BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Tomul LIX (LXIII), Fasc. 6, 2013
Secția
CONSTRUCȚII. ARHITECTURĂ

IMPROVING STRUCTURAL RESPONSE OF WOOD BEAMS BY REINFORCING WITH CARBON FIBRE REINFORCED POLYMER ELEMENTS

BY

IOANA-SORINA ENȚUC*, NICOLAE ȚĂRANU, GABRIEL OPRIȘAN, PETRU MIHAI and VLAD MUNTEANU

"Gheorghe Asachi" Technical University of Iași
Faculty of Civil Engineering and Building Services

Received: November 29, 2013
Accepted for publication: December 19, 2013

Abstract. The flexural behavior of hybrid systems made of wood and carbon fibre reinforced polymer (CFRP) composite strips subjected to bending is analysed in this paper. The analysis is completed with an optimization study, based on the percentage of CFRP reinforcement and the strength classes of wood, relating to the hybrid beams.

The results obtained from the analytical study are compared to those determined from numerical modelling, revealing the efficiency of the discussed reinforcing solutions based on CFRP strips.

Finally, the authors highlight the importance of using these hybrid systems to achieve lightweight structures with convenient properties that meet the design requirements imposed by using large spans and resisting additional loads.

Key words: CFRP strips; wood beams, hybrid system; stiffness; numerical modelling.

---

* Corresponding author: entuc@ce.tuiasi.ro

1. Introduction

Wood is a building material often used to design and construct structural elements in civil engineering. The convenient properties of wood as a construction material such as high strength/weight ratio and easy processing, lead to the obtaining engineering structures with low self weight and therefore, easy handling, lower costs related transport and reduced construction time. The type of exposure and the loads assessment, acting on load bearing wood elements, impose a careful selection of strength classes of the chosen material.

The use of hybrid elements made of wood and reinforced with carbon fibre reinforced polymer (CFRP) strips is justified by the current civil engineering trends (Ţăranu *et al*., 2009a, Ţăranu *et al*., 2009b) to optimize the structural systems using lightweight construction materials with high values of strength and stiffness properties (Ţăranu *et al*., 2012; Bejan *et al*., 2013), to increase the load capacity and ductility of structural elements and also to reduce the consumption of building materials by decreasing the dimensions of the cross sections (Ţăranu *et al*., 2013).

Current studies (Yusof, 2013; Gentile *et al*., 2002; Stănilă *et al*., 2011), underline various techniques using combination of wood with fibre reinforced polymer (FRP) composite products. FRP composite elements can be applied to both structural rehabilitation and to new structures in case of change of function or increased loads.

2. Beam Elements and Materials Characteristics

Numerous researchers (Valipour *et al.* 2011; Yusof *et al*., 2010, Enţuc *et al*., 2012; Dinga, 2010) have presented various strengthened techniques applied to wood beams using FRP products to increase the load bearing capacity and the ductility of beam elements.

The stiffness of hybrid beams depends on the cross section geometry, the strength class of the wood (EN 338, 2010) and on the characteristics of the CFRP strips (Sika, 2013).

Table 1
Geometrical Properties and Characteristics of Elements and Materials

Element type	b mm	h, t_f mm	E_{wood}, E_{frp} GPa
Wood beam C18, C22, C24, C24, C27, C30, C35, C40	100	200	9…14
Carbon fiber reinforced polymer (CFRP) plate [Sika]	50; 60; 70; 80; 90; 100	1.2	165

The wooden beam geometry, analysed in this paper, is given by section sizes 100 mm × 200 mm and its length equal to 3,000 mm. The mechanical and the elastic properties of wood E_{wood}, f_{mk}, are selected according to the strength classes, starting with C18 to C40. The CFRP strips are made by pultrusion having the thickness, t_f equal to 1.2 mm and variable width, b_{frp}, Table 1.

3. The Analytical Evaluation of the Bearing Capacity of Simple and Hybrid Beams

In case of the analytical evaluation, the area of the CFRP cross section strip was transformed into an equivalent wood cross section area, using the ratio between the elastic moduli of the materials

$$n = \frac{E_{\text{wood}}}{E_{frp}} . \tag{1}$$

The CFRP strip reinforcement percentages for the studied wood beam are presented in Table 2, considering the widths of the reinforcing strips.

Table 2
The FRP Reinforcement Percentages for the Selected Wood Beam

The strip type	CarboDur S512	CarboDur S612	CarboDur S712	CarboDur S812	CarboDur S912	CarboDur S1012
The reinforcing percentage of CFRP	0.3	0.36	0.42	0.48	0.54	0.60

The geometrical characteristics of hybrid beams, such as the neutral axis position (z_g)

$$z_g = \frac{\sum_i A_i z_i}{\sum_i A_i} , \tag{2}$$

the moment of inertia,

$$I_{\text{hyb}} = \sum_i I_i + \sum_i A_i d_i . \tag{3}$$

and the section modulus have been evaluated. The second moment of inertia values for the equivalent sections are given in Table 3.

z_g is the centre of gravity position of the hybrid beam from the bottom face of the beam, [mm]; d_i – the distance between the hybrid beam centre of gravity and the centres of gravity of the wood section and of the CFRP strip, [mm].

A four points loading flexural test method, Fig. 1, has been considered for the evaluation of the maximum bending moment and of the maximum midspan deflection.

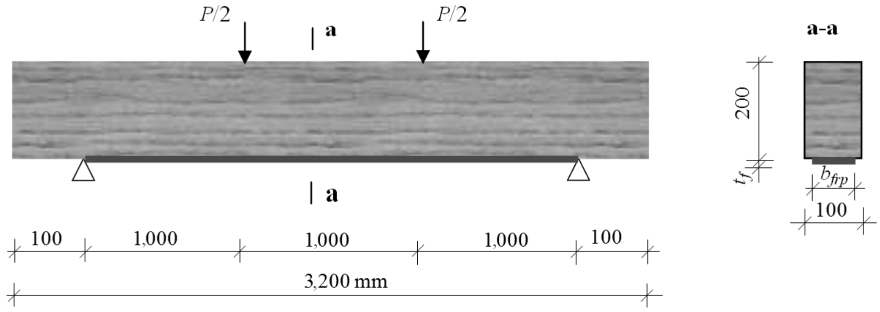


Fig. 1 – Timber beam plated with CFRP.

Table 3
The Moment of Inertia for the Hybrid Beams

I_{hyb} mm^4	CarboDur S512	CarboDur S612	CarboDur S712	CarboDur S812	CarboDur S912	CarboDur S1012
C18	7.72E+07	7.92E+07	8.11E+07	8.30E+07	8.49E+07	8.67E+07
C22	7.62E+07	7.80E+07	7.98E+07	8.15E+07	8.32E+07	8.49E+07
C24	7.54E+07	7.70E+07	7.87E+07	8.03E+07	8.18E+07	8.34E+07
C27	7.50E+07	7.66E+07	7.82E+07	7.97E+07	8.12E+07	8.27E+07
C30	7.47E+07	7.62E+07	7.77E+07	7.92E+07	7.96E+07	8.21E+07
C35	7.41E+07	7.55E+07	7.69E+07	7.83E+07	7.96E+07	8.10E+07
C40	7.36E+07	7.49E+07	7.62E+07	7.75E+07	8.00E+07	8.00E+07

3.1. The Analytical Evaluation of the Bending Moment Capacity of the Hybrid Beams

The bending moment capacity, M_{wood}, and the corresponding concentrated load, P_c, for simple sections, were determined and the values are given in Table 4. The bending moment capacity values for hybrid solutions, M_{hyb}, were evaluated and its increase for different wood strength classes and strip types are presented in Table 5.

Table 4
The Load Bearing Capacities of the Wood Beam

Element type	C18	C22	C24	C27	C30	C35	C40
M_{wood}, [kN.m]	5.54	6.77	7.38	8.31	9.23	10.77	12.31
P_u, [kN]	11.08	13.54	14.77	16.62	18.46	21.54	24.62

Table 5

The Relative Increase of the Bending Moment Capacity for the Hybrid Elements

M_{hyb} /M_{wood}	CarboDur S512	CarboDur S612	CarboDur S712	CarboDur S812	CarboDur S912	CarboDur S1012
C18	1.21	1.25	1.29	1.34	1.38	1.43
C22	1.19	1.22	1.26	1.30	1.34	1.38
C24	1.17	1.20	1.24	1.27	1.31	1.35
C27	1.16	1.19	1.23	1.26	1.30	1.33
C30	1.15	1.19	1.22	1.25	1.28	1.32
C35	1.14	1.17	1.20	1.23	1.26	1.29
C40	1.13	1.16	1.19	1.21	1.24	1.27

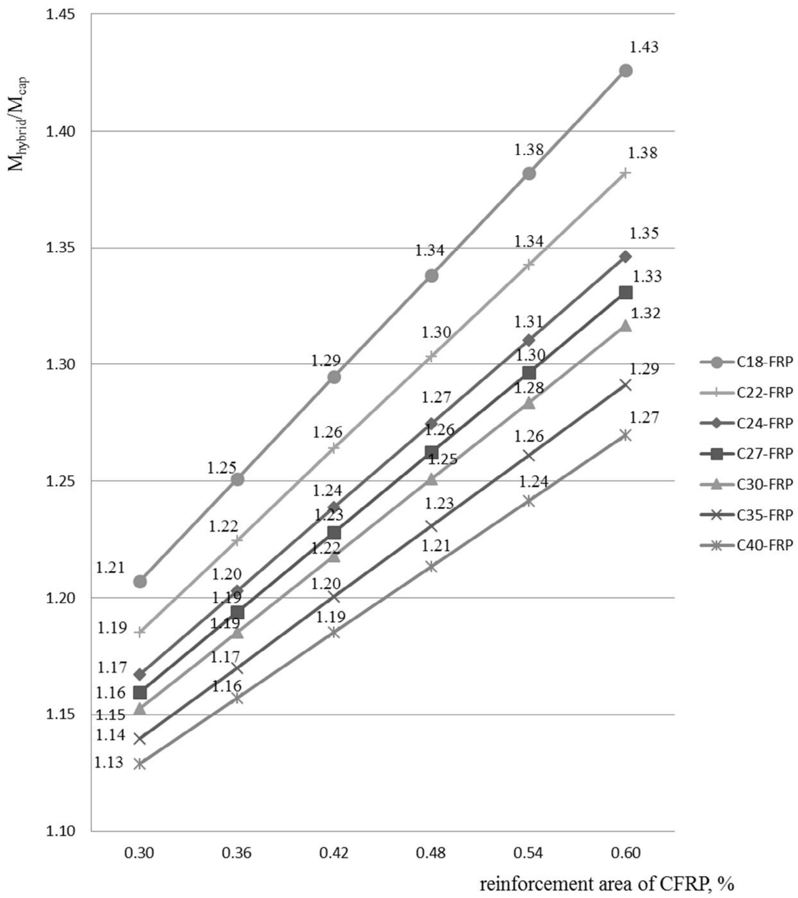


Fig. 2 – The influence of CFRP percentage area on the normalized bending moment.

Fig. 2 presents the variation of the relative increase of the bending moment capacity for the hybrid beams with respect to the wood strength classes and the percentages of CFRP reinforcement. It can be noticed that the CFRP laminated strip attached to the tension part of the wood beam leads to an increase of the resisting bending moment. By modifying the CFRP percentage for the C18 wood strength class, an increase of the resisting bending moment from 1.21 to 1.43 has been noticed. An increase of the resisting bending moment from 1.13 to 1.27 has been obtained for the C40 wood strength class having the same CarboDur strips.

3.2. The Analytical Evaluation of the Hybrid Beams Stiffnes

The stiffness of the hybrid beams can be evaluated by calculating the effective moment of inertia for the hybrid beams. The relative increase can be seen in Table 6 for various percentages of CFRP reinforcement and for different strength classes of wood.

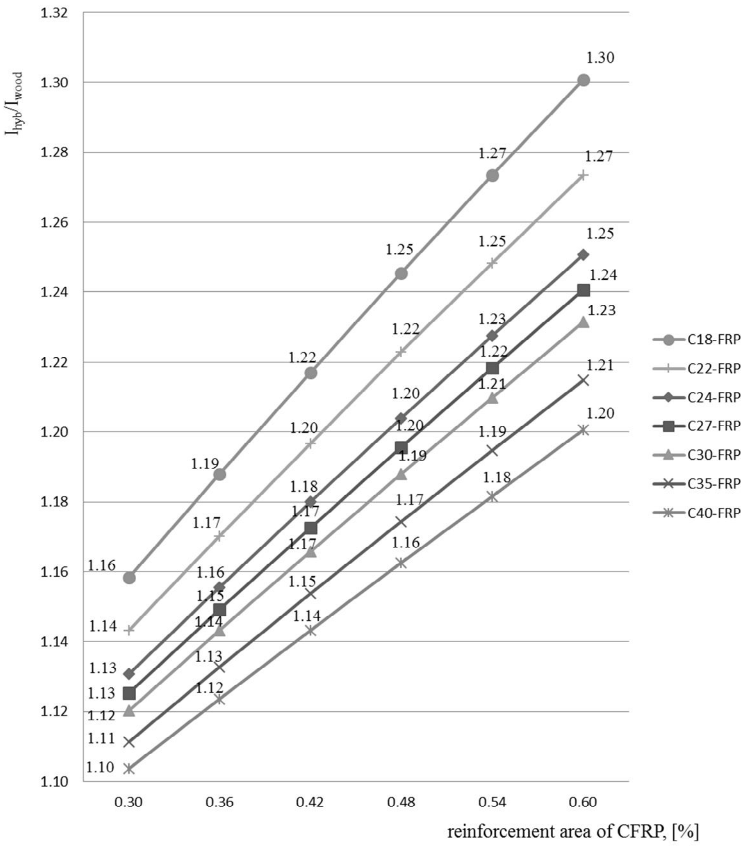


Fig. 3 – The influence of CFRP percentage on the rigidity of the hybrid beams.

Table 6
The Relative Increase of Moment of Inertia for the Hybrid Beams with Respect to the Wood Beam

I_{hyb}/I_{wood}	CarboDur S512	CarboDur S612	CarboDur S712	CarboDur S812	CarboDur S912	CarboDur S1012
C18	1.158	1.888	1.217	1.246	1.274	1.301
C22	1.143	1.170	1.197	1.223	1.248	1.274
C24	1.131	1.156	1.180	1.204	1.228	1.251
C27	1.125	1.149	1.173	1.196	1.218	1.241
C30	1.120	1.143	1.166	1.188	1.210	1.231
C35	1.111	1.133	1.154	1.174	1.195	1.215
C40	1.104	1.124	1.143	1.163	1.182	1.201

Fig. 3 presents the increase of the rigidity for wood-composite hybrid beams with respect to the CFRP reinforcement percentage and the wood strength classes. It can be observed that the CFRP composite strips attached to the tension part of the wood beam lead to a noticeable increase of the hybrid beam rigidity.

By modifying the CFRP percentage in case of the C18 wood strength class, an increase of the moment of inertia from 1.16 to 1.30 has been noticed. An increase of the resisting moment from 1.10 to 1.20 has been obtained for the C40 wood strength class having the same CarboDur strips.

4. The Numerical Modelling of the Structural Response for Wood and Hybrid Beams Subjected to Bending

A Lusas finite element software has been used to carry out the numerical analysis. The aim of numerical modelling was to determine and compare the results from the analytical calculation (Table 4) and those from

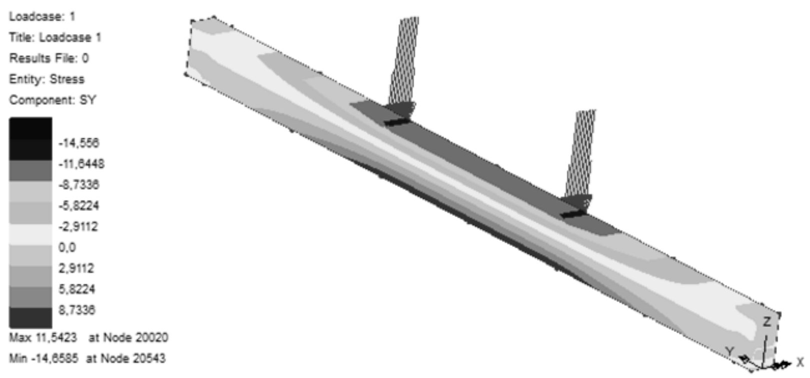
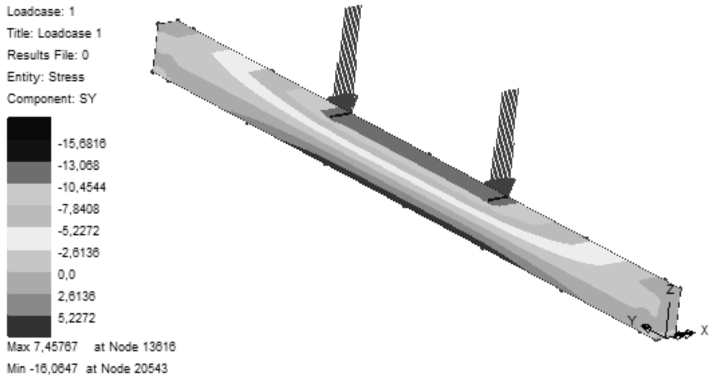
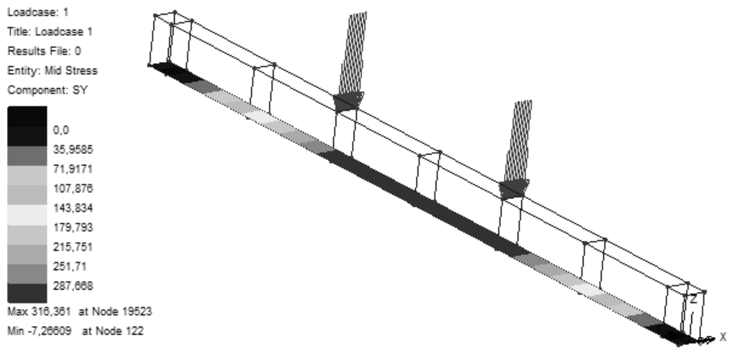


Fig. 4 – The tensile stress map for C24 wood beam.

numerical analysis. The map showing the stress variation with a maximum value equal to 11.54 MPa for the wood beam is illustrated in Fig. 4. By multiplying the maximum stress with the section modulus, a bending moment equal to 7.69 kN.m was determined, value which is closed to the theoretical moment value, 7.38 kN.m, given in Table 4. In Fig. 5 the stress maps for the hybrid beams are ilustrated; the maximum values are 10.36 MPa and 7.45 MPa in wood fibres for hybrid beam plated with CFRP strips. These values fulfil the strength requirements for the C24 wood strength class.



a



b

Fig. 5 – The tensile stress maps in the hybrid beam with the wood strength class C24 plated with CFRP: *a* – tensile stress in the extreme tensioned wood fibre; *b* – tensile stress in the extreme fibre of the CFRP strip.

5. Conclusions

The paper presents the bending behaviour of hybrid wood – CFRP composite strips. The effects of the wood class strength, the properties of the composite elements as well as the influence of the reinforcing percentage are analysed.

The obtained results indicate noticeable increases of the bending moment capacities and of the bending stiffness for the hybrid beams compared to the wood beams.

The largest increase of the bending moment capacity for the hybrid beams has been observed for the widest CFRP strip, attached to the bottom of the element when a wood beam with C18 strength class was analysed.

The largest increase of the bending stiffness has been obtained for the hybrid beams made of C18 wood strength class and the highest reinforcing percentage.

The numerical results are in good agreement with those obtained from analytical calculation.

REFERENCES

Bejan L., Ţăranu N., Sirbu A., *Effect of Hybridization on Stiffness Properties of Woven Textile Composites*. Appl. Comp. Mater., **20**, *2*, 185-194 (2013).

Dinga F., *Optimization Load Bearing Elements for Low Rise Buildings*. Ph. D. Diss., "Gheorghe Asachi" Techn. Univ. of Iaşi, 2010.

Enţuc I., Munteanu V., Ţăranu N., Oprişan G., *Improving of Load Bearing Capacity of Timber Beams Using FRP Strengthening Techniques – a Critical Evaluation.* Proc. 12th Internat. Sci. Conf. VSU'2012, **I**, June 7-8, Sofia, Bulgaria, II-181-186.

Gentile C., Svecova D., Rizkalla S., *Timber Beams Strenghthened with GFRP Bars: Development and Applications*. J. Compos. Constr., **6**, *1*, 11–20 (2002).

Javaid A., Javed A.B., *Flexural Strengthening of Timber Beams Using Carbon Fibre Reinforced Polymer Plates*. Internat. J. of Civil Engng. a. Technol. (IJCIET), **4**, *5*, 42-54 (2013).

Schober K. U., Rautenstrauch K., *Post-Strengthening of Timber Structures with CFRP's*. Mater. a. Struct., **40**, *1*, 27-35 (2007).

Stănilă O, Ţăranu N., *Analysis of Hybrid Polymeric Composite-Timber Beams Using Numerical Modelling.* Bul. Inst. Politehnic, Iaşi, s. Constr., Archit., **LVII (LXI)**, *1*, 19-30 (2011).

Ţăranu N., Banu D., Oprişan G., *et al.*, *Strengthening of Thin Reinforced Concrete Slabs with Composite Strips.* Roman. J. of Mater., **43**, *1*, 3-13 (2013).

Ţăranu N., Oprişan G., Enţuc I., Budescu M., Munteanu V., Ţăranu G., *Composite and Hybrid Solutions for Sustainable Development in Civil Engineering.* Environ. Engng. a. Manag. J., **11**, *4*, 783-793 (2012).

Ţăranu N., Oprişan G., Enţuc I., Munteanu V., Cozmanciuc C., *The Efficiency of Fiber Reinforced Polymer Composites Strengthening Solutions in the Construction Industry*. 6th Internat. Conf. on the Manag. of Technol. Changes, **1**, Alexandroupolis, Greece, 2009, 733-736.

Ţăranu N., Oprişan G., Enţuc I., Oltean R., Munteanu V., *Modern Strengthening Techniques in Civil Engineering Structures*. 6th Internat. Conf. on the Manag. of Technol. Changes, **1**, Alexandroupolis, Greece, 2009, 737-740.

Valipour H.R., Crews K., *Efficient Finite Element Modelling of Timber Beams Strengthened with Bonded Fibre Reinforced Polymers*. Constr. a. Build. Mater., **25**, 3291-3300, 2011.

Yusof A., *Bending Behavior of Timber Beams Strengthened Using Fibre Reinforced Polymer Bars and Plates*. Universiti Teknologi Malaysia, 2010.

Yusof A., *Ductility of Timber Beams Strengthened Using Fiber Reinforced Polymer*. J. of Civil Engng. a. Archit., **7**, *5*, 535-544 (2013).

Yusof A., Saleh A.L., *Flexural Strengthening of TimberBeams Using Glass Fibre Reinforced Polymer*. Electron. J. of Struct. Engng., *10*, 45-56 (2010).

* * * *CNR-DT 201: Guidelines for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures. "Timber Structures"*. National research Council, 2005.

* * * http://rou.sika.com/

* * * *Structural Timber. "Strength Classes"*. EN 338, European Committee for Standardisation. 2010.

ÎMBUNĂTĂŢIREA RĂSPUNSULUI STRUCTURAL AL GRINZILOR DIN LEMN PRIN ARMARE CU FÂŞII COMPOZITE POLIMERICE CU FIBRE DIN CARBON

(Rezumat)

Se analizează comportarea la încovoiere a unor sisteme hibride alcătuite din lemn şi armate cu fâşii compozite polimerice cu fibre din carbon, (CPAF).

Analiza este completată cu un studiu de optimizare al grinzilor hibride luând în considerare procentul de armare cu fâşii din CPAF şi clasele de rezistenţă ale lemnului.

Rezultatele obţinute pe cale analitică sunt comparate cu cele determinate prin modelare numerică, reliefând eficienţa soluţiilor de armare bazate pe fâşii compozite din CPAF.

Se evidenţiază importanţa folosirii acestor sisteme hibride pentru realizarea unor structuri uşoare având proprietăţi convenabile care răspund cerinţelor de proiectare corespunzătoare folosirii unor deschideri mari şi preluării unor încărcări adiţionale.