Mechanical Properties Study of Composite Materials in Beech Beams Strengthening Case

AURORA CATALINA IANASI, MINODORA MARIA PASARE *
"Constantin Brâncuşi" University of Târgu-Jiu, Department of Industrial Engineering, 30 Eroilor Str., 210135, Târgu-Jiu, România

This work reports on a study concerning the behaviour of the reinforced beech beams with CFRP (carbon fiber reinforced plastic) under a bending load. An experimental program was proposed to characterize the strength response of CFRP-wood beams. Mechanical tests on the reinforced wood showed that CFRP materials may produce flexural displacement and lifting increases of the beams. Observations of the experimental load–displacement relationships showed that bending strength increased for wood beams reinforced with CFRP composite plates (Megaplate), compared to those without CFRP reinforcement.

Keywords: carbon fiber, bending strength, wood, pretension device

Wood is amongst the oldest naturally and renewable construction materials and is also, a very efficient material. Its notable resistance at compressive and tension loads must be take in consideration when compared with its limited weight density [1-3]. Wood elements, such as beams, have been reinforced using various techniques such as CFRP reinforcement [4]. Improvement of the bending properties of wood beams by the addition of reinforcement, is not a new concept. In recent years, carbon fiber reinforced plastic (CFRP) composite material has been widely used in the retrofit and rehabilitation of buildings and bridges due to the merits of its high strength-to-weight ratio and high elastic modulus. Unidirectional composites are particularly suited to the reinforcement and repair of wood beams, are widely available as thin pultruded elements of different shapes with continuously decreasing costs, and present a lighter weight than conventional engineering materials. The calculation of bending loads for wood elements is carried out by means of simplified approaches based on classic linear analysis [5-6]. On one hand, this approach allows a quick and consistent evaluation of the current stress state of the wood element while, on the other hand, it does not take into account the non-linear behaviour that a wood element can exhibit, either with or without reinforcements with CFRP composites.

Experimental part

The main objective of this paper is to investigate the bending performance of beech wood beams reinforced with CFRP (carbon fiber reinforced plastic) materials, showing crushing damage at their compression region. One of the ideas pursued for obtaining hard structure with low price and cheap materials, easy to process, was the addition of composite materials at the beam structure. It was found that the major building element subjected to great efforts is the beam. The main stress of a beam is the bending one. Therefore we relied on classical solution of addition quality materials in highly stressed areas such as strength beam increases correspondingly. Reinforcement solution is easily explained on the basis of the scheme from figure 1 and figure 2.

A wood beam (fig. 1) can withstand a relatively small concentrated bending force F_0, because the maximum bending strength σ_0 that can handle the material is also

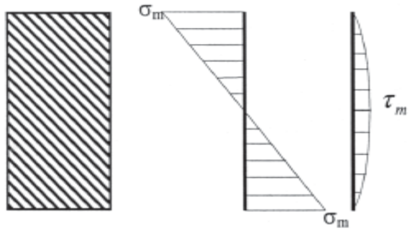

Fig. 1. Normal tension s_m for a bending load in an un-reinforced wood beam

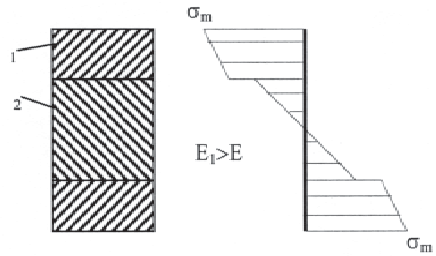

Fig. 2. Normal tension σ_m for a bending load in a reinforced wood beam
1-composite plates (CFRP), 2-wood beam

small. If in the great strength area of the beam is added composite with greater strength than wood (fig. 2) then the wood beam can withstand the force F_1>F because the maximum strength is $\sigma_m > \sigma_0$. Stress distribution σ_0 shows that the middle beam (per section) is not required (in the center section $\sigma_0 = 0$), which entitles us to say that the material in this area is not used economically. For an efficient use of the material we propose to use a homogeneous section of two materials: wood and composite plates material (Megaplate). In the middle of the section we use a low resistance material with a small elasticity modulus E (wood) and in the extreme areas (top-down) we have a greater resistance material with a great elasticity modulus E_1 (composite plates). The bending force F applied in the middle of the beam will be expressed by:

$$F = \frac{48 E I_y}{l^3} \cdot f_m = k \cdot f_m; \quad (1)$$

where:

f_m - maximum displacement (flexural),

* Tel.: 0723254241

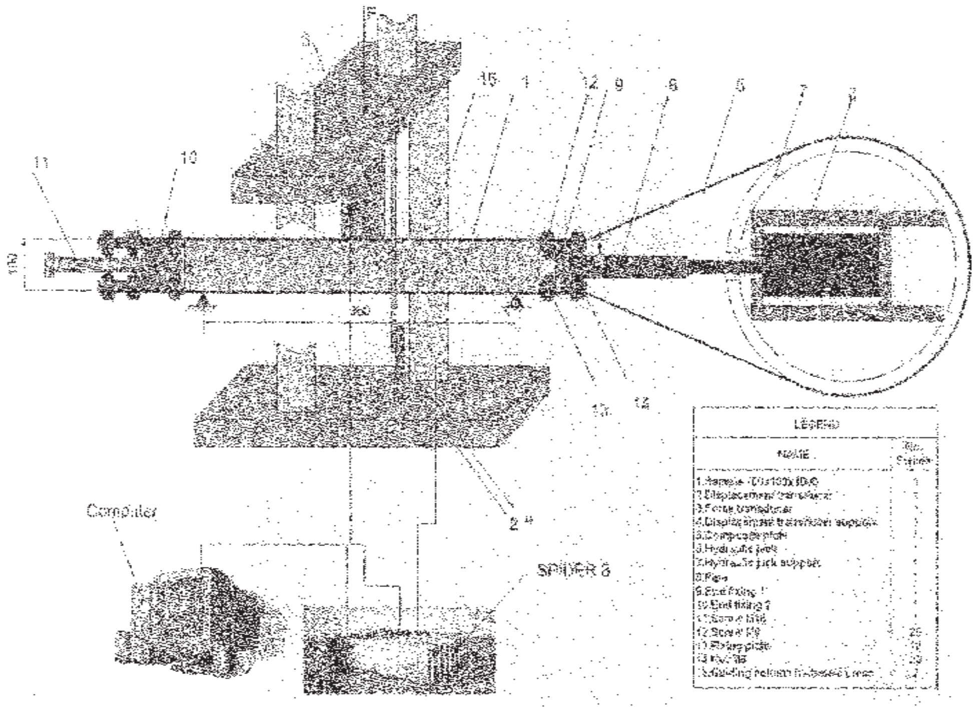

Fig. 3. Tensioning device

l - beam length,

E - elasticity modulus of material (wood),

I_y - moment of inertia of beam cross section, [8-9].

For the same displacement f_m, but with a composite reinforcement, can define an equivalent elastic modulus $E_1 > E$. The bending load force F_1 of the reinforced beam will be given in formula (2):

$$F_1 = \frac{48 E_1 I_y}{l^3} \cdot f_m = k_1 \cdot f_m ; \qquad k_1 > k ; \;\; E_1 > E. \quad (2)$$

The main conclusion that result from formula (1) and (2) is:

$$F_1 > F \qquad (3)$$

To study this reinforcement solution we used a special device, especially conceived [7], to keep tight the wood beam and get a pre-tension of the composite plate. We increased the strength beam by applying an initial axial force (pre-tension) to the composite plate. The device allowed obtaining a higher bending strength of the wood beam reinforced with CFRP composite. Tensioning device is schematically shown in figure 3.

The tensioning solution is based on a composite plate 5 that is fixed in the end fixing 9 and 10. On the 9 end fixing is hydraulic jack 6 that allows axial strain of the wood beam sample 1. The transverse tensioning force is measured with force transducer 3. The displacement of the beam is measured with a displacement transducer 2. The tensioning device is mounted on a universal machine for mechanical tests. The entire work equipment was composed of: a universal machine for mechanical tests (hydraulic press), an acquisition system Spider 8 with 12 bit resolution and an IBM ThinkPad R51 Notebook (j) as is shown in figure 3.

For experimental data processing was used “Presa.tst” program, especially created. Test procedure had the following phases: calibration of the measuring system, positioning the beam in the tensioning device on the machine test, mechanical loading beam, tracking and recording parameters, noting the details of the test (materials behaviour, anomalies, etc.). The recorded parameters were: F (kN) - compressive transverse strength of the mechanical tests machine and Crs (mm) - Race linear piston of the machine for mechanical tests (the beam displacement).

Results and discussions

Experimental tests were performed on four beech beams (Fagus sylvatica), un-reinforced and reinforced with CFRP composite plates. The first sample was the reference beam without reinforcement. The results for the un-reinforced beams are reported solely for the purpose of quantitatively evaluating the effectiveness of the interventions through a comparison with the results for strengthened beams. Others three samples were reinforced with Megaplate composite plates and bending subjected. All beams were surveyed for both their geometric dimensions and wood defects. The average value of the wood humidity ratio was 12%, while that of the wood density was 449.6kg/m^3. The CFRP materials were conditioned in an environment of 65±5% relative humidity and temperature of 20±2°C as this is the service environment in which CFRP reinforced beams are expected to be used.

The observed mode of failure was due to cracking of the beam as is shown in the graphs from figures 4, 5, 6 and 7. In this graphs are the characteristics recorded and processed with the “Presa.tst.” program. We used an own graphic with two sliders with the possibility of reading the instantaneous values in displays positioned in the inner and with suggestive names associated with the cursor and path.

The load-displacement behaviour of the un-reinforced beam is shown in figure 4. In figure 4a is represented the displacement-time dependence and in figure 4b is represented the load-displacement dependence.

The initial load-displacement behaviour was linear until wood beam yield occurred in bending and crushing. After yielding, the wood beam evidenced a hysteresis phenomenon resulting in a charge and discharge cycle of the frame from the mechanical tests machine. The area covered by the hysteresis loop is a measure of energy dissipated in the wood beam required to bending.

In 5, 6, 7 (a, b) figures are represented the displacement-time dependence and load-displacement dependence for the other three reinforced beech wood beams denoted with I, II and III.

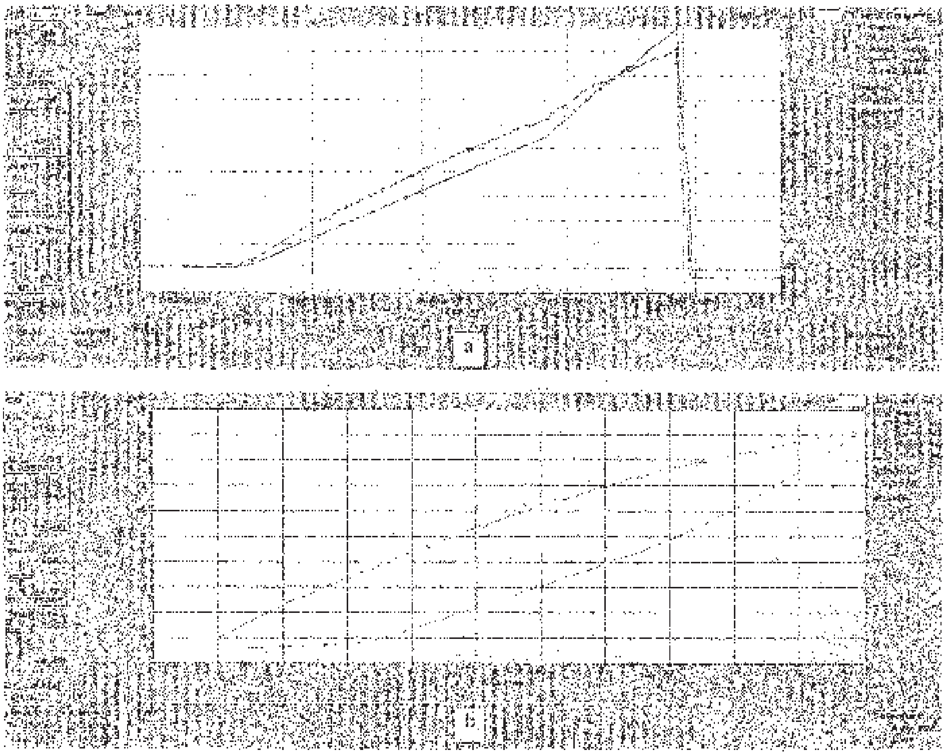

Fig. 4. Characteristics determined for un-reinforced beech beam

We can observe that the wood beam (case I) evidenced a hysteresis phenomenon like the un-reinforced beam. The maximum load force and the maximum displacement for the reinforced beam get bigger values compare to those of the un-reinforced beam. As for the un-reinforced wood beam the area covered by the hysteresis loop is a measure of energy dissipated in the beam required to bending. This is possible because of the carbon fiber plates used to strengthen the wood beam. The carbon fiber plates help the beam taking the bending force and distributing it evenly on the outer surface of the wood beam which is subject to the stretching phenomenon.

Transverse compressive force applied by machine and denoted F (kN), has a black color. Maximum beam displacement, the same with the machine moving frame, denoted Crs (mm), has a red color.

Analyzing the graphs from figure 4 -7 we observe that the force and displacement values for the un-reinforced beech beam are smaller than the force and displacement values for the reinforced beams (I, II, III). The maximum force value for the un-reinforced beam is F = 16 kN and the maximum displacement value is f_m = 20 mm when the maximum force value for the reinforced beam is F = 22,1 kN and the maximum displacement value is f_m = 27 mm (wood beam from I case).

There were tested four beech beams of 100×100×1000mm, up-down reinforced with Megaplate plates of 100×1,2×2000mm bought from a specialized firm in carbon fibers trade. The composite plate was axially tensioned with a hydraulic jack system. The beam is leaning at both ends, loaded with centered force and driven to failure recording cross-strain and maximum displacement.

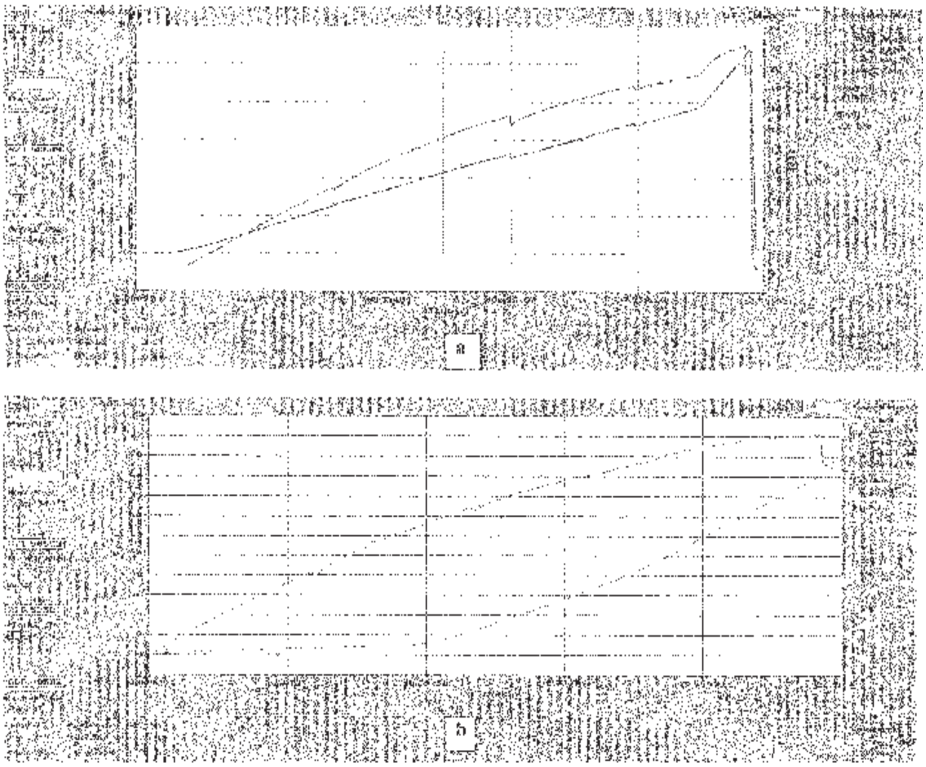

Fig. 5. Characteristics determined for a reinforced beam (I)

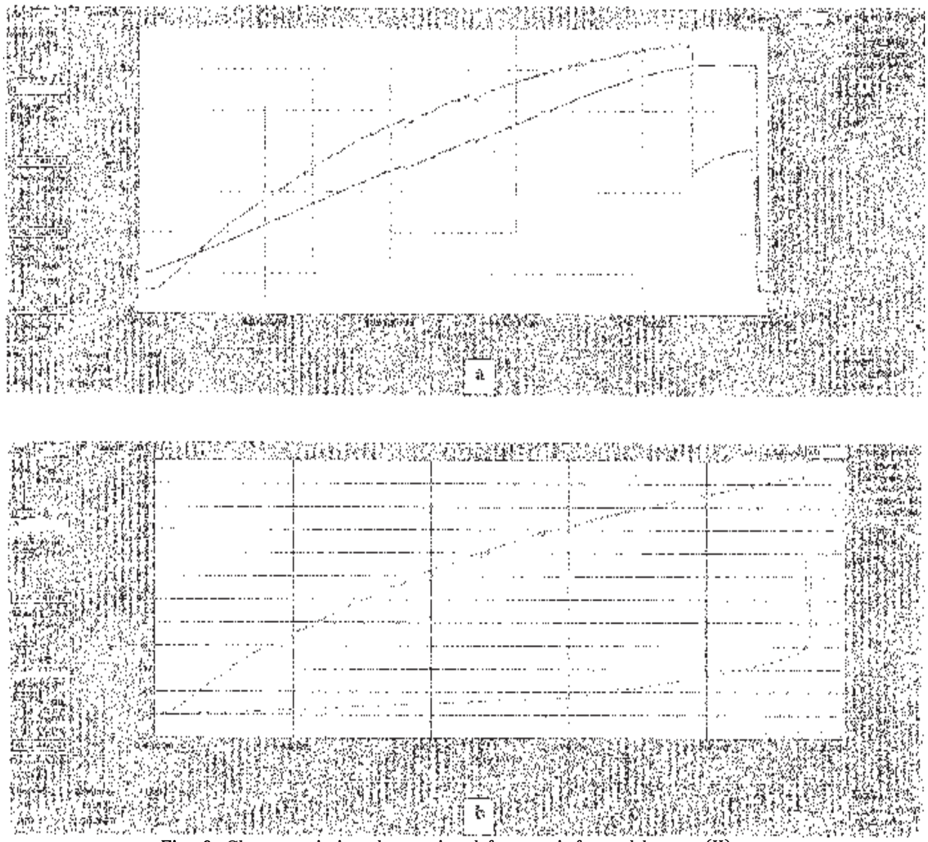

Fig. 6. Characteristics determined for a reinforced beam (II)

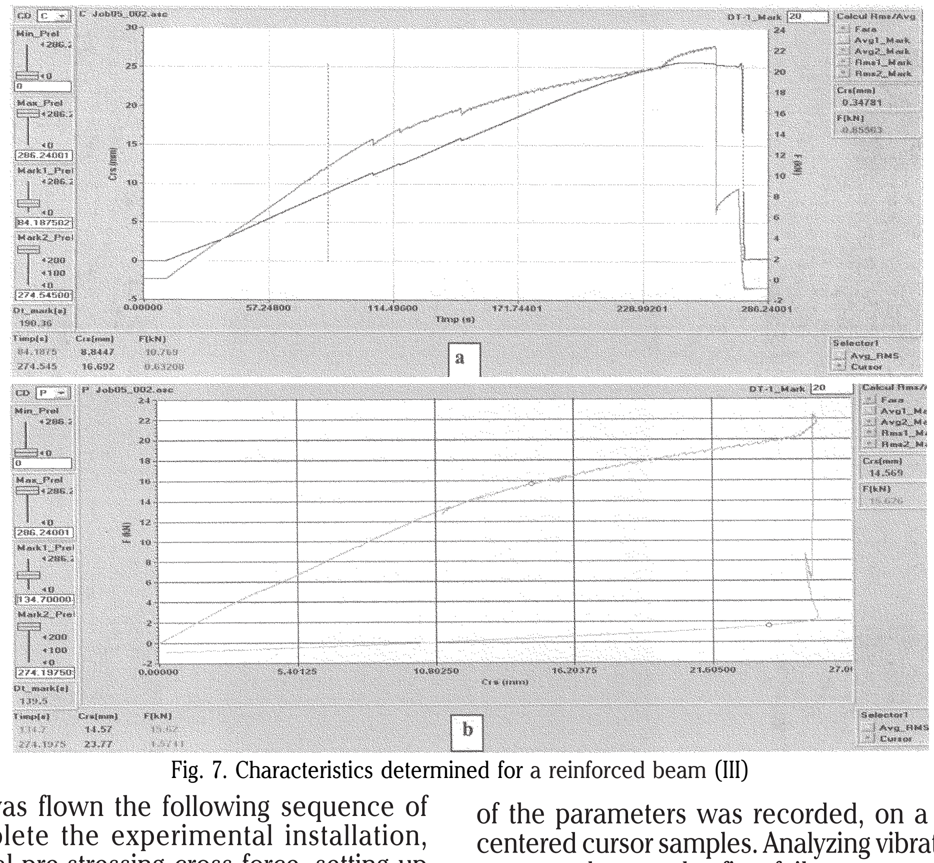

Fig. 7. Characteristics determined for a reinforced beam (III)

For each test was flown the following sequence of operations: complete the experimental installation, adjustment of initial pre-stressing cross force, setting up the test characteristics and launch the data acquisition, gradually increase the bending force, maintaining manual compression on a high pre-tensioning force, download the bending force, stopping the data acquisition system and save the data files.

Experimental data were visualized and, with Mark1 cursor, from the Presa.tst program, were selected moments of time separated within 5 and 10 s, in terms of stability, for action force. For each point, the average value of the parameters was recorded, on a sequence of 40 centered cursor samples. Analyzing vibration acceleration we can observe the first failure moments of the beam wood fibers, resulting in gradual decrease of pre-tensioning force. This decrease has required manual intervention to increase, through screw-nut system tensioning force of the hydraulic jack.

So, getting a larger force, for the same displacement, is a measure of increasing strength beam. Percentage increase in force (for the same displacement) or decrease displacement (for the same force) shows eloquently improving lift reinforced beam. The maximum load force and the maximum displacement may be, therefore, experimental parameters to quantify the strength beam quality. It should be mentioned that results are easily interpreted in the context of a reference beam (un-reinforced). One un-reinforced wood beam was tested in order to find its bending capacity. The results for the un-reinforced beam are reported solely for the purpose of quantitatively evaluating the effectiveness of the interventions through a comparison with the results for the strengthened beams.

Conclusions

The performance of the CFRP plates adhered to the tensile side of beech wood beams was investigated in this paper. Observations of the experimental load–displacement relationships show that bending strength increased and middle vertical displacement decreased for wood beams reinforced with CFRP composite plates, compared to those without CFRP plates.

During the performed tests, a first difficulty encountered was the basic inhomogeneous material (wood), found in fairly large changes in mechanical strength (from one sample to another). This has required the use of eleven tests for the same material. Experimental results allowed drawing the follow conclusions:

-the wood beams must be secured to the composite plates, in the mechanical device, to prove the effectivenes of the solution so the type of solidarity was mechanical-link wood beam ends;

-initial tension force decreases as the beam is loaded due to local subsidence of wood (in the tensioning device);

-pre-tensioning does not change, in general, the elastic behaviour of the wood beams because of the limitations that occur in the mechanical device assembly;

-if the mechanical system worked correctly, the lift of the beams increased up to 33 kN, meaning 220% higher than the un-reinforced beam;

-the first cracks in the wood beams appeared at least two times higher than the un-reinforced beam, due to quality wood (beech dry, carefully processed and without tension concentrators in its mass);

-elastic lift of the reinforced beams is significantly influenced by pre-tensioning, most samples having a maximum 5-6 mm flexural displacement that is an improvement over the displacement of the un-reinforced beam.

The main conclusion of the tests is that the tensioning forces allow beam taking a maximum load for a while, something that is particularly useful when we consider a real construction, so in case of excess lift beam, we have time to take strengthening measures and when is about a catastrophic request (earthquake) the construction remain partially functional.

The experiments have shown that the method of increasing resistance of wood construction with composite materials is an available one. The solution is easy to implement and with low costs. Effectiveness of composite reinforcing using is still modest, imposing itself further and deeper studies.

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Manuscript received: 14.02.2011