Potential of Hardwoods Harvested in Croatian Forests for the Production of Glued Laminated Timber

Ivica Boko [1], Ivana Uzelac Glavinić [1,*], Neno Torić [1], Tin Hržić [1], Jelena Lovrić Vranković [1], and Mario Abramović [2]

[1] Department for Metal and Timber Structures, Faculty of Civil Engineering, Architecture and Geodesy, University of Split, Croatia; Email: ivica.boko@gradst.hr (I.B.), neno.toric@gradst.hr (N.T.), tin.hrzic@gradst.hr (T.H.), jelena.lovric@gradst.hr (J.L.V.)
[2] Drvene Konstrukcije d.o.o., Voćin, Croatia; Email: mario@drvene-konstrukcije.hr (M.A.)
*Corresponding author: ivana.uzelac@gradst.hr (I.U.G.)

***Abstract*—This paper presents experimental results for shear strengths of glue lines of glued laminated timber (GLT) made from hardwoods. GLT samples were produced from *Carpinus Betulus L.*, *Quercus Cerris L.* and *Acer Campestre L.*, all harvested in Croatian forests. For each hardwood species three sets of samples were produced varying different surface treatments. The adhesive used is melamine-urea. The results presented here show that surface treatment made no difference on shear strength of glue lines for GLT made from Turkey oak and Maple, while it had some influence on shear strength of glue lines for GLT made from European hornbeam, with roughest surface treatment being least favorable.**

***Keywords*—hardwood, glued laminated timber, shear strength, European hornbeam, Turkey oak, maple**

I. Introduction

Recently, we have witnessed an increased interest in timber as a building material, primarily due to its sustainability and aesthetics [1, 2]. This interest has been additionally boosted by global and national strategies promoting the use of timber in order to reduce carbon emission [3, 4]. Today the younger generations are more inclined to take a holistic look of the structure valuing life cycle assessment, carbon footprint as well as living comfort [5, 6]. The application of engineered wood products such as GLT supports sustainability, quality of structural product and allows for various designs possibilities.

Most of the GLT produced today is made of softwoods [7]. Moreover, structural timber in general is more dominated by softwood species despite available resources in hardwood [8–10]. Reasons for widespread application of softwoods include good workability, simpler production process (primarily gluing) and availability of raw materials in countries of central and northern Europe. Even though the potential of hardwoods for the production of GLT has been well recognized, the practical application of these beams still encounters shortcomings in current regulations. In Europe, GLT made from hardwood is still considered as a non-standard construction product and is covered only in recent EAD (European Assessment Document) [11] cited in 2021. EAD [11] is also limited only to certain hardwood species, leaving the use of GLT from species not included in [11] to a fully experimental basis.

Hardwoods generally have higher tensile strengths compared to softwoods, meaning hardwood GLT can achieve higher strength classes [7]. In order to use a particular hardwood specie for the production of GLT, it is necessary to achieve integrity of the glue lines. As defined in [10], bonding strength of glue lines is verified either by delamination test or by shear test, depending on the environmental conditions to which the structure will be exposed to. Delamination test method is intended for service class 3, i.e. when the structure is exposed to atmospheric conditions. Shear strength of glue lines for European hardwoods has been the subject of numerous studies, each covering specific hardwood species [12–15]. This paper includes experimental results for shear strengths of glue lines of GLT made from three hardwood species: Turkey oak, hornbeam and maple. For each hardwood specie three different sets of GLT were produced by varying different surface treatments. Several studies have investigated the influence of different surface preparation methods on bonding performance of hardwoods [16]–[21]. Below, fabrication of GLT beams is presented in detail. Hardwood used for the production of GLT has been harvested in Croatian forests. So far, authors have not found sufficient data on bonding strength of glue lines for the selected tree species.

II. Fabrication of GLT Beams

GLT beams were fabricated from three different hardwood species including *Quercus Cerris L.* (Turkey oak), *Carpinus Betulus L.* (hornbeam) and *Acer Campestre L* (maple). All hardwoods originated from a

Manuscript received April 24, 2023; revised July 29, 2023; accepted September 25, 2023.

forest area near Voćin, Slavonija, and were selected by GLT manufacturer Drvene konstrukcije Ltd. Laminations were assembled to form GLT beams with dimensions 60x80x1700 mm, and bonded with melamine-urea resin adhesive. Individual lamellas were 20 mm thick, 60 mm wide and processed with different surfacing methods before the adhesive was applied. To study the effects on selected hardwood species, planing, and sanding with grit 60, and planing and sanding with grit 80 were performed. Since GLT beams are 1700 mm long no finger joints were used. The mean density for maple is 640 kg/m^3, for hornbeam is 800 kg/m^3 and for Turkey oak is 770 kg/m^3 [22].

A. *Surface Treatment of the Laminations*

The laminations from three different hardwood species were stored at temperatures varying from 18 ℃ to 21 ℃ and 65% relative humidity (RH). After cutting and drying, the surfaces of laminations were processed with three methods: i) just planing (P), ii) planing and then sanding with coarse grit 60 (S60), iii) planing and then sanding with fine grit 80 (S80). Planing is the prevailing surfacing method which provides a uniform thickness of the timber element. It was carried out on a machine with planing knives to improve surface smoothness, Fig. 1.

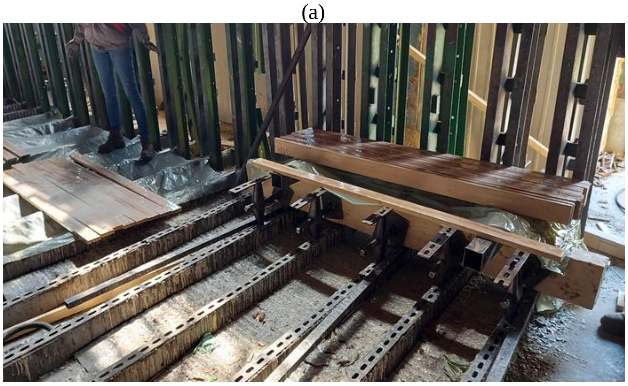
Figure 1. Planing of laminations.

The moisture content of each lamination during production was measured with the Gann Hydromette HT 65, an electronic wood moisture meter that uses the electrodes driven into one face of the board for measuring resistance. The measured moisture content of each board was between 9 and 15 %.

B. *Assembly Process of GLT Beams*

Following different surface preparations mentioned before, the bonding was performed in accordance with the instructions from adhesive manufacturer [23]. The laminations of 20 mm thickness are glued one-sided with the mixture of the melamine-urea resin adhesive (Prefere 4535) and hardener (Prefere 5035) in relation 100:25. The curing reaction starts once resin and hardener are mixed and it depends on the temperature and the amount of hardener (Fig. 2). The recommended application rate of 400g/m^2 was used for bonding the laminations. Assembly time which counts from a glue application to a pressure application can be subdivided in open and closed assembly time. The maximum assembly time in this experiments was 30 minutes. After bonding, the laminations were transferred onto the press beds and tightened with cramping pressure up to 1.2 N/mm^2 using clamping jigs and screws, Fig. 2. Finally, the GLT beam made of 4 laminations was planned on all sides to obtain dimensions of 60×80×1700 mm.

(a)



(b)

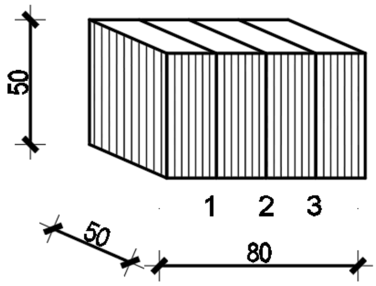
Figure 2. The curing reaction starts once resin and hardener are mixed and it depends on the temperature and the amount of hardener (a) Application of the melamine-urea resin adhesive and the hardener (b) Tightening laminations using clamping jigs and screws.

III. Shear Test of Glue Lines

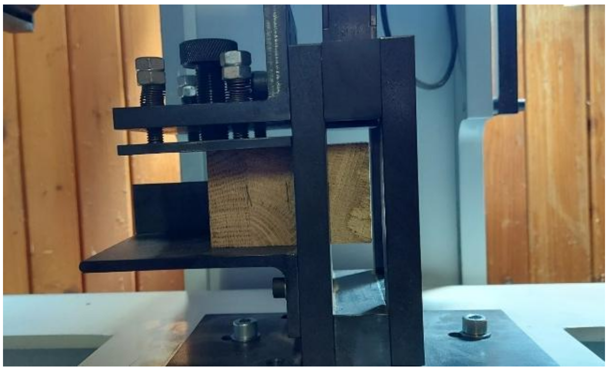
Shear tests of glue lines were carried out as specified in [10], following instructions from Annex D. The test pieces were extracted from nine types of GLT beams, industrially manufactured as described above. Each test piece had three glue line. The number of segments with the dimensions of 50×50×80 mm, Fig. 3., varied per each species and per each of three different surface methods. In total, there were 18 shear tests on GLT extracted from oak, 18 shear tests on GLT extracted from hornbeam, and 27 from maple.

A. *Test Set up and Procedure*

The shear tests were carried out in force controlled regime on a universal testing machine as shown in Fig. 3, with a constant cross head displacement rate [10]. Displacement rate was such that failures occurred after no less than 20 s. The test pieces are located between the jaws of a test machine with the glue line oriented parallel to the loading direction and with the proper alignment (max. 1 mm deviation). All glue lines in each segment were tested.



(a)



(b)

Figure 3. The shear tests were carried out in force controlled regime on a universal testing machine (a) Test pieces, (b) Universal testing machine.

In each test, the shear strength f_v [N/mm^2] was calculated from the failure load F_u [N] and the sheared area A [mm^2] as follows:

$$f_v = k\frac{F_u}{A} \quad . \tag{1}$$

In N/mm^2, with k=0, 78+0, 044 t, with t being the thickness of the sample.

B. Results and Discusion

According to the requirements taken from EN 14080 the minimal shear strength of the adhesive bond must be at least 6 N/mm^2. The results of the shear tests of glue lines for three wood species and three surface methods are summarized in Fig. 4. All shear tests, including all timber species and surface preparations, exhibit values greater than 6 N/mm^2.

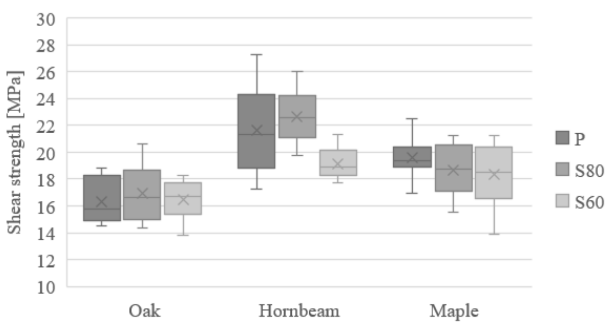


Figure 4. Experimental results for shear strength of the glue lines.

Within this study, no significant differences were found between results of the shear tests of glue lines for Turkey oak and maple regarding different surface methods. Shear tests on test pieces made of European hornbeam and processed with planing and sanding with finer grit generated higher values of shear strength compared to test pieces sanded with coarser grit. Moreover, shear strength for European hornbeam treated with finer surface method and planing displayed somewhat larger variation of results compared to rougher surface treatment.

Results presented here are in accordance with previously conducted studies regarding influence of surface preparation on bonding quality [16–21]. Even though the results of previous studies are not completely consistent, it has been shown that slightly rougher surface treatment can improve bonding quality. Moreover, it should be noted that the reported results are valid only for selected hardwood species, and further investigations are suggested in order to increase the confidence of the results.

IV. Conclusion

In accordance with sustainable development goals, a wider use of timber products at the expense of mineral based materials is being promoted. The aim of the present research work was to evaluate the effects of different surface preparations on selected hardwood species. The increasing use of hardwood for the production of GLT calls for sufficient data on bonding strength of glue lines. Hardwood species presented in this paper lack experimental results on bondline shear strength and are not included in the adhesives approved for structural hardwood bonds in EU. Results here suggest that surface preparation method (planing, sanding with fine grit and sanding with coarse grit) did not have significant influence for GLT made from Turkey oak and Maple. On the other hand, there are some discrepancies in the bondline shear strength for GLT made from European hornbeam. Rougher surface treatment (grit 60) showed lower shear strengths in average, when compared to planing and finer surface treatment (grit 80). Due to the small sample size presented here, verification of those findings on a larger sample size is needed.

This paper presents a first step in production of GLT beams from local hardwood species not includes in EAD. The next step in this research will include full-scale bending tests on GLT structural elements made of local and underutilized hardwoods (Turkey oak, hornbeam and maple). The authorshope that the results presented here will contribute to the increasing use of hardwoods in the construction sector.

Acknowledgment

This research is partially supported through projects:

- IRI-2 KK.01.2.1.02.0330 "Increasing the development of new products in timber industry used in civil engineering."
- KK.01.1.1.02.0027, a project co-financed by the Croatian Government and the European Union through the European Regional Development

Fund-the Competitiveness and Cohesion Operational Programme.

REFERENCES

[1] C. Hill and K. Zimmer, "The environmental impact of wood compared to other building materials," *Technical Report*, Norwegian Institute for Bioeconomy Research, January 2018.

[2] F. Lattke and S. Lehmann, "Multi-storey residential timber construction: Current developments in Europe," *Journal of Green Building*, vol. 2, no. 1, pp. 119–129, Feb. 2007.

[3] G. Churkina, A. Organschi, C. P. O. Reyer, A. Ruff, K. Vinke, Z. Liu, B. K. Reck, T. E. Graedel, and H. J. Schellnhuber, "Buildings as a global carbon sink," *Nature Sustainability*, vol. 3, pp. 269–276, Jan. 2020.

[4] M. Maniak-Huesser, L. G. F. Tellnes, and E. Z. Escamilla, "Mind the gap: A policy gap analysis of programmes promoting timber construction in Nordic countries," *Sustainability*, vol. 13, 11876, 2021.

[5] M. Petrucha and D. Walcherb, "Timber for future? Attitudes towards timber construction by young millennials in Austria-Marketing implications from a representative study," *Journal of Cleaner Production*, vol. 294, 126324, 2021.

[6] R. Rinne, H. E. Ilgın, and M. Karjalainen, "Comparative study on life-cycle assessment and carbon footprint of hybrid, concrete and timber apartment buildings in Finland," *International Journal of Environmental Research and Public Health*, 19, 774, 2022.

[7] I. Uzelac Glavinić, I. Boko, N. Torić, and J. Lovrić Vranković, "Application of hardwood for glued laminated timber in Europe," *Građevinar*, vol. 7, no. 72, pp. 607-616, 2020.

[8] V. Krackler, D. Keunecke, P. Niemz, and A. Hurst, "Possible fields of hardwood application," *Wood Research*, vol. 56, no. 1, 2011.

[9] J. V. Acker, "Opportunities and challenges for hardwood based engineered wood products," in *Proc. 9th Hardwood Conference*, Sopron, Hungary, 2021, pp. 5-14.

[10] Timber structures-Glued laminated timber and glued solid timber – Requirements, EN 14080, 2013.

[11] Glued Laminated Timber made of solid hardwood, EAD 130320-00-0304, European Organisation for Technical Assessment, June 2018.

[12] S. Aicher, Z. Ahmad, and M. Hirsch, "Bondline shear strength and wood failure of European and tropical hardwood glulams," *European Journal of Wood and Wood Products*, vol. 76, pp. 1205–1222, 2018.

[13] A. Suleimana, C. S. Sena, J. M. Branco, and A. Camões, "Ability to glue Portuguese eucalyptus elements," *Buildings*, vol. 10, no. 7, p. 133, 2020.

[14] A. Morin-Bernard, P. Blanchet, C. Dagenais, and A. Achim, "Buildings as a global carbon sink," *European Journal of Wood and Wood Products*, vol. 78, pp. 891–903, Sep. 2020.

[15] J. Lovrić Vranković, I. Boko, V. Divić, N. Torić and M. Goreta, "Experimental and numerical analysis of glued laminated timber beam," presented at the 9th International Congress of Croatian Society of Mechanics, Split, Croatia, September 18-22, 2018.

[16] M. Knorz, E. Neuhaeuser, S. Torno, J. W. Van de Kuilen, "Influence of surface preparation methods on moisture-related performance of structural hardwood–adhesive bonds," *International Journal of Adhesion & Adhesives*, vol. 57, pp. 40–48, Mar. 2015.

[17] L. Mingyue, Z. Shuangbao, G. Yingchun, T. Zhaopeng, and R. Haiqing, "Gluing techniques on bond performance and mechanical properties of Cross-Laminated Timber (CLT) made from larix kaempferi," *Polymers*, vol. 13, no. 5, p. 733, Feb. 2021.

[18] O. Klausler, K. Rehm, F. Elstermann, and P. Niemz, "Influence of wood machining on tensile shear strength and wood failure percentage of onecomponent polyurethane bonded wooden joints after wetting," *International Wood Products Journal*, vol. 5, no. 1, pp. 18–26, 2014.

[19] L. Zhaohua, Z. Haibin, L. Yuchao, and H. Chuanshuang, "Effects of surface treatment and adhesives on bond performance and mechanical properties of cross-laminated timber (CLT) made from small diameter Eucalyptus timber," *Construction and Building Materials*, vol. 161, pp. 9–15, Feb. 2018.

[20] D. B. Moanda, M. Lehmann, and P. Niemz, "Investigation of the impact of micro-structuring on the bonding performance of beechwood (Fagus Sylvatica L.)," *Forests*, vol. 13, no. 113, Jan. 2022.

[21] J. Iždinsky, L. Reinprecht, J. Sedliačik, J. Kúdela, and V. Kučerová, "Bonding of selected hardwoods with PVAc adhesive," *Applied Sciences*, vol. 11, no. 67, 2021.

[22] Durability of wood and wood-based products–Testing and classification of the durability to biological agents of wood and wood-based materials, EN 350, 2016.

[23] Technical Data Sheet Prefere 4535, Dynea, edition October 2019.