applied sciences

MDPI

Article

An Investigation of the Impact of Water on Certain of the Mechanical and Physical Properties of Laminated Veneer Lumber (LVL) as Used in Construction

Milda Jucienė [1,*], Vaida Dobilaitė [1] and Darius Albrektas [2]

[1] Institute of Architecture and Construction, Kaunas University of Technology, Tunelio st. 60, LT-44405 Kaunas, Lithuania
[2] Faculty of Technology, Kaunas University of Applied Sciences, Pramonės pr. 20, LT-50468 Kaunas, Lithuania
* Correspondence: milda.juciene@ktu.lt

Abstract: Timber and timber products are renewable materials that, due to their durability and strength properties, meet the requirements of the construction industry, are widely used in buildings. An analysis of the scientific literature has shown that there is a lack of detailed research that fully investigates the influence of the rate of increase of the moisture content of the timber on the mechanical and, especially, the strength properties of the LVL panels. Upon immersion into water of the bottom of the specimen, the water starts rising quite quickly at the edge of the specimen, and the first six hours are the most critical. The levels of water rise inside the LVL specimen were less significant than at the edges. It was found that water significantly affects the bending strength of the panels, which, when the strength of the wet panel compared to the strength of the dry panel, decreases to 45% after one soak cycle and almost to 52% after two soak cycles. The tensile strength of the wet specimens is ~40% less than that of the dry specimens. The strength of the panels that were dried back to their initial state was found to be sufficient again, different from the initial strength only within the error limits; the strength properties of the building structure will not be affected.

Keywords: laminated veneer lumber (LVL); strength; water rise level; water absorption

check for updates

Citation: Jucienė, M.; Dobilaitė, V.; Albrektas, D. An Investigation of the Impact of Water on Certain of the Mechanical and Physical Properties of Laminated Veneer Lumber (LVL) as Used in Construction. *Appl. Sci.* **2023**, *13*, 925. https://doi.org/10.3390/app13020925

Academic Editor: Muhammad Junaid Munir

Received: 17 November 2022
Revised: 4 January 2023
Accepted: 6 January 2023
Published: 9 January 2023

1. Introduction

Timber and timber products are renewable materials that are widely used in the construction sector. Timber has good sound insulation qualities, along with highly important thermal properties. It is durable and has the strength properties that are required in the construction industry. As timber structures are much lighter than other building materials with which timber can be compared, this will help to reduce installation and transportation costs.

Laminated veneer lumber products (LVL panels) are developed to obtain timber products with higher levels of dimensional stability. An important factor in this particular case is the arrangement of layers in the LVL panels, which must be in accordance with the orientation of the timber fiber to achieve the maximum required strength levels of the product.

The problem of the durability of the wood becomes relevant as the wood is exposed to the atmosphere impacts, rains on it, and therefore has the ability to absorb large amounts of water. This causes deformation and swelling of the wood and, after longer exposure of these factors, the wood is vulnerable to destructive fungus and biological pests [1–8]. For economic purposes, the production of various timber articles (laminated timber) has a purpose both in economic and ecological terms. The demand for these materials is projected to increase continuously [9,10].

The structure of any timber determines its different mechanical properties in terms of transverse and longitudinal fiber orientation [11]. It should also be emphasized here that the mechanical properties of timber may vary throughout the product in its entirety.

Constructions made using glued timber materials, such as laminated veneer lumber (LVL) and cross laminated timber (CLT), can be used to reinforce concrete and steel structures and ensure better levels of protection against earthquakes [12].

In order to improve physical and mechanical properties, the LVL panels were reinforced with interwoven glass fibers [13,14]. It was found that the density, impact bending, and shear strength of reinforced LVL were higher, while the tangential and volumetric swelling, moisture content, and specific impact bending were lower than those of LVL. Based on the results obtained during these studies, it can be stated that reinforced LVL can be used in load-bearing areas.

The direction of the applied load was found to have an influence on the strength properties, both for timber and for LVL [15]. Lustosa et al. have examined plywood using high-density polyethylene (HDPE), which was made by using supermarket plastic bags as a binder [16]. Increased density levels were found to exist alongside an increase in HDPE, which had a positive effect on the mechanical and physical properties of the LVL-HDPE composite board.

The popularity and relevance of LVL panels is also evidenced by the number of studies carried out on the subject, which have examined and investigated various types of timber, along with the properties of combinations of different types of timber and their fiber orientations, the effect on the properties of LVL panels and the effect of various adhesives, binders, or finishing agents on the quality indicators of these building panels [17–24].

During a study aimed to determine the effect of the span-to-depth ratio on the pendulum impact bending strength, it was found that the highest impact bending strength is at a span-to-depth ratio of twenty, and the lowest at a span-to-depth ratio of ten. Furthermore, the test results showed that the impact bending strength of all the specimens that underwent testing in the flatwise direction was significantly higher than that of the specimens that were tested in the edgewise direction [25].

The SPF was found to have a higher plane shear strength and modulus than the LVL [26]. The bending properties of common CLTs improved with the use of LVL in parallel layers, whereas they could be seen to decrease with the use of LVL in the cross-layer.

LVL lumber specimens with fiber orientation (parallel and perpendicular) and with the tension angle of the dividing line set at 45°, 60°, and 90° were tested during the study [27]. Specimens with their main fibers orientated perpendicular to the load direction showed low strength levels and a brittle fracture. Specimens with their main fibers orientated parallel to the load direction showed higher strength levels and more plastic behavior, while the spread of fractures was not concentrated at a specific site and/or on a specific surface. The size of the notch was found to have a strong influence on the yield and maximum strengths, as well as the slip modulus of the 45° angled specimens.

Polyvinyl acetate adhesive and plywood thin veneers in three types of low-density wood—silver maple, yellow poplar, and aspen—were used in the production of LVL structural timber products [28]. LVL produced using silver maple plywood had better properties when compared to those of yellow maple poplar products and aspen. Silver maple may be suitable for use in the manufacture of laminated veneer floors.

The aim of the study by Melo R. et al. was to evaluate the influence of the thickness of the plywood that had been produced from the trees of a *Schizolobium amazonicum* plantation on the physical and mechanical properties of the LVL panels [29]. It has been established that the use of plywood of different thicknesses tends to affect the performance of the manufactured LVL panels. Thinner plywood provided residual swelling of the panels, higher levels of bending strength (flat) and perpendicular shear stress. Panels that have been produced with a higher volume of glue were considered less effective than those that had been produced with thicker plywood [29].

The scientific literature analysis showed that LVL panels are a relevant and popular building material which is of interest both to workers and scientists in the construction sector. One of the most important properties that is often emphasized in research is the strength properties, which are relevant in building structures. However, in this case, it is relevant to evaluate whether the strength properties of the LVL panels do not change under certain outdoor environmental conditions, especially in the presence of humidity, which is relevant in certain geographical areas, when rain is possible during certain stages of construction. However, an analysis has shown that there is a lack of detailed research that fully evaluates the rate of increase in terms of timber moisture content in—and its effect upon—the mechanical and, especially, strength properties of LVL panels. Therefore, the aim of this study was to evaluate the effect of water on certain physical and mechanical properties of LVL panels. This study will determine the absorption capacity of LVL panels and the effect of water soak on the mechanical properties (bending and tensile strength) of LVL panels.

2. Materials and Methods

The object of the study is laminated veneer lumber (LVL) (Table 1), which is intended for use in buildings as a structural or nonstructural element produced from veneer (*Picea abies spruce*) with a nominal thickness of 3 mm after pressing. Veneers are bonded with phenol-formaldehyde adhesive.

Table 1. LVL panel technical specifications.

Parameter		
Nominal thickness, mm	45	
Density, kg/m^3	497	
Number of plies	15	
Lay-up	II-IIII-IIII-II	

The moisture content in the samples varied within the range of 8.9–12.0%, with the density varying within the range of 650–760 kg/m^3. Moisture content was determined according to the EN 322 standard [30], and density was determined according to the EN 323 standard [31]. Before testing, the specimens were stored under consistent conditions (temperature 23 ± 2 °C, humidity 60 ± 5%) and constant weight.

The height of the water rise in the sample was also tested. Six samples with dimensions of 450 × 350 × 45 mm were used for this test. The samples were immersed in ink-stained water at a depth of 2 cm (Figure 1a). The water rise height at the edges K1 and K10 of the sample at regular intervals was also measured after 24 h and again after 96 h.

After the test, when the specimens had dried out (and a consistent weight was formed), all of the specimens were cut every 5 cm, following which the height of the water rise inside the specimen was measured (Figure 1b). On the graphs, the results of the measurements at these places are marked V2–V9, the measures at the end of the specimen are marked K10. As the height of the rise of the water in the LVL panel tends to differ, the height of each bonded element was measured where the water had risen (the sections in which the water had not risen were not measured).

Bending and tensile strength tests were carried out in order to evaluate the influence of water on the mechanical properties of LVL panels. The bending test was carried out using a universal test machine, a BTI-FB 050 TN (Zwick, Shanghai, China). The bending strength was determined by applying a load to the center of the specimen which itself had been placed on two supports in accordance with EN 310 (Figure 2) [32].

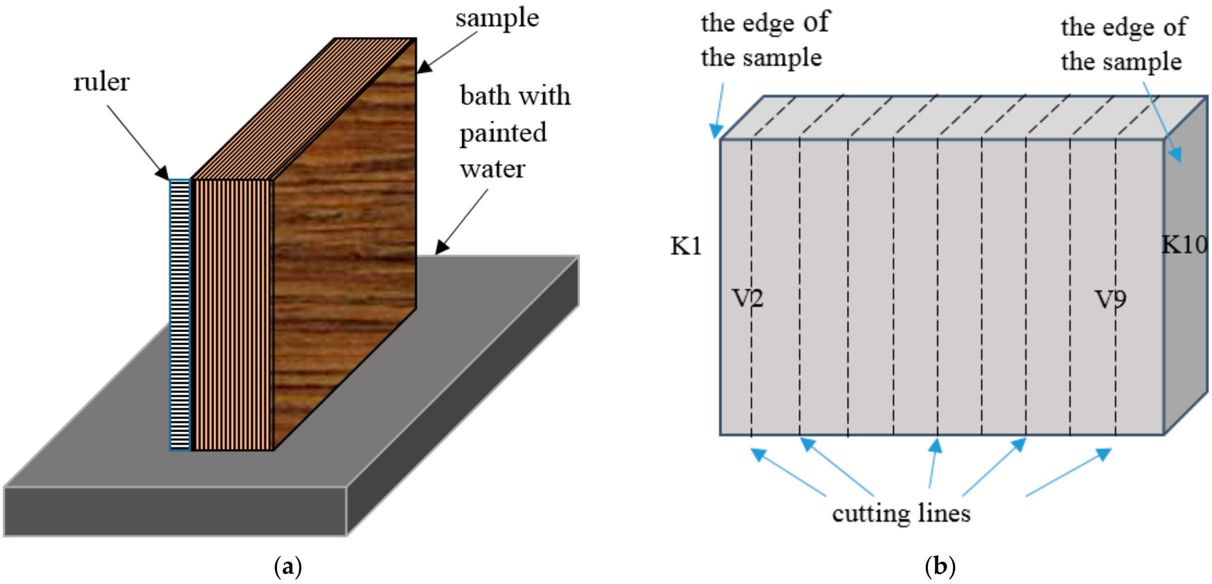


Figure 1. A determination of the height to which water rises in the sample: (**a**) measurement carried out at a fixed time after immersion; (**b**) after the test, the measurement is carried out after 24 h and 96 h, where K—the edges of the sample, V—inside of the sample.

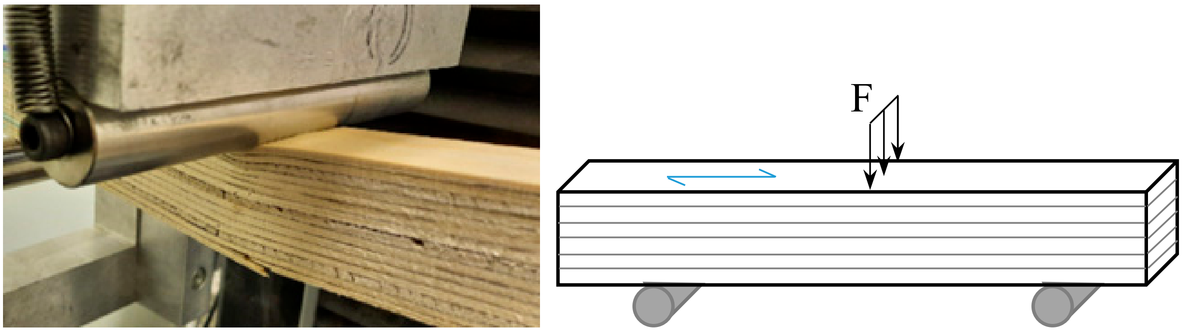


Figure 2. A determination of the bending strength of the specimens.

The specimens were intended to determine changes in their bending properties after different levels of exposure were divided into four groups (Figure 3). Ten specimens were involved in each group. In order to investigate the effect of soaking on any potential change in bending strength, Group 2 samples were soaked in water at 20 ± 1 °C for forty-eight hours. Group 3 samples were soaked under analogous conditions, and then dried at 23 ± 2 °C, 60 ± 5% relative humidity to a consistent weight, i.e., when the result of two concurrent weight tests at 24 h intervals can be seen to differ by less than 1% of the weight of the sample, after which they were soaked for a second time for a period of 48 h. The specimens in these groups were subjected to the bending test as soon as they were removed from the water. Group 4 specimens were soaked once. The samples taken from the water were dried under conditions of temperature 23 ± 2 °C, humidity 60 ± 5% until a stable weight. After being soaked, after drying to a stable mass, the specimens were broken according to the same test methodology. Then any change in the percentages of thickness, length, width, and water absorption (which refers to the water content as a percentage of the mass of the sample) was calculated.

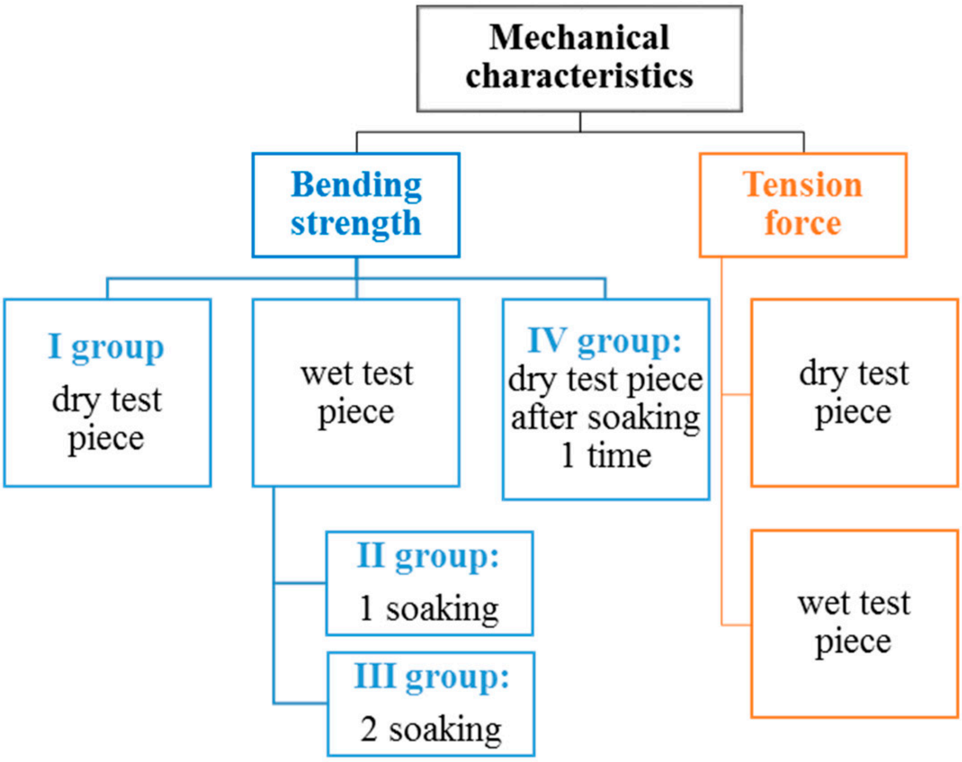


Figure 3. Test pieces for classification in order to determine mechanical properties.

The water absorption w (%) was calculated following Equation (1):

$$w = \frac{m_1 - m_0}{m_0} \times 100 \quad (1)$$

where m_0 is the initial weight of the specimens before immersion in water, m_1 is the weight of the soaked specimens, in grams. The change in thickness, length, and width was calculated analogously to Equation (1), taking the thickness (or length, width) values before and after soaking, respectively. The number of samples used for this study was 10. Thickness was measured using an electronic caliper with an accuracy of 0.1 mm; width and length were measured using a metal tape measure with an accuracy of 1 mm; and weight was determined using an electronic laboratory scale with an accuracy of 0.01 g.

The longitudinal to grain tension strength experiment was carried out on a universal test machine, a BTI-FB 050 TN (Zwick), using curved edge grippers in which a specimen was affixed (Figure 4). This is a nonstandard test to find out the "weakest point" of the LVL under such a load (the tensile load is not applied across the fiber, but along it, a kind of "shear"). As a standard, the specimen is pulled perpendicular (across) the fiber. It is known that in this case of natural wood, the resistance perpendicular (across) the fiber is about 20 times lower than (longitudinal) along it [1,33]. The clamp speed was 100 mm per minute, while the load was measured using a 5 kN load sensor. Seven specimens with a dimension of 50 × 50 mm were prepared for the tension strength experiment. The drilling was carried out using an electric low speed drill to prevent the formation of additional cracks around the edges of the holes (Figure 4).

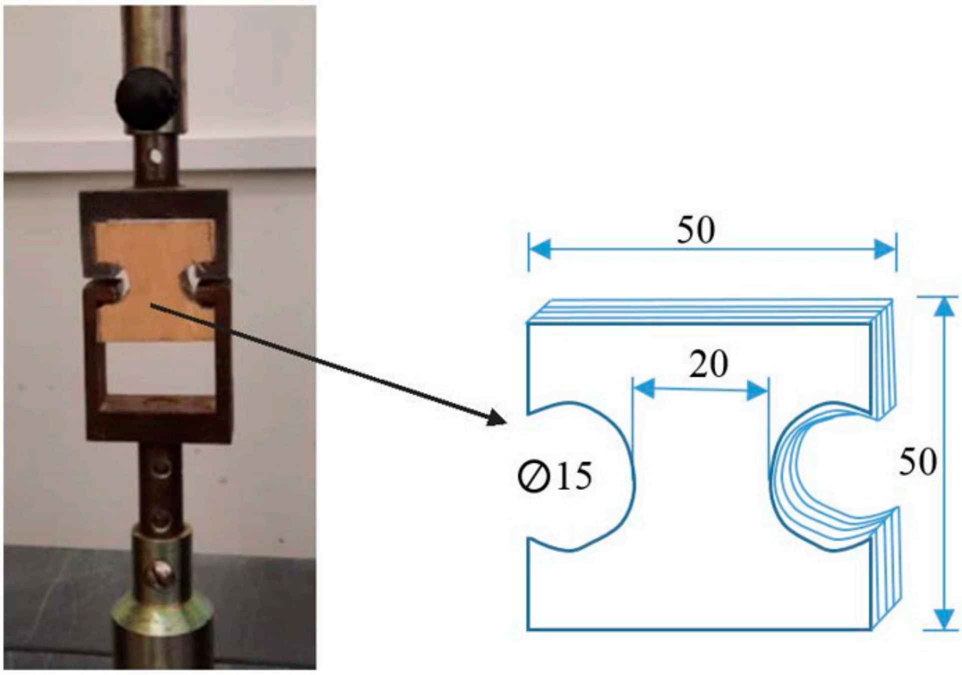


Figure 4. Tensile test specimen and the setup of the experiment, dimensions in mm.

The tensile strength and the breakage nature of the specimens (in terms of delamination) were determined during the test. All study results were statistically processed to be able to calculate the standard deviation and the variation coefficient.

3. Results and Discussions

The water rise height results at the edges of the specimens over time are shown in Figure 5, presenting two average curves, one obtained from a set of values of the samples soaked for 24 h and the other of the samples soaked for 96 h. The dispersion of the results (comparing only these results) was small; the coefficient of variation did not reach 5%. On the basis of the results obtained, water at the edges of the specimen can be seen to increase significantly during the first few minutes of soaking (Figure 5). During the first hour, a rapid water rise was observed near the edge of the specimen. Later, further water rise can also be observed, but not as rapidly as at the beginning of the process, with water rise along the specimen generally being seen to slow down. When evaluating the results after six hours and again after twenty-four hours, the level of water rise in the sample was found to be similar. However, when the test was carried out and the water rise in the specimen was again evaluated after 96 h, it was found that the water had indeed risen, albeit slowly. In this case, when evaluating the results after twenty-four hours and after ninety-six hours, in individual cases, the water increased by between 1–2 cm higher along the specimen after ninety-six hours compared to the height which had been measured after twenty-four hours. Of course, because of the large dispersion of the sorption and structure properties of wood, these results cannot be considered absolute. These regularities are characteristic only in the case of these samples.

After the specimen was immersed, the water rose along all of the bonded elements, at the edges of the LVL panel, with water ingress sometimes occurring at a lower point in the sample and sometimes higher, but in all elements the water actually rose during the first few minutes of the test. Analysis of the water rise levels inside the specimen revealed slightly different results (Figure 6).

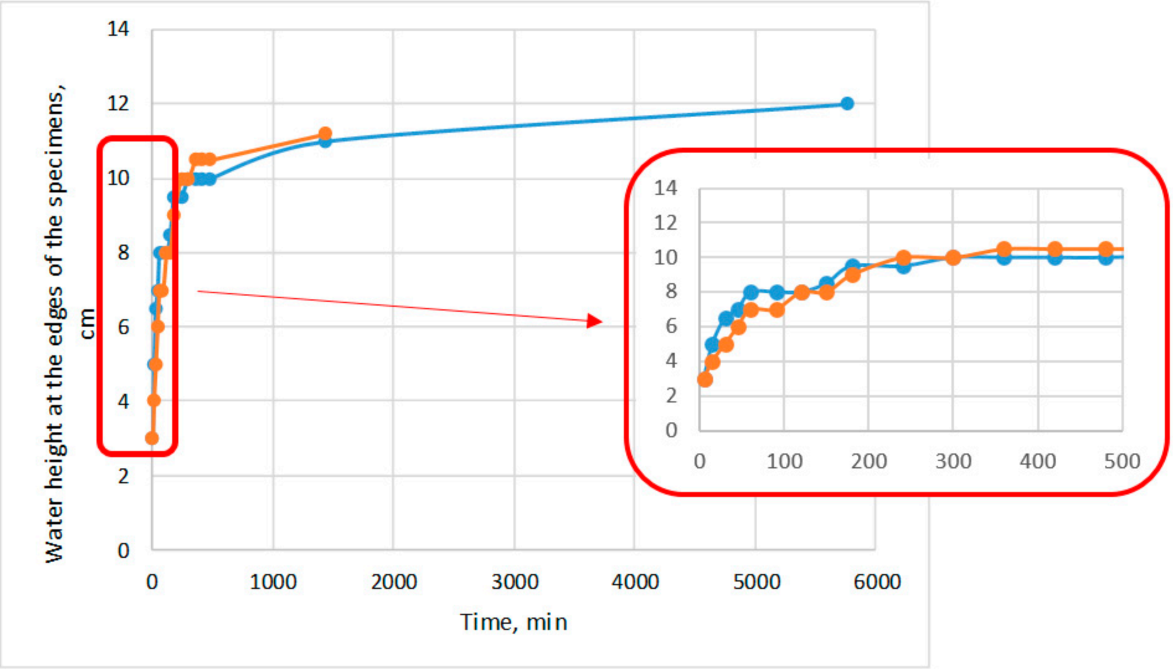
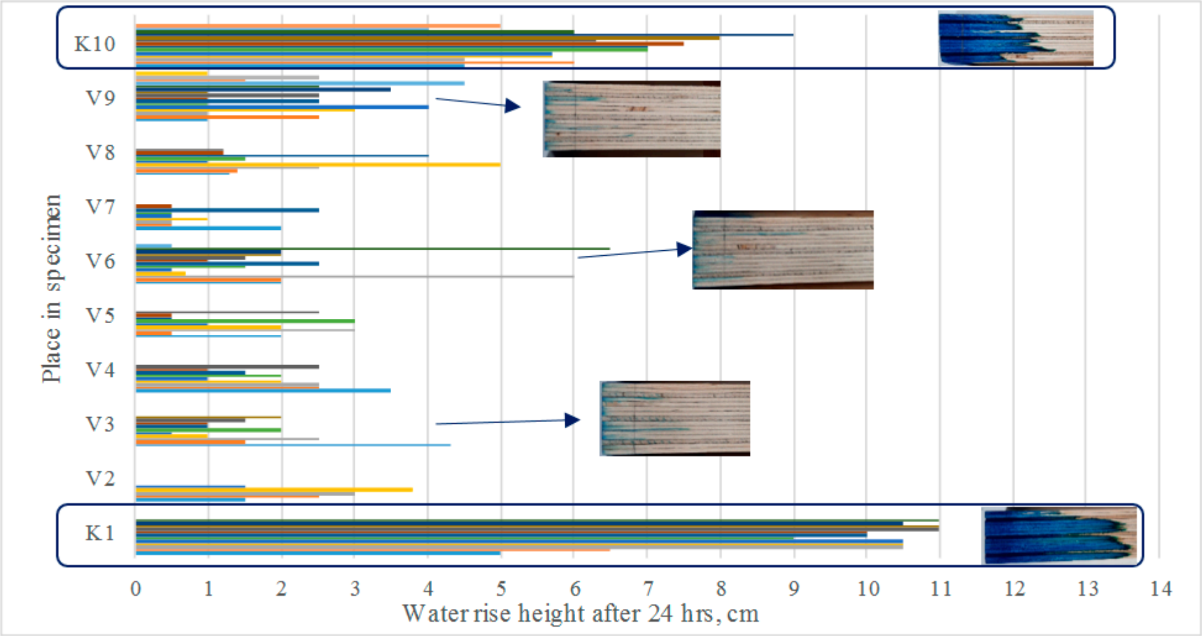


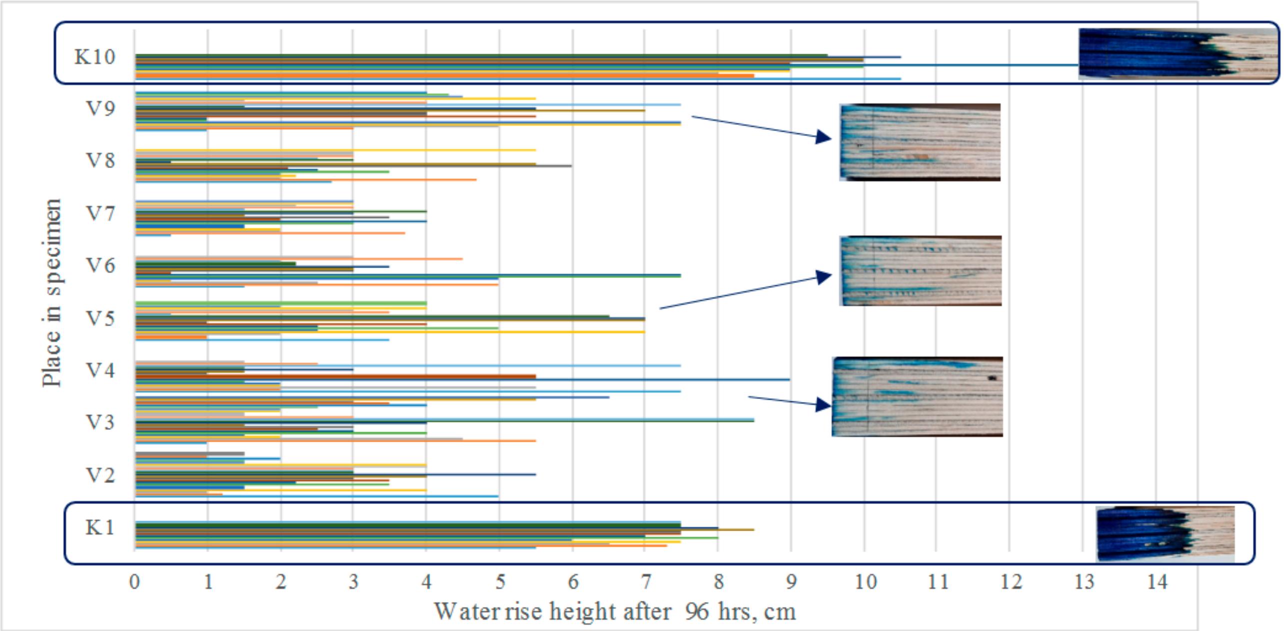
Figure 5. Water height at the edges of the specimens soaked 24 h (●) and 96 h (●), in cm.

In order to evaluate the final water rise height, not only along the edges of the specimen but also inside the specimen, each specimen had to be cut lengthwise and the water rise height was measured in the bonded elements of the LVL panels after a period of 24 h and again after a period of 96 h, by immersing the specimens in water at a depth of 2 cm. Irrespective of the length of time, water at the edges of the specimen was found to have risen higher than it did inside the sample (Figure 6). Not all elements of the LVL bonded panel absorbed water within the same period of time on the inside of the LVL panel. For some elements, the water rise was not detected after twenty-four hours of soaking (Figure 6a). When evaluating those specimens that had been soaked for 96 h, it was found that although the water did tend to rise to insignificant levels, the rise height differed slightly after 24 h and after 96 h, and yet it was found that after 96 h most of the bonded elements had absorbed water and that water had crept upwards along the element (Figure 6b). When an assortment of wood with a moisture content below the fiber saturation limit is immersed end in a liquid, the liquid rises up under the action of capillary pressure. The macrocapillaries fill first with liquid, followed by microcapillaries. The air removed from the capillaries opposes the movement of the liquid. The liquid stops rising when the capillary pressure equals the force of the liquid's weight. In the case of LVL, the regularities are likely to be slightly different, as both the properties and fiber orientation of each layer may differ.

Therefore, the research revealed quite rapid water egress along the LVL panel. Thanks to this finding, another study was conducted, this time to evaluate the level of immersion and how it served to alter the dimensions of the panel. The results of any change in the dimensions of the specimens and water saturation levels after the samples had been soaked in water at (20 ± 1) °C for 48 h are given in Table 2. It was found that after soaking the specimens under the above conditions, the length of those specimens did not actually change, and the width did not change or changed little, with the most significant difference being the change in thickness. According to the requirements of the EN 312 standard, swelling in thickness varied between 8–14%, depending on the type of panel. Upon focusing on these values, it can be said that the value of each change in terms of thickness, which was determined during the study, does not reach the minimum allowable limit even when the specimen is wet and the value decreases by more than double after long-term conditioning. The level of water that rises differently in each layer could be determined by many factors: the density of the individual layer, sorption properties, and orientation with respect to the sample surface. There could also be small cracks in the wood. Cracks could also be between layers due to not-high-quality gluing. Such cracks could be caused by many factors: insufficient amount of glue in a certain area, bad compression due to various factors, dirt on the surface to be glued, etc.).



(**a**)



(**b**)

Figure 6. Height of the water rise in the specimen after: (**a**) twenty-four hours; and (**b**) ninety-six hours, where the location of the specimen is: K for the edge of the specimen, and V for the inside of the specimen; different colors of bars indicate the height of the water rise of each plie of the LVL panel.

Table 2. The results of dimensional changes in the specimens and water absorption levels.

Performance	Changes in Specimen Dimensions, %			Water Absorption w ± SD, %
	Length	Width	Thickness ± SD	
after soaking for 48 h	0	0–3	7 ± 1.91	34 ± 1.9
after long-term conditioning	0	0	3 ± 0.2	

The results show that the water absorption of the samples changed by an average of 34% during soaking. The results of a weight loss over time (standard deviation between 7–11%) are shown in Figure 7. It can be seen that the drying process under which the specimen were soaked during the subsequent four days was rapid: on average, the levels of water soaking tended to decrease, from 34–20% each day, with the full four-day decrease bringing the level down to 8%. After a full twenty-five days, the change in weight of the soaked samples did not exceed 1% when compared to the initial changes.

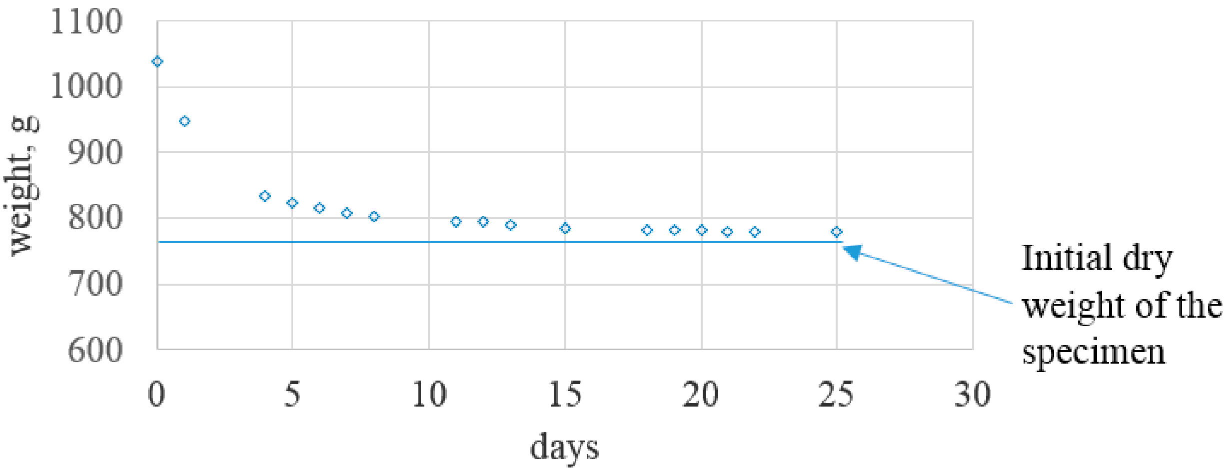


Figure 7. Loss of weight for wet specimens under conditioning (temperature 23 ± 2 °C, humidity 60 ± 5%), in days.

The results of the bending strength are given in Figure 8, the coefficient of variation was less than 8%. An analysis showed that the bending strength of wet specimens decreased by almost double when compared to the figures for primary strength, by 45% and 52% respectively after the first and second periods of soaking (Figure 8). As a result of the cyclic process that can be referred to as 'soaking, drying, soaking', the bending strength was reduced by 13% compared to those specimens that were soaked only once. However, the soaking process of the specimens did not have any particular long-term effects on the change in bending properties. Bending strength after soaking and long-term conditioning changed only slightly (by about 4%).

The tensile strength results are shown in Table 3. The test, as mentioned, was not carried out as specified in the standard to find out the "weakest point" of the LVL under this load. During tensioning, cracks usually appeared at the edges of the specimens, around the clamps, and propagated in the direction of tension, while the veneer layer began to break due to the increasing load. The minimum strength that could be sustained by the specimen differed from the average levels of strength by 9%.

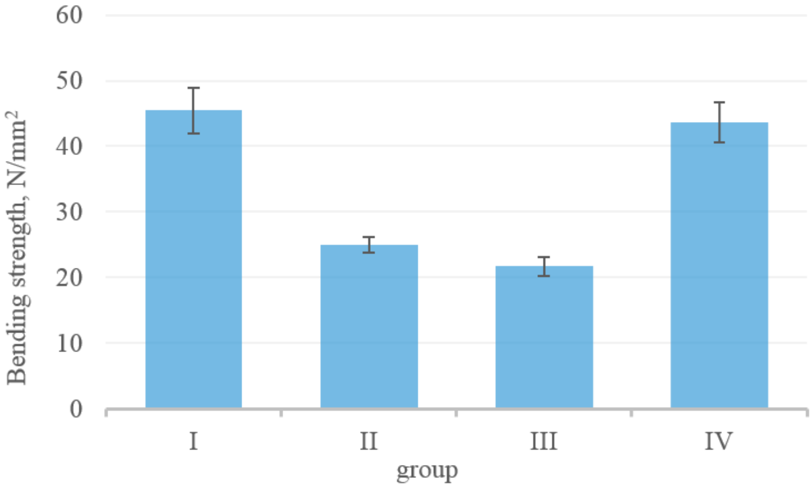


Figure 8. Bending strength results when specimens were soaked in different ways.

Table 3. Tensile test results for LVL panels.

Characteristic	Value	Wet, after Soaking for 48 h	Decrease, %
Average tensile force, N	3582	2062	42
Minimum tensile force, N	3290	1840	44
Coefficient of variation, %	7	9	—

The next stage of the test involved carrying out an evaluation of the tensile strength when the panel was completely soaked in water for forty-eight hours. In this case, a negative effect was revealed in terms of the water acting against the strength of the slabs. The observed decrease in the average tensile strength is equal to a figure of 42%, while the minimum tensile strength was shown to have decreased by 44%. The samples, as expected, disintegrated at the weakest point. It is clear that even with such a load, moisture has a great influence not only on natural but also on glued laminated wood.

4. Conclusions

When considering the time it took for water absorption to be carried out in the LVL panels, it was found that, upon immersion into water of the bottom of the specimen, the water starts rising quite quickly at the edge of the specimen and, in this case, the first six hours are the most critical. This is when the highest levels of water rise can be seen along the length of the specimen. The water continues to rise along the specimen after that time but at a slower speed. This can be attributed to the increasing opposing force of gravity on the water. Water rise levels along the specimen were observed throughout the entire 96 h of testing.

Uneven water rise was observed at the edges of the specimen. After the initial twenty-four hours of testing and again after the full ninety-six hours of testing, a significant amount of water rise was observed at the edges of the specimen. The water rise levels inside the specimen were less significant. After an evaluation of the results was performed and especially after the 24 h test, it was found that only some veneers were water-soaked. After 96 h, water content levels in virtually all of the veneers were raised, but at different heights. Most likely, this is related to the large dispersion of the sorption properties of the material and possible defects.

The study showed that, despite the good water absorption levels of the LVL panels that had been tested (absorption levels were found to be at 34%), the observed changes in panel thickness were significantly less than those allowed by the EN 312 standard. Therefore, despite the relatively high water absorption levels of the LVL panel, the correct dimensions of the panel remain ensured.

During the assessment of the impact of water on the bending strength properties of the LVL panels, it was found that water significantly affects the strength of the panels, which, compared to the strength of the dry panel, decreases to 45% after one soaking cycle and almost to 52% after two soaking cycles. Analogous results were obtained during an evaluation of the nonstandard tensile strength of both dry and wet specimens. The tensile strength of wet specimens is ~40% less than that of dry specimens.

The strength of those panels that were dried back to their initial state was found to be sufficient again, differing from the initial strength only within the error limits. Therefore, as in the case of natural wood, in the case of LVL, the mechanical properties of the material depend on its moisture content and change as the moisture content changes.

Author Contributions: Conceptualization, M.J. and V.D.; methodology, M.J., V.D. and D.A.; validation, M.J., V.D. and D.A.; formal analysis, V.D. and D.A.; investigation, M.J. and V.D.; writing—original draft preparation, M.J.; writing—review and editing, M.J., V.D. and D.A.; visualization, V.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Forest Products Laboratory. *Wood Handbook 2010: Wood as an Engineering Material*; General Technical Report FPL-GTR-190; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, 2010; 509p.
2. Zlahtic-Zupanc, M.; Lesar, B.; Humar, M. Changes in moisture performance of wood after weathering. *Constr. Build. Mater.* **2018**, *193*, 529–538. [CrossRef]
3. Rindler, A.; Pöll, C.; Hansmann, C.; Müller, U.; Konnerth, J. Moisture related elastic and viscoelastic behaviour of wood adhesives by means of in-situ nanoindentation. *Int. J. Adhes. Adhes.* **2018**, *85*, 123–129. [CrossRef]
4. Subhani, M.; Globa, A.; Al-Ameri, R.; Moloney, J. Flexural strengthening of LVL beam using CFRP. *Constr. Build. Mater.* **2017**, *150*, 480–489. [CrossRef]
5. Gilbert, B.P.; Bailleres, H.; Zhang, H.; McGavin, R.L. Strength modelling of Laminated Veneer Lumber (LVL) beams. *Constr. Build. Mater.* **2017**, *149*, 763–777. [CrossRef]
6. Markström, E.; Kuzman, M.K.; Bystedt, A.; Sandberg, D.; Fredriksson, M. Swedish architects view of engineered wood products in buildings. *J. Clean. Prod.* **2018**, *181*, 33–41. [CrossRef]
7. Musselman, E.S.; Dinehart, D.W.; Walker, S.M.; Mancini, M.L. The effect of holes on the creep behavior and flexural capacity of laminated veneer lumber (LVL) beams. *Constr. Build. Mater.* **2018**, *180*, 167–176. [CrossRef]
8. Albrektas, D.; Ivanauskas, E. An Assessment of Environmental Impact on Glued Wood Building Elements. *Drv. Ind.* **2021**, *72*, 39–47. [CrossRef]
9. Risse, M.; Weber-Blaschke, G.; Richter, K. Ecoefficiency analysis of recycling recovered solid wood from construction into laminated timber products. *Sci. Total Environ.* **2021**, *661*, 107–119. [CrossRef]
10. Hildebrandt, J.; Hagemann, N.; Thrän, D. The contribution of wood-based construction materials for leveraging a low carbon building sector in Europe. *Sust. Cities Soc.* **2017**, *34*, 405–418. [CrossRef]
11. Jakimavičius, Č. *Medienotyra*; Technologija: Kaunas, Lithuania, 2004.
12. Pilon, D.S.; Palermo, A.; Sarti, F.; Salenikovich, A. Benefits of multiple rocking segments for CLT and LVL Pres-Lam wall systems. *Soil Dyn. Earthq. Eng.* **2019**, *117*, 234–244. [CrossRef]
13. Bal, B.C. Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber. *Constr. Build. Mater.* **2014**, *51*, 9–14. [CrossRef]
14. Bal, B.C. Some physical and mechanical properties of reinforced laminated veneer lumber. *Constr. Build. Mater.* **2014**, *68*, 120–126. [CrossRef]
15. Ido, H.; Nagao, H.; Kato, H.; Miyatake, A.; Hiramatsu, Y. Strength properties of laminated veneer lumber in compression perpendicular to its grain. *J. Wood Sci.* **2010**, *56*, 422–428. [CrossRef]
16. Lustosa, E.C.d.B.; Menezzi, C.H.S.D.; de Melo, R.R. Production and Properties of a New Wood Laminated Veneer/High-Density Polyethylene Composite Board. *Mater. Res.* **2015**, *18*, 994–999. [CrossRef]

17. Awaludin, A.; Shahidan, S.; Basuki, A.; Zuki, S.S.M.; Nazri, F.M. Laminated Veneer Lumber (LVL) Sengon: An Innovative Sustainable Building Material in Indonesia. *Int. J. Integr. Eng.* **2018**, *10*, 17–22. [CrossRef]
18. Zdravković, V.; Lovrić, A.; Džinčić, I.; Pantović, N. Some Properties of LVL Composed of Poplar and Beech Veneer and Possibilities of Their Application for Window Frames. 2017. Available online: http://www.doiserbia.nb.rs/img/doi/0353-4537/2017/0353-45371715167Z.pdf (accessed on 13 December 2021).
19. Kurt, R.; Mengeloglu, F. The effect of boric acid/borax treatment on selected mechanical and combustion properties of poplar laminated veneer lumber. *Wood Res.* **2008**, *53*, 113–120.
20. Nordin, K.; Jamaludin, M.A.; Ahmad, M.; Samsi, H.W.; Salleh, A.H.; Jalaludin, Z. Minimizing the environmental burden of oil palm trunk residues through the development of laminated veneer lumber products. *Manag. Environ. Qual.* **2004**, *15*, 484–490. [CrossRef]
21. Lokaj, A.; Vavrusova, K. Longitudinal bonded joints of timber beams using plywood and LVL plates. *Procedia Struct.* **2017**, *5*, 1363–1369. [CrossRef]
22. Bal, B.C. Some technological properties of laminated veneer lumber produced with fast-growing Poplar and Eucalyptus. *Cienc. Tecnol.* **2016**, *18*, 413–424. [CrossRef]
23. Del Menezzi, C.; Mendes, L.; de Souza, M.; Bortoletto, G. Effect of Nondestructive Evaluation of Veneers on the Properties of Laminated Veneer Lumber (LVL) from a Tropical Species. *Forests* **2013**, *4*, 270–278. [CrossRef]
24. de Souza, F.; Del Menezzi, C.H.S.; Júnior, G.B. Material properties and nondestructive evaluation of laminated veneer lumber (LVL) made from *Pinus oocarpa* and *P. kesiya*. *Eur. J. Wood Prod.* **2011**, *69*, 183–192. [CrossRef]
25. Bal, B.C. The effect of span-to-depth ratio on the impact bending strength of poplar LVL. *Constr. Build. Mater.* **2016**, *112*, 355–359. [CrossRef]
26. Wanga, Z.; Fu, H.; Gong, M.; Luo, J.; Dong, W.; Wang, T.; Chui, Y.H. Planar shear and bending properties of hybrid CLT fabricated with lumber and LVL. *Constr. Build. Mater.* **2017**, *151*, 172–177. [CrossRef]
27. Rad, A.R.; Burton, H.; Weinand, Y. Out-of-plane (flatwise) behavior of through-tenon connections using the integral mechanical attachment technique. *Constr. Build. Mater.* **2020**, *262*, 120001. [CrossRef]
28. Shukla, S.R.; Kamdem, D.P. Properties of laminated veneer lumber (LVL) made with lowdensity hardwood species: Effect of the pressure duration. *Holz Roh. Werkst.* **2008**, *66*, 119–127. [CrossRef]
29. de Melo, R.R.; Del Menezzi, C.H.S. Influence of veneer thickness on the properties of LVL from Parica' (Schizolobium amazonicum) plantation trees. *Eur. J. Wood Prod.* **2014**, *72*, 191–198. [CrossRef]
30. *EN 322:1993*; Wood-Based Panels—Determination of Moisture Content. European Committee for Standardization: Brussels, Belgium, 1993.
31. *EN 323:1993*; Wood-Based Panels—Determination of Density. European Committee for Standardization: Brussels, Belgium, 1993.
32. *EN 310:1993*; Wood-Based Panels—Determination of Modulus of Elasticity in Bending and of Bending Strength. European Committee for Standardization: Brussels, Belgium, 1993.
33. Ardalany, M.; Deam, B.; Fragiacomo, M.; Crews, K.I. Tension perpendicular to grain strength of wood, laminated veneer lumber (LVL), and cross-banded LVL (LVLC). In *Incorporating Sustainable Practice in Mechanics of Structures and Materials*; Taylor & Francis Group: London, UK, 2011.