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Laboratory Testing for Evaluating Bio-Based Building Materials Behavior Subjected to near Pyrolysis Temperature

Ruxandra Erbașu[1]
Ioana Teodorescu[2]
Andrei Dan Sabău[3]

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Abstract: *This paper is based on the background offered by an extended research project aiming to analyze and develop a testing system for the mechanical behavior of some new configurations of bio-based composite materials (more specifically glued laminated timber) when subjected to high temperatures.*

The need for this type of materials is becoming more topical due to the attempt to replace the building materials whose production is energy-intensive (especially steel and concrete) with bio-renewable building materials (as, for example, wood) within the framework of the European "Green New Deal" policy to reduce greenhouse gas emissions, of which the construction industry is considerably responsible. Current engineering practice focuses on normal environmental temperatures, however radical behavior changes may occur during a fire. The subject of the present paper deals with the assessment of changes occurring in the mechanical parameters of massive wood products (more specifically glued laminated timber-glulam) due to temperature variation, especially close to pyrolysis temperature.

The testing samples were prepared using current adhesive solutions and wood essences as in the case of the real-scale structural glulam elements.

The heating gear was embedded in the glued midplane of the sample to apply different temperatures. Tests were performed in direct shearing equipment, where the glued section was fitted in the middle of the shear box.

Changes in the mechanical behavior of wood at high raised temperatures are monitored but the focus is on the variation of the adhesive parameters during testing.

1. INTRODUCTION

In the context of climate change, the reduction of gas emissions while building (Parlato & Pezzuolo, 2024) and creating new bio-degradable materials is essential for the creation of a sustainable economy. These materials have lower global warming characteristics due to the property of absorption of carbon from the atmosphere (Sudhoff, 2024) and are becoming an alternative for friendlier environments (Anwar et al., 2024).

Glued laminated timber (glulam) elements have gained significant popularity in recent years and widespread use globally for several key reasons: their design flexibility, no restrictions concerning the dimensions of the elements (Lestari et al., 2018), dimensional stability, better properties due to the elimination of defects (Pulngern et al., 2020), strength-to-weight ratio, sustainability, and why not visual appeal.

[1] Technical University of Civil Engineering Bucharest, Bdul. Lacul Tei 124, 020936 Bucharest, Romania
[2] Technical University of Civil Engineering Bucharest, Bdul. Lacul Tei 124, 020936 Bucharest, Romania
[3] Technical University of Civil Engineering Bucharest, Bdul. Lacul Tei 124, 020936 Bucharest, Romania

These advantages, combined with advancements in manufacturing techniques and an increasing awareness of sustainable construction practices, have played a crucial role in the global acceptance and success of glulam structures.

When talking about fire, and high temperatures applied on wooden elements, the research campaigns are significant in order to find the perfect combination and dimensions of elements formed by timber and adhesives. Heated glulam elements subjected to shear forces necessitate thorough attention to their mechanical properties, the impact of temperature, and possible reinforcement strategies. Grasping these factors is crucial for maintaining the structural integrity and safety of Glulam in scenarios where they might be exposed to heat and shear stresses (Swedish Wood, 2024).

In the same time, thermal modification technology can improve wood properties by enhancing its dimensional stability and resistance to deterioration, as well as minimizing shrinkage and swelling caused by changes in moisture content in the environment (Udtaranakron et al., 2023).

Concerning pyrolysis, the process takes place when a material is heated without the presence of oxygen, leading to its decomposition into char, tar, and combustible gases (Barnasan et al., 2017). The general definition of pyrolysis is a thermochemical conversion process that transforms biomass into energy and fuel by exposing it to high temperatures in an inert atmosphere. The type of biomass combined with the reactor and the operating mode of the pyrolysis together with the parameters used in the process are contributing to the changes in the properties of the material (Valois et al., 2024). The behaviour of pyrolysis is influenced by factors such as temperature, duration of exposure, and the presence of any fire retardants (Jones & Brischke, 2017). This is why laboratory pyrolysis testing serves as an essential method for assessing the fire performance and safety of bio-based building materials when exposed to high temperatures. The data obtained from these tests aids in enhancing material selection and optimizing designs for improved fire resistance.

2. MATERIALS AND METHODS

2.1. Materials Used for the Experiments

The experimental campaign has been made on samples of glued laminated timber elements formed by wood elements and commonly used adhesives for this composite material such as Melamine Urea Formaldehyde (MUF).

Figure 1. Samples of wood laminated timber with adhesives
Source: Own illustration

These samples considered for this project seen in Figure 1 are parallelepiped in shape, with dimensions of 600x600x20 mm following the Eurocode 5 requirements as the existing mechanical drive system of the shear box has a side of 600 mm.

For the whole experimental campaign, a total of 40 active samples were utilized, of which only 7 samples were recycled. These samples incorporated a Nickel Chromium resistance element glued within the glued laminated timber in a predetermined pattern, designed to facilitate uniform heat transfer between the adhesive and the wood component.

2.2. Preliminary Tests

The experimental campaign has been carried out in the Geotechnics laboratory of UTCB-Technical University of Civil Engineering Bucharest.

In order to create the final shear box in which the force has been applied to the wooden samples, other 2 boxes were created that did not withstand the force when it was applied. For the first one, it was considered sufficient to make a frame from aluminum elements. For the second, a system was designed and built from steel metal profiles to withstand the stresses necessary for shearing the wood sample, respectively a shear force of up to 5000kPa and an axial pressure of up to 2500kPa. Even this failure system failed, the oversizing factor not being sufficient to take over the material nonlinearities of the wood, which caused the failure of the shear system to occur in the presence of knots in the wood samples. The configuration of the boxes can be seen in Figure 2.

Finally, in the last stage, shearing equipment for ballast samples was adapted with an oversizing factor of 3 compared to the maximum possible strength of the wood. Under these conditions, all the tests proposed in this stage were carried out.

The adaptation of the ballast shear box to the wooden samples was done by means of an intermediate reduction system.

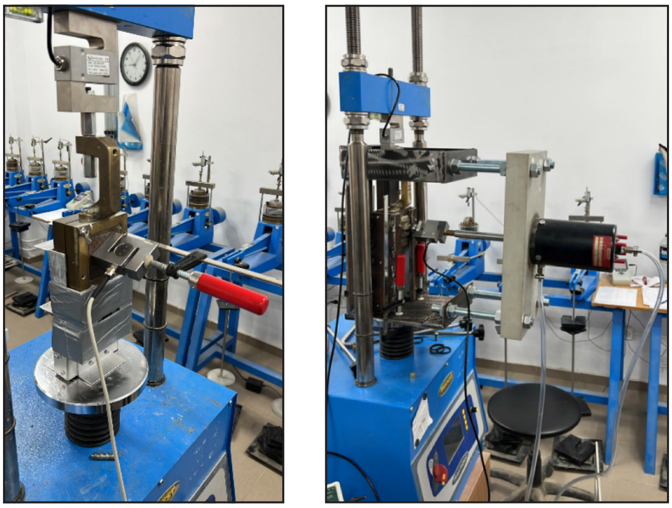


Figure 2.The first two wood sample shear boxes

Source: Own illustration

For the analysis of the loss of volatile elements, samples were made from the wooden samples, and subjected to feasible target temperatures for the present project, using ovens. Through successive weighings of the samples seen in Figure 3, no notable change in mass was observed, which shows that for the temperatures to be analyzed in the present project, the loss of volatile elements is not a determining factor.

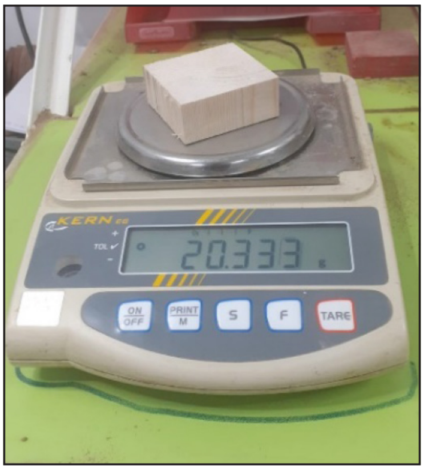


Figure 3. Mass loss assessment
Source: Own illustration

Another preliminary test made before the start of the actual experimental campaign was the verification experiment that was designed to replicate the setup used during the mechanical testing of the system. The thermal mass was heated using a resistor made from a Nickel-Chromium alloy, while the temperature was monitored by a previously calibrated sensor. For this verification experiment seen in Figure 3, the target temperature was established at 40°C, and the NiCr resistor was energized with an external electrical voltage of 30V. The system functioned properly, achieving the target temperature of 40°C within the specified tolerance of 0.5°C.

This has been made in order to find the most relevant resistance arrangement for obtaining a more uniform distribution of temperatures along the targeted surface where it is desired to study the behavior of composed element depending on shear stress and temperature.

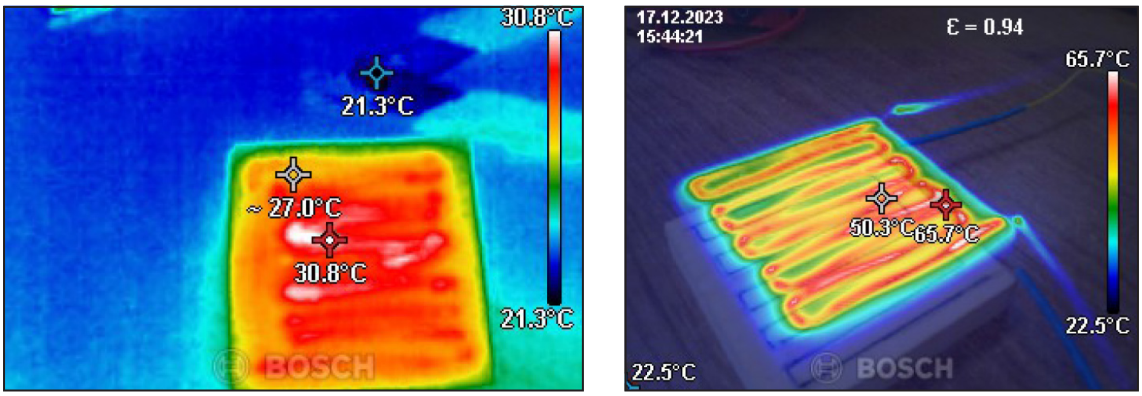


Figure 4. Verification of the temperature maintenance system on a wooden sample
Source: Own illustration

The system was tested on a wood sample, in order to obtain a Nickel-Chromium resistance arrangement, seen in the figure above, that would lead to a more uniform distribution of temperatures at the level of the heated surface, namely the surface filled with adhesive, where it is desired to study the behavior of the adhesives according to the shear and temperature stress.

3. EXPERIMENTAL CAMPAIGN

For the actual experimental campaign, the last shearing box configuration seen in Figure 5 that resisted the application of the force has been used. The tests were performed in direct shearing equipment, where the glued section was fitted in the middle of the shear box.

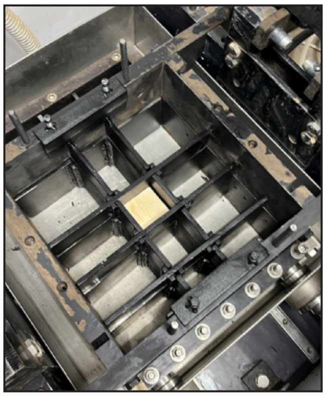
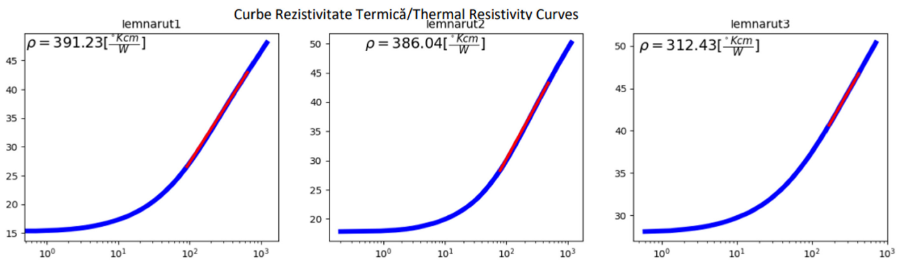


Figure 5. Final box configuration used for the experimental campaign
Source: Own illustration

The wooden element disposed in the shear box has been exposed to thermal energy by the heating device at certain values of temperature found in a range of 40°C up to 120°C helped by the NiCr device embedded in the element.

Finally, the force was applied to the element until the breaking point to see which part of the composed element, the wooden piece or the adhesive, did not resist this combination of force and high temperature.

The heating gear was embedded in the glued midplane of the sample to apply different temperatures. The measured temperature values during the test were transmitted via a serial port and recorded in the terminal, which were also displayed via an LCD screen, which allows programming of the target temperature.



	#1	#2	#3
Timp total incercare / Total test time (s):	1200.00	1200.00	1200.00
Inceput regim permanent/Beginning of steady state (s):	91.00	79.00	168.80
Interval de timp / Time lapse (s):	553.00	404.60	249.90
Diferenta de temperatura / Temperature gradient (K):	16.40	14.98	6.08
Rezistivitate termica / Thermal resistivity (K·cm/W)	391.23	386.04	312.43
Media / Average		363.24	

Figure 6. Wood thermal resistivity analysis report
Source: Own illustration

Figure 6 presents some preliminary results of 3 sample elements tested in the shear box where the thermal resistivity curves can be seen with readings of the time of the test, temperature and resistivity. It can be seen that when the density of the element is lower, the average values for the preliminary results are also lower.

4. CONCLUSION

This experiment is used in order to analyze and develop a testing system for the mechanical behavior of some new configurations of bio-based composite materials (more specifically glued laminated timber) when subjected to high temperatures and temperature variation.

Until now, in the research campaigns presented in the literature, the mechanical behavior of wood-adhesive composite material is poorly studied one of the reasons being the fact that it requires thermo-mechanically coupled laboratory tests. Also, it is not recommended to subject glued areas to high temperatures due to the possibility that they give off harmful compounds.

At the same time, if the combination of the wooden sample, the adhesive and the high temperature applied on the element works, the focus will be on the attempt to replace the building materials whose production is energy-intensive (especially steel and concrete) with bio-renewable building materials.

The application of this type of wooden element is in sustainable structures because it can replace materials whose production is energy-intensive in the form of cement or steel with bio-renewable materials such as wood.

The evaluation of the above-mentioned behavior and the evaluation of compounds obtained by pyrolysis of these structural elements, but also the follow-up of newly emerged materials from this point of view, is an objective of maximum interest.

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