

STRUCTURAL INTEGRITY OF HOLLOW GLUE-LAMINATED TIMBER BEAMS IN FIRE

Nikola Perković¹, Vlatka Rajčić², Jure Barbalić³,

ABSTRACT: This study deals with hollow glulam elements developed for prefabricated building systems. The lamellas are made from recycled waste material and the sawdust produced when cutting the cavity can be reused as insulation material or processed into pellets. Beams with varying degrees of perforation were tested, with the maximum degree of perforation being around 30%. This system is compared with existing systems to highlight the main characteristics and behavior of the hollow glulam elements under fire conditions. Due to the geometry of the hollow GLT elements and the thin vertical timber segments between the cavities, fire exposure can lead to irregular residual cross-sections with greater charring depth compared to standard GLT elements. The research consists of an experimental part and a FEM analysis. The research has shown that the reduced cross-sectional area of the timber element and the possibility of air circulation through the cavities accelerate the combustion process. In addition, the reduced bond area of the laminated joint can lead to delamination, which was found to be the main reason for the failure of hollow beams in this research. A simplified calculation model was developed to determine the charring depth and the zero-strength layer.

KEYWORDS: timber, hollow, FEM, fire, glue laminated.

1 – INTRODUCTION

Cross-laminated timber (CLT) and glued laminated timber (GLT) have become increasingly popular in mass-produced building design and construction in recent years. This is due to the fact that wood is the sole material that can absorb carbon dioxide, among other factors. In addition, compared to conventional, mostly noncombustible materials and structures, timber building meets architectural goals and could eventually lead to lower prices and faster construction times. By burning or decomposing at the end of its life cycle, lumber releases stored carbon into the atmosphere. Thus, ensuring sufficient fire resistance through the use of passive and active fire protection measures is the primary need for the use of timber in structures. Passive protection systems consist of different boards and coatings, among other things. One method is to apply fire-resistant coatings or impregnate wood with fire retardants. Many methods for completely impregnating wood with fire retardants have been researched, despite the fact that many coatings offer considerable fire protection for wood, they are susceptible to mechanical damage [1]. The numerous requirements of its qualities present a problem in the development of an appropriate fire retardant. It must be long-lasting, meaning that neither its mechanical qualities nor

durability will deteriorate; it must not be poisonous or contribute to production of smoke; and when applied to external surfaces, it must be difficult to wash off. By releasing inert gas, which breaks down the previously combustible gas mixture, certain fire retardants stop combustion; in other words, the concentration of oxygen in the area that comes into contact with wood, which is necessary for burning, drops. Conversely, there are certain fire retardants that encourage the creation of a charred layer, which is a natural fire protection method for wood because it decreases heat and oxygen penetration into the interior, or into the non-charred wood area. Chu et al. have examined the impact of fire retardants in their two related publications [2,3]. This study examined the compression recovery and fire resistance of poplar treated with a functionalized surface layer created by a unique pre-impregnation nitrogen-phosphorus fire retardant (NP) combination treatment and densification by thermomechanical means (TM). The CO yield was 68.4% lower than that of simply NP-treated wood, while the combined treated wood's heat release rate was 48.1% lower than that of untreated wood. Additionally, the thickness's recovery was 77.2% less than that of wood that had only been treated with TM [3]. Subsequent to this study, the impact of bonding strength and dynamic wettability has also been demonstrated [2]. During the

¹ Nikola Perković, Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia, nikola.perkovic @grad.unizg.hr

² Vlatka Rajčić, Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia, vlatka.rajcic@grad.unizg.hr

³ Jure Barbalić, Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia, jure.barbalic@grad.unizg.hr

wetting process, the TM- only treated poplar's low compression stability results in surface swelling, which weakens the connection. In contrast to wood that was solely heat-treated, the NP-TM combined surface bonding strength 53.3% more poplar was treated [2]. The two primary byproducts of fire action—high temperatures and copious amounts of smoke—are what cause a fire to have such serious effects. High temperatures will impact the structure's safety and load-bearing capability, whilst smoke will have an impact on individuals by making it harder for them to breathe and decreasing their visibility when trying to escape. If the building can fulfill the necessary load-bearing capacity (R), thermal insulation (I), and/or other predicted attributes during the fire event, it might be deemed fire resistant. Additionally, every product or material contributes to the spread of fire through its own breakdown, which happens when it burns under specific test conditions (response to fire). When it comes to non-flammable materials, mass loss and temperature increase are the primary factors, whereas ignition ease, flame spread, smoke, and heat release rate are the primary factors of flammable materials. Category D includes lumber as a material and timber-based panels [4]. Although the timber element cannot be categorized as non-combustible (class A1 or A2), it can be classified as class B if it is covered with coatings that inhibit the spread of fire. Installing an automatic fire extinguishing system within a building can minimize reaction to fire by one class [5]. Additional material separation involves the separation of manufacturing fumes (s1–s3), which is also connected to the fuel of leaking material in the event of a fire (d0–d2) [5,6].

1.1 OBJECTIVES

The primary objective of this study was to assess the behavior of novel hollow-glued laminated timber beams in both ambient and fire conditions, and to compare them with standard GL timber elements. The contribution aim can be characterized as follows:

- The impact of adhesives on the load-carrying capacity of glued laminated hollow timber elements;
- The effect of elevated temperature on the adhesive and the load-carrying capacity of glued-laminated hollow timber elements;
- The influence of the perforation of the timber element

on the development of temperature toward the interior of the element.

- The effect of the reduced glued surface influences the potential separation of the lamellae delamination.
- The effect of passive fire protection on the fire resistance of hollow timber beams (one-dimensional and notional charring rate)
- Introduction of all mentioned problems in the form of the analytical or numerical model.

2– BACKGROUND

This study builds upon and expands upon earlier studies conducted by Perkovic et al. [7]. This pertains to timber components that have had their cross-section perforated to reduce their mass. Moreover, this makes it much easier to manipulate parts that can be put together to create ceilings and walls. The leftover perforated elements are also recycled and put to further use for a variety of uses, which lowers carbon emissions and guarantees and maintains global energy stability. The samples' material properties remained consistent with those of the earlier study. The softwood used to make the elements was primarily European fir (*Abies alba*). In earlier research, the fundamental findings on the actions of these novel components were presented, along with the limitations and suggestions for additional study. The placement of the lamellae and hollows, the kind of hole (elliptical or circular), and the glue used to link the lamellae are the main concerns. As a result, elliptical-holed samples were shown to have a greater and more suitable load capacity. In order to prevent stress accumulation in the edge zones, the edge lamellas were produced without holes and the research was conducted using moisture-curing, one-component polyurethane adhesive PUR Kleiberit 510.0 with reinforced fibers [8]. This is a one-component approved PUR adhesive for load-bearing wood construction in accordance with DIN EN 14080 and DIN EN 15497. SANS 10183-2 approves it as a wood adhesive for load-carrying wood components in service class S3 (service class S3), meaning it can be used outdoors for extended periods of time even when it comes into direct contact with the ground. *Figure 1* shows the new and enhanced timber elements used in this paper.

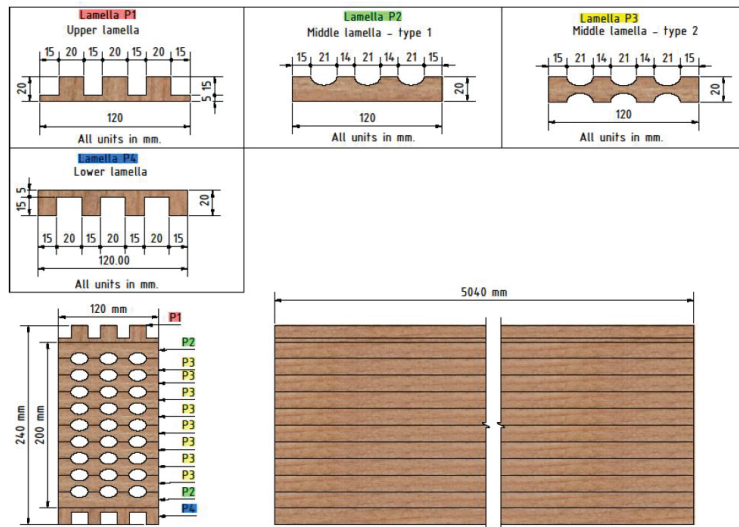


Figure 1. Glue-laminated hollow timber beam

By establishing the ideal residual cross-section (Figure 2) in accordance with EN 1995-1-2 [9] and comparing the

actual bending stress, which depends on the residual cross-section values at a given time, one can determine the fire resistance duration for a typical GL timber beam.

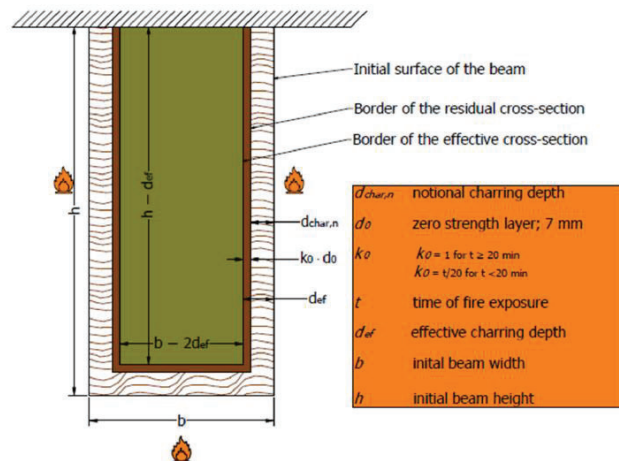


Figure 2. Definition of ideal residual cross-section

$$I_{y,ef}(t) = \frac{((h - d_{ef}(t))^3 \cdot (b - 2d_{ef}(t)))}{12} \quad (1)$$

$$\beta_n = 0.8 \frac{mm}{mn}; k_0 = 1; d_0 = 7 \text{ mm} \quad (3)$$

$$\sigma_{Ed} = \frac{M_{Ed}/I_{y,ef}(t) \cdot h - d_{ef}(t)}{2} \leq f_{m,u,occ} \quad (2)$$

The acting moment depends on the load level $m_{u,fi}$ related to the bending moment resistance at normal temperature:

$$I_{y,20} = \frac{h^3 b}{12} \quad (4)$$

The values for β_n , k_0 , and d_0 are taken from Eurocode 5 (EN 1995-1-2, 2004) [9]:

$$M_{Ed} = m_{u,fi} \cdot \frac{(2 \cdot I_{y,20} \cdot f_{m,u,occ})}{h} \quad (5)$$

This means fire resistance does not depend on the bending strength but the load level factor:

$$m_{u,fi} \leq \frac{(h - d_{ef}(t))^2 \cdot (b - 2d_{ef}(t))}{(h^2 \cdot b)} \tag{6}$$

Prior to the test, the applied load level for the fire test must be established. Since time is the only unknown

component left in the inequality, it can be calculated for every load level with ease. The load in this study is determined while maintaining serviceability limit state, or the highest permitted deflection $L/300$, which in this instance is 14.4 mm. This is about 30% of the failure load at room temperature, which is the load threshold that numerous researchers have suggested [10]. Four-point bending tests on timber elements were conducted in accordance with EN 408 [11] to ascertain the load level for the fire test. Result can be seen in Table 1.

Table 1 Ambient temperature - results

Specimen	Failure Load (kN)	Final Displacement (mm)	Moisture (%)
MP_5m_1	66.36	84.075	9.5
MP_5m_1	47.50	59.835	9.9
MP_5m_3	44.64	66.743	10.6
MP_5m_4	59.10	75.639	9.6
MP_5m_5	55.84	65.283	9.6
MP_5m_6	62.00	74.969	10.1
Average	55.90	71.09	9.93
Standard deviation	8.42	8.76	0.54
Variation coefficient	15.05%	12.32%	5.45%

Specimen	Failure Load (kN)	Final Displacement (mm)	Moisture (%)
ME_5m_1	31.48	54.625	11.2
ME_5m_2	46.60	71.522	9.6
ME_5m_3	29.53	51.443	10.2
ME_5m_4	39.05	61.094	9.9
ME_5m_5	28.85	52.289	9.2
Average	35.10	58.19	9.93
Standard deviation	7.60	8.35	0.59
Variation coefficient	21.65%	14.36%	5.99%

Figure 3. Definition of ideal residual cross-section

3 – PROJECT DESCRIPTION

This chapter explains the fire test of glued laminated timber elements with solid and hollow cross-section, in accordance with the procedures of the reference standards EN 1363-1:2020 [12] and HRN EN 1365-3:2002 [13]. The dimensions of the specimens were the same as for the tests under ambient conditions ($b \times h \times l = 120 \times 240 \times 5040$ mm), described in chapter before. The moisture content was measured in each specimen and the average equilibrium moisture content was 10.7 % for all specimens. The laminated timber specimen consisted of a total of twelve glued lamellas. The lamellas were made of softwood (fir), 20 mm thick and made so that the fibers inside the wood were oriented in the direction of the beam length. The lamellas were glued with glue K. 510.0 manufactured by Klebchemie-M.G. Becker GmbH [8]. Three different types of wooden beams were tested to compare the innovative hollow glued laminated timber

elements with a standard GL beam. Therefore, the first sample was a standard GL wooden beam, and the other two were hollow GL beams with fire protection. In the first hollow beam, the protection was a fire protection coating, Promadur [14], applied around the perimeter of the beam and inside the cavities, while in the second, stone wool was placed in the cavities, and the fire protection coating was also applied to the outer, fire-exposed surfaces of the sample. In the event of a fire, Promadur expands to create a protective insulating foam that protects the surface from contact with air (oxygen), reduces flammability and slows down the transfer of energy (heat) from the fire to the wooden elements, thus increasing the fire resistance of the wooden beams. The general idea was to use the cavities in such a way as to (partially) stop the penetration of fire and temperature into the interior of the beam. Figure 4 and Figure 5 shows different types of cross-sections of the tested wooden beams, as well as the loading scheme and the position of thermocouples within the samples.

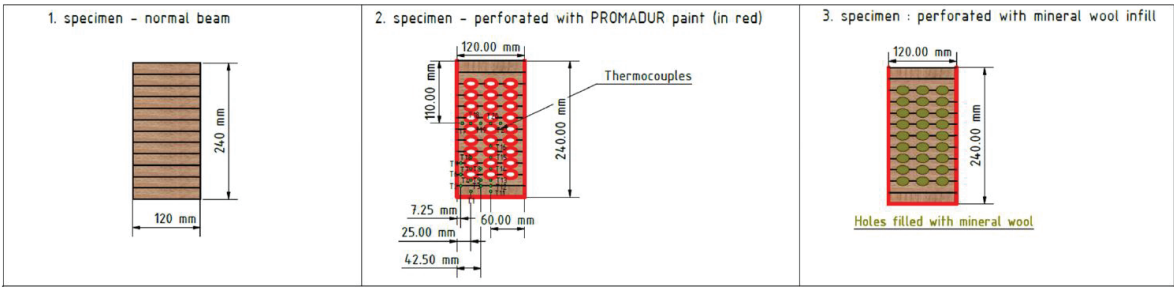


Figure 4. Specimens type.

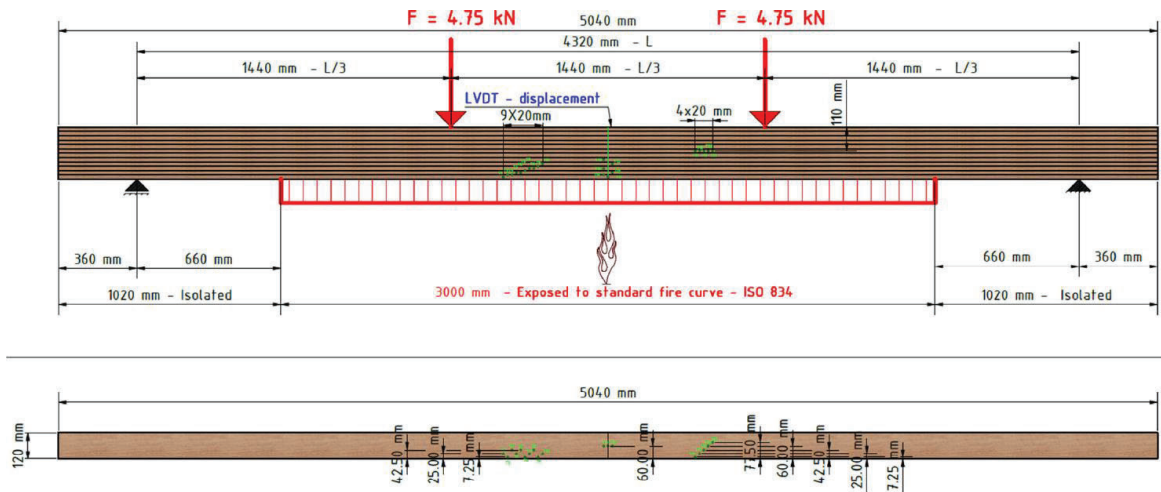


Figure 5. Experimental setup

4 – EXPERIMENTAL SETUP

Three sides (bottom and sides) of the samples were subjected to fire. A vertical load-bearing structure with a hydraulic system for applying the load supported the load-bearing beam specimen. The horizontal was where the load-bearing structure was positioned test furnace so that just a portion of the 3000 mm long beam was in direct contact with the flames. The longer side of the portion (240 mm) was positioned vertically due to the beam's orientation. The beam supports were spaced 4320 mm apart and situated outside the test furnace. One support was fastened on one side of the beam, and on the other side, it was sliding longitudinally on the side. Figure 5

depicts everything mentioned above. Slabs of aerated concrete, 150 mm thick, were used to construct the furnace's ceiling. A sample was placed inside the 320 mm-wide gap that was left between them at the furnace's center. This allowed the sample to be exposed to fire from three sides. The sample's upper surface was covered with a calcium silicate plate that was 40 mm thick and strong enough to support a load. The plate was wide enough to seal the gap in the test furnace's ceiling. The space between the sample and the test furnace's boundaries was sealed with ceramic wool. Figure 6 depicts the sample's orientation, composition, and construction as well as the kind of sample supports on the load-bearing structure.



Figure 6. Furnace and general fire test scheme

In compliance with HRN EN 1363-1: 2020, section 8.1 [28], the test sample was kept in a laboratory setting with ambient conditions maintained at around 50% relative humidity and 20 °C prior to installation. Just before to the test, the sample's moisture retention percentage was measured and found to be 12.7%. Standard exposure of test specimens to fire in terms of pressure and heat exposure was made possible by thbeforece. Six burners running on liquid fuel (heating oil) created the fire in the furnace's fire area in compliance with HRN EN 1363 [12]. Chapters 4.1 and 4.2, 2020 [28]. The test room's air temperature was kept at 20 (±5) °C for 24 hours prior to the fire test. A standard temperature curve was used to calculate furnace heating in compliance with HRN EN 1363-1: 2020, 5.1[12]. Six thermocouples of type K, whose hot junction was mounted in the geometric center

of the plate in compliance with the standard HRN EN 13631: 2020, 4.5.1.1 [12], were used to measure the temperature in the furnace. In addition to the test sample, the thermocouples were equally spaced and placed 100 mm from the side of the test sample that was exposed to the fire, away from the burner's open flame. 21 NiCr-Ni thermocouples with a wire diameter of 0.5 mm (type K) were used to measure the temperatures across the sample cross-section. *Figure 7* illustrates the thermocouple installation procedure. Following insertion, the thermocouples were further secured using hardwood wedges, and fireproof silicone was used to seal the gaps. The thermocouples' location and depth were thus completely guaranteed.

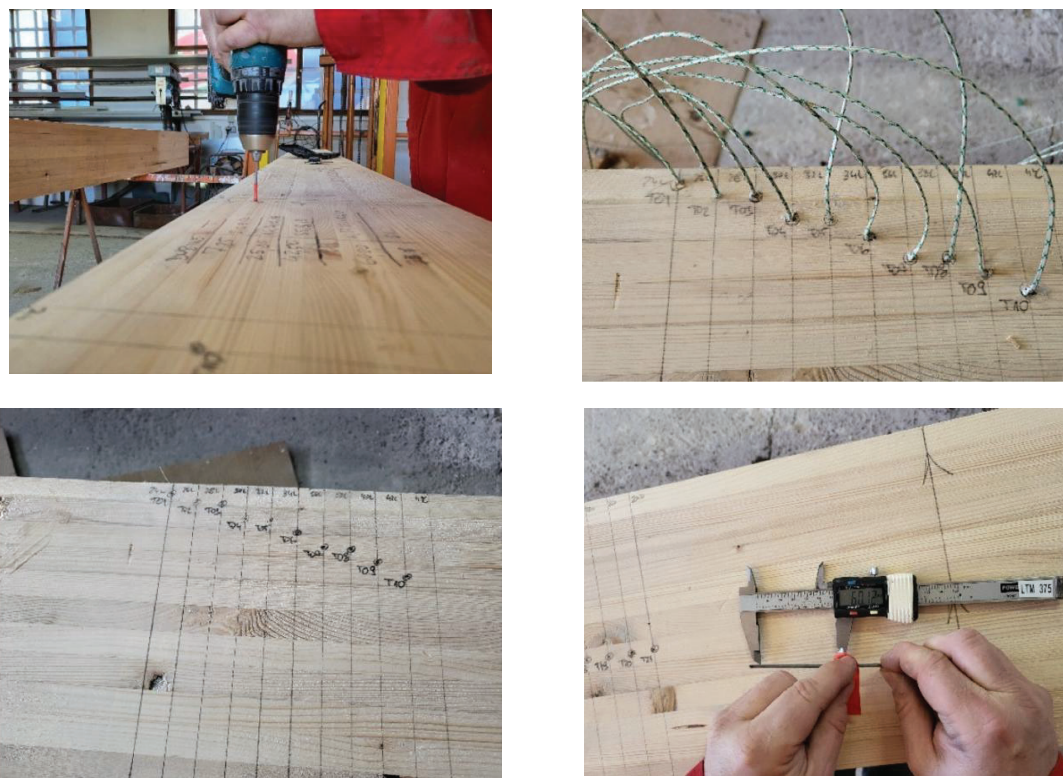


Figure 7 Thermocouple installation process:

The deflection D_1 at the center of the beam was measured in addition to temperature development. To meet the sample load criteria, the deflection must be less than:

$$D_{limit} = \frac{L^2}{(400 \cdot d)} = 4320^2 / (400 \times 240) \quad (7)$$

$$= 194.4 \text{ mm}$$

Additionally, the rate of deflection increment must be smaller than:

$$\left(\frac{dD}{dt}\right)_{limit} = \frac{L^2}{9000 \cdot d} = \frac{4320^2}{9000 \times 240} \quad (6)$$

$$= 8.64 \text{ mm/min}$$

The load conditions were implemented in compliance with HRN EN 1365-3:2002 standard, paragraph 7.3 [13]. The sample was loaded with 6.5 kN, or the total applied force, at two locations (in thirds) of the beam's length between the supports load on the sample of 4.8 kN (in thirds) and 13 kN (for the normal beam), for a total of 9.6 kN for hollow beams.

5 – RESULTS

The main benefit of this fire test is that a tiny window was created in the furnace so that the beams' behaviour could be seen and recorded. The main events that transpired during a typical beam's fire test are displayed in Figure 8.

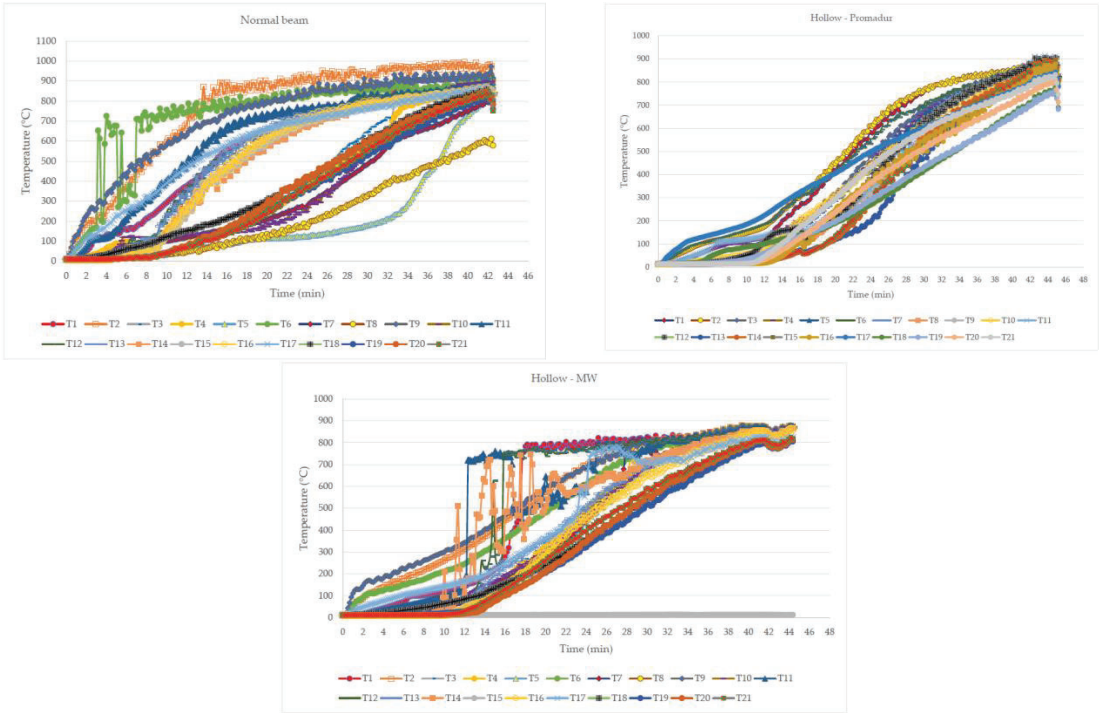


Figure 8 Observations and temperature development

Different phases of timber beams in the fire tests are shown in Figure 9.



Figure 9 Observations and temperature development

Furthermore, deflection is one of the key factors that determines a beam's fire resistance. As a physical result, the deflection is conditioned and directly correlated with the beam's burning and temperature growth. Specifically, during a fire incident, a burned layer forms on the fire-exposed timber surfaces, shielding the inside

of the wood from heat buildup. The distance between the outside edge of the element prior to the fire and the inner edge of healthy, unburned timber following the fire load is known as the "char depth." As the temperature rises, the material and geometric properties diminish, increasing deflection. The deflection's magnitude and rate of growth are displayed below (Figure 10).

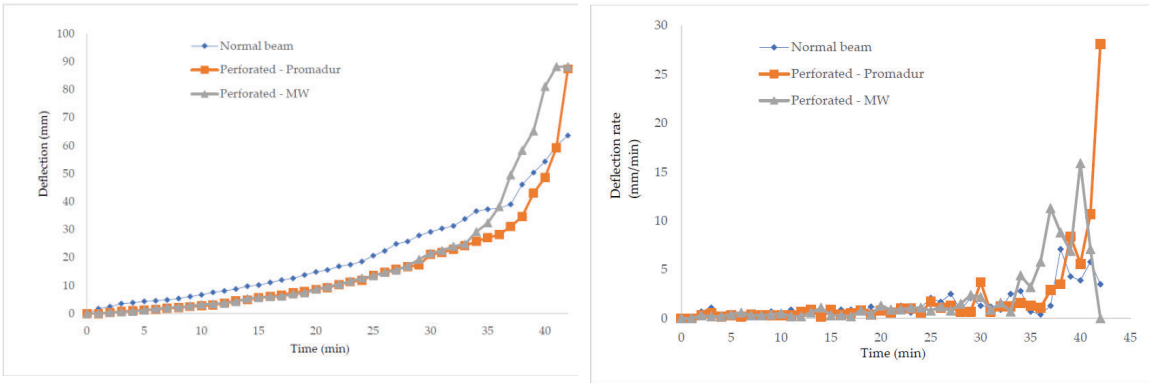


Figure 10 Deflection and deflection rate

6 – FEM analysis

The results of the char layer obtained using an numerical modeling (FEM) approach are presented below, for

wooden specimens exposed to fire from three sides. The char layer depths for a GLT beam, after 45 minutes, are presented in Figure 11.

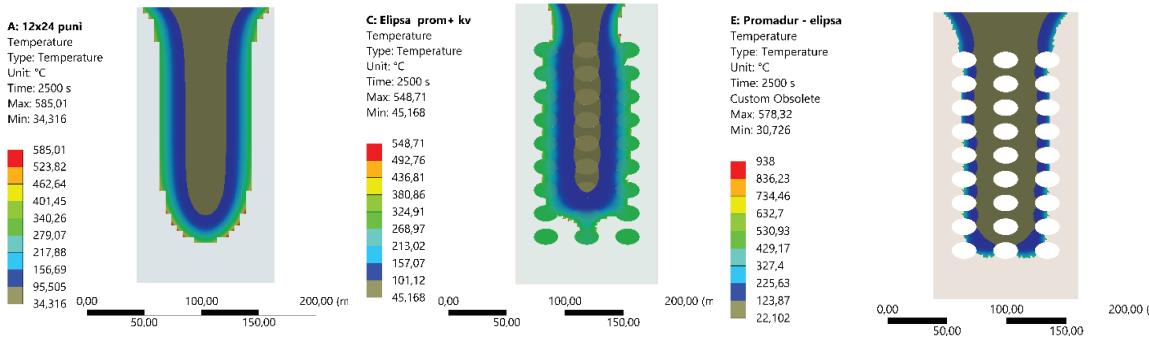


Figure 11 Evaluation of the char layer – solid, mineral wool infill, and intumescent paint timber beam

By examining the results, it can be concluded that the results obtained by numerical modeling are in good

agreement with the results of the fire test. The thickness of the charred layer of a solid beam measured after 45 minutes of fire exposure can be seen in Figure 12.

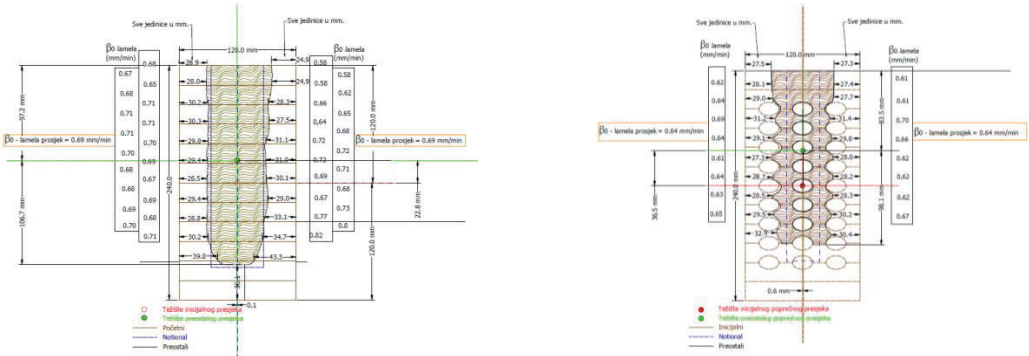


Figure 12 Remaining cross-section analyzed using CAD software

If we compare the dimensions of the actual charred layer with those obtained by FEM, the only minor difference occurs on the unexposed (topside of the element. The reason for this is the ideal conditions assumed in the numerical model, while in the experimental study, towards the end of the test and at high temperatures, extremely dynamic burning processes occur. Rock wool is defined as a non-combustible material (melting temperature 1000 °C), therefore the representation of rock wool in the simulation results is stable until the end. The effect of fire protection is visible, i.e. charring only began after the 15th minute. After that, a second charring phase occurs where accelerated charring occurs.

7 – CONCLUSION

This investigation shows that both the adhesive performance and the adhesive-timber interaction determine the bond line behavior. When applied to the bond line between the lamellas, the behavior of several adhesive types (PUR) at high temperatures had minimal impact on the glued laminated timber pieces' ability to withstand fire. This is because, in general, the adhesive line was too thin to significantly affect heat development and, ultimately, the fire resistance of timber elements. The impact of various adhesive types is minimal because the adhesive disintegrated at a temperature of roughly 300 degrees Celsius, and this experimental study indicates that the mechanical properties (density, strength, and Young's modulus) of timber approach zero at that temperature. is comparable to the 0.70 mm/min value specified in EN 1995-1-2 [9]. Additionally, for typical GL beams, the notional charring rate ($\beta_n = 0.78$ mm/min) was shown. There was a delay in the case of hollow GL beams since intumescent paint provided fire protection. in the burning of wood, leading to a reduced one-dimensional rate of charring ($\beta_0 = 0.64$ mm/min). Regardless of the presence of holes, it may be inferred that hollow GL elements have the inherent fire resistance of timber (charred layer) and the ability to stop heat from spreading to the specimen's interior. Because of this, the temperatures inside the hollow GL components did not vary. Since heat propagation is independent of adhesive, it may be concluded that the type of adhesive used had no effect on the spread of char past the sticky line. When regular glue-laminated beams and hollow ones are compared, the failure modes differ mainly because the hollow parts appeared to exhibit debonding and delamination. The char did not fully pierce the first lamella's thickness when delamination took place. The first explanation for this is the decreased glued surface brought on by the components' perforation. Due to the absence of air in the cavities, the specimen with mineral wool insulation inside had improved fire resistance;

nonetheless, the non-flammable substance prevented fire from penetrating to the bonding line. The behavior and fire resistance of glue-laminated timber elements were much improved by intumescent paint, which extended the thermal wave to the adhesive line and subsequently caused delamination. Delamination was noted between 100 and 300 °C. When compared to crucial bond-line temperatures of 200 °C in large-scale tests, the design temperature of 130 °C may be overly conservative. The process for evaluating how glue and wood interact in both ambient and fire settings needs to be standardized. Future studies will examine a greater number of samples for all varieties of GL wood elements, offering a more thorough examination of how these materials behave during a fire. This is especially true for the hollow GL wood components, where the behavior of such items during a fire event is influenced by new additional characteristics. These mostly relate to the sample's shape, or the cavity, and sporadically to the air that flows through the holes. Lastly, the data will allow for a numerical and analytical evaluation of GL wood elements' fire performance.

Finally, numerical simulations can provide a more detailed insight into the behavior of hollow glued laminated timber elements under fire conditions. Thermo-mechanical analysis was performed in the ANSYS software package, and numerical simulations confirmed the experimental research. An innovative numerical approach to char layer evaluation was developed, based on the finite element method. Thermal and thermo-mechanical analysis showed a very good correlation between predicted and measured developed temperatures in wooden elements exposed to a standard fire. A very good agreement was found between the results obtained by numerical modeling (FEM) and the results of fire tests. The ratio of char depths estimated by numerical modeling ($d_{char,MKE}$) in relation to char depths measured after fire tests ($d_{char,test}$) is 1.05, which indicates a very good correlation of the results (5%).

Based on a review of the state of the art and conclusions drawn from experimental and numerical research in the paper, the main questions that could be addressed in further research were regarding detail investigation of the influence of air circulation in the cavities of glued laminated timber elements on their behavior in fire conditions, and to investigate the impact of fire protection coatings on charring phases, and unify the calculation rules for fire-protected wooden elements.

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8 – REFERENCES

1. Sauerbier, P.; Mayer, A.K.; Emmerich, L.; Militz, H. Fire Retardant Treatment of Wood – State of the Art and Future Perspectives. *Wood & Fire Safety*, **2020**, 97–102.
2. Chu, D.; Mu, J.; Avramidis, S.; Rahimi, S.; Liu, S.; Lai, Z. Functionalized Surface Layer on Poplar Wood Fabricated by Fire Retardant and Thermal Densification. Part 2: Dynamic Wettability and Bonding Strength. *Forests* **2019**, Vol. 10, Page 982, **2019**, 10, 982.
3. Chu, D.; Mu, J.; Avramidis, S.; Rahimi, S.; Liu, S.; Lai, Z. Functionalized Surface Layer on Poplar Wood Fabricated by Fire Retardant and Thermal Densification. Part 1: Compression Recovery and Flammability. *Forests* **2019**, Vol. 10, Page 955, **2019**, 10, 955.
4. Östman, B.; Schmid, J.; Klippel, M.; Just, A.; Werther, N.; Brandon, D. Fire Design of CLT in Europe. *Wood and Fiber Science*, **2018**, 50, 68–82.
5. Pravilnik o otpornosti na požar i drugim zahtjevima koje građevine moraju zadovoljiti u slučaju požara. Available https://narodne-novine.nn.hr/clanci/sluzbeni/2013_03_29_505.html (accessed on August 29, 2022).
6. Rukavina, M.J.; Carević, M.; Pečur, I.B. Zaštita Pročelja Zgrada Od Požara / Priručnik Za Projektiranje i Izvođenje Zaštita Pročelja Zgrada Od Požara.
7. Perković, N.; Rajčić, V.; Pranjić, M. Behavioral Assessment and Evaluation of Innovative Hollow Glue-Laminated Timber Elements. *Materials* **2021**, Vol. 14, Page 6911, **2021**, 14, 6911.
8. Kleiberit 510. Available https://www.kleiberit.com/fileadmin/Content_new/Infoblaetter/deutsch/5103_TragenderHolzbaue_D.pdf (accessed on October 30, 2024).
9. Eurocode 5: Design of timber structures -- Part 1-2: General - Structural fire design (EN 1995-1-2:2004/A2:2014): Available <https://www.phd.eng.br/wp-content/uploads/2015/12/en.1995.1.2.2004.pdf> (accessed on June 27, 2022).
10. Fahrni, R.; Klippel, M.; Just, A.; Ollino, A.; Frangi, A. Fire Tests on Glued-Laminated Timber Beams with Specific Local Material Properties. *Fire Saf J*, **2019**, 107, 161–169.
11. EN 408:2012: Timber structures -- Structural timber and glued laminated timber -- Determination of some physical and mechanical properties. Available <https://standards.iteh.ai/catalog/standards/cen/6fae6c9-5eaf-4c84-8bf3-5132cbfc563c/en-408-2010a1-2012> (accessed on July 2, 2022).
12. CEN. EN 1363-1:2020 - Fire Resistance Tests - Part 1: General Requirements; European Committee for Standardization: Brussels, Belgium, **2020**.
13. HRN EN 1365-3:2002 / Hrvatski normativni dokument / HRN4You - Hrvatski zavod za norme. Available <https://repozitorij.hzn.hr/norm/HRN+EN+1365-3%3A2002> (accessed on September 13, 2022).
14. PROMADUR® - Promat. Available <https://www.promat.com/en/construction/products-systems/products/intumescent-paints/promadur/> (accessed on July 2, 2022).