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FLEXURAL STIFFNESS OF HYBRID WOOD - FIBRE REINFORCED POLYMER COMPOSITES ELEMENTS

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Abstract: *An analytical evaluation of hybrid section made of wood and Fibre Reinforced Polymer (FRP) composites which consist of several FRP applying techniques is studied. The main objectives of using FRP and wood to obtain composite elements is for increasing capacity of timber beam. The favourable performances of wood as a building material recommend its utilisation in the various and complex timber structures with large spans having significant deflection and requirements of the rigidity. The increasing of wood elements stiffness can be reached by applying FRP reinforcement. The flexural stiffness of the hybrid elements made of wood products and Carbon and Glass fibre reinforced polymer composite strips and bars is analysed in the paper.*

Key words: ***flexural stiffness, hybrid section, wood, FRP composites***.

1. Introduction

Wood is a natural building material that offers suitable properties such as light weight, easy of processing and availability. These performances recommend its utilisation in wooden structure house as well as in complex timber structures with large spans having significant deflections. [10]. The increasing of wood elements stiffness can be reached by applying FRP reinforcements using different techniques and solutions [1, 2].

Numerous studies have describe different techniques to apply FRP products such as strips and bars on the wood beams in order to improve the load capacity and the serviceability of new or existing timber members and structures under loading conditions [3, 12-14].

The hybrid members made of wood and FRP have a behaviour considerable better than the timber elements. The properties of FRP reinforcements such as high strength and high modulus along with compatible adhesives can significantly improve the rigidity and strength of the wood, and ductility. [7, 9, 11]

In case of new structures, the objective is to select the most suitable solution for the hybrid elements providing a maximum load capacity for a minimum cross section of structural elements and a reduced consumption of the materials and, consequently a smaller self-weight of the structures.

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2. Timber and FRP Elements and their Characteristics

The present study is based on an analytical evaluation of the hybrid section of wood and FRP products. The geometry and properties of the elements and materials are presented in Table 1. The improvement of the stiffness performance is provided by the FRP characteristics, fibres type and area of the FRP products applied on the wood beam.

Geometry and material properties of wood elements and FRP products Table 1

Elements and strengthened technique [%]	b x h, [mm]	Af, [mm^2]	E_{wood}, E_{frp}, [GPa]
Wood beam	50 x 60	3000	10,235
Carbon plate, (Mapei) EBR, EBR14C	1.4 x 14	19.6	170
Carbon plate (Mapei) NSM, NSM14C	1.4 x 14	19.6	170
Carbon plate, (Mapei) EBR, EBR20C	1.4 x 20	28	170
Carbon plate (Mapei) NSM, NSM20C	1.4 x 20	28	170
Carbon bar (Mapei), NSM, NSM6C	6	28.27	155
Glass bar (Mapei), NSM, NSM6C	6	28.27	40.8

The wooden beam length is considered equal to 1100 mm. The elastic properties, E_{wood} is given by experimental tests realised according to Romanian standard SR EN 408:2004 and its value is 10.235 [GPa] (Figure 1), [6]. The FRP plates and bars [15] have the thickness equal to 1.4 mm and 14 and 20 mm for the width, and the diameter equal to 6mm, (Table 2). CFRP strips with the different widths are externally applied on the tensioned part of the wood beam as shown in Figure 2a. The application of the vertical CFRP strips, with the same area, is illustrated in Figure 2b. A comparative analysis when CFRP strips as well as CFRP bars and GFRP bars are utilised is provided in this work (Figure 2c).

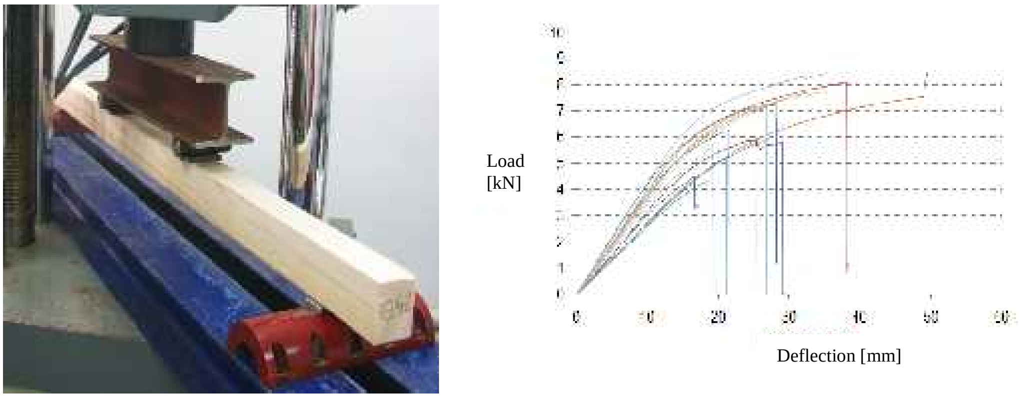
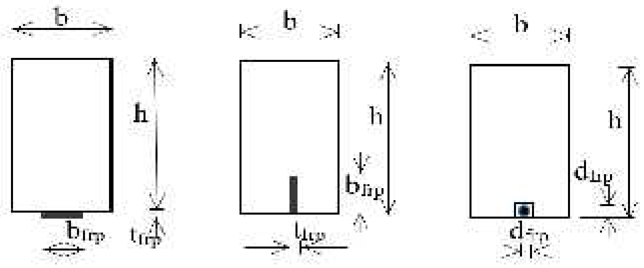


Fig. 1. *Experimental test for wood properties*, [6]

3. The Analytical Evaluation of the Hybrid Elements Stiffness

The analytical evaluation of hybrid members stiffness is based on the equivalent cross section area of the composite section, using the ratio of the elastic moduli of the materials, ($n=E_{wood}/E_{frp}$ or $n^*=E_{frp}/E_{wood}$). The equivalent areas, A_{eq} as well as the neutral axis position, y_g, and the second moment of area, I_{hyb} will be determined, [4, 5, 8, 15].



a. b. c

Fig. 2. *Hybrid elements made of wood and FRP with different configurations (Table 2):*

a. externally bonded plate:EBR14C, EBR20C;

b. near surface mounted strip*:NSM14C; NSM20C;*

c. near surface mounted bar: *NSM6C; NSM6G*

$$n^* = \frac{E_{frp}}{E_{wood}} \tag{1}$$

$$A_{ech} = b \cdot h + n^* \cdot (h_{frp} \cdot b_{frp}) \tag{2a}$$

$$A_{ech} = b \cdot h + n^* \cdot (\text{®} \cdot \frac{d_{frp}^2}{4}) \tag{2b}$$

$$z_g = \frac{\sum A_i \cdot z_i}{\sum A_i} \tag{3}$$

$$I_{hyb} = \sum I_i + \sum A_i \cdot d_i^2 \tag{4}$$

where:
n^* - ratio of the elastic moduli of the materials
E_{frp} - elasticity modulus of FRP;
E_{wood} - elasticity modulus of wood;
b - width of timber beam;
h - height of timber beam;
b_{frp} - width of FRP plate;
h_{frp} - height of FRP plate;
d_{frp} – diameter of FRP bar;
z_g – neutral axis position of the hybrid beam from the bottom face of the wood beam;
z_i – distance between the gravities centre of the wood section and the FRP strip or bar and bottom part of the wood element;
d_i – distance between the hybrid neutral axis position and the gravities centre of the wood section and the FRP strip or bar.

4. Results and Discussion

The analytical results presents the moment of inertia variation regarding the adopted solutions. The second moment of area of the hybrid beams are affected by applied solutions, geometric and mechanical characteristics and percentage of FRP. The values of the moment of inertia of the hybrid sections are given in Table 2.

The moment of inertia for the hybrid beams Table 2

Wood and hybrid beams	**I_{hyb}, mm^4**
Wood beam	900,000
EBR14C = hybrid section: wood - CFRP externally bonded plate with 14 mm width	1,176,906
NSM14C = hybrid section: wood - CFRP near surface mounted strip; Carbon strip with 14 mm width	1,107,208
EBR20C = hybrid section: wood - CFRP externally bonded plate with 20 mm width	1,279,692
NSM20C = hybrid section: wood - CFRP near surface mounted strip, Carbon strip with 20 mm width	1,300,268
NSM6C = hybrid section: wood - CFRP near surface mounted bar. Carbon bar with 6 mm diameter	1,212,286
NSM6G = hybrid section: wood - GFRP near surface mounted bar. Glass bar with 6 mm diameter	961,196

In Figure 3 is presented the influence of the variation of the FRP percentage area and characteristics of the moment of inertia. In each case it can be noticed an increasing of inertia moment and the highest value is obtained for CFRP near surface mounted with the largest width.

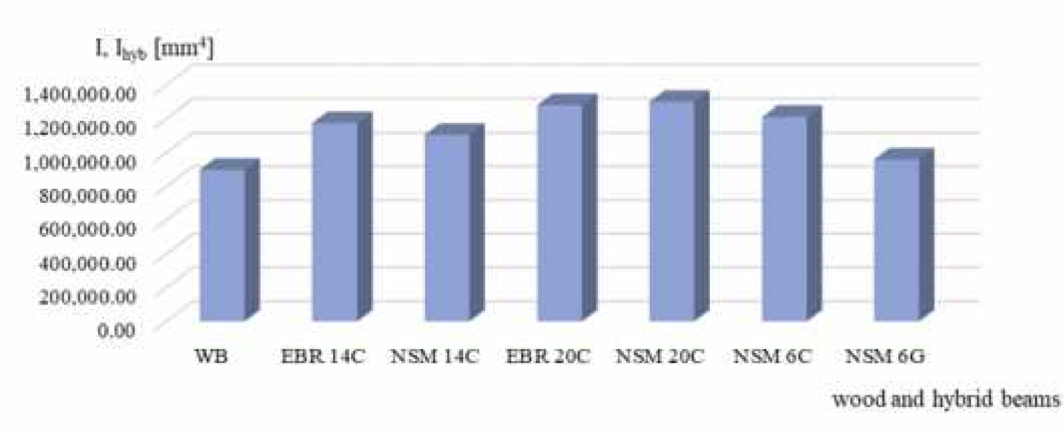


Fig. 3. *Moment of inertia of wood and hybrid elements with different configuration*

Modifying the type of applications of composite products on the wood member, for the same percentage of FRP area, is highlighted the most appropriate solution, as well as, the smallest value in case of using glass bar (Figure 4). In situation of CFRP products, the near surface mounted CFRP bar solution leads to the smaller values of rigidity increasing by 1.35 than the externally bonded plate, 1.42 as well as the near surface mounted strip, 1.44. In case of applied FRP bar, in Figure 4, for the glass product is shown a smaller value of increasing inertia moment than carbon fibre products.

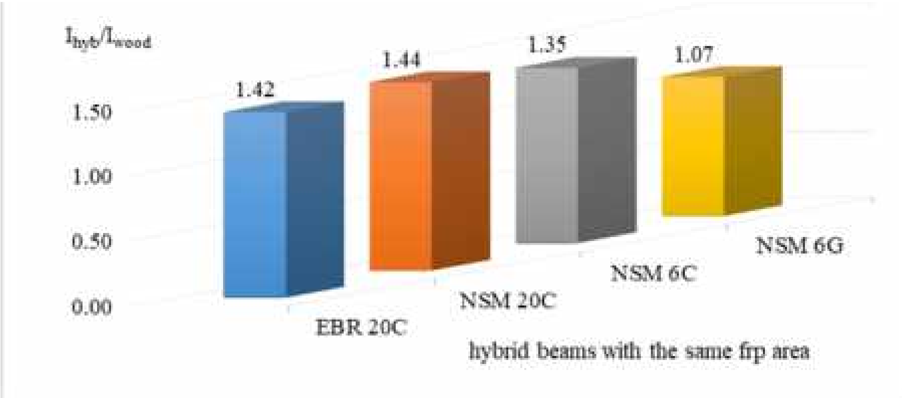


Fig. 4. *The influence of FRP applying and characteristics of the hybrid beam moment of inertia, for the same area of composite reinforcement*

5. Conclusions

The paper presents the rigidity evaluation of hybrid section wood –FRP. The influence of the FRP properties as well as the geometry configuration are analysed.

The obtained results show significant improvements of the second moment of area and the stiffness of hybrid members compared to the wood beams.

The smallest value of inertia moment increasing has been noticed for the GFRP bar inserted at the bottom part of wood beam compared to the other solutions.

The largest increase of the inertia moment has been observed for the vertical CFRP strip inserted at the tensioned part of wood member.

This study highlights the possibilities of rehabilitating wood beams by using fibre-reinforced polymeric composite materials. The choice of the optimal solution depends on the load capacity level expected for the hybrid beams made of composite material and timber, during the post-rehabilitation period, as well as by the allowed execution technology. It is well known that for the vast majority of buildings declared architectural monuments, the rehabilitation of the part of the structure made of wood is difficult and often, for architectural reasons, the total replacement of degraded elements is used, which affects the architectural monument value. The use of fibre-reinforced polymer composite materials, as the cases presented in the paper, can be effective solutions, from all points of view, for strengthening the degraded timber beams.

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