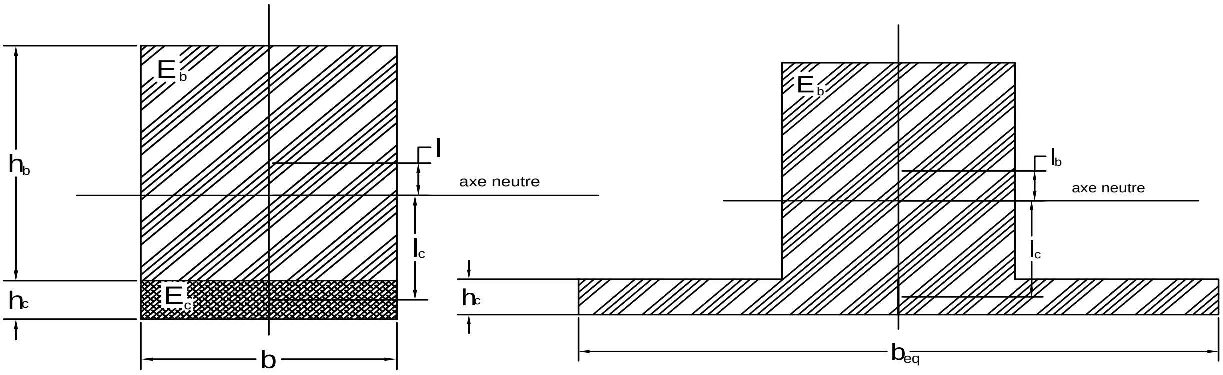
$$b_{eq} = b\frac{E_c}{E_b}$$

Equivalent wood section in T-sharp to sandwich section

$$I_{eq} = I = \frac{b.h_b^3}{12} + l_b^2.b.h_b + \frac{b_{eq}.h_c^3}{12} + l_c^2.b_{eq}.h_c$$

E_{eq} is a function of E_b and E_c. Through the tests, E_{eq} is calculated to deduce the module E_c of carbon.

Equivalent sandwich section:



3.3.1 Determination of carbon's modulus using a strain gauge at mid-span.

The strain of the lower fiber is measured and plotted as a function of load (fig.5). Hence the curvature, and the equivalent flexural rigidity $(EI)_{eq}$ are deduced, and then the composite Young's modulus.
On the beam with 10 layers of carbon, the Young's modulus of CFRP varies between 94 GPa and 86 GPa where $E_{m,l}$ varies between 10.22 and 11.21 GPa. With 12 layers, CFRP Young's modulus varies between 104 and 111 GPa. It seems that a scale effect is introduced during wrapping.

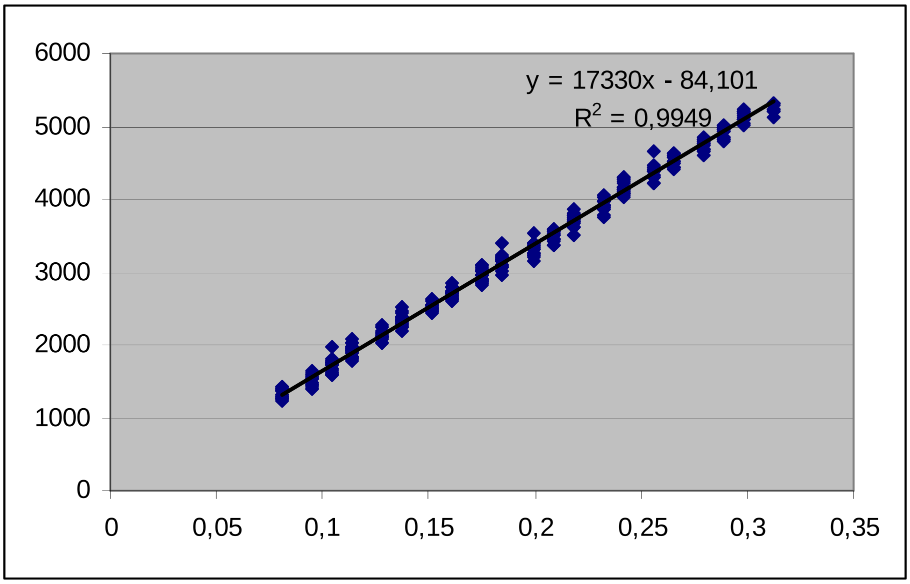


Figure 5. Force (N) versus strain at mid-span ($x10^3$) -
4 points bending test of wood-composite beams, section 13 x 9 cm ²

3.3.2 Determination of carbon's modulus with three displacement transducers.

By this method of measurement, the beam with 10 layers of carbon, the Young's modulus of carbon varies between 101 and 81 GPa when E_b varies between 10.22 and 11.21 GPa. For 12 layers, the carbon Young's modulus varies between 116 and 95.4 GPa, respectively. (see results in Table 2).

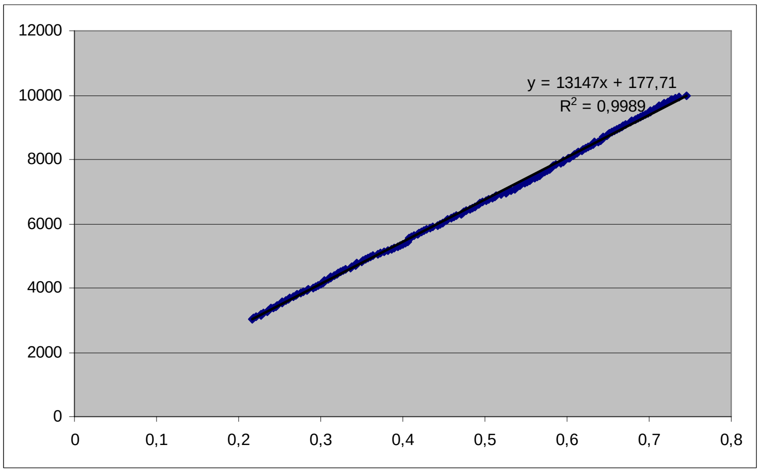


Figure 6. Force (N) versus relative deflection (mm)
4 points bending test of wood-composite beams, section 13x9cm ²

The results for the two beams are slightly different. The result for the 10 layers beam is closer than the modulus deduced from the following tensile test performed on a single sample of 5 layers.

4. Direct tensile test.

A carbon sample, 30 cm long and with a width of about 21 mm, was taken from the wood-composite beam. Only 5 layers were glued on the intrados of the GL beam. The section is 37.8 mm² corresponding to a total thickness of 1.8 mm (layer thickness = 0.36 mm) and a width of 21 mm. The longitudinal and transverse strains were measured using strain gauges. The following results were obtained:

E_{longi}= 90.4 GPa
ν_{LT}= 0.231

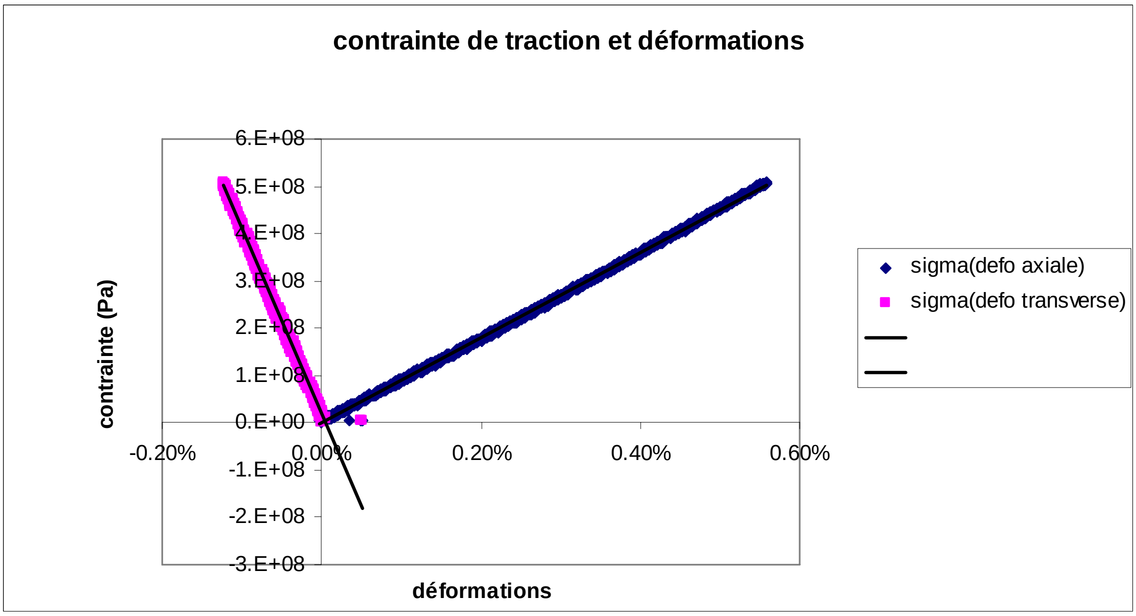


Figure 7. Stress (Pa) versus longitudinal strain (blue) and transverse strain (pink) during direct tensile test

Synthesis

The results are summarized in the following tables. Table 1 gives the values for the wooden beam in reference and reversed position (where are reversed intrados and extrados, tensile and compression chords). Table 2 shows the values of CFRP modulus for the beam of 10 (P10c) and 12 carbon layers (P12c). The wood GL section of the reinforced beams is not exactly the same as the one of wooden beam. It is assumed that the modulus of wood is the same for all beams (they are GL28 class coming from the same delivery).

Wooden beam		Cycle 1	Cycle 2	Cycle 3	Excel files
Reference position	$E_{m,l}$	10.4 GPa	10.7 GPa	10.2 GPa	P_BOIS_18X9_4P_290107_12kN_2.xls
	G	0,550 GPa	0.563 GPa	0.549 GPa	Flex3p_bois_18x9x78_250107.xls
Reverse position	$E_{m,l}$	11.2 GPa	11.2 GPa	11.1 GPa	P_BOIS_18X9_4P_290107_12kN_1.xls

Table 1 : longitudinal Young's modulus and shear modulus value of wood

Note: The values of ***G*** (detailed in the file *flex3p*.xls*) are calculated with $E_{m,l}$ = 10.790 GPa

Reinforced beam		Cycle 1	Cycle 2	Cycle 3	Excel files
P10c	E_c *sensor*	87 GPa	93,5 GPa	108 GPa	bois_comp_9x13_10couches_4p_bending.xls
	E_c *gauges*	90 GPa	90 GPa	90 GPa	bois_com_10c_jauge_a_milieu_2401.xls
P12c	E_c *sensor*	109 GPa	111 GPa	112 GPa	bois_comp_9x13_12couches_4p_bending.xls
	E_c *gauges*	113 GPa	113 GPa	113 GPa	bois_com_12c_jauge_a_milieu_2401.xls

Table 2 : Carbon Young modulus value, obtained with an average wood modulus $E_{m,l}$ = 10790Mpa,

The data processing was carried out considering that the thickness of each carbon layer is 0.36mm.

The direct tensile measurement with layer thickness e = 0.36 mm for the sample of 5 layers gives the following results:

E_{longi} = 90.4 GPa
ν_{LT} = 0.231

Finally, a mean value of total measurement was chosen as:

E_{longi} = 98 GPa