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Assessment of the durability of the adhesive bond in a carpentry product to atmospheric fluctuations

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Abstract. Wood and wooden glued products are widely used as building structures in various construction industries that operate within a wide range of atmospheric factors and require

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stability and durability. Therefore, the goal was to conduct experimental studies to determine the stability of the adhesive bond of a window element made of wood under the influence of temperature and moisture static fluctuations. In this regard, a comprehensive approach was applied to experimentally establish the effectiveness of the glued wood layer by investigating the resistance of the adhesive layer to destruction when changing temperature and humidity fields within a wide range. According to the experimental values of the adhesive layer boundary after exposure to temperature and humidity fields such as glued wood, it was established that the best result of the tensile strength (0.29 N/mm^2) was obtained for polyurethane adhesive. For rubber glue and PVA, the tensile strength was 0.17 N/mm^2 , which provides adhesion quite well due to its properties. This is due to the fact that the adhesive composition must have sufficient elasticity to allow the wood to expand and dry out under the influence of temperature. In turn, the glued layer based on bustilate and liquid glass, has the tensile strength set at a pressure of 0.07 N/mm^2 and 0.12 N/mm^2 accordingly. A decrease in the adhesive capacity for bustilate is due to the fact that at a low-temperature level, it loses its properties. The liquid glass-based adhesive has an alkaline environment and interacts with the components of wood resin acids, reducing adhesion. The results obtained allow selecting effective adhesives for the production of composite materials from wood, depending on the operating conditions, and provide for the properties of glued wood

Keywords: glued wood; technological parameters; temperature and humidity fields; stability; strength of the adhesive layer

Introduction

Wood, as a building material, is widely used in construction and architecture due to its mechanical and operational properties. For more efficient use of wood, composite products are widely used (Frederick *et al.*, 2007), which are a combination of wood itself and various adhesives.

When these products are operated under the influence of atmospheric fluctuations, the stability of geometric dimensions and resistance to the external environment change (Frihart, 2011). Therefore, the operational reliability and efficiency of using effective wood adhesives depend on the wood itself (Treu *et al.*, 2019), the quality and reactivity of the adhesive (Gavrilović-Grmuša *et al.*, 2016), and the class of operating conditions of the facility where these materials are used. The reliability of wooden structures is also necessary for objects of mass stay of people that are operated

in different temperature conditions (Kol *et al.*, 2009; Perçin & Uzun, 2014).

V. Sebera *et al.* (2020) investigated the properties of the adhesive bond during the three-point bending test with incisions at the end and the pliability-based beam method. The three-point test with incisions at the ends was established to be suitable for emulsion polymer-isocyanate, urea-formaldehyde, phenol-resorcinol-formaldehyde adhesives, while it is less suitable for bonding with polyurethane adhesives due to its noticeable plastic behaviour. However, the resistance of adhesives to atmospheric fluctuations is not indicated and the adhesive properties of the adhesive layer are not given.

Determining the effectiveness of an adhesive bond for chemically modified wood is important not only for commercial applications but also for understanding the durability of wood element joints. C.R. Frihart *et al.*

(2021) investigated two modifications of yellow poplar (*Liriodendron tulipifera* L.): acetylation (Ac), which bulk converts the hydroxyl group of wood to an ester, and butylene oxidation (BO), which preserves the hydroxyl group. The effect of these chemical modifications of wood on the efficiency of the compound using four adhesives was investigated: resorcinol-formaldehyde (RF), melamine-formaldehyde (MF), emulsion polymer isocyanate (EPI), and epoxy. The shear strength of ASTM D 905 for both dry and wet samples showed that the results of BO were fairly similar to unmodified wood, but melamine-formaldehyde and emulsion-polymer-isocyanate adhesives showed poor results for Ac-modified wood, in contrast to the results for resorcinol-formaldehyde and epoxy resins. This is not said about the mechanism of formation of adhesive bonds of the obtained wood-polymer materials.

A. Can *et al.* (2021) investigated the effect of heat treatment in open (atmospheric pressure) and closed (under pressure) systems on the shear strength and adhesion of Scots pine wood (*Pinus sylvestris*). Thermal modification substantially reduced the strength by 31% to 39% in an open system. In the closed system, a decrease from 2% to 38% was recorded. The lower shear strength of modified wood can be explained by reduced chemical bonding or mechanical adhesion of adhesives and reduced strength of the modified wood base itself. Therefore, it becomes necessary to examine the conditions of barrier formation to ensure adhesion and establish the effective action of the adhesive of a certain concentration.

Previous studies show that the mechanical properties of low-industrial wood species, such as Poplar, can be improved by mechanical compaction. In addition, in studies I. Yalçın & R. Esen (2023) established that the bonding process further improves the mechanical properties of wood material. But there are still

unresolved issues related to the effect of fibre on the rigidity of the product. The reason for this may be the principles of operation of the reinforcing material, which accordingly makes such studies difficult.

X. Tao *et al.* (2023) identified an environmentally friendly emulsion polymer-isocyanate (EPI) adhesive that was used to prepare electrothermal plywood with embedded carbon fibre paper. The authors established that wet treatment has a substantial effect on the joint strength and electrothermal performance of electrothermal plywood bonded with an emulsion polymer-isocyanate adhesive. However, the corresponding physical and chemical data on changes in the strength of the compound during changes in temperature and humidity fields are not given.

A. Bilik & R. Trianoski (2022) evaluated the potential of the breed *Pinus glabra* for the production of laminated panels, and the influence of veneer density and their combination on product quality. Plywood was examined by testing the apparent specific gravity, static bending, and shear strength of the adhesive in accordance with European standards. It is established that the combination of veneer of different densities provides an increase in the strength and rigidity of the material. However, the effect of changing the adhesive layer on reducing the strength and durability of the resulting material has not been examined, and it is not said about the environmental friendliness of the adhesive.

Thus, from the analysis, it can be seen that the use of wood adhesives is their reliability with the formation of resistant adhesives and should be characterised by non-toxicity, cost-effectiveness, ease of application and weather resistance. All this gives grounds for conducting a study dedicated to determining the parameters that ensure the use of wood adhesives.

The purpose of the study was to exper-

imentally substantiate the stability of the adhesive bond of a window element made of wood under the influence of temperature and humidity fluctuations.

The task was set to conduct a complex of experimental studies of the adhesive bond of a window corner made of wood under the influence of temperature and humidity fluctuations to achieve this goal.

Materials and Methods

A study to determine the resistance of the glued layer to temperature and humidity fluctuations was conducted in 2023 at the National

University of Life and Environmental Sciences of Ukraine.

For the research, lumber made of pine wood with a thickness of 40 mm was used, which was dissolved into blanks with a width of 65 mm, planed, and milled, grooves were selected and window elements with a connection area of 0.022 m² were obtained (Fig. 1, 2).

The prefabricated parts with a tongue and a groove are joined by a corner end-to-end connection using a single tongue (Fig. 3).

Accordingly, 15 pairs of corner joints were manufactured for research. Table 1 shows the amount of adhesive applied to the samples.

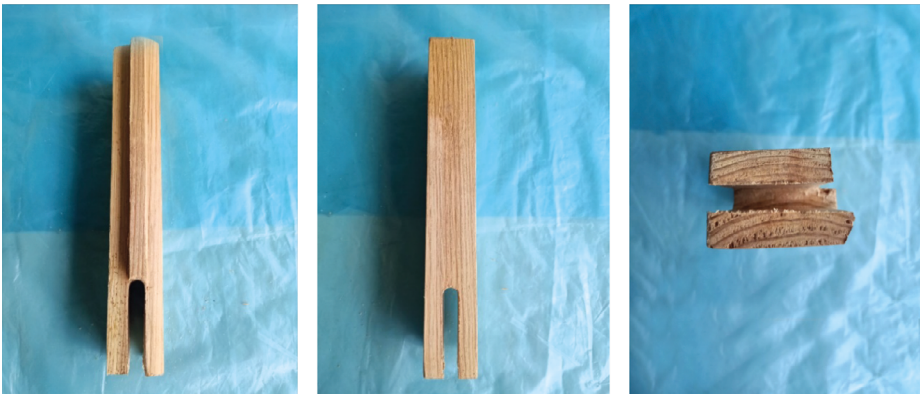


Figure 1. Detail of a wooden window with a groove

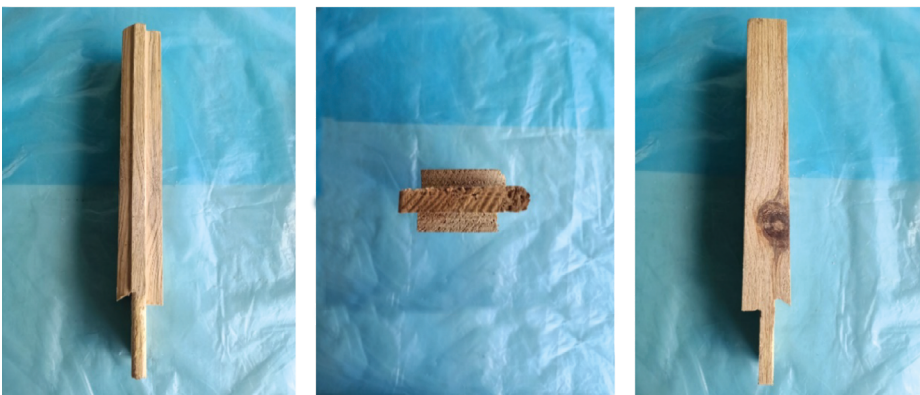


Figure 2. Detail of a wooden window with a tongue



Figure 3. Connecting parts through a tongue

Table 1. Results of determining the amount of glued agent per sample

No.	Name of the adhesive product	Weight before bonding, g	Weight after bonding, g	Glue consumption per sample, g	Amount of product applied, kg/m ²
1	PVA “Lux” D4 (Ukraine)	421.15	444.15	23.00	1.04
2	Polyurethane adhesive Soudal 66A D4 (European Union)	473.54	490.79	17.25	0.78
3	Tytan Classic FIX rubber adhesive (European Union)	456.87	477.57	20.70	0.94
4	Construction glue “BUSTILAT-D” (Ukraine)	428.60	497.60	69.00	3.13
5	Liquid glass (Ukraine)	433.19	467.69	34.50	1.57

Source: compiled by the authors

A freezer was used to keep wood at subzero temperatures (Fig. 4.), the inner surface of which

is heat-insulated with polystyrene, with a refrigeration unit and a temperature control unit.

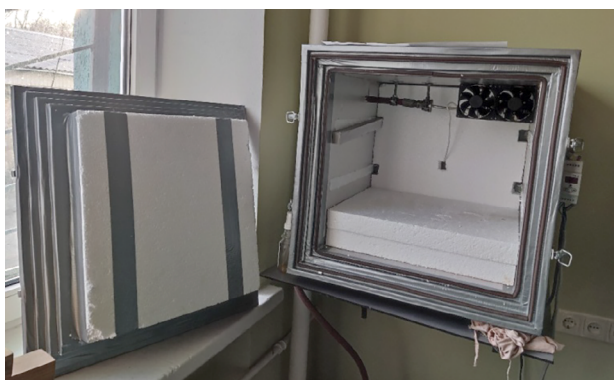


Figure 4. Freezer compartment

The essence of the method of testing resistance to atmospheric fluctuations was to simulate the processes of destruction of the adhesive layer by artificial means and determine changes in the estimated indicators before and after the action of changes in temperature and humidity fields (Tsapko *et al.*, 2021a).

The technique involved several stages of laboratory tests of the adhesive layer according to estimated indicators: appearance, the presence of cracking, weathering, peeling, dissolution, blistering, moisture absorption, and salt formation.

The test cycle for changing temperature and humidity fields on the wood adhesive layer included the following stages:

- ◆ first stage: the samples are moistened with a spray gun and kept at a temperature of $(20 \pm 2)^\circ\text{C}$ and relative humidity $(97 \pm 3)\%$ for 10 minutes;

- ◆ second stage: samples are transferred to the cold chamber and kept at a temperature of minus $(15 \pm 3)^\circ\text{C}$ within 6 hours;

- ◆ third stage: samples are transferred from the refrigerator to the room and conditioned at a temperature of $(20 \pm 2)^\circ\text{C}$ and relative humidity $(97 \pm 3)\%$ for 6 hours;

- ◆ fourth stage: samples are kept in the air at a temperature of $(20 \pm 2)^\circ\text{C}$ and relative humidity $(97 \pm 3)\%$ for 9 hours.

After exposure to temperature and humidity fluctuations, the samples were left for 4 days, after which they were re-weighed, humidity measured, and the results were recorded.

The strength of the adhesive bond was determined using an experimental destructive machine R-5 (manufactured by LLC Scientific-production company “Standard-M”, Ukraine) (Fig. 5, 6).

The fracture sample was placed in a special structure designed to break the corner joints in the same way as shown in Figure 6.



Figure 5. Experimental destructive machine P-5



Figure 6. Structure for destructive testing of corner joints

This machine belongs to the type of tearing machines with a constant deformation speed. It is equipped with a recording device for the testing process on a diagram apparatus in the “pressure-deformation” coordinates. The absolute elongation of the specimen is determined by a deformation counter. The machine is equipped with an electric drive with smooth speed regulation.

The process of determining the maximum destructive force was conducted by destroying samples (Fig. 7).

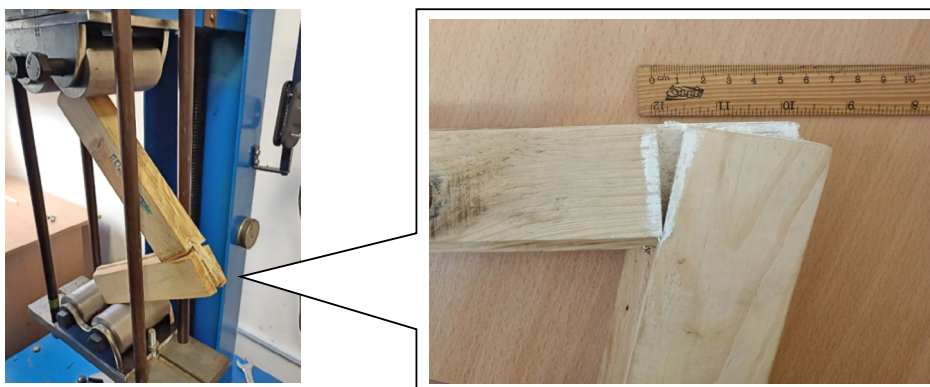


Figure 7. Destruction of the window corner sample

Using the three-factor simplex-centroid method of experimental design in the statistical software Statistica 12, the statistical analysis of the results for determining the strength of the wood adhesive layer was performed.

The mathematical modelling of the strength of the wood adhesive layer was conducted by determining the optimal conditions for the bonding process of the specimen, controlling the fracture process based on the mathematical

model, and transferring the results to the research object in the form of a regression equation.

Results and Discussion

In the first stage, the samples were exposed to a temperature-humidity environment. Table 2 presents the results of determining the weight of the specimens after exposure to temperature and humidity fluctuations, and their moisture content.

Table 2. Results of determining the stability of the adhesive bond under the influence of temperature-humidity fluctuations, depending on the number of cycles

Glue type	Number of test cycles	Average sample weight, g		Change in sample mass, G	Humidity, %
		before	after		
		the test			
Bustilat	6	497.60	535.30	37.70	22
	12	535.30	528.10	-7.20	21
	24	528.10	531.50	3.40	23
	34	531.50	536.80	5.30	20
Liquid glass	6	467.69	499.30	31.56	19
	12	499.25	503.60	4.35	23
	24	503.60	502.10	-1.50	22
	34	502.10	506.40	4.30	20
PVA	6	444.15	480.20	36.05	20
	12	480.20	478.60	-1.60	22
	24	478.60	482.90	4.30	21
	34	482.90	481.50	-1.40	23

Table 2, Continued

Glue type	Number of test cycles	Average sample weight, g		Change in sample mass, G	Humidity, %
		before	after		
		the test			
Rubber	6	477.57	511.10	33.53	22
	12	511.10	508.80	-2.30	24
	24	508.80	514.70	5.90	22
	34	514.70	512.20	-2.50	20
Polyurethane	6	490.79	524.50	33.71	20
	12	524.50	527.10	2.60	20
	24	527.10	525.60	-1.50	21
	34	525.60	528.30	2.70	22

Source: compiled by the authors

From the appearance and results of determining the resistance of the adhesive bond to the effects of temperature and humidity fluctuations, no evident signs of the destruction of the glued wood layer were established.

In this regard, experimental studies were conducted to determine the strength of the glued layer.

The results of studies on maximum destructive pressure are shown in Table 3.

Table 3. Research results maximum destructive pressure

Glue type	Tensile strength, N/mm ²	Maximum force, N	Elongation by L ₀ , %	Elongation by L ₁ , %
Polyurethane	0.29	2125.42	6.83	968.30
Rubber	0.17	1236.64	8.71	987.10
PVA	0.17	1248.87	10.21	1002.00
Liquid glass	0.12	885.94	5.60	956.00
Bustilat	0.07	515.68	14.23	1042.00

Source: compiled by the authors

Experimental studies conducted to determine the maximum force for the destruction of the adhesive layer of the corner of a wooden window showed that the use of an adhesive based on bustilate and liquid glass showed a tensile strength at a pressure of 0.07 N/mm² and 0.12 N/mm² accordingly. The decrease in the adhesive capacity for bustilate is due to the fact that it is a water-dispersion adhesive that is not frost-resistant and loses its properties at low temperatures. The glue based on Liquid Glass has an alkaline environment (pH more than 10), wood contains individual com-

ponents of resin acids that interact with the adhesive layer, reducing adhesion.

The application of rubber adhesive and PVA showed a strength limit of 0.17 N/mm², which ensures good adhesion due to their properties since the adhesive composition should have sufficient elasticity to allow the wood to expand and contract under the influence of temperature. An even better result was obtained for polyurethane glue, which showed the highest tensile strength (0.29 N/mm²), which allows asserting that the identified mechanism of formation corresponds to the properties of the

adhesive layer and its practical attractiveness. Considering the results of Table 2, statistical processing of the results was performed. The

following factors were chosen as variation factors: elongation of the angular joint sample by L_0 , % (factor X_1); maximum force, N (Table 4).

Table 4. Factors of variation

Factors	Code	Variation levels			Variation interval
		-1	0	+1	
Elongation of the angular joint sample by L_0 , %	X_1	5	10	15	5
Maximum force, N	X_2	500	1700	2200	1700

Source: compiled by the authors

The tensile strength (N/mm²) was chosen as the initial parameter (response function), the value of which was recorded during the

testing of samples. The experiment planning matrix and its mathematical interpretation are shown in Table 5.

Table 5. Experiment matrix and its implementation

No.	Factors, type		Planning matrix		Response function	
	X_1	X_2	elongation of the angular joint sample by L_0 , %	Maximum force, N	Y factor	Y calc.
1	1	1	7	2200	0.29	0.28
2	1	-1	15	500	0.70	0.59
3	-1	1	6	2200	0.27	0.34
4	-1	-1	13	500	0.08	0.06
5	1	0	15	1200	0.26	0.38
6	-1	0	8	1200	0.19	0.14
7	0	1	9	2200	0.24	0.18
8	0	-1	17	500	0.06	0.19
9	0	0	10	1200	0.21	0.13
10	0	0	10	1200	0.16	0.13
11	0	0	10	1200	0.22	0.13

Source: compiled by the authors

The F-criterion is calculated, which for this system is $F_R = 15.78$ and a tabular F-criterion is defined, the value of which is $F_T = 19.3$, which is greater than the calculated one, and therefore the equation is adequate.

As a result of modeling, regression equations are obtained and ternary surfaces of changes in the initial parameter are constructed depending on changes in variation factors (Fig. 8).

Regression equation:

$$Y_p = 0,127 + 0,118 \cdot X_1 - 0,007 \cdot X_2 + 0,133 \cdot X_1 \cdot X_1 + 0,058 \cdot X_2 \cdot X_2 - 0,150 \cdot X_1 \cdot X_2. \quad (1)$$

Thus, based on the computer modelling performed, the lowest elongation value of the angular joint sample by L_0 is determined, which is 5.2%. This ensures that the task is completed and the maximum breaking force is about 30.0 H.

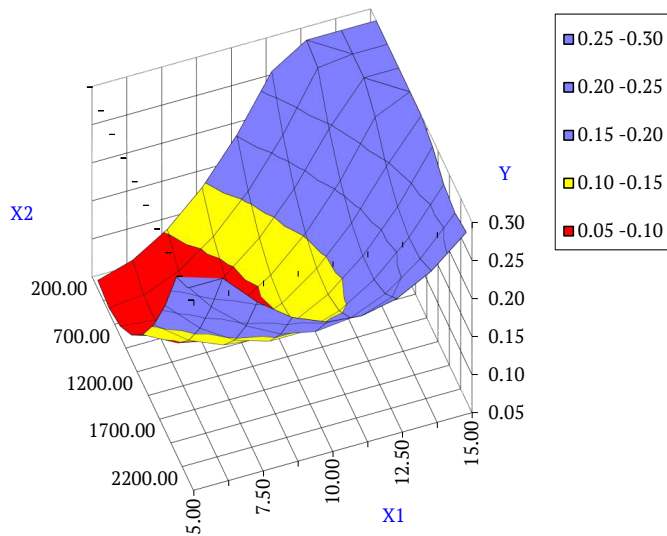


Figure 8. Ternary surfaces of changes in the output parameter depending on changes in the factors of variation in the elongation of the angular joint sample by L_0 and maximum breaking force

Source: compiled by the authors

Wood and wood products are widely used in building structures. The problem lies in ensuring their stability and durability since they have a number of disadvantages that limit their use. In this sense, there is an interpretation of the results for determining the quality of the film, namely, inherent adhesion as the ability to glue wood. The absence of delamination of the adhesive contact on the wood surface during the action of the maximum destructive pressure indicates a positive result (Ülker, 2016).

When considering adhesive layers or surfaces, cohesive rigidity and the possibility of delamination during operation are usually neglected, which leads to a reassessment of the pressure-bearing capacity of the structure. Therefore, B. Kawecki (2023) developed guidelines for complex nonlinear modelling of adhesive bonds in wood composite materials.

When investigating the adhesive layer on pine wood after temperature and humidity fluctuations, as follows from the results obtained

(Fig. 8, Table 3), the process of forming a solid smooth coating with high adhesive contact is natural. In this sense, there is an interpretation of the results of determining the quality of the film, namely, the inherent adhesion to the ability to glue wood. This indicates that there is no stratification of the adhesive contact on the wood surface, which can be identified under the maximum destructive pressure. This means that considering the fact of wood sticking opens up the possibility for effective regulation of the properties of wood products in industrial production conditions.

Modification does not always improve the characteristics of the adhesive. Thus, D.R. Trisatya *et al.* (2023) evaluated the use of tannin resorcinol formaldehyde (TRF) for the manufacture of Cross-laminated timber (CLTs). According to the results, the rupture modulus met the standard, but the moisture content and elastic modulus did not. In addition, the compositions showed low formaldehyde emissions in the extreme ranges of 0.001-0.003 mg/L.

F. Stoeckel *et al.* (2013) also claimed a substantial difference between solid wood adhesives and composite materials. Moreover, the latter show stronger connections. It is necessary to consider factors affecting the adhesive properties – temperature, humidity or aging of joints.

A study conducted by I. Gavrilović-Grmuša *et al.* (2016) focused on investigating the effect of specific pressure during the pressing process on the penetration of urea-formaldehyde (UF) adhesive into Poplar materials, and on the shear strength of compounds formed at different pressures. An epifluorescence microscope was used to measure adhesive penetration, and penetration was examined by analysing microtome sections (20 microns thick) cut from compound samples. The total penetration depth (dap) and the size of the interfacial region (I) increased with increasing pressure from 0.5 to 1.0 N/mm². A further increase in pressure to 1.5 N/mm² did not lead to substantial changes in dap or I. On the other hand, the area of filled lumens and rays (A) showed a constant decrease with increasing specific pressure. This behaviour also affected the filled interfacial region (If), which decreased with increasing pressure. Samples, where penetration occurred in the tangential direction, had higher shear strength values and showed a lower dependence on specific pressure compared to radial penetration. The higher shear strength based on radial penetration corresponded to the larger interfacial region of these samples. The highest shear strength in both directions of penetration was obtained at a specific pressure of 1.0 N/mm².

Analysis of the nature of adhesives and the results of research data to determine the tensile strength, maximum force and effects of temperature and humidity fluctuations indicates changes in the quality of the adhesive layer, since the stability of polyurethane glue is more stable compared to bustilate and liquid glass.

N. Hariz *et al.* (2023) also claimed the effectiveness of using polyurethane (PU 1.2) adhesives in the manufacture and operation of cross-laminated wood (CLT) from the wood of Mangium (*Acacia mangium*) and Schima (*Schima wallichii*). Despite the different physical and chemical properties of Mangia and Schima wood, they have the same wettability with PU 1.2. Thus, the Schima-Mangium-Schima CLT hybrid has the potential to improve dimensional stability and mechanical properties. Along with high mechanical performance for glued structures, considerable attention is paid to the safety of operation of such products. Y. Jang & K. Li (2015) investigated a new adhesive made from natural materials – low-fat soy flour (SF) and magnesium oxide (MgO). The resulting structural material met the industrial water resistance requirements for Interior plywood. The high strength of the composition was noted, assumably due to the low solubility of SF-MgO in water.

This does not differ from the practical data well known from the study by Yu. Tsapko *et al.* (2021b), which also links a decrease in the quality of the glued wood layer with a change in the structural composition. The obtained data on the influence of the adhesive layer on the properties of wood products, in particular, on adhesion and environmental friendliness, allow stating the following:

- ◆ the main regulator of the process of resistance to destruction is not only the formation of an adhesive coating layer but also the chemical transformations of components that provide resistance to destruction;

- ◆ a substantial impact on the environmental friendliness of wood products is conducted in the area of the use of safe substances.

Such conclusions can be considered appropriate from a practical standpoint since they allow a reasonable approach to both the formation of the adhesive layer and the determination of the required amount of it. From a

theoretical standpoint, they allow asserting the determination of the mechanism of adhesive action processes, which are certain advantages of this study. However, the results of determining the adhesion of the wood adhesive layer (Table 1) indicate an ambiguous influence of the structure of the wood product. This is primarily manifested in the nature of the destruction of the adhesive layer when the strength limit is determined in tests. Such uncertainty imposes certain restrictions on the use of the results obtained, which cannot be interpreted as shortcomings of this study. The inability to remove these restrictions in the framework of this study creates a potentially interesting area for further research. In particular, tests can be focused on identifying the time point at which an intense decrease in the adhesion of the adhesive layer on wood begins. This detection will allow examining the structural transformations of wood that begin to occur at this time, and identify the input variables of the process that substantially affect the beginning of such a transformation.

Conclusions

When using wooden building materials, the stability of the adhesive layer to the action of atmospheric factors is important, as over time, the building structure can deteriorate which necessitates the use of reliable adhesive materials and prompts the search for them. Therefore, the mechanism of wood bonding with various adhesive mixtures, the influence of moisture and temperature changes on the adhesive layer, has been thoroughly substantiated. However, there is also a need to assess this process. The research results showed that the application of adhesive based on butylate and liquid glass, after exposure to temperature and moisture fields, resulted in a strength limit of 0.07 N/mm^2 and 0.12 N/mm^2 accordingly. The decrease in adhesive capacity for butylate is due to its non-frost-resistant water-based adhesive

nature, which loses its properties at low temperatures. The adhesive based on liquid glass has an alkaline environment (pH greater than 10), and wood contains individual components of resinous acids that interact with the adhesive layer, reducing adhesion.

The application of rubber adhesive and PVA showed a strength limit of 0.17 N/mm^2 , which ensures good adhesion due to their properties since the adhesive composition should have sufficient elasticity to allow the wood to expand and contract under the influence of temperature. The best result was obtained for polyurethane adhesive, which showed the highest strength limit (0.29 N/mm^2), confirming the correspondence of the identified mechanism of adhesive layer formation.

The scientific originality consists in determining the quality of the adhesive layer on the surface of wood formed by polymerisation of adhesives by assessing adhesion and stability to justify its use for wood.

Thus, the analysis of various types of adhesives and experimental studies to determine the strength limit, maximum destructive pressure, and the influence of temperature and moisture fluctuations on the adhesive layer indicate changes in the quality of the wood adhesive bond. This fact allows examining the surface transformation of the adhesive contact of wood affected by temperature and moisture fluctuations and identifying parameters that considerably affect the initiation of the transformation process of the adhesive layer's destruction. This opens up a new area for investigating the interrelation between adhesive components, properties, and their impact on wood adhesion processes.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgements

None.

References

- [1] Bilik, A.C.B., & Trianoski, R. (2022). Evaluation of the physico-mechanical properties of plywood panels and laminated veneer lumber of *Pinus glabra* Walt. *Floresta*, 52, 323-331. [doi: 10.5380/rev.v52.i2.80147](https://doi.org/10.5380/rev.v52.i2.80147).
- [2] Can, A., Krystofiak, T. & Lis, B. (2021). Shear and adhesion strength of open and closed system heat-treated wood samples. *Maderas. Ciencia y Tecnología*, 23, article number 32. [doi: 10.4067/S0718-221X2021000100432](https://doi.org/10.4067/S0718-221X2021000100432).
- [3] Frederick, A., Kamke, J., & Lee, N. (2007). [Adhesive penetration in wood – a review](https://doi.org/10.1002/for.2007). *Wood and Fiber Science*, 39(2), 205-220.
- [4] Frihart, C.R. (2011). Wood adhesives: Vital for producing most wood products. *Forest Products Journal*, 61(1), 4-12. [doi: 10.13073/0015-7473-61.1.4](https://doi.org/10.13073/0015-7473-61.1.4).
- [5] Frihart, C.R., Brandon, R., Ibach, R.E., Hunt, C.G., & Gindl-Altmatter, W. (2021). Comparative adhesive bonding of wood chemically modified with either acetic anhydride or butylene oxide. *Forests*, 12(5), article number 546. [doi: 10.3390/f12050546](https://doi.org/10.3390/f12050546).
- [6] Gavrilović-Grmuša, I., Dunky, M., Djiporović-Momčilović, M., Popović, M., & Popović, J (2016). Influence of pressure on the radial and tangential penetration of adhesive resin into poplar wood and on the shear strength of adhesive joints. *Bioresources*, 11(1), 2238-2255. [doi: 10.15376/biores.11.1.2238-2255](https://doi.org/10.15376/biores.11.1.2238-2255).
- [7] Hariz, T.M.R., Hadi, Y.S., Lubis, M.A.R., Sari, R.K., & Hidayat, W. (2023). Physical and mechanical properties of cross-laminated timber made of a combination of mangium-puspa wood and polyurethane adhesive. *Jurnal Sylva Lestari*, 11(1), 37-65. [doi: 10.23960/jsl.v11i1.645](https://doi.org/10.23960/jsl.v11i1.645).
- [8] Jang, Y., & Li, K. (2015). An all-natural adhesive for bonding wood. *Journal of the American Oil Chemists' Society*, 92, 431-438. [doi: 10.1007/s11746-015-2610-y](https://doi.org/10.1007/s11746-015-2610-y).
- [9] Kawecki, B. (2023). Numerical modelling and experimental testing on polyurethane adhesively bonded joints behaviour in wood-wood and wood-carbon fibre reinforced polymer layouts. *Advances in Science and Technology Research Journal*, 17(2), 36-52. [doi: 10.12913/22998624/159723](https://doi.org/10.12913/22998624/159723).
- [10] Kol, H.S., Özbay, G., & Altun, S. (2009). Shear strength of heat-treated tali (*Erythrophleum ivorense*) and iroko (*Chlorophora excelsa*) woods, bonded with various adhesives. *Bioresources*, 4(4), 1545-1554. [doi: 10.15376/biores.4.4.1545-1554](https://doi.org/10.15376/biores.4.4.1545-1554).
- [11] Perçin, O., & Uzun, O. (2014). Determination of bonding strength in heat treated some wood materials. *Faculty of Forestry Journal*, 15, 72-76. [doi: 10.18182/tjf.91069](https://doi.org/10.18182/tjf.91069).
- [12] Sebera, V., Pečnik, J.G., Azinović, B., Milch, J., & Huč, S. (2020). Wood-adhesive bond loaded in mode II: experimental and numerical analysis using elasto-plastic and fracture mechanics models. *Holzforschung*, 75(7), 655-667. [doi: 10.1515/hf-2020-0141](https://doi.org/10.1515/hf-2020-0141).
- [13] Stoeckel, F., Konnerth, J., & Gindl-Altmatter, W. (2013). Mechanical properties of adhesives for bonding wood – A review. *International Journal of Adhesion and Adhesives*, 45, 32-41. [doi: 10.1016/j.ijadhadh.2013.03.013](https://doi.org/10.1016/j.ijadhadh.2013.03.013).
- [14] Tao, X., Tian, D., Liang, S., Li, S., & Fu, F. (2023). Effects of wet treatment on bonding strength and electrothermal performance of electrothermal plywood bonded with emulsion polymer-isocyanate adhesive. *Polymer Composites*, 44(2), 1331-1342. [doi: 10.1002/pc.27173](https://doi.org/10.1002/pc.27173).

- [15] Treu, A., Bredeesen, R., & Bongers, F. (2019). Enhanced bonding of acetylated wood with an MUF-based adhesive and a resorcinol-formaldehyde-based primer. *Holzforschung*, 74(4). [doi: 10.1515/hf-2019-0056](https://doi.org/10.1515/hf-2019-0056).
- [16] Trisatya, D.R., Santoso, A., Abdurrachman, A., & Prastiwi, D.A. (2023). Performance of six-layered cross laminated timber of fast-growing species glued with tannin resorcinol formaldehyde. *Journal of the Korean Wood Science and Technology*, 51(2), 81-97. [doi: 10.5658/WOOD.2023.51.2.81](https://doi.org/10.5658/WOOD.2023.51.2.81).
- [17] Tsapko, Y., Horbachova, O., Bondarenko, O., & Mazurchuk, S. (2021a). Justification of conditions of application of thermo modified veneer for protection of wooden products from moisture. *IOP Conference Series: Materials Science and Engineering*, 1164, article number 012050. [doi: 10.1088/1757-899X/1164/1/012050/](https://doi.org/10.1088/1757-899X/1164/1/012050/).
- [18] Tsapko, Yu., Vasylyshyn, R., Melnyk, O., Lomaha, V., Tsapko, A., & Bondarenko, O. (2021b). Regularities in the washing out of water-soluble phosphorus-ammonium salts from the fire-protective coatings of timber through a polyurethane shell. *Eastern-European Journal of Enterprise Technologies*, 2(10(110)), 51-58. [doi: 10.15587/1729-4061.2021.229458](https://doi.org/10.15587/1729-4061.2021.229458).
- [19] Ülker, O. (2016). Wood adhesives and bonding theory. In *Adhesives – applications and properties* (pp. 271-288). London: InTechOpen. [doi: 10.5772/65759](https://doi.org/10.5772/65759).
- [20] Yalçın, İ., & Esen, R. (2023). Adhesive type's effects on adhesive strength of densified reinforced laminated wood obtained from black poplar (*Populus nigra* L.). *BioResources*, 18(1), 1155-1165. [doi: 10.15376/biores.18.1.1155-1165](https://doi.org/10.15376/biores.18.1.1155-1165).

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Анотація. Деревина та деревинні клеєні вироби широко застосовуються як будівельні конструкції в різних галузях будівництва, що експлуатуються в широких межах впливу атмосферних чинників та потребують забезпечення стійкості та довговічності. Тому мета полягала у проведенні експериментальних досліджень для визначення стійкості клейового з'єднання віконного елемента з деревини під впливом температурних та волого статичних коливань. У зв'язку з цим застосовано комплексний підхід для експериментального встановлення ефективності клеєного шару деревини шляхом вивчення стійкості адгезійного шару до руйнування при зміні температурно вологісних полів в широких межах. За експериментальними значеннями межі клейового шару після дії температурно вологісних полів на зразок клеєної деревини встановлено, що найкращий результат межі міцності (0,29 Н/мм²) отримано для поліуретанового клею. Для каучукового клею та ПВА межа міцності склала 0,17 Н/мм², що досить добре забезпечує адгезію завдяки своїм властивостям. Це пояснюється тим, що клейовий склад повинен володіти достатньою еластичністю, щоб дозволяти деревині розширюватися і всихати під впливом температури.

Натомість для клеєного шару на основі бустилату та рідкого скла встановлено межу міцності при навантаженні 0,07 Н/мм² та 0,12 Н/мм² відповідно. Зниження адгезійної здатності для бустилату пов'язано з тим, що при низькому рівні температури він втрачає свої властивості. Клей на основі рідкого скла має лужне середовище та взаємодіє з компонентами смоляних кислот деревини, знижуючи адгезію. Отримані результати дозволяють підібрати ефективні клеї для виготовлення композиційних матеріалів з деревини залежно від умов експлуатації та передбачити властивості клеєної деревини

Ключові слова: клеєна деревина; технологічні параметри; температурно-вологісні поля; стійкість; міцність адгезійного шару