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EXPERIMENTAL STUDIES ON GLUED LAMINATED TIMBER BEAMS REINFORCED WITH POLYMER FIBERS SUBJECTED TO THE BENDING TEST

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Abstract: This paper presents the results of an experimental program concerning the comparative analysis between the behavior of glue laminated timber beams (glulam) reinforced with polymer fibers (FRP) and the common, unreinforced beams when subjected to bending. The goal of this experimental program is to seek various solutions for enhancing the capacity of massive wood structural elements and for this purpose a series of experimental tests on glued laminated timber beams reinforced with polymer materials had been carried out. Although successfully used in the case of other construction materials, reinforcing the massive wood beams is a relatively new solution but proved to be of great interest. Used mostly in the case of rehabilitation of wood structural elements, it can also be a viable solution for new elements. Thus, a series of studies have been carried out to conclude advantages and disadvantages of this composite material. At the same time, the elements may allow a decrease in the cross section while sustaining large spans, being thus lighter, easier to assemble and transport and reducing the total weight of the structure together with the construction time.

Keywords: FRP, composite material, glulam, fiber reinforced polymers, wood, construction

INTRODUCTION

Reinforced glued laminated timber elements are sustainable building materials having improved physical–mechanical properties (strength, stiffness and deformation) compared to the common glued laminated timber ones.

Strengthening solutions using composite materials on wood buildings is a subject of major research, since there are a series of aspects that may be clarified only experimentally. Variations of wood properties on three directions, its dimensional stability that depends on temperature and humidity variations, the ratio between the quantity of adhesive (mass basis) and the timber volume in the sections, the adhesive's durability as well as the fact that the two materials (wood and matrix) must work together, are a number of parameters to be taken into account in the analysis of the use of these types of reinforced solutions and in the choice of materials. Due to these multiple variables, the use of these reinforced materials must be based on satisfactory experimental results proving the properties of durability and structural behavior.

Opportunity to achieve greater values for strength, stiffness and deformations when subjected to various stresses, possibility to work on site without moving or destroying the affected item and without total interruption of the activity in the building, are just some of the advantages that have made composite solutions to be accepted and became the topic of research in national and international programs. So far, concern for strengthening with modern polymer materials was focused primarily on the consolidation of existing concrete elements.

This research aims to establish the correlation between different solutions of massive wood elements reinforced with composite materials in terms of strength and deformations when referred to a standard element.

This study is based on the results of a previous experimental program [1], concerning the search for enhancing the capacity of massive wood structural elements. The solution offering the best features was chosen for forward testing, the analysis results and conclusions being detailed in the present paper.

The specimens were composed cross section glulam wood beams reinforced with fiber polymer systems placed in different positions along the element, according to the details given in Figure 1. Laboratory tests were performed on 5 types of wood specimens.

The timber humidity was measured in the laboratory before testing. In the laboratory, flexure and deformation tests were performed on the wood elements.

MATERIALS AND METHODS

▦ Wood species

A common wood essence (spruce) was the material currently used for glued laminated timber elements according to the standard SR EN 338 [3].

Glued laminated timber, currently known as glulam, of strength class GL24h [2] was used for all the specimens. Fifteen specimens were used in the test.

Fiber reinforced polymer systems

By fiber reinforced polymer system it is understood the bicomponent system formed by the fiber reinforced polymer itself and the adhesive used to create the composite cross sections when used.

Fiber reinforced polymer

Based on the results obtained in the previous research program comprising a series of adherence tests performed on different specimens subjected to shear forces [1], two types of fiber reinforced polymers were considered to fulfil the physical and mechanical demands required for further testing, these being:

- Sika Wrap®–230 C having 0.129 mm thickness with a surface weight of 235g/m^2 + 10g/m^2 (carbon fibre only) a mass on the surface of 235g/m^2 + 10g/m^2 (carbon fibre only) and a fibre density: 1,82 g/cm^3. Sika Wrap–230® is a unidirectional medium–strength carbon fibre (textile) fabric designed for installation through the wet or dry application process. [4]
- Sika CarboDur® S NSM (located near–surface) [5] having the plates bonded into slots near the surface of the element. Sikadur® –330, an epoxy resin based adhesive is used as binder for the plates in case of normal application temperatures.

Adhesives

For joining together the glulam elements and the polymer fibre system an epoxy resin based adhesive is necessary:

The two types of epoxy resin are:

- Melamine–urea–formaldehyde adhesives MUF, the adhesive used for processing the glued laminated timber elements. MUF (melamine–urea–formaldehyde) is made of melamine or polyurethane and is one of the most commonly used adhesives in the wood industry. The same adhesive was also used for joining the fiber reinforced polymer and the wood elements in some of the tests.
- For some other tests, Sikadur 330 adhesive was used to join the fiber reinforced polymer and the wood elements, which is a bicomponent impregnating, solvent–free, thixotropic epoxy resin.

EXPERIMENTAL PROGRAM

Test specimens

The tests in this study were performed on glued laminated timber beams reinforced with FRP, the reinforcement being chosen among a series of polymeric reinforcement solutions.

Characteristics:

- use of different types of adhesive and different polymeric reinforcement solutions,
- variation of the reinforcement position along the beam length as shown in Figure 1.

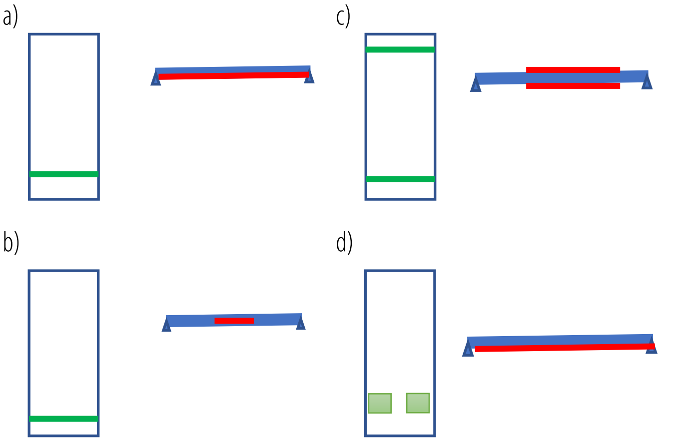

Figure 1. Arrangement of the reinforcement lengthwise: a) at the lower part of the cross section, along its entire length; b) at the bottom, on the central third of the span; c) at the bottom and at the top, on the central third of the span; d) NSM type carbon fibers.

Materials used for the polymer fibre system are:

- 2 types of adhesive: Melamine–urea–formaldehyde adhesives (MUF), SikaDur 330
- 2 types of polymeric materials: Sika Wrap–23^0C, NSM type carbon fibers

Tests were performed on specimens using the materials specified in Table 1.

Three elements of each specimen were subjected to the bending test and flexural force F_{fin} and deflection of the beam at failure were recorded.

This force represents the value displayed by the testing machine when failure is produced in the specimen.

The detailing of the tested specimens is given in the table below (Table 1), where Type 1 is the pilot specimen containing no reinforcement and was considered as the reference for further analysis.

Table 1. Specimens used for the tests

Specimen	Section b x h x l	Reinforced position	Adhesive	Polymeric reinforcement
Type 1	120 x 280 x 4000		MUF	No Polymeric reinforcement
Type 2			SikaDur 330	Sika Wrap 230C
Type 3			SikaDur 330	Sika Wrap 230C
Type 4			SikaDur 330	Sika Wrap 230C
Type 5			SikaDur 330	NSM

Specimen Type 2 had the polymeric reinforcement fully developed along its length, glued between the first two laminations of the beam cross section.

For specimen Type 3 the reinforcement was located at the bottom of the cross section along the middle third of the tensioned side.

For specimen Type 4 the reinforcement was located at the top and the bottom of the cross section along the middle third of the tensioned side.

For specimen Type 5 the NSM–type carbon fibers reinforcement used was located along the tensioned side of the element.

EXPERIMENTAL SET UP AND TESTS

The beams were tested in simple bending in the CERS laboratory of the Bucharest Technical University of Construction (Figure 3).

Metal plates were installed near the supports as well as at the points of force application to reduce deformations due to local crushing of the wood. All beams were loaded until failure, with loading steps of 1kN and 2kN (Figure 2). The test conditions of the laboratory environment were relative humidity 47 % and temperature 23°C.

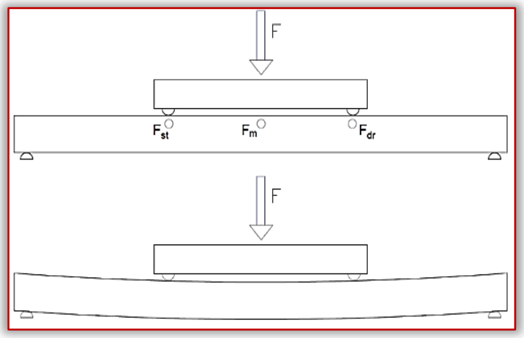

Figure 2. Scheme of beam loading, force positioning, positioning of clocks (LVDT Linear variable differential transformer): F_{st}, F_m and F_{dr} (on the left side, under the load support, on the middle and on the right side, under the load support) and the deformation of the beam under the load

Figure 3. Unreinforced beam loading

RESULTS AND DISCUSSIONS

The tests results led to a series of conclusions on the influence of the reinforcement in the glulam cross section on its mechanical characteristics. The analysis was performed for all the specimen types referred to the pilot one. The failure patterns of the tested specimens are emphasized in figures 4–8.

Figure 4. Failure patterns of the tested specimen Type 1 (No Polymeric reinforcement)

Figure 5. Failure patterns of the tested specimen Type 2 (SikaDur 330 + Sika Wrap 23^0C)

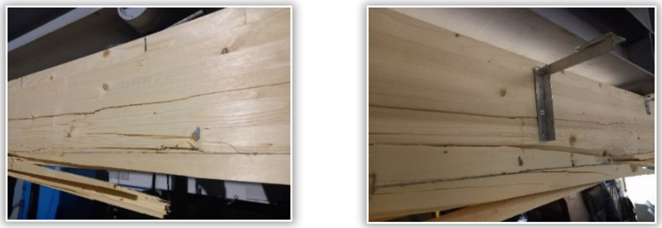

Figure 6. Failure patterns of the tested specimen Type 3 (SikaDur 330 + Sika Wrap 23^0C)

Figure 7. Failure patterns of the tested specimen Type 5 (SikaDur 330 + NSM)

Table 2 summarizes the tests maximum failure force and the time interval until the failure for each tested specimen.

Table 2. Experimental results for shear test

Specimen	Reinforced materials	Deflection (mm)	Failure force F_{fin} (kN)
Type 1	No Polymeric reinforcement	40,32	81,0
Type 2	SikaDur 330 +SikaWrap	63,80	120,0
Type 3	SikaDur 330 +SikaWrap	73,72	139,0
Type 4	SikaDur 330 +SikaWrap	41,37	88,0
Type 5	SikaDur 330 +NSM	61,55	130,0

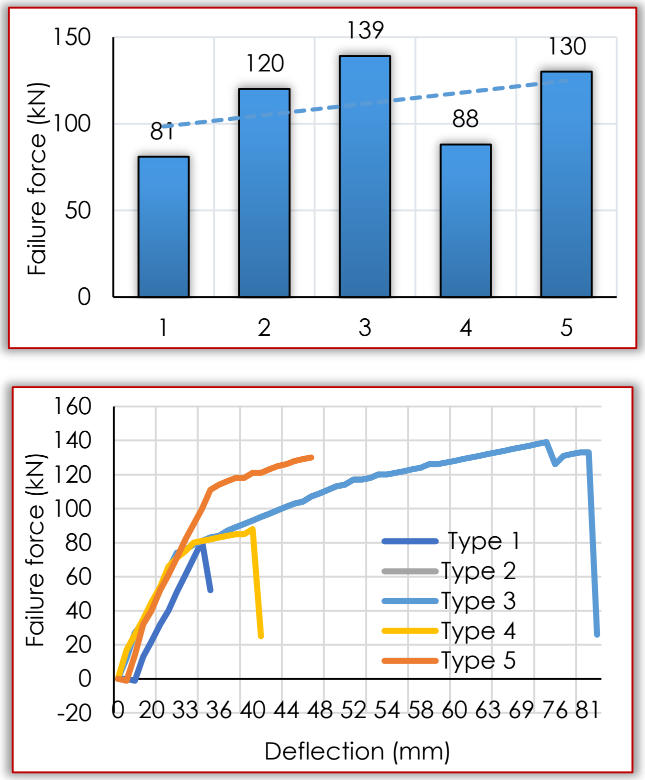

Figure 9. Breaking strength of the analyzed elements: Type 1 beam – unreinforced beam; beam Type 2 – reinforced beam at the bottom; beam Type 3 – reinforcement at the bottom, on the central third of the element; beam Type 4 – reinforcement at the bottom and at the top, on the central third of the element; Type 5 beam – NSM type carbon fiber reinforced beam.

Analysing the testing results referred to the pilot specimen Type 1, a series of conclusions may be drawn:

- Specimen Type 3 – displays the maximum value for the failure force and for the deflection among all tests, in this situation the elements arrangement in specimen Type 3 can be considered to offer the best solution is terms of strength capacity and deformations.
- Specimens Type 2 and 5 – displays similar results, the differences between the values for the maximum failure force and deformations being of about 10%.
- Specimen Type 4 – displays no significant increase in physical and mechanical characteristics of the element with respect to the pilot values, when both upper and lower reinforcement are located along the element.
- The values of maximum failure forces obtained on the 5 types of specimens may be evaluated, a percentage comparison can be made resulting in the fact that the reinforced sections have a higher strength capacity than the pilot one.
- Specimen Type 3 had the largest increase in strength capacity of 71% compared to the resistance capacity of the pilot Type 1 beam.
- Specimen Type 2 shows a strength increase of 48% compared to the strength capacity of the Type 1 pilot beam.
- Specimen Type 4 shows an insignificant increase in strength of 8.4% compared to the one of the Type 1 standard beam.
- Specimen Type 5 was reinforced using NSM profiles, completely different from types 2, 3, 4. The tests show a satisfactory behaviour by increasing the strength of 60.50% compared to the strength capacity of the Type 1 pilot beam.

NUMERICAL ANALYSIS

A numerical analysis was performed in parallel to the experimental one. The goal was to determine an amplification factor that can be applied to the strength of the unreinforced elements to directly compute the resulting strength of the reinforced elements.

The amplification factor represents the ratio between the ultimate moment computed for the current specimen (with reinforcement) and the ultimate moment computed for the simple (unreinforced) specimen.

The amplification factor ($k_{m.a}$) is computed as follows:

$$k_{m.a} = \frac{M_u}{M_{uGL}}$$

where:

M_u the ultimate moment for the current specimen (with reinforcement)

M_{uGL} the ultimate moment for the simple (unreinforced) specimen

The ultimate moments are computed based on the maximum stress in the tensioned fiber of the specimen:

$$M = \sigma_{max} \frac{I}{y_{NA}}$$

where:

σ_{max} the maximum stress in the tensioned fiber of the specimen considering the plane section hypothesis

I the (equivalent) moment of inertia of the section

y_{NA} the height of the neutral axis with respect to the tensioned fiber

In the previous relation, in the case of the reinforced specimen, the equivalent moment of inertia was computed for the composite section based on the transformed section method. [11]

It can be viewed as the relative increase in strength of the reinforced specimens with respect to the unreinforced one (e.g. a factor of 1.48 represents an increase in strength of 48%).

The numerical analysis was based on the Euler – Bernoulli assumptions considering the equivalent stiffness of the reinforced beam as if it had a homogenous section.

Also, based on the results of the experimental tests on the pilot beam, a value for the modulus of elasticity of the glued laminated timber of 8044 MPa was determined and used for the computation of the reinforced elements. This was the average of the elasticity modulus values obtained for all loading steps under 40% of the breaking force.

The results of the numerical analysis are summarized in the following table:

Table 3. Amplification factor

Specimen	Amplification factor	Maximum displacement error
Type 1	1.00	0
Type 2	1.48	2.98%
Type 3	1.713	3.2%
Type 4	1.1	0.1%
Type 5	1.60	0.09%

After the correlation with the experimental results, the maximum error in the numerical evaluation of the maximum displacement was about 3%, resulting that the computed amplification factors may be used in similar scenarios with a very high certainty factor (close to 97%).

CONCLUSIONS

The experimental tests presented in this article are based on the background obtained in a prior study containing a series of adhesion tests performed on different constructive solutions [1].

Aiming to find a series of performing cross–sectional composition of glulam and polymeric fiber reinforcing system. Following the previously obtained results, the most favourable composite cross sections was obtained using Sika wrap polymeric fiber system and SikaDur 330 adhesives. In addition, tests were done using NSM plates as reinforcement.

The results analysis show that specimen Type 3 provide the most satisfactory results with an increase of 71% of the maximum failure force. The solution of using NMS plates as reinforcement (Type 5) brings an increase of 60.5% which is also a satisfactory result. In both situations the reinforcement is laid–out along the bottom of the beams only, along different lengths.

The tests show that double reinforcing the glulam beam (Type 4) brings insignificant addition to the strength capacity.

A numerical analysis was performed together with experimental testing. This analysis was aiming to determine an amplification factor that can be applied to the strength of the unreinforced elements to directly compute the resulting strength of the reinforced ones.

Through this factor it is possible to co–ordinate the strength capacity of a reinforced glulam element with the strength capacity of the unreinforced one, together with the cross–sectional dimensions aiming to obtain an optimum cross section and improved physical and mechanical characteristics.

Acknowledgments

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References

[1] Ioana Teodorescu, Daniela Țăpuşi, Ruxandra Erbaşu, Adrian–Alexandru Savu, Răzvan Butucescu, Andrei Papurcu – Experimental studies on glued laminated timber beams reinforced with polymer fibers, Scientific Journal – Modelling in civil and environmental engineering;
[2] SR EN 14080 – Structuri de lemn. Lemn lamelat încleiat şi lemn masiv încleiat. Cerințe;
[3] SR EN 338 – Lemn pentru construcţii. Clase de rezistenţă;
[4] Sikawrap; https://gcc.sika.com/
[5] Sika CarboDur® S NSM; https://gcc.sika.com/
[6] A Berindean, teză de doctorat cu titlul Contribuții privind conceperea și realizarea elementelor de construcție compozite alcătuite din lemn asociat cu alte materiale, Cluj–Napoca;
[7] Khaled Saad, András Lengyel, Strengthening Timber Structural Members with CFRP and GFRP: A State–of–the–Art Review, Polymers 2022, 14, 2381
[8] Y Kim. J. F. Davalos, E. J~ Barbero, Delamination buckling of FRP layer in laminated wood beams, 1997 Elsevier;
[9] J.A. Balmori, J.M. Branco and L.A. Basterra, Behaviour of the adhesive bond between low–grade wood and GFRP reinforcements using epoxy resin, Construction and Building Materials, 2020;
[10] Harrach Dániel, Muayad Habashneh & Majid Movahedi Rad, Reliability-based numerical analysis of glulam beams reinforced by CFRP plate, 2022
[11] A.C. Ugural, S.K. Fenster, Advanced Mechanics of Materials and Applied Elasticity, 6th Edition, 2019, Pearson.

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