On the role of CFRP reinforcement for wood beams stiffness

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Abstract. In recent years, carbon fiber composites have been increasingly used in different ways in reinforcing structural elements. Specifically, the use of composite materials as a reinforcement for wood beams under bending loads requires paying attention to several aspects of the problem such as the number of the composite layers applied on the wood beams. Study consolidation of composites revealed that they are made by bonding fibrous material impregnated with resin on the surface of various elements, to restore or increase the load carrying capacity (bending, cutting, compression or torque) without significant damage of their rigidity. Fibers used in building applications can be fiberglass, aramid or carbon. Items that can be strengthened are concrete, brick, wood, steel and stone, and in terms of structural beams, walls, columns and floors. This paper describes an experimental study which was designed to evaluate the effect of composite material on the stiffness of the wood beams. It proposes a summary of the fundamental principles of analysis of composite materials and the design and use. The type of reinforcement used on the beams is the carbon fiber reinforced polymer (CFRP) sheet and plates and also an epoxy resin for bonding all the elements. Structural epoxy resins remain the primary choice of adhesive to form the bond to fiber-reinforced plastics and are the generally accepted adhesives in bonded CFRP–wood connections. The advantages of using epoxy resin in comparison to common wood-laminating adhesives are their gap-filling qualities and the low clamping pressures that are required to form the bond between carbon fiber plates or sheets and the wood beams. Mechanical tests performed on the reinforced wood beams 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 and sheets compared to those without CFRP reinforcement. 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 constructions with composite materials is good for it. The solution is easy to implement and has low costs.

1. Introduction
Carbon fiber is used in many areas where a combination of high strength and low weight are required. The strongest are approximately five times stronger than steel and considerably lighter. Other useful properties it has are its ability to withstand high temperatures and its inertness. Carbon fiber is a textile consisting mainly of carbon. It is produced by spinning various carbon-based polymers into fibers, treating them to remove most of the other substances, and weaving the resulting material into a fabric. This is usually embedded in plastic — typically epoxy — to form carbon fiber reinforced plastic. The
physical properties of composite materials (CFRP) are generally not isotropic in nature, but rather are typically anisotropic (different depending on the direction of the applied force or load). The majority of composite materials use two constituents: a binder or matrix and reinforcement. The reinforcement is stronger and stiffer, forming a sort of backbone, while the matrix keeps the reinforcement in a set place [1]. For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. In contrast, isotropic materials (for example, aluminum or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments.

2. Experimental results
The main purpose of this paper is to analyze bending phenomenon due to fracture at the wood-composite samples. By using composite materials (CFRP) in reinforcement is expected growth flexural strength and shearing and confinement elements tablets (increased wood resistance).

The type of reinforcement used on the beams is the carbon fiber reinforced polymer sheet SikaWrap 230C with E module of elasticity 230 000 N/mm² and traction resistance 4100 N/mm², carbon fiber reinforced polymer plates SikaCarbodur S 512 with E module of elasticity E=165000 N/mm² and an epoxy resin for bonding all the elements Sikadur 30. The wood part of all 11 beams was formed by beech dry wood which size is equal to 25 by 50 by 500 mm [2]. The beams were reinforced using one carbon fiber plate of thickness equal to 1,5 mm, width equal to 25 mm and the length is equal to 500 cm. The finished dimension of one of the beams is equal to 25 by 51,5 by 500 mm because is a beam stick together with one carbon fiber plate Sika Carbodur S 512 and epoxy resin Sikadur 30 [3,4]. Structural epoxy resins remain the primary choice of adhesive to form the bond to fiber-reinforced plastics and are the generally accepted adhesives in bonded CFRP–wood connections [5]. Advantages of using epoxy resin in comparison to common wood-laminating adhesives are their gap-filling qualities and the low clamping pressures that are required.

Composite material used to strengthen wood samples is the type of carbon fiber sheet carbon fiber plates and an epoxy matrix supplied by Building Velmix Ltd., from Sika S.A Romania. Structural epoxy resins remain the primary choice of adhesive to form the bond to fiber-reinforced plastics and are the generally accepted adhesives in bonded CFRP–wood connections. Advantages of using epoxy resin in comparison to common wood-laminating adhesives are their gap-filling qualities and the low clamping pressures that are required.

To achieve the objective proposed in this paper was presented a particular computer program, Presa.txt, for experimental determination of bending strength for the samples. This was done with Spider 8 data acquisition equipment connected to fixtures and fittings of the samples tested on the universal testing machine. Work equipment and instrumentations used in this case are: universal machine for mechanical tests [6], data acquisition system Spider 8, 12 bit resolution linear WA300 race inductive transducer, force transducer S9 50kN, signal conditioning NEXUS 2692 - A-014, 4391 type piezoelectric accelerometer, IBM ThinkPad R51 notebook. Parameters recorded after the bending tests are: F (kN) - compressive strength of hydraulic press, Ft (kN - transverse compressive strength, CRS (mm) - race piston, Acc (m/s²) - acceleration of beam vibration (sensor break). The beam is leaning against the head and driven across to the breaking strength recorded maximum cross and displacement (no longer measured axial tensioning force). 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. The main purpose is to analyze bending phenomenon due to fracture at the wood-composite samples like we see in the figure number 1 from below. The samples tested were not subjected to lateral instability during loading. The total load on the beam was applied equally at one point equidistant from the reactions (the half length of the beam). We used the bending device of the universal machine for mechanical tests which has the distance between the rollers l = 460 mm.

In figure 2 it can be seen the way of fracture for the reinforced beams with one and two CFRP plates.
**Figure 1.** Tension failure of an unreinforced beam [2].

**Figure 2.** Samples of reinforced beams [2]. a) with one carbon fiber plate and one down slide of wood b) with two carbon fiber plates and two up and down slides of wood.

The graphs of these reinforcement are presented in figure 3.

The graphs show that for the un-reinforced beam cracks appear at a low displacement such as 6-7 mm (a) instead of 10 mm (b) for the reinforced beam with one carbon fiber plate and one down slide of wood and 13-14 mm for the reinforced beam with two carbon fiber plates and two up and down slides of wood (c). That it means the CFRP improve the resistance of the beams and permit a growth in flexural properties.
Studying the graphs we can see that the reinforcement is more efficient for the beam with one carbon fiber plate and one down slide of wood and for the beam with two carbon fiber plates and two up and down slides of wood. The force and displacement growth for these type of beams rising values more bigger than at the un-reinforced beam \[7,8\]. The un-reinforce beam is broken very quickly at a small load. The other wood beams are broken at a bigger load and have a bigger displacement. The tested wood beams reinforced with carbon fiber sheets are shown in figure 4.

The functional dependency graphs for the reinforced wood beam are represented in figure 5 from below.

In the case of the reinforcement with carbon fiber sheets we can observe on the graphs that the results indicate that the behavior of reinforced beams is totally different from that of un-reinforced one. The reinforcement also has changed the mode of failure for the tested beams. The experimental load–displacement relationships shown us that this kind of reinforcement is not so resistant like the carbon fiber reinforcement. Observations of the experimental load–displacement relationships show that flexural strength increased and middle vertical displacement decreased.

Experimental results allowed drawing the follow conclusions:

- the wood beams must be secured to the composite plates, in the mechanical device, to prove the effectiveness 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);
- 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 8-13 mm flexural displacement that is an improvement over the displacement of the un-reinforced beam.

The maximum load force and the maximum displacement may be, in this case, 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).

By using composite materials in constructions is expected growth flexural strength and shearing, and confinement elements tablets (increased concrete and wood resistance). The reinforcement technology with composite materials offers many advantages over conventional methods, because the composite materials show:
- very high resistance to bending, greater than steel;
- increased resistance and ductility construction without changing the geometry or stiffness;
• consolidation and reinforcement for different materials such as: concrete, wood, steel;
• costs of intervention extremely competitive;
• small weight, high flexibility and availability in various lengths.

Experiments have shown sustainability of the method for wood construction reinforced with composite materials. The use of composites can be applied as a strengthening technique without necessitating the removal of the overhanging portion of the structure. The technique used proved to be easy and fast to execute, even when on in situ parts. In particular, it demonstrated to be very promising in many cases of reinforcement of old, historical structural wood parts. The CFRP pre-tensioning is easy to implement and with low costs. Effectiveness of using composite reinforcements is still modest, requiring further and deeper studies and trying new methods and design alternatives for the tested samples.

3. Conclusions
Following conclusions can highlight: wood is a material with a certain degree of heterogeneity, which makes its mechanical properties vary in a range too wide, so it is especially necessary to improve resistance with composite reinforcement.

As a rigid material with good strength and relatively low cost, we use a composite. Several un-reinforced and reinforced wood beams were tested in order to find their flexural capacity. 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 results indicate that the behavior of reinforced beams is totally different from that of un-reinforced one. The reinforcement has changed the mode of failure from brittle to ductile and has increased the load-carrying capacity of the beams. Observations of the experimental load-displacement relationships show that flexural strength increased and middle vertical displacement decreased for wood beams reinforced with CFRP composite plates, compared to those without CFRP plates. If in the great strength area of the beam is added composite with greater strength than wood then the wood beam can withstand a bigger force because the maximum strength is bigger too. The presence of carbon plates and sheets causes an interesting increase in stiffness varying from 20,2% to 29,6%, when compared to that of the same wood beams before reinforcement.

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