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PRESS-GLUED CONNECTIONS WITH STAPLES AND NAILS – AN EFFICIENT ALTERENATIVE TO CURRENT STANDARDISATION?

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ABSTRACT: Current European standards do not permit the use of staples or nails for structural press-glued connections. Nevertheless, this method has the potential to offer a quick and cost-effective alternative to the already established screw-press bonding technique. The objective of this study was to investigate the potential of staple- and nail-press bonding. It specifically examined the influence of the pressing pressure generated in a portal system on bond line performance under manufacturing tolerances. The findings indicate that bonding this way can deliver acceptable results if there are no production inaccuracies. However, the typical level of inaccuracy from the manufacturing process results in insufficient bonding.

KEYWORDS: press-glued connections; staples and nails; manufacturing tolerances; portal systems; PUR adhesives

1 – INTRODUCTION

Structural adhesive bonding is a widely used technique in timber construction [1]. In the production of conventional engineered wood products such as glued-laminated timber (GLT), cross-laminated timber (CLT), plywood, or fiberboards, large-format presses are used to optimally adjust the pressing pressure, pressing time, and, if necessary, temperature to the wood product [2]. The production processes and quality assurance measures have been regulated at the European level for years and continue to be optimized. For example, the requirements for GLT are covered in EN 14080:2013 [3].

In addition to conventional engineered wood products, there is also the application of press-gluing with screws, which enables the production of composite systems such as ribbed slabs, hollow core elements, or double-web beams (Kairi, 2000) [4]. Another field of application is the local reinforcement of joints, openings, and notches. This type of bonding is not only used in new construction but can also be applied as a retrofitting method to strengthen damaged components. Information on the execution of staple press-gluing can be found in the Austrian annex of Eurocode 5 (ÖNORM B 1995-1-1:2023 [5], in the draft of German standard DIN 1052-10:2023 [6], and in the draft of Eurocode 5 EN 1995-3:2023 [7].

In addition to screw press-gluing, research has been conducted across Europe on various fasteners, ranging from nails and screw nails to staples for press-gluing applications [8], [9], [10]. Until 2004, nail press gluing was normatively covered in DIN 1052-1:1988 [11], but since then, only screw press-gluing has been addressed in standards. According to DIN 1052-1:1988 [11], nail press-gluing could be used for lamellae up to 33 mm thick and wood-based panels up to 50 mm thick. The nail length had to be 2.5 times the thickness of the lamellae or panels, with a maximum area of 6,500 mm² per nail and a maximum nail spacing of 100 mm.

A study by Kairi et al. (1999) [12] showed that polyurethane (PU) adhesives exhibit less brittle behaviour compared to conventional adhesives, which helps to smooth out local stress peaks. As a result, PU bonding improves the ductility of glulam and the stability of ribbed elements [12]. In line with these findings in recent times, one-component, moisture-curing polyurethane adhesives have gained significance in wood bonding, particularly in engineered timber construction [13], [14]. According to

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Brockmann et al. (2005) [2], the advantages of this adhesive class include:

- Lower application quantities
- Nearly loss-free usage
- Ready-to-use without a mixing process, as supplied by the manufacturer – no need for a glue kitchen, no wastewater
- Option for short to extremely short reaction times
- Discreet adhesive joints with wood-like aging behaviour
- Approved for indoor and outdoor applications, as well as for free spans

The most important quality assurance criterion for the application of these adhesives is the bond line thickness. According to ÖNORM B 1995-1-1:2023 [5], adhesives conforming to EN 15425:2023 [15] and Type I adhesives under EN 301:2023 [16] can be used with a maximum bond line thickness of 0.3 mm. Therefore, the most critical prerequisite for successful bonding is two sufficiently smooth, flat surfaces [4].

However, as the use of staples or nails could be a quick and cost-effective option compared to screws, this was investigated in the current research project. The principal challenge is that a markedly reduced pressing pressure can be achieved with these fasteners in comparison to screws. Although the bonding itself does not require the application of a high pressing pressure, it is essential to ensure that any unavoidable production tolerances can be compensated for. Such imperfections may include, for instance, unevenness in the wood surfaces or between the parts to be joined.

2 – MATERIALS AND METHODS

In order to determine the maximum pressure that is achievable with staples, in a first step different staples were compared to each other on their system performance. The main goal was to find the configurations that are well suited for the application of a staple press-gluing. In a second phase of the project, the bonding quality was tested on small size samples and on elements having a protrusion, see Figure 4, in the laboratory and on first industrial productions; these topics are covered in the publication of Räber et al. [17]. This paper mainly focuses on the determination of the bonding quality achieved using press-gluing with staples and nails with additional pressing pressure from a portal system on an industrial level. Therefore, a series of ribbed slab elements were produced in a carpentry.

2.1 Preliminary tests: Comparison of the performance of different staples

In a first step, the performance of a wide range of staples with varying lengths, wire thickness, and coating from the company Prebena has been evaluated. For this phase of the project, the following tests were performed: the two-side pullout test according to EN 1382:2016 [18], one side pullout and head pull through test according to EN 1382:2016 [19] and a test to evaluate the pressing force, see Figure 1. In order to ascertain the pressing force, three recesses were milled into a Duo beam, into each of which a load cell (10 kN Burster 8402 6010) was then inserted. The recesses were arranged in a triangle configuration, with the inserted load cells having a protrusion of 2 mm. Subsequently, a three-layer panel was positioned on the top of the load cells. The staple to be tested was then inserted as a connecting element between the three-layer panel and the solid wood within the triangle formed by the load cells. All tests were carried out with a connection between a 27 mm thick three-layer panel of grade B/C+ and solid wood made of spruce (*Picea abies*).

2.2 Press gluing on an industrial level with varying preloads

To determine the bonding quality achieved through the use of press-gluing with staples and nails and varying preloading applied through a portal system, a series of ribbed slab elements were produced in a carpentry, see Figure 2. Four ribs were screwed together with two cross beams to form a frame, onto which a three-layer panel was press-glued with staples or nails. The ribs and cross beams were constructed from spruce (*Picea abies*) solid timber with a cross section of 80 x 120 mm, which were planed prior to bonding. The three-layer panel was 27 mm thick and assigned a quality of B/C+.

Prior to the bonding process, the preload of the portable system was investigated under the same bonding conditions that were later used for the actual adhesive bonding. A similar test setup, as described in Section 2.1, was used to measure the load during the fastener insertion process. The technique of inserting a staple with the staple aggregate at maximum preload is shown in Figure 3. First, the aggregate moves onto the plate, causing a force peak of up to 1200 N. Then, the preload stabilizes at around 740 N before the staple is inserted. Immediately after insertion, the aggregate releases the test specimen.

The staple aggregate configuration was varied to achieve preloads of 0 % (20 N), 50 % (450 N), and 100 % (740 N) in order to determine its influence. The percentage refers to the planned preload as a proportion of the maximum possible preload of the aggregate, with the effective measured force shown in parentheses. The same procedure was applied for the nails, with preloads of 50 % (460 N) and 100 % (430 N). However, in this case, adjusting the aggregate resulted in a reduction of the force rather than an increase.

In addition to the staple and nail press-gluing, a screw press-gluing was performed according to ÖNORM [2] as a normative reference press-gluing. This configuration was press-glued as a smaller element in the laboratory of the Bern University; further information is given in Räber et al. [17].

To simulate manufacturing tolerances and determine their influence, one of the two cross beams per element was intentionally allowed to protrude by 2 mm when assembling the frames, see Figure 4.

The bonding process was conducted using a 1C PUR adhesive with an automatic application by the portal system with a quantity of 200 g/m^2. The pressing pressure was applied by inserting staples or nails (Z64CSVHA-ETA / CW 3.1/80 rille-blank GC600) with a fastener spacing of 40 mm on a portal system with varying preloads.

To determine the adhesive bond thickness after the bonding process, small samples were cut, sanded on the end-grain side (usually with 800-grit) and examined under a Leica DMLM light microscope at 50x magnification in an axial viewing direction. The bond line shear strength was tested according to the standard EN 14080:2013 [3], but with deviations in the specimens shear area to approximately 40 mm height and 30 mm width. Due to the limited cutting guidance caused by the fastener, some specimens had even smaller widths of at least 20 mm.

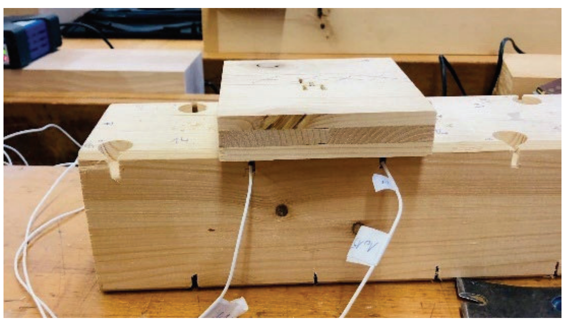

Figure 1. Evaluation of the pressing force with 3 load cells

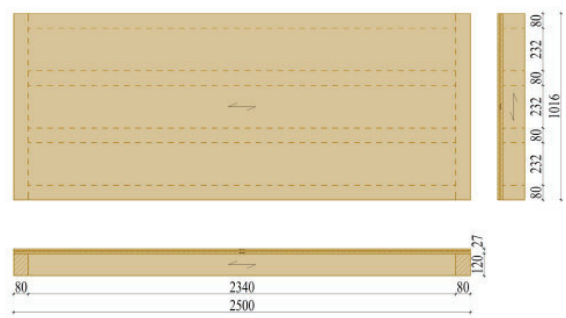

Figure 2. Illustration of the Ribbed slab element

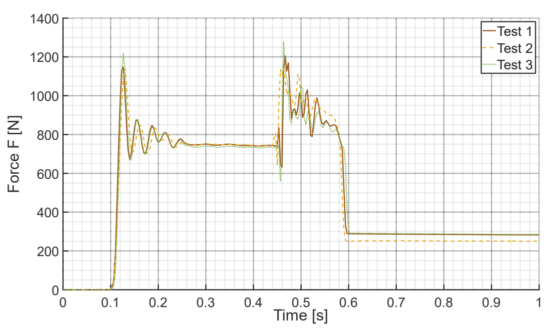

Figure 3. Pressing force during inserting of staples with the maximal possible preload of 740 N

Figure 4. Part of the frame, where the cross beam was produced with a 2 mm protrude, represented using a 2 mm thick beechwood strip

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3 – RESULTS AND DISCUSSION

3.1 Preliminary tests: Evaluation of characteristic properties of staples

In general, comparing the performance of the different staples was challenging due to the extremely high variation in the coefficient of variation (CoV) across the various configurations. As an example, the results of the pressing forces are shown in Figure 5. For the two configurations of the staple "Z64CSVHA-ETA", the CoV varies between 16.7 % and 81.5 %. This confirms the high CoV of 48 % for the pressing force of staples found by Schiere et al. [9]. Further results of these test series can be found in Räber et al. [17].

The authors concluded that the big influence of the wood parameters, especially the middle layer of the three-layer panel, in combination with the sample size n = 5 leads to an overlay of the staple's specific performance. Further, it must be mentioned that two different examiners did the testing, which includes the manual handling of the staple machine, which can have an influence on the results.

3.2 Press gluing on an industrial level

The bond line thickness as a function of the element length for the configurations with the fastener nail, staple, and screw with a protruding cross beam on one side of the element is illustrated in Figure 6. The points displayed represent the average values derived from the respective four ribs per element. It is evident that a bond line thickness of approximately 1.8 mm was measured near by the protruding cross beam for all variants. This value aligns with the planned overlap. Subsequently, bond line thickness decreases and remains relatively constant at approximately 0.2 mm to 0.3 mm for all configurations from a distance of about 50 cm. The nail configurations show a faster decrease in bond line thickness than the staples configurations, whereby the variation of the staples without preload clearly showed the thickest bond line occurred. It is evident that the reference bonding with screws has already reached below 0.2 mm after approximately 25 cm and is at the lower limit of the adhesive joint thicknesses. While the nail configurations at the same positions still are at 0.5 mm and the staples show up to 0.9 mm bond line thickness.

The configuration without a protrusion of the cross beam with a preload of 740 N is shown in Figure 7. The average bond line thickness is around 0.2 mm to 0.3 mm and similar to the other configurations from a distance of about 50 cm.

As illustrated in Figure 8 and Figure 9, the microscopic examinations were conducted to provide representative views. It is imperative to note that these figures are not intended to be representative of the configuration in question (nail vs. staple), but rather to illustrate the distance to the protruding cross beam. As illustrated in Figure 8, the test specimen was obtained at a proximity of a few centimetres from the aforementioned edge beam, while Figure 9 depicts a specimen obtained from a distance of almost 2 m. It is evident that the production inaccuracy of 2 mm exerts a substantial influence on the quality of the bonded joint. The adhesive joint thickness was found to be significantly larger near the protrusion.

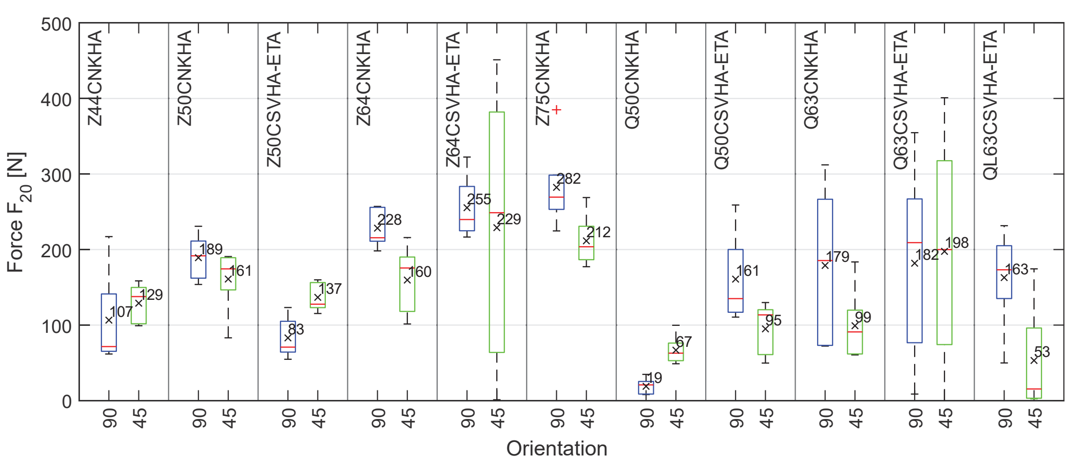

Figure 5. Boxplots of the pressing force of different staples in relation to the angle of the staple back to the grain; with the mean value

Furthermore, the adhesive quantity applied was inadequate to fill this joint thickness. This is evident in the substantial areas that remain unfilled, indicating insufficient adhesive application. However, both the three-layer board and the Duo beam were found to be wetted with adhesive, indicating that they were in contact with each other, albeit for a brief period. However, at greater distances, the adhesive joint exhibits a significantly reduced thickness. However, the presence of numerous air pockets is also evident in this area.

An example of the determination of the wood failure percentage is given with the fastener nails and a preload of 460 N, see Figure 10. The order of the pictures from left to right is adequate to the protrusion of 2 mm (left) to 0 mm (right).

A comparison of the wood failure percentage and shear strength between the configurations of different preloads with the fastener nails and staples and the reference configuration with screws is shown in Figure 11. The red line indicates the requirements for the individual and the yellow, dashed line the requirement for the mean values. The marks without filling were taken from the end of the element with a 2 mm protrusion up to 50 mm. Except the reference screw press-gluing, which already showed good results after 25 cm, nearly all samples failed the requirements of the standard EN 14080:2013 [3]. After the 50 mm mark, most of the tests passed the requirements. The filled marks and the marks with a transparent filling are the samples from 50 mm until the end of the element. The marks with a transparent filling showed big knots in the testing area, or some areas in the shear plane were not wetted with adhesive. After the 50 mm mark, most of the tests passed the requirements; however, some samples still failed the requirements, especially from the configuration staples with a preload of 20 N. Partly the bad results can be explained by big knots in the shear plane or simply not enough adhesive or pressure to distribute the adhesive to cover the whole shear plane.

The configurations without a protrusion of the cross beam with a preload of 740 N are shown in Figure 12. Most of the samples passed the requirements of the standard EN 14080:2013 [3], some clearly did not fulfil the requirements and showed an insufficient distribution of the adhesive on the shear surface.

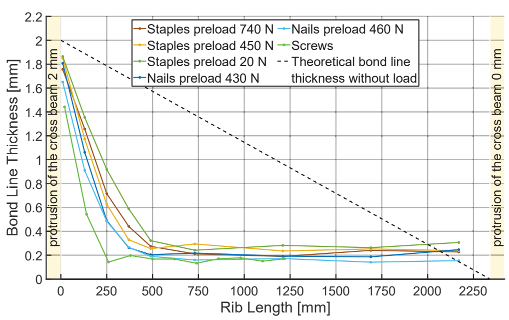

Figure 6. Bond line thickness as a function of the element length with a one side protrusion of 2 mm, created by the cross beam.

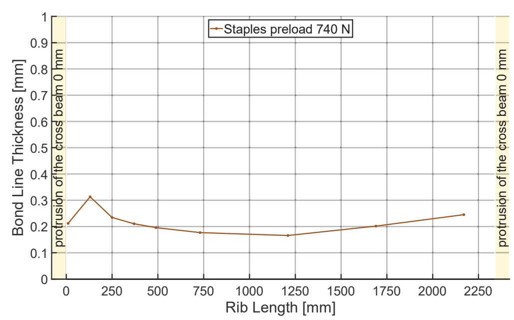

Figure 7. Bond line thickness as a function of the element length without a protrusion.

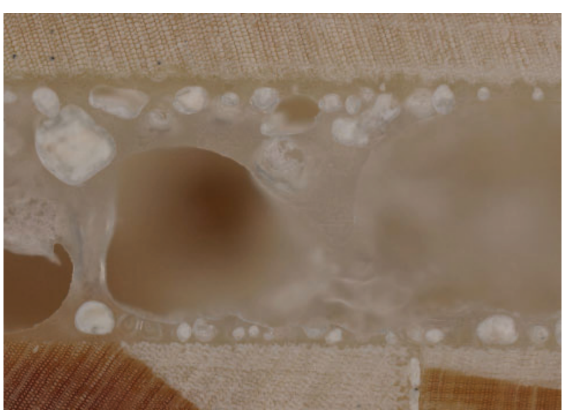

Figure 8. Bond line thickness at the position 44 mm and the configuration nails with a preload of 430 N; 50x magnification.

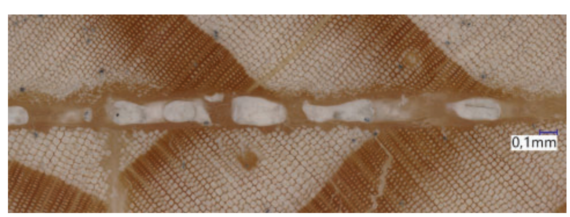

Figure 9. Bond line thickness at the position 1964 mm and the configuration staples with a preload of 740 N; 50x magnification.

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Figure 10. The wood failure percentage of the bonding for nails preload with 460 N, a 2 mm protrusion on the furthest left sample to no protrusion to the furthest the right sample, where red areas indicate wood failure and bright yellow areas indicate adhesive failure (Wiesner Test)

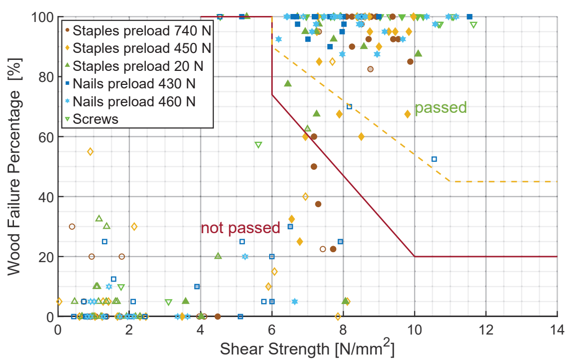

Figure 11. Comparison of the wood failure percentage and shear strength between the configurations with a one side 2 mm protrusion of different preloads with the fasteners nails, staples and the reference configuration with screws. The red line indicates the requirements for the individual and the yellow, dashed line the requirement for the mean values.

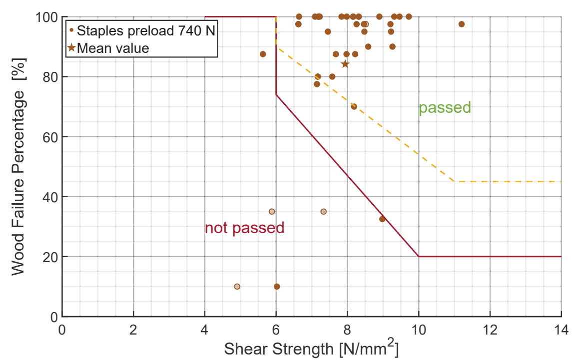

Figure 12. Comparison of the wood failure percentage and shear strength of the element with staples, 740 N preload and no protrusion. The red line indicates the requirements for the individual and the yellow, dashed line the requirement for the mean values.

4 –CONCLUSION AND OUTLOOK

The research project has demonstrated that the contact pressure that can be achieved with staples is minimal. While there are disparities among the various staples, the material-related dispersion of the wood is notably elevated in comparison, exerting a consequential influence on the contact pressure. Consequently, the location and point of impact on the wood are of greater significance than the staple itself. The standardization of additional pre-forces, such as those generated by the operator's weight or the slider's movement, poses significant challenges due to their inherent variability and potential adverse effects resulting from operator positioning, such as standing on or between the beams. While pre-forces from the aggregates of gantry systems are repeatable and beneficial, their positive effect remains comparatively minimal.

The manual application of the staple pressing technique is not regarded as a realistic option in practical settings. It is recommended to utilize the screw pressing method according to ÖNORM B 1995-1-1:2023 [5] or E DIN 1052-10:2023 [6]. Clamping or nailing on the portal system with additional pressure is conceivable for flat elements without cross beam protrusion, although a very narrow process window must be taken into account. It is acknowledged that the validation of quality assurance for each company would be a prerequisite. However, it should be noted that the validity of this assumption is constrained by the fact that it is based on the results of only two different companies. To ensure the reliability and general validity of the findings, it is essential to extend the study to encompass a larger sample of companies and a more substantial testing volume. It is recommended that future research efforts concentrate on the examination of this variability and the development of robust, reproducible methods that meet the requirements of industrial practice.

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REFERENCES

[1] C. R. Frihart, "Introduction to special issue: wood adhesives: past, present, and future," Forest Products Journal, Vol. 65, No.1/2, pp. 4–8, 2015.

[2] W. Brockmann, P. L. Geiss, J. Klingen, and B. Schröder, Klebtechnik: Klebstoffe, Anwendungen und Verfahren. Weinheim: Wiley-VCH, 2005.

[3] EN 14080, Holzbauwerke - Brettschichtholz und Balkenschichtholz - Anforderungen, European Committee for Standardization (CEN). 2013.

[4] M. Kairi, Ed., Schraubenverleimungen erlauben neue Möglichkeiten im Ingenieurholzbau. Garmisch-Partenkirchen, 2000.

[5] ÖNORM B 1995-1-1, Eurocode 5: Bemessung und Konstruktion von Holzbauten - Teil 1-1: Allgemeines - Allgemeine Regeln und Regeln für den Hochbau - Konsolidierte Version mit nationalen Festlegungen, nationalen Erläuterungen und nationalen Ergänzungen zur Umsetzung der Önorm EN 1995-1-1, Austrian Standards International (ASI), 2023.

[6] E DIN 1052-10:2023, Entwurf: Holzbauwerken - Herstellung und Ausführung von Holzbauwerken – Teil 10: Ergänzende Bestimmungen zu Verbindungsmitteln und nicht europäisch geregelten geklebten Produkten und Bauarten., Deutsches Institut für Normung (DIN), 2023.

[7] prEN 1995-3, Entwurf: Eurocode 5 - Bemessung und Konstruktion von Holzbauten - Teil 3: Ausführung, European Committee for Standardization (CEN). 2023.

[8] W. Rug, K. Gümmer, and S. Gehring, "Schraubenpressklebung mit Nagelschrauben," Bautechnik, vol. 87, no. 1, pp. 33–43, 2010.

[9] M. Schiere, S. Franke, and B. Franke, Investigation and analysis of press glued connections for timber structures. Bern University of Applied Sciences, 2018.

[10] H. M. Fürst, "Überprüfung und Optimierung der Regelungen für steifen- und plattenförmige Schraubpressverklebungen in ÖNORM B 1995-1-1," Master’s Thesis, Structural Engineering, Graz University of Technology, 2019.

[11] DIN 1052-1, Holzbauwerke - Teil 1: Berechnung und Ausführung, Deutsches Institut für Normung (DIN), 1988.

[12] M. Kairi, E. Kaloinen, S. Koponen, T. Nokelainen, M. Fonselius, and A. Kevarinmäki, Screw gluing Kerto-LVL structures with polyurethane. Espoo: Helsinki Univ. of Technology, 1999.

[13] A. Brandmair, S. Clauss, P. Hass, and P. Niemz, "Verklebung von Laubhölzern mit 1K-PUR-Klebstoffen für den Holzbau," Bauphysik, vol. 34, no. 5, pp. 210–216, 2012.

[14] B. Radovic and C. Rothkopf, "Eignung von 1K-PUR-Klebstoffen für den Holzbau unter Berücksichtigung von 10-jähriger Erfahrung," Bauen mit Holz, no. 6, 2003.

[15] EN 15425, Klebstoffe - Einkomponenten-Klebstoffe auf Polyurethanbasis Klebstoffe - Einkomponenten-Klebstoffe auf Polyurethanbasis (PUR) für tragende Holzbauteile - Klassifizierung und Leistungsanforderungen, European Committee for Standardization (CEN). 2023.

[16] EN 301, Klebstoffe, Phenoplaste und Aminoplaste, für tragende Holzbauteile - Klassifizierung und Leistungsanforderungen, European Committee for Standardization (CEN). 2023.

[17] V. Räber, D. H. Lins, M. Lehmann, S. Franke, B. Franke, and J. Karolin, Renaissance der Pressverklebung mit Nägeln oder Klammern. to be published, 2024.

[18] EN 1383, Holzbauwerke - Prüfverfahren - Prüfung von Holzverbindungsmitteln auf Kopfdurchziehen, European Committee for Standardization (CEN). 2016.

[19] EN 1382, Holzbauwerke - Prüfverfahren - Ausziehtragfähigkeit von Holzverbindungsmitteln, European Committee for Standardization (CEN). 2016.

https://doi.org/10.52202/080513-0398