RĂSPUNSUL STRUCTURAL AL GRINZILOR DIN LEMN CONSOLIDATE CU MATERIALE COMPOZITE POLIMERICE MODERNE
STRUCTURAL RESPONSE OF TIMBER BEAMS STRENGTHENED WITH ADVANCED POLYMERIC COMPOSITE MATERIALS

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Fibre reinforced polymeric (FRP) composites have been successfully utilized for strengthening elements made of traditional materials, such as wood. A research program carried out at The Faculty of Civil Engineering and Building Services of Iaşi tested the structural response of wood beams strengthening using carbon fibre reinforced polymeric composites, in different solutions.

The need for realistic analysis of structural behaviour of strengthened timber beams pushed researchers to find analytical and numerical evaluation methods that can correctly replace experimental programs, thus lowering the costs imposed by laboratory tests. The paper presents analytical computations and numerical modelling studies, involving three strengthening methods of timber beams using FRP composites.

Compozitele polimerice armate cu fibre (FRP) au fost utilizate cu succes pentru consolidarea elementelor realizate din materiale tradiționale, cum ar fi lemnul. Un program de cercetare efectuat la Facultatea de Construcții şi Instalații din Iaşi a evidențiat răspunsul structural al grinzilor din lemn consolidate folosind compozite polimerice armate cu fibre de carbon, în soluții diferite.

Necesitatea de analiză realistă a comportamentului structural al grinzilor din lemn consolidate au determinat pe cercetători să identifice metodele analitice şi numerice de evaluare, care pot înlocui în mod corect programele experimentale, reducând astfel costurile impuse prin teste de laborator. Lucrarea prezintă metode de calcul analitic şi studii de modelare numerică pentru trei soluții de consolidare a grinzilor din lemn folosind compozite FRP, confirmate de rezultatele experimentale.

Keywords: *wood beams, reinforcing, FRP composites, numerical modelling, analytical computation*

1. Introduction

Timber elements that, due to various factors are damaged, degraded or require an increase in load capacity must undergo structural strengthening involves a process that improves the structural behavior of elements. The main reasons for strengthening timber beams are the increase of live load and, in consequence, the exceeding of allowable deflection limits, or the reduction, due to certain factors, of the element cross-sections, [1, 2].

The strengthening solutions and needed materials depend on the type, cause and degree of degradation or damage, and on the loads that the element must sustain.

Composite materials were used in the civil engineering domain since 1960 and many studies were then carried out on timber strengthening, in a number of research programs, [3 - 12]. Today, there is a vast range of shapes and sizes in which the fibre reinforced polymeric (FRP) composites can be utilized, as bars, strips, plates or weaves.

During an extended research program, carried out at the Faculty of Constructions and Building Services of Iaşi, the flexural behaviour of timber beams strengthened with FRP composite products has been analyzed. External bonding and near surface method (NSM) were utilized by applying carbon fibre reinforced polymeric composite (CFRP) plates, strips and bars to the tensioned side of timber beams.

The main objective of this research was to find analytical and numerical models for evaluating the behaviour of compound timber - CFRP beams. Therefore, analytical and numerical methods were investigated and certified by the obtained experimental results.

2. Experimental program

Three alternatives were chosen for detailed study, using CFRP products applied on the tensioned side of the timber beams. The experimental program included testing nine real-sized spruce beams with dimensions of approximately 100 x 160 x 2600 mm, denoted as follows: G1, G2, G3, for strengthening solution A, G4, G5, G6, for solution B, and G7, G8, G9, for

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alternative C (Fig.1). Solution A implied applying a CFRP plate on the beam surface, while solutions B and C utilized the NSM method for inserting one round bar, and, four narrow strips respectively, in channels (slots) cut near the beam surface.

The CFRP elements were 2000 mm long and were dimensioned so that their total cross-sectional areas to be equal to A_s = 78.5 mm^2, for each strengthening system. The bonding between wood and the composite products was created using a water-based primer, Mapewood Primer 100, and an epoxy adhesive, Mapewood Paste 140, applied in accordance with the producers' instructions.

The technological steps for the strengthening solutions were carefully applied to avoid failure due to bad surface preparation or wood chipping while cutting the channels into the beam.

The surface preparation techniques varied according to the strengthening systems. For solution A, the surface of the beam was prepared by rough polishing and brushed while, for solutions B and C, which involved cutting the slots into the wood, the waste was vacuumed and then the inside of the slots were brushed. The water-based primer was applied on the prepared surface, by brushing, and then a thin layer of epoxy adhesive

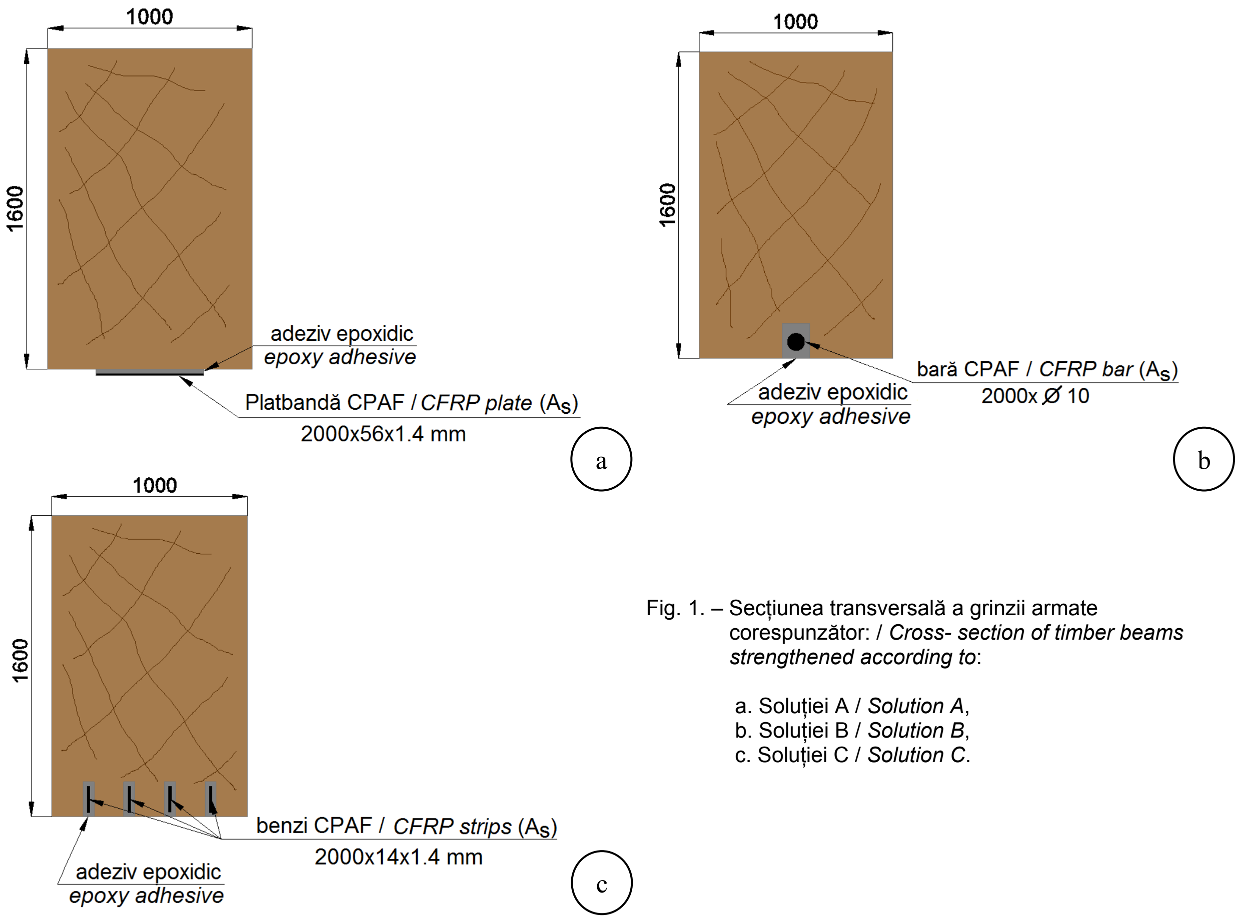

Fig. 1. – Secțiunea transversală a grinzii armate corespunzător: / *Cross- section of timber beams strengthened according to*:

a. Soluției A / *Solution A*,
b. Soluției B / *Solution B*,
c. Soluției C / *Solution C*.

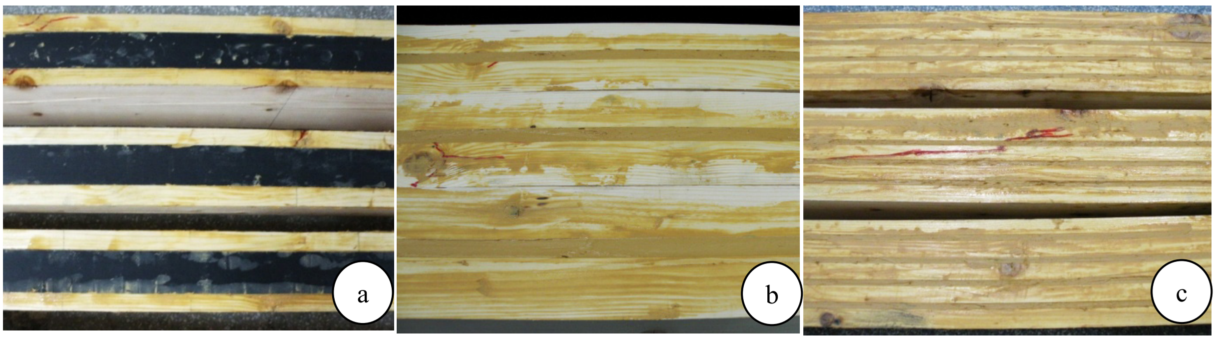

Fig. 2. – Intradosul grinzilor din lemn consolidate conform: / *Tensioned side of beams strengthened according to*: a) Soluției A / *Solution A*, b) Soluției B / *Solution B*, c) Soluției C / *Solution C*.

was applied on the wood surface, or inserted into the slots. The CFRP plate was applied on the epoxy adhesive layer. The round bar and narrow strips utilized in the strengthening systems B and C were directly inserted into the half-filled with adhesive slots and then covered with another layer of epoxy adhesive.

The final appearance of the wood-CFRP beams is shown in Figure 2. The strengthened beams were left for primer and adhesive curing for 7 days, and then the experimental tests were done.

Tables 1, 2 and 3 present the main properties of wood beams and materials used in the implemented strengthening systems, [13, 14].

2.1. Testing procedure

The beams have been considered simply supported, with a span L= 2400 mm, and subjected to bending with equal bending moment on the central portion of the beam. The loads were applied at a distance a = L/3 from the supports. The tests were carried out according to the Romanian standard SR EN 408: 2004 and the "Annual book of ASTM standards", using a computerized universal hydraulic press, WAW-600E, [15-19]. Figure 3 illustrates the experimental setting and equipment used during the bending tests. The applied forces have been monitored and the mid-span displacements were measured using a transducer attached to the beam neutral axis level.

Table 1

Proprietăţi fizice şi mecanice ale grinzilor din lemn / *Physical and mechanical properties of the considered timber beams*

Denumire grindă / *Beam name*	Clasă de rezistenţă / *Strength class*	Modul de elasticitate longitudinal / *Longitudinal elasticity modulus* E_{x1}, [MPa]	Densitate / *Density* ρ_k, [kg/m^3]	Coeficientul lui Poisson / *Poisson ratio* ν_{YZ}	Rezistenţa la tracţiune paralelă cu fibrele / *Tensile strength parallel to the grain* $f_{t\parallel}$, [MPa]	Rezistenţa la compresiune paralelă cu fibrele / *Compression strength parallel to the grain* $f_{c\parallel}$, [MPa]
G1 –G9	C18	9281.72	493.12	0.372	189.05	65.84

Table 2

Proprietăţi fizice şi mecanice ale adezivului epoxidic utilizat / *Physical and mechanical properties of the epoxy adhesive* (Mapewood Paste 140)

Proprietate / *Property*	U.M. / *M.U.*	Valoare / *Value*
Densitate / *Density*, ρ_A	kg/m^3	1500
Modul de elasticitate longitudinal/ *Longitudinal elasticity modulus*, $E_{x,A}$	MPa	4 000
Coeficientul lui Poisson / *Poisson ratio*, ν_A	–	0.4
Rezistenţa la întindere / *Tensile strength*, $f_{t,A}$	MPa	18
Rezistenţa la compresiune/ *Compression strength*, $f_{c,A}$	MPa	45
Rezistenţa la încovoiere / *Bending strength*, $f_{b,A}$	MPa	30

Table 3

Proprietăţi fizice şi mecanice ale materialelor CPAFC utilizate / *Physical and mechanical properties of the CFRP products*

Proprietate / *Property*	U.M / *M.U.*	Valoare / *Value*
Platbande şi benzi înguste / *Plates and narrow strips* (Carboplate E170)		
Densitate, ρ_{CPAFC} / *Density*, ρ_{CFRP}	kg/m^3	1610
Modul de elasticitate longitudinal, $E_{x,CPAFC}$ / *Longitudinal elasticity modulus*, $E_{x,\ CFRP}$	MPa	$1.7 \cdot 10^5$
Coeficientul lui Poisson, ν_{CPAFC} / *Poisson's ratio*, ν_{CFRP}	–	0,3
Rezistenţa la întindere, $f_{t,CPAFC}$ / *Tensile strength*, $f_{t,CFRP}$	MPa	3100
Bare rotunde / *Round bars* (Maperod Φ10)		
Densitate, ρ_{CPAFC} / *Density*, ρ_{CFRP}	kg/m^3	1540
Modul de elasticitate longitudinal, $E_{x,CPAFC}$ / *Longitudinal elasticity modulus*, $E_{x,\ CFRP}$	MPa	$1.55 \cdot 10^5$
Coeficientul lui Poisson, ν_{CPAFC} / *Poisson's ratio*, ν_{CFRP}	–	0.3
Rezistenţa la întindere, $f_{t,CPAFC}$ / *Tensile strength*, $f_{t,CFRP}$	MPa	2000

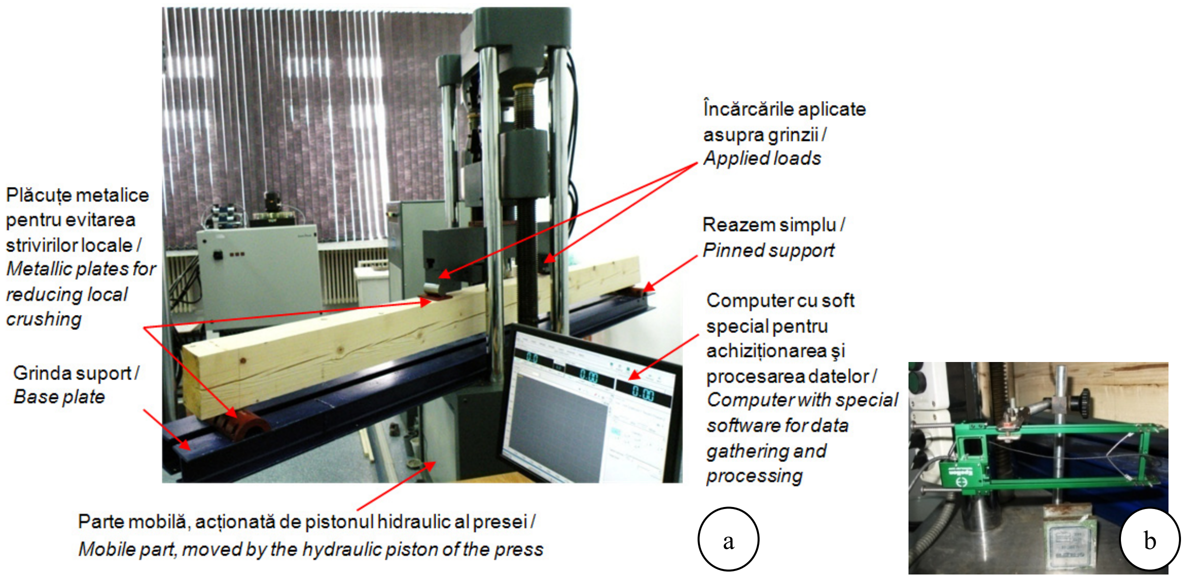

Fig. 3 - Standul experimental pentru încercările la încovoiere efectuate / *Experimental sitting for the bending tests*
a) standul experimental / *general setting*; b) modelul şi poziţionarea extensometrului / *LVDT model and position.*

2.2. Experimental results

The simple (un-strengthened) beams have been initially tested up to the appearance of the first cracks under static loading, using a constant displacement rate of the loading system of 0.1 mm/ sec. Their ultimate loads values and deflections were estimated in accordance with previous similar experimental tests.

The timber beams strengthened with CFRP composite have then been tested up to failure, in identical conditions as the simple beams. The behaviours of the simple and then strengthened beams are identified by their load – displacement curves, presented in Figure 4.

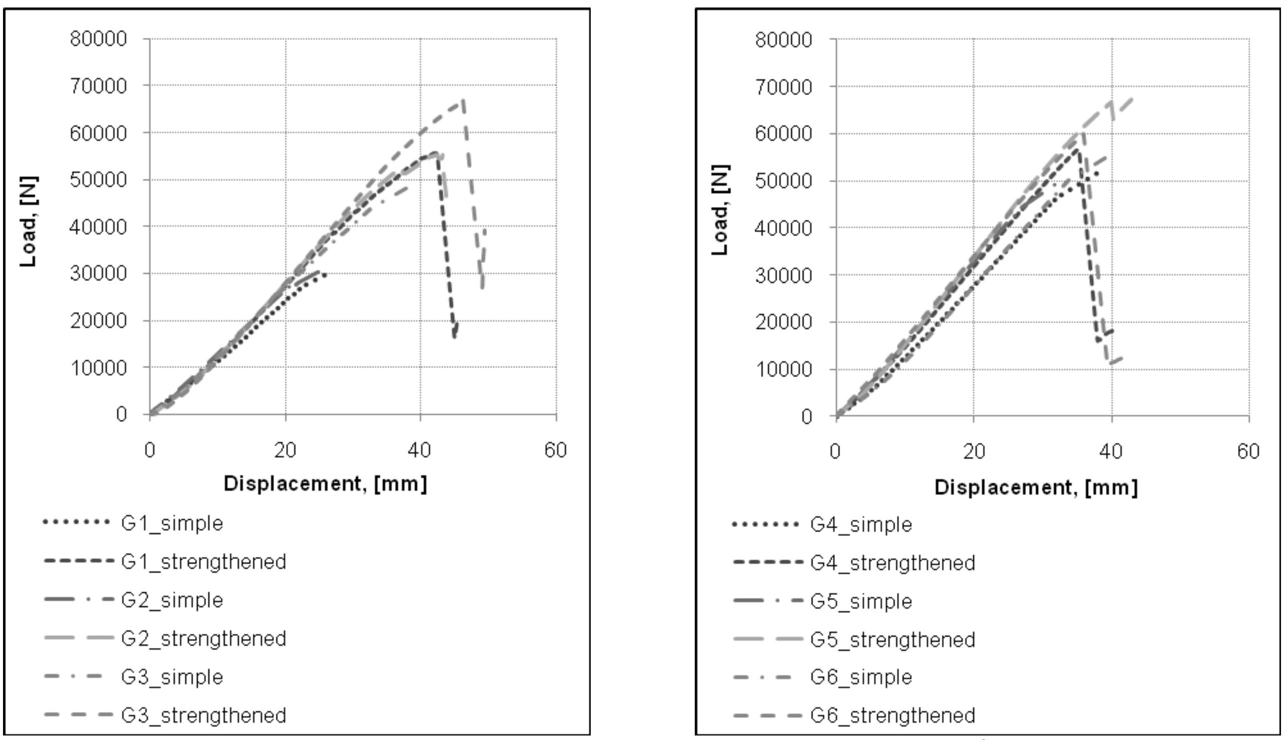

Fig. 4 - Curbele încărcare – deplasare pentru: / *Load – displacement curves for*:
a. grinzi nearmate şi consolidate conform Soluţiei A / *simple and strengthened beams according to Solution A*,
b. grinzi nearmate şi consolidate conform Soluţiei B / *simple and strengthened beams according to Solution B*,

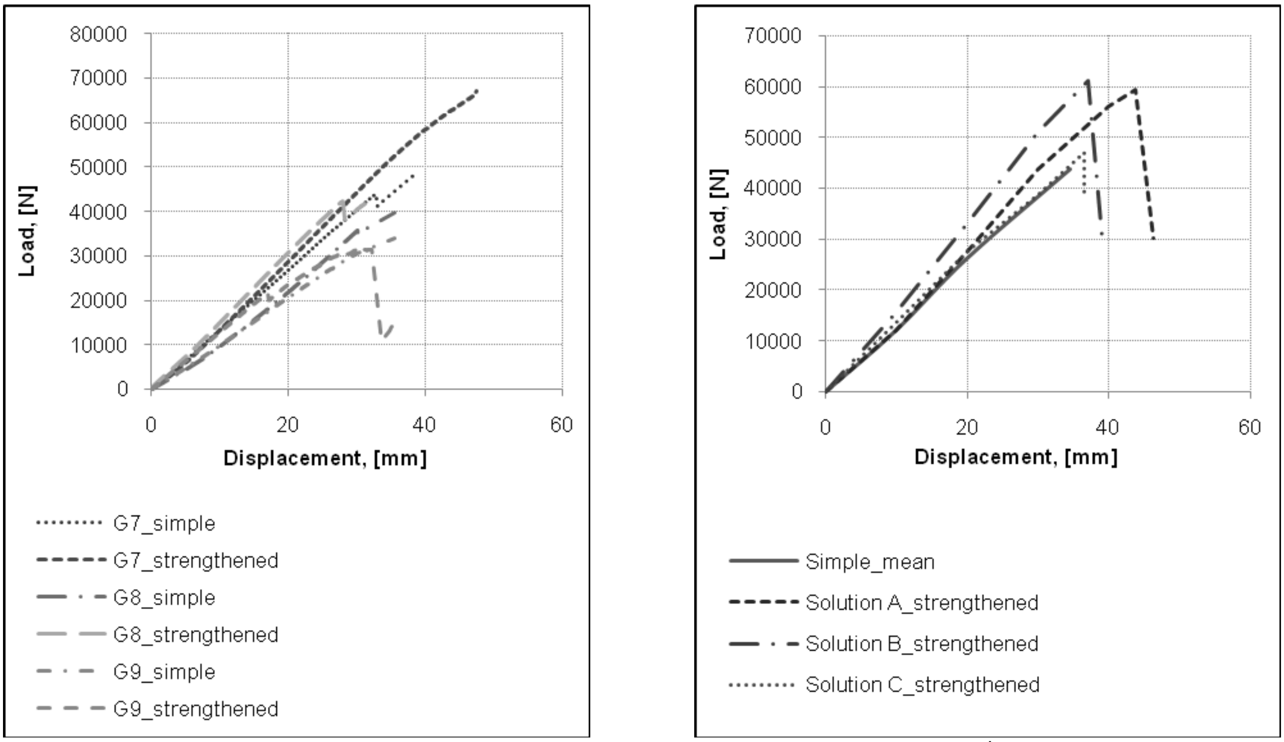

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Fig. 4 - Continuare / *Continuation*
c. grinzi nearmate şi consolidate conform Soluției C / *simple and strengthened beams according to Solution C*,
d. valorile medii pentru toate grinzile nearmate şi consolidate / *mean values for all simple and strengthened beams*

The ultimate load for the beams strengthened according to solution A, B and C has increased by 66.2%, 16.8% and 16.1% respectively, compared to the simple beams. These values demonstrate that the composite reinforcement provides an increase in beams bearing capacity.

The flexural deflections were also reduced in comparison with the simple elements. The maximum displacement for beams using the reinforcing system A was reduced by 10%. The stiffness gains for the beams using alternatives B and C had similar values, of 12.1% and 12.2%, respectively. The experimental program results are presented in Table 4.

Table 4

Rezultatele experimentale / *Experimental results*

Soluția aplicată *Applied solution*	Denumirea grinzii *Beam name*	Grinzi neconsolidate *Simple beams*				Grinzi consolidate *Strengthened Beams*	
		Încărcarea maximă aplicată *Maximum applied load*, [N]	Deplasarea corespunzătoare *Corresponding displacement*, [mm]	Forța capabilă calculată *Evaluated ultimate load*, [N]	Deplasarea evaluată *Evaluated displacement*, [mm]	Forța capabilă *Ultimate load*, [N]	Deplasarea corespunzătoare *Corresponding displacement*, [mm]
Soluția A / *Solution* A	G1	27400	22.74	30414	26.85	55600	42.27
	G2	28000	21.84	31080	25.79	55400	42.48
	G3	44000	32.76	48840	38.67	67200	46.26
	Media / *Average*	33133.33	25.78	36778	30.44	59400	43.67
Soluția B / *Solution* B	G4	46600	32.15	54726	37.96	56600	35.25
	G5	45000	27.43	49950	32.38	66600	39.87
	G6	50200	33.81	55722	39.92	60000	35.85
	Media / *Average*	47266.67	31.13	53466	36.75	61066.67	36.99
Soluția C / *Solution* C	G7	43800	32.77	48618	38.64	67000	47.49
	G8	35800	30.19	39738	35.64	41800	31.22
	G9	30600	30.15	33978	35.59	32200	30.77
	Media / *Average*	36733.33	31.04	40778	36.62	47000	36.49

For the strengthened beams G1 and G2 a debonding was noticed, starting from the ends of the CFRP plates, which occurred in the superficial wood layer and the adhesive, due to the large tensile stresses at the interface area. Beams G4, G6, G7 and G9 presented brittle timber failure due to shear stresses, near to the supports area. Therefore, the failure modes of the strengthened beams have been induced in the wood element, mainly by tensile stresses, in the case of external reinforcements, and shear stresses, for near surface strengthening, as shown in Figure 5. Natural defects, such as nodes and fissures, and existing cracks in wood had a significant influence on the failure modes of the flexural strengthened beams.

3. Analytical analysis

Figure 6 presents the geometrical characteristics of the reinforced beams, according to the three applied strengthening systems.

The equivalent cross-sectional area, A_{eq}, computation was done according to equation (1), for strengthening solutions A and C, and equation (2) for strengthening system B, [20,21].

$$A_{eq} = b \cdot h + n \cdot (h_c \cdot b_c) \cdot nr \quad (1)$$

$$A_{eq} = b \cdot h + n \cdot (\pi \cdot \frac{d_c^2}{4}) \cdot nr \quad (2)$$

$$n = \frac{E_{x,l}}{E_{x,CFRP}} \quad (3)$$

Where:

n – equivalence coefficient, depending on the ratio between the elasticity moduli of wood and CFRP composites, as shown in equation (3);

$E_{x,l}$, $E_{x,CFRP}$ – elasticity modulus of wood and CFRP composite materials, respectively, in MPa;

b, h – width and height of wood beam, in mm;

b_c, h_c – width and height of the CFRP composite plate or strip, in mm;

d_c – diameter of the CFRP composite bar, in mm;

nr – number of composite reinforcements utilized for a specific strengthening solution; for solutions A and B, nr equals to 1, while for solution C, nr equals to 4.

For each beam, the new center of gravity position, for the equivalent cross-section, y_c, was computed. In addition, the equivalent moments of inertia, $I_{z,eq}$, were determined, using equation (4), for solution A and C, and equation (5) for alternative B.

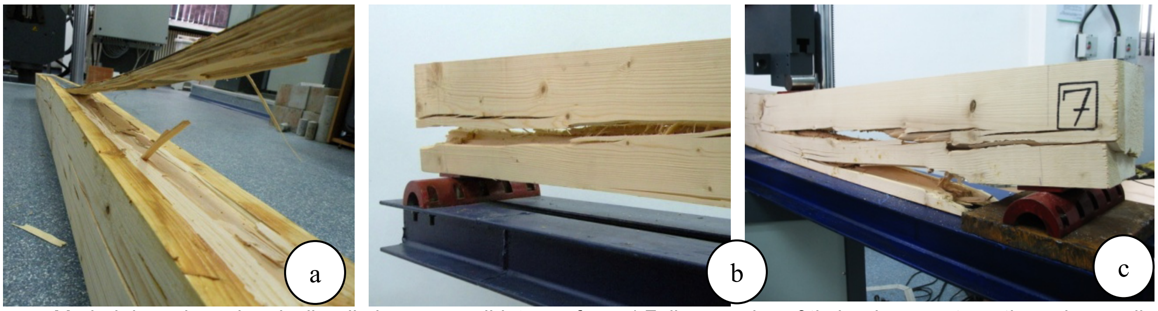


Fig. 5 – Moduri de cedare ale grinzilor din lemn consolidate conform: / *Failure modes of timber beams strengthened according to*: a) Soluției A / *Solution A*, b) Soluției B / *Solution B*, c) Soluției C / *Solution C.*

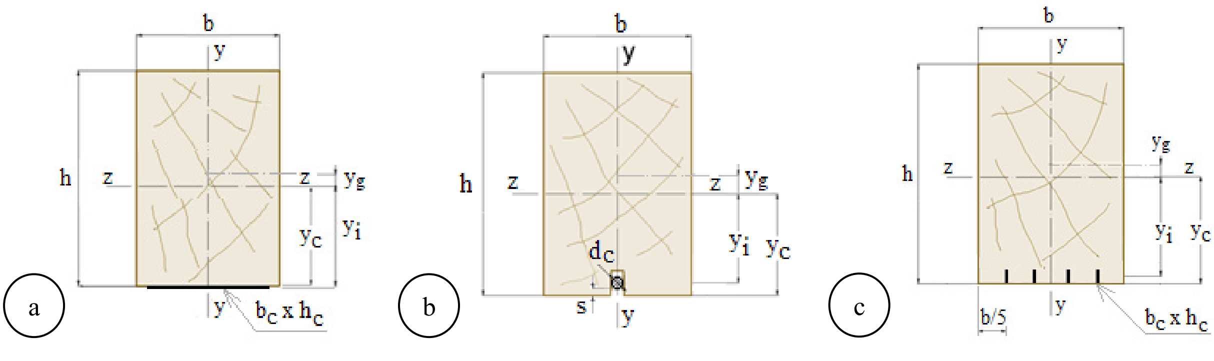


Fig. 6 – Secțiunea transversală a grinzilor din lemn consolidate cu produse CPAFC conform: / Cross- section of timber beams strengthened with CFRP products, according to: a) Soluției A / *Solution A*, b) Soluției B / *Solution B*, c) Soluției C / *Solution C.*

$$I_{z,eq} = \frac{b \cdot h^3}{12} + b \cdot h \cdot y_g^2 + nr \cdot [\frac{b_c \cdot h_c^3}{12} + h_c \cdot b_c \cdot n \cdot y_i^2] \quad (4)$$

$$I_{z,eq} = \frac{b \cdot h^3}{12} + b \cdot h \cdot y_g^2 + nr \cdot [\frac{\pi \cdot d_c^4}{64} + h_c \cdot b_c \cdot nr \cdot n \cdot y_i^2] \quad (5)$$

Where:

y_g – distance from the initial center of gravity, of the wood element, to the new center of gravity, of the strengthened cross-section, in mm,

y_i – distance from the new center of gravity, of the strengthened cross-section, to the center of gravity of the composite element, in mm.

The Mohr-Maxwell method was used to compute the beams deflections on Y axis direction, v_y, according to equations (6) and (7).

$$v_y = \sum \int_{i=0}^{Lc} \frac{M_p \cdot \overline{M_i}}{E_{x,l} \cdot I_i} dx \quad (6)$$

$$v_y = \frac{P \cdot (a-d)^3}{6 \cdot E_{x,l} \cdot I_{z,l}} + \frac{P \cdot d}{6 \cdot E_{x,l} \cdot I_{z,eq}} \cdot (3 \cdot a^2 - 3 \cdot a \cdot d + d^2) + \frac{5 \cdot P \cdot a^3}{16 \cdot E_{x,l} \cdot I_{z,eq}} \quad (7)$$

Where:

M_p and M_1 – diagrams of real and fictive bending moments, in N·mm;

P – ultimate load, determined during the experiments, in N;

d – distance between the load application point and the end of the CFRP product, in mm;

a – distance between loads application points, in mm.

Table 5 presents the obtained analytical results. To compare the experimental results with the analytical results, the experimentally obtained values for the maximum deflections, $v_{y,real}$, are presented in the last column of this table. The average errors obtained from analytical calculus are between 4.2% and 4.8%.

4. Numerical modelling

4.1. Geometry of the beams

The numerical modelling of the analyzed beams has been made using the finite element program ANSYS12. Individual models have been created for each simple and strengthened beam, using precise dimensions and characteristics. The general geometries of the beams and the prismatic cells used for the models meshing are illustrated in Figure 7.

The models were meshed using prismatic, tetrahedral or pyramidal cells of maximum 10-20 mm sides. The wood-CFRP system has been modelled using the Static Structural analysis from the software package, for which the mechanical and physical properties for the materials have been defined, based on values obtained experimentally and from literature, [14].

All the components, namely wood, epoxy adhesive and CFRP products, have been modelled as elastic isotropic materials. It has been considered that there is a perfect bonding at all interfaces.

4.2. Numerical modelling results

The applied loads used in the numerical modelling were:

- the experimentally obtained loads, for which the first cracks appeared, in the case of the simple wood beams;

Table 5

Rezultatele calculului analitic / *Analytical calculus results*

Soluția aplicată *Applied solution*	Denumirea grinzii *Beam name*	$E_{x,l}$ [MPa]	A_{eq} [mm^2]	y_c [mm]	$I_{z,eq}$ [mm^4]	P [N]	v_y [mm]	$v_{y,real}$ [mm]
Soluția A *Solution A*	G1	7236.77	17599.34	82.98	40429671	55600	46.62	42.27
	G2	8106.36	17599.74	82.98	40432479	55400	41.47	42.48
	G3	9219.51	17329.25	82.48	39335531	67200	45.46	46.26
	Media *Average*	8187.55	17509	82.81	40065893.67	59400	44.52	43.67
Soluția B *Solution B*	G4	8945.08	17539.52	83.48	40781166	56600	38.06	35.25
	G5	10586.34	17435.35	82.97	40058149	66600	38.53	39.89
	G6	10316.71	17330.22	82.47	39337917	60000	36.27	35.85
	Media *Average*	9949.38	17435	82.97	40059077.33	61066.667	37.62	37
Soluția C *Solution C*	G7	8678.10	17282	81.48	38274443	67000	49.48	47.49
	G8	7567.27	17433.49	82.98	40042983	41800	33.84	31.22
	G9	6418.31	17432.96	82.98	40040461	32200	30.74	30.77
	Media *Average*	7554.56	17383	82.48	39452629	47000	38.02	36.49

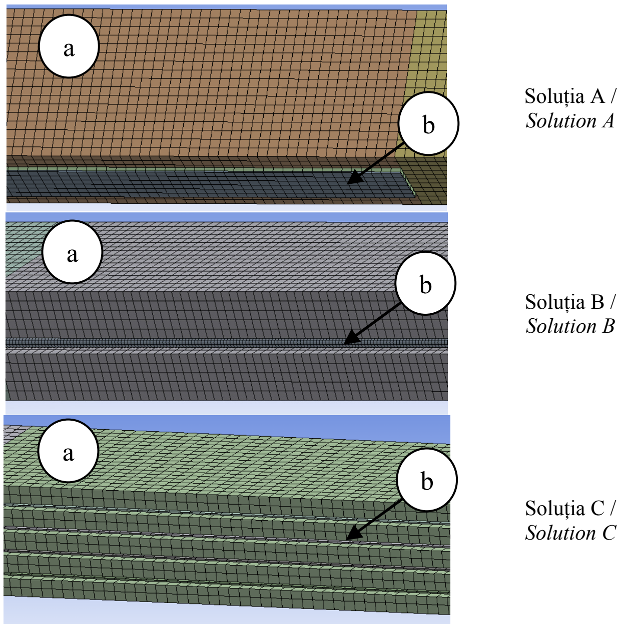


Fig. 7 – Modele geometrice discretizate şi elementele component: / *Geometrical models mesh and components*: a) elementul din lemn / *timber element*; b) produsul CPAFC / *CFRP composite product*

- the experimentally obtained ultimate loads, in the case of the strengthened beams.

The beams flexural behaviours are shown in Figure 8 and the numerical modelling results are presented in Table 6.

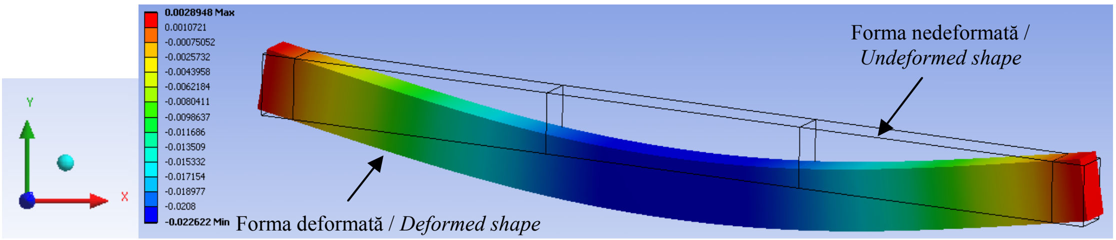
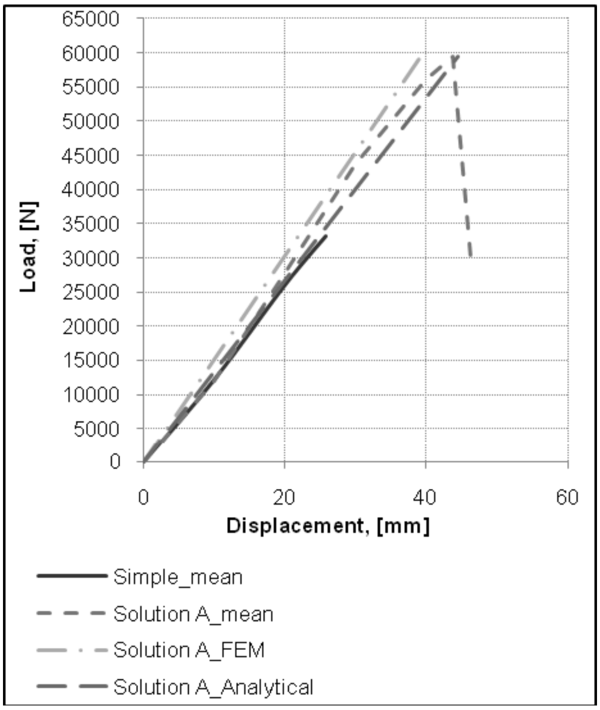


Fig. 8 – Reprezentarea grafică a grinzilor deformate pe direcția axei Y / *Graphical representation of beams displacement on Y axis direction*

Table 6

Deplasările maxime rezultate din modelarea numeric / *Maximum deflections resulted from numerical modelling*

Soluția aplicată *Applied solution*	Denumirea grinzii *Beam name*	Grinzi neconsolidate *Simple beams*		Grinzi consolidate *Strengthened beams*	
		Forța aplicată *Applied load*, [N]	Deplasare *Displacement*, [mm]	Forța aplicată *Applied load*, [N]	Deplasare *Displacement*, [mm]
Soluția A *Solution* A	G1	27400	23.24	55600	37.45
	G2	28000	21.24	55400	37.22
	G3	44000	33.83	67200	42.93
	Media *Average*	31133	**26.10**	59400/31133	39.20/**20.55**
Soluția B *Solution* B	G4	46600	32.34	56600	34.36
	G5	45000	25.92	66600	39.77
	G6	50200	30.77	60000	32.76
	Media *Average*	47266	**29.68**	61067/47266	35.63/**27.58**
Soluția C *Solution* C	G7	43800	32.77	67000	45.56
	G8	35800	29.90	41800	31.78
	G9	30600	30.01	32200	27.55
	Media *Average*	36733	**30.89**	47000/36733	34.96/**27.33**



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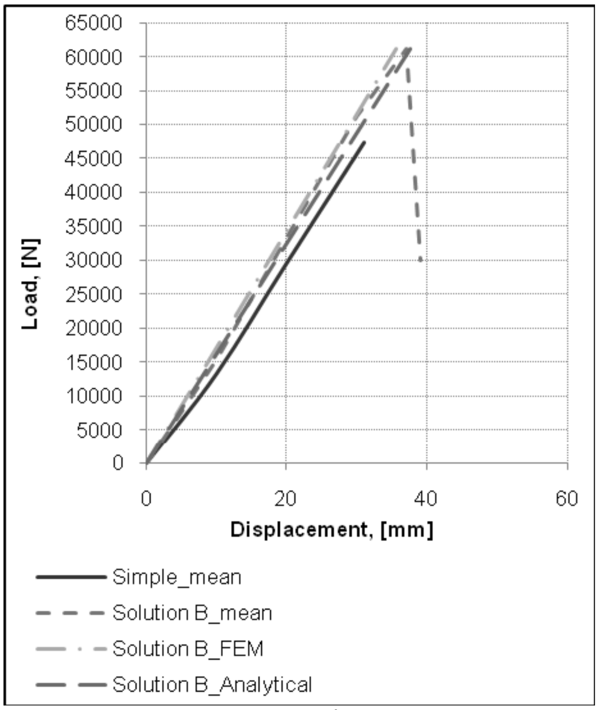

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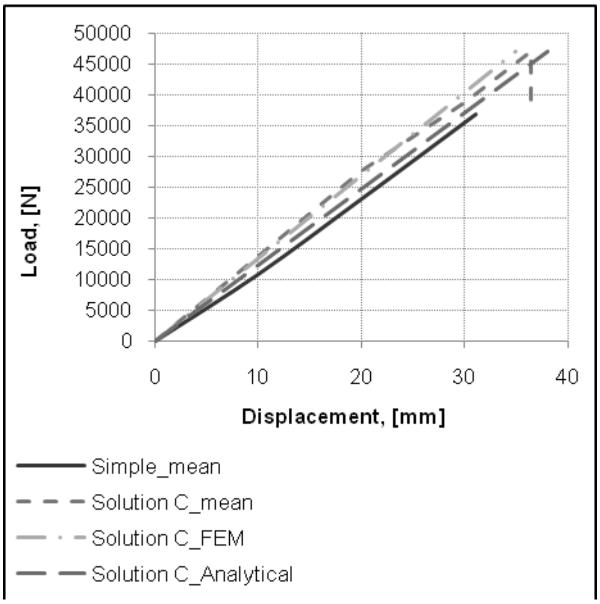

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Fig. 9 - Curbele încărcare – deplasare pentru rezultatele experimentale, analitice şi numerice în cazul: / *Load – displacement curves for the experimental, analytical and numerical results for:*
a. Soluția A / *Solution A*
b. Soluția B / *Solution B*
c. Soluția C / *Solution C*

The results obtained from the numerical models for the simple and reinforced wood beams have proven the efficiency of implementing the strengthening systems A, B and C as it is shown in Figure 9.

5. Discussion on the results

The mean values of the computational errors, when comparing experimental results with analytical values, are between 4.2% and 4.8%. These errors could have appeared due to the variability of the physical and mechanical properties of wood, or its natural defects and existing degradations.

In the case of the simple beams, the average simulation error, when comparing the numerical modelling to the experimental tests results, was of 2.5%. For the strengthened beams, the average numerical modelling error was of 6.5%. For the beams that utilized the strengthening system A, the error had a value of 10.6%, while the beams reinforced corresponding to solutions B and C had an error of 4% and 5.4%, respectively.

The large error met in case of strengthening alternative A can be explained due to the unfit bondage between wood-adhesive and adhesive-composite plate, which was observed during the laboratory tests.

All the differences that occurred between experimental tests and numerical modelling results have a series of potential explanations, like the fact that, during the numerical simulation, the materials were introduced as isotropic, or that wood defects, as well as the strengthening systems defects, were neglected. In addition, a perfect unreal bondage was considered between wood – adhesive - CFRP products.

6. Conclusions

Strengthening timber beams using CFRP products proved to be an effective method to enhance the structural response of wood elements. The experimental results indicated that applying CFRP reinforcing at the tensioned side of timber beams increased the stiffness and bearing capacity to more than 12% and 66%, respectively, in comparison to the simple beams.

The results highlight the fact that strengthening technology is a key factor for building the desired goal, namely to increase the bearing capacity. Note that the largest increase for bearing capacity was achieved by solution A. In this solution, the force required to break the beam increased by 66%.

To obtain satisfactory results, the technological steps for each strengthening system have to be thoroughly followed: the surface preparation, primer and adhesive application, the position of products used for strengthening.

Laboratory tests results proved that the bonding between the components of the wood-CFRP beam is crucial for the overall structural behaviour of the system. Regarding the debonding problem, the solutions that applied the NSM method offered less difficulties, as the composite products were inserted inside narrow slots and the interface surfaces were maximized. Failure modes indicated that the beam element will fail due to tensile and shear stresses, close to the wood natural defects and existing cracks.

The analytical calculus, consisting in computing the strengthened timber beam as an equivalent homogeneous element, presented errors in evaluation up to 4.8% of the experimental results. The differences between experimental and analytical values can be explained due to wood defects and existing longitudinal cracks in timber beams.

The numerical modelling evaluated the structural response of simple and strengthened beams and proved to be a valid starting point for developing better computer simulations of experimental tests. The numerical modelling results are affected by several factors, like the assumptions of perfect bondage between wood-adhesive-CFRP, and the neglect of wood material complexity.

Obtained error margins are small, and it can be said that the two presented methods of investigation, analytical and numerical, can be used to assess flexural behavior of various sized wood beams strengthened according to one of the proposed solutions.

REFERENCES

1. CNR–DT 201/2005 - „Guidelines for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures. Timber structures", National Research Council, Advisory Committee on Technical Recommendations for Construction, Rome, Italy, 2005.
2. G. Pajchrowski, A. Noskowiak, A. Lewandowska, and W. Strykowski, Wood as a building material in the light of environmental assessment of full life cycle of four buildings, Construction and Building Materials, 2014, **52**, 428.
3. J. Ahmad, and J.A. Bhat, Flexural strengthening of timber beams using carbon fiber reinforced polymer plates, International Journal of Civil Engineering and Technology (IJCIET) , 2013, **4** (5), 61.
4. A. Borri, M. Corradi, and A. Grazini, FRP reinforcement of wood elements under bending loads, Proc. Int. Conf. Structural faults and Repair 2003, London, United Kingdom, 2003.
5. Gentile C., Svecova D., Rizkalla and S. H., Timber beams strengthened with GFRP bars: Development and applications, Journal of Composites for Construction, 2002, **6**, 11.
6. J.R. Gilfillan, S.G. Gilbert, and G.R.H. Patrick, Improving the structural performance of timber beams with FRP composites: a review, FRP Composites in Civil Engineering - CICE 2004, Seracino R. (editor), A.A. Balkema Publishers, London, United Kingdom, 2005.
7. Y.J. Kim, and K.A. Harries, Modeling of timber beams strengthened with various CFRP composites, Engineering Structures, 2010, **32**, 3225.
8. N. Plevris,and T. Triantafillou, FRP reinforced wood as structural material, Journal of materials in Civil Engineering, 1992, **4** (3), 300.
9. R.E. Rowlands, R.P. Van Deweghe, T.L. Laufenberg, and G.P. Krueger, Fiber- reinforced wood composites, Wood and fiber science, 1986, **81** (1), 39.
10. K.U. Schober, and K. Rautenstrauch, Post-strengthening of timber structures with CFRP's, Materials and Structures, 2006, **40**, 27.
11. K.U. Schober, and K. Rautenstrauch, Strengthening of timber structures in-situ with an application of fiber-reinforced polymers, FRP Composites in Civil Engineering - CICE 2004, Seracino R. (editor), A.A. Balkema Publishers, London, United Kingdom, 2005.
12. A. Yusof, and A.L. Saleh, Flexural strengthening of timber beams using glass fibre reinforced polymer, Electronic Journal of Structural Engineering, 2010, **10**, 45.
13. D. Isopescu, O. Stănilă, I. Astanei, and C. Corduban, Experimental analysis of wood mechanical properties from bending, tensile and compression tests, Romanian Journal of Materials, 2012, **42** (2), 204.
14. Forest Products Laboratory, Wood handbook—Wood as an engineering material, General Technical Report FPL-GTR-190, Madison, WI: U.S. Department of Agriculture, Forest Service, 2010.
15. A. Andre, R. Kliger, and L.E. Asp, Compression failure mechanism in small scale timber specimens, Construction and Building Materials, 2014, **50**, 130.
16. xxx, ASTM 04.10 Wood D143-09 Standard test methods for small clear specimens of timber, American National Standard Institute, USA, 2004.
17. xxx, Eurocode 5, ENV 1995-1-1-1994, Design of timber structures. Part 1.1: General rules for buildings.
18. xxx, SR ISO 3133:2008, Determination of resistance to static bending, 2008.

19. xxx, SR EN 408:2004: Timber structures. Solid wood and glued laminated timber. Determination of some physical and mechanical properties, 2004.
20. M.-C. Ntibarikure, Task 9 real life case study trials, Sub-task 9.2: Installation and monitoring, Contribution from Legnodoc SRL: Palazzo Nobili in Lucca, Italy, 2005.
21. I. Olariu, and M. Petrina, Determination the equivalent moment of inertia for lattice ginders with parallel flanges. Scientific Bulletin of I.P.C-N, 1976, **19**, 36-38

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MANIFESTĂRI ŞTIINŢIFICE / SCIENTIFIC EVENTS

Al XI-lea SIMPOZION NAŢIONAL
PULBERI CERAMICE, Bucureşti 07.11.2014
Organizat de

Societatea Română de Ceramică | **Institutul de Chimie Fizică al Academiei Române** | **Universitatea POLITEHNICA Bucureşti**

PROGRAM, 07.11.2014

Moderatori: Prof. Adrian VOLCEANOV
Dr. Victor FRUTH

1.PULBERE CERAMICĂ OBŢINUTĂ DIN NANOCOMPOZITE HIBRIDE ANORGANIC-ORGANICE
Anita RADU[1], Andrei SÂRBU[1], Victor FRUTH[2], Anamaria ZAHARIA[1], Verona IORDACHE[1], Irina ATKINSON[2], Luminita MARA[3], Celina DAMIAN[4], Stela IANCU[1], Steluța APOSTOL[1], A.RUSU[2], Liliana SÂRBU[1], Fănica BACALUM[1]
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[3]*National Research- Development Institute for Nonferrous and Rare Metals- IMNR*
[4]*Polytechnic University, Department of Bioresources and Polymer Science*

2.SINTEZA COBALTITULUI DE STRONȚIU NESTOECHIOMETRIC PRIN ACTIVARE MECANICĂ INTENSIVĂ
Georgeta VELCIU[1], Adelina IANCULESCU[2], Alina MELINESCU[2], Maria PREDA[2], Delia PATROI[1], Virgil MARINESCU[1]
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3.MATERIALE NANOSTRUCTURATE CU APLICAȚII ÎN TERAPIA ANTI-TUMORALĂ
Roxana C.POPESCU, Ecaterina ANDRONESCU, Mihai Alexandru GRUMEZESCU
Universitatea POLITEHNICA Bucureşti,, Department Ştiinţa şi Ingineria Materialelor Oxidice şi Nanomateriale

4.PREPARAREA ŞI CARACTERIZAREA $SrTiO_3$ MEZOPOROS DOPAT CU AZOT
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5.BIOMATERIALE COMPOZITE PE BAZĂ DE COLAGEN ŞI HIDROXIAPATITĂ PENTRU INGINERIA ȚESUTULUI
Alberto ION, Ecaterina ANDRONESCU, Mihai Alexandru GRUMEZESCU
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Alexandru MICU, Alberto ION, Ştefania STOLERIU
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Vera SPIRESCU, Ecaterina ANDRONESCU, Mihai Alexandru GRUMEZESCU
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