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# Effect of the operating environment conditions of wood composites on the adhesive joint strength

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**Abstract**. To ensure the durability and safe operation of wood composite products, it is necessary to clearly understand how operating conditions affect the adhesive properties of materials. The aim of the study was to experimentally investigate the influence of operating conditions on the change in weight and size of samples with a base of chipboard and medium-density fibreboard, laminated with oak veneer using glues of different degrees of moisture resistance was experimentally investigated. The regularities of these factors effects on the materials and the strength of the glue joint have been established. It was found that the increase in weight of samples with a chipboard base was at the level of 6.25%. For medium-density fibreboard, the value was slightly different and was 4.3%. If the environmental conditions were combined, the indicators of chipboard and medium-density fibreboard samples decreased to 3.72 and 2.99%, respectively. It had also been established that the most stable was glue "Rakoll Express D3". While the worst performance was demonstrated by the glue "Woodmax WR 13.50M". The maximum increase in linear dimensions was recorded in chipboard samples with "Rakoll Express D3" glue – 5.25%. Stability coefficients were calculated, indicating a significant decrease in strength, especially under the influence of humidity and temperature at the same time. The least stable was the combination of medium-density fibreboard and "Woodmax WR 13.50M" glue. Instead, the best resistance was demonstrated by the combination of chipboard with "Rakoll Express D3" glue. It was found that the humidity of the environment has a more significant influence on the linear dimensions. The use of wood composites in structures where materials are exposed to changes in temperature, humidity, and ultraviolet radiation is important to ensure the long-term service and reliability of such products

**Keywords**: wood materials; operating conditions; linear dimensions; wet environment; temperature and humidity fluctuations; destructive pressure

## Introduction

As the increase in greenhouse gas emissions due to industrial development accelerates global warming, architecture in the 21st century is moving toward meeting not only structural stability, but also energy efficiency and environmental considerations. Along with reliability, building codes and standards require buildings to be airtight, which helps save energy and avoid structural damage, as well as providing good sound and thermal insulation (Lysenko *et al.*, 2019).

Gluing is an important technological stage of connection in many industries, including furniture. The adhesive joint is gaining more and more interest due to the increasing demand for the combination of disparate structural elements When two materials are in contact, proper adhesion between them is essential. Therefore, according to M. Derikvand *et al.* (2021), it is necessary to successfully combine methods of achieving the required joint strength, even between different types of wood materials. A. Pizzi & K.L. Mittal (2018) noted that the main reason adhesion cannot be clearly defined is its very complex nature. Adhesion research over the years has resulted in a more consistent and multidirectional definition of adhesion.

People have long built construction using wooden elements. The large size and uniformity of the properties of Cross Laminated Timber Structures (CLT) panels determine their potential for construction (bearing walls, floors). As with solid wood, CLT structures are significantly affected by the humidity of the environment.

F. Brandstätter *et al.* (2023) showed that moisture transport model can be used to realistically simulate moisture absorption and drying under adverse conditions. The effect of adhesive lines connecting the layers of CLT panels during the experiment on moisture transfer was investigated. It was found that the adhesive line has little effect on the moisture content of the surface layers of CLT, but the effect increases towards the middle layer. However, the environmental conditions of the operation of these panels were not investigated.

Research into the manufacture of bonded structures and their manufacturing processes has contributed to finding ways to make such products cheaper. This approach can provide a significant reduction in overall construction costs. The main aim of the work by P. Resnais *et al.* (2021) was to study the use of residual materials resulting from the processing of CLT panels. That is, assessed the possibility of reprocessing residual materials resulting from the processing of glued wooden structures. During the testing of the panels, two main objectives were realized: to compare the technical characteristics of the remnants of the CLT panels with the classic CLT panel and to evaluate the effect of two types of resins (melamine-urea-formaldehyde (MUF) and polyurethane (PU)) on the structural properties of the recycled CLT materials. Research results show that the recycling of glulam construction waste can give good results, and the waste of CLT panel production can be successfully used in construction, reducing the cost of CLT panel production. However, the influence of operating environment conditions on such products has not been investigated.

Many studies have been directed to the modification of adhesive compositions. Thus, V.G. Ravindra (2023) investigated the effect of adding N-methylol acrylamide (NMA) co-monomer to PVA-based wood glue on water resistance and thermal stability. Compared with the traditional water-resistant wood adhesives, the water resistance of the polymer-based starch-stabilized PVAc-NMA emulsion adhesive was similar to that of the PVA-stabilized PVAc-NMA emulsion-based adhesive. The cross-linking reaction between the amide groups of the copolymer chain and the hydroxyl groups of aluminium chloride and starch and PVA forms a cross-linked structure, which occurs quickly at room temperature, according to Fourier transform infrared analysis. The effectiveness of starch-stabilized PVA-NMA wood adhesives was evaluated by measuring the shear stress of wood joints in water according to the EN 204:2002 (2002), EN 205: 2003 (2003) D3 standard. The starch-modified adhesive demonstrated superior water resistance, mechanical strength characteristics, and geometric stability in contrast to cross-linked stabilized PVA wood adhesive.

The use of dry powder mixtures of polyester resins is encouraged in adhesive structures using environmentally safe technology. As a result of experimental studies by S. Mazurchuk *et al.* (2023), proved the convenience of plywood production based on dry adhesive mixtures of polyester resins was substantiated. The strength limit of the surface layer of plywood was proven to exceed 1.2 times the standard value for plywood pressed at 200°C and 1.04 times the standard value at 240°C. With regard to the chipping strength of the adhesive layer of the plywood, an improvement was observed. The obtained indices exceeded the standard values after dry exposure and after dipping for both types of plywood – 2.13, 1.86, 1.88 and 1.73 MPa at the standard 1.5 MPa. The chemical changes in the wood during pressurization at high temperatures were not analysed.

The chipboard industry cannot meet the needs of the market, so fillers have been used to save raw materials. Also, their use helps to change the properties of plates and expands the scope of their use. M.E. Ergun *et al.* (2023) investigated the effect of adding different proportions of activated carbon (0, 1.5, 4.5 and 7.5%) on the physical properties (density, moisture content, swelling in thickness and water absorption) of chipboard. As a result, it was found that the density became greater and the water content decreases with an increase in the content of activated carbon. This indicates improved dimensional stability and water resistance. The mechanical properties (internal joint strength, modulus of rupture, and modulus of elasticity) are significantly improved with the addition of activated carbon. The actual analysis showed that the addition of activated carbon reduced in mass loss by 6.15% compared to the control group. There is no data on the surface characteristics of the material and the ability to joint with other materials.

Usually, products made of wood and wood materials are within wide limits of temperature and humidity conditions of the environment. Their surface can be protected by applying paint and varnish materials, including oil-waxes. This measure slightly extends the service life of the products. It is also possible to apply adhesive compositions of various degrees of resistance, which will ensure the dimensional stability of the elements and reliability. In this regard, there is a need to establish the physical and mechanical parameters of the adhesive layer depending on the influence of various environmental factors, which determined the need to conduct this study.

Based on the analysis of literary sources, it was established that not only the characteristics of wood or wood materials are important for the manufacture of a durable construction or product. The technical parameters of the applied glues also affect the strength of the elements due to the formation of stable adhesives. Adhesive compositions should be characterized by non-toxicity, economic efficiency, easy application and resistance to atmospheric influences. These provide the basis for conducting studies to determine the parameters that warrant the use of wood and wood material adhesives in the manufacture of various products.

The aim was experimental substantiation of the stability of the adhesive joint based on glues of different degrees of water resistance under the influence of temperature and humidity changes. To achieve the aim, the task was set to conduct a set of this research to determine the influence of the operating environment of the product on the change in physical characteristics and strength of the adhesive layer.

## Materials and Methods

The choice of material for facades and furniture frames has a significant impact on the quality and appearance of the final product. Medium-density fibreboard (MDF) and chipboard have their advantages and are used in various products. For the study, these two bases were faced with oak veneer using three brands of glues – Rakoll Express (D3) (Germany), Rakoll ECO-4 (D4) (Germany), Woodmax WR 13.50M (D3) (WR) (Poland) – which were chosen based on the prioritization method (Table 1).

**Table 1.** The final matrix for calculating the complex priority of glue

| Glue brand | Glue priority according to indicators | | | | | Indicator priority | | Comprehensive priority |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | number | value | |
| Rakoll Express D3 | 0.26 | 0.22 | 0.27 | 0.23 | 0.20 | 1 | 0.17 | 0.24 |
| Rakoll ECO-4 | 0.13 | 0.20 | 0.23 | 0.23 | 0.16 | 2 | 0.15 | 0.19 |
| FOLLMANN FOLCO LIT D4 W91 | 0.17 | 0.20 | 0.18 | 0.23 | 0.17 | 3 | 0.20 | 0.19 |

*Table 1, Continued*

| Glue brand | Glue priority according to indicators | | | | | Indicator priority | | Comprehensive priority |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | number | value | |
| FOLLMANN FOLCO LIT X 3000 | 0.17 | 0.20 | 0.18 | 0.16 | 0.25 | 4 | 0.26 | 0.19 |
| Glue Woodmax WR 13.50M, class D3 | 0.26 | 0.18 | 0.14 | 0.14 | 0.22 | 5 | 0.22 | 0.18 |

**Note:** 1 – glue viscosity, mPa·s; 2 – density, kg/m$^3$; 3 – consumption norm, g/m$^2$; 4 – minimum pressing time, min.; 5 – price

**Source:** compiled by the authors

Glue was applied with rollers for a more uniform distribution of glue. Gluing took place on a vacuum press – holding for 15 minutes at a temperature of 55 °C, pressing pressure of 0.7 atm. (Fig. 1). After technological aging, the pressed plates were cut into samples of 50×50 mm size.

a

b

**Figure 1.** Preparation of samples

**Note:** a – pressing of plates, b – cutting of experimental samples

**Source:** compiled by the authors

For experiments, the samples were divided into 5 groups and labelled accordingly (Fig. 2).

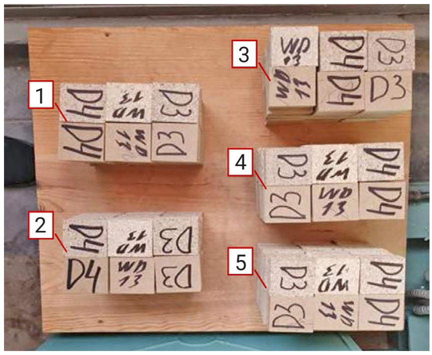



**Figure 2.** Experimental samples with an MDF/chipboard base are faced with oak veneer using glues of various degrees of water resistance

**Note:** 1 – control samples; 2 – aging in conditions of high humidity; 3 – at elevated temperature (+80°C); 4 – at low temperature (-15°C); 5 – combined influence of environmental conditions (humidity, high and low temperature)

**Source:** compiled by the authors

During the experiment, a comprehensive approach was employed to experimentally determine the effectiveness of the adhesive joint by examining the resistance of the adhesive layer to degradation following exposure to varying temperature and humidity conditions. The testing method for resistance to atmospheric fluctuations involved simulating the effects of external environmental conditions on the stability of the adhesive layer to assess changes in evaluation metrics before and after the temperature and humidity alterations. The test cycle of changes in temperature and humidity fields on the adhesive layer of wood included several stages (Fig. 3). At the beginning, the samples were moistened with a sprayer and kept at a temperature of 20 ± 2°C and a relative humidity of 97 ± 3% for 6 hours. Then holding at a low temperature -15 ± 3°C for 6 hours. Then conditioning at a temperature of 20 ± 2°C and a relative humidity of 65 ± 3% for 6 hours. At the end of keeping the samples at a high temperature 80 ± 2°C for 6 hours. Each stage was accompanied by weighing and measuring the dimensions of the samples.

a b c

**Figure 3.** Exposure of experimental samples in different temperature and humidity conditions
**Note:** a – humid environment, b – high temperature (80 ± 2)°C, c – low temperature (-15 ± 3)°C
**Source:** compiled by the authors

To determine the operational stability of the adhesive layer, the strength of the connection during chipping and the influence of environmental factors on this indicator were determined. Determination of the amount of moisture absorption by the samples was carried out according to the method, the essence of which was the periodic determination of the amount of absorbed moisture after exposure in different temperature and humidity conditions (Tsapko *et al.*, 2022).

Determination of the strength of adhesive layers was carried out in accordance with ISO 9653:1998 (1998).

## Results and Discussion

During the exposure of the samples in different climatic conditions, the change in their humidity at the end of each cycle (the duration of the cycle is 6 days) was determined. For greater convenience, the average values for each of the groups were calculated (Table 2).

**Table 2.** Change in weight of samples in different environmental conditions

| Operating environment conditions | Glue | Weight, g | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | initial value | 1 cycle | 2 cycle | 3 cycle | 4 cycle | initial value | 1 cycle | 2 cycle | 3 cycle | 4 cycle |
| | | chipboard | | | | | medium-density fibreboard | | | | |
| The humidity of the environment (97%) | D3 | 28.17 | 29.28 | 29.39 | 29.70 | 29.98 | 33.31 | 33.83 | 33.98 | 34.41 | 34.63 |
| | D4 | 28.42 | 29.36 | 29.64 | 30.12 | 30.14 | 34.20 | 34.83 | 35.39 | 35.51 | 35.83 |
| | WR | 28.36 | 29.37 | 29.76 | 29.97 | 30.14 | 33.11 | 33.59 | 34.02 | 34.19 | 34.49 |

*Table 2, Continued*

| Operating environment conditions | Glue | Weight, g | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | initial value | 1 cycle | 2 cycle | 3 cycle | 4 cycle | initial value | 1 cycle | 2 cycle | 3 cycle | 4 cycle |
| | | chipboard | | | | | medium-density fibreboard | | | | |
| Ambient temperature (+80°C) | D3 | 28.41 | 27.18 | 26.91 | 27.02 | 27.98 | 33.71 | 32.41 | 32.15 | 32.25 | 33.03 |
| | D4 | 28.55 | 27.34 | 27.10 | 27.22 | 28.13 | 34.43 | 33.21 | 32.92 | 33.06 | 33.87 |
| | WR | 29.50 | 27.91 | 27.63 | 27.78 | 28.77 | 33.19 | 31.82 | 31.56 | 31.69 | 32.54 |
| Ambient temperature (-15 °C) | D3 | 28.30 | 28.33 | 28.29 | 28.28 | 28.00 | 33.51 | 33.53 | 33.55 | 33.45 | 33.28 |
| | D4 | 28.56 | 28.66 | 28.61 | 28.54 | 28.38 | 34.02 | 34.23 | 34.23 | 34.14 | 34.00 |
| | WR | 29.04 | 29.00 | 28.78 | 28.87 | 28.63 | 32.94 | 32.92 | 32.94 | 32.84 | 32.70 |
| Combination of environment parameters | D3 | 28.40 | 27.54 | 27.65 | 27.19 | 27.47 | 33.55 | 32.52 | 32.50 | 32.21 | 32.45 |
| | D4 | 28.83 | 27.87 | 27.99 | 27.54 | 27.81 | 34.27 | 33.42 | 33.49 | 33.07 | 33.35 |
| | WR | 29.34 | 28.14 | 28.27 | 27.77 | 28.06 | 33.23 | 32.25 | 32.39 | 31.93 | 32.24 |

**Source:** compiled by the authors

Analysing the results of the Table 2, it is noted that in conditions of high humidity, an increase in the weight as of chipboard and MDF samples is observed. The largest weight increase occurs in chipboard samples – 6.25% versus 4.3% for MDF. When the samples are kept at a high temperature, a predicted decrease in weight is observed. However, towards the end of the experiment, a slight increase in the weight of chipboard and MDF samples is observed, which may mean some problems in observing the conditions of the experiment. In general, the weight of the samples decreased by only 1.84%. At low temperatures, the weight of the samples practically does not change (the mass decreases by 0.77%). Under combined environmental conditions, chipboard and MDF samples show a decrease in weight by 3.72 and 2.99%, respectively.

In general, the humidity of the environment has the greatest influence on the change in the weight of the samples. Thus, the conducted studies allow us to conclude that chipboard and MDF are sensitive to the influence of the humidity of the environment, which leads to the absorption of moisture by the material, an increase in its weight and the stability of the adhesive layer. Also, during the experiment, the dimensions of the experimental samples were fixed. The percentage change in the linear dimensions of the samples was determined (Table 3).

**Table 3.** The influence of environmental conditions on the change in the linear dimensions of the samples

| Operating environment conditions | Glue | Change of linear dimensions, [%] | | | | | |
|---|---|---|---|---|---|---|---|
| | | chipboard | | | MDF | | |
| The humidity of the environment 97% | D3 | +0.20 | +5.25 | +0.33 | +0.07 | +2.99 | 0.00 |
| | D4 | +0.15 | +4.44 | +0.22 | +0.10 | +4.28 | +0.08 |
| | WR | +0.18 | +2.94 | +0.10 | +0.08 | +3.85 | +0.07 |
| Ambient temperature (+80°C) | D3 | -0.17 | -1.20 | -0.15 | -0.18 | -2.02 | -0.13 |
| | D4 | -0.13 | -0.97 | -0.12 | -0.39 | -1.54 | -0.12 |
| | WR | -0.05 | -2.10 | -0.28 | -0.23 | -0.88 | -0.12 |

*Table 3, Continued*

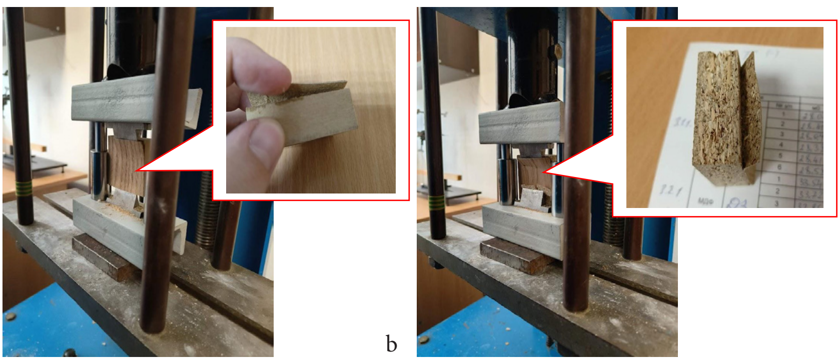
| Operating environment conditions | Glue | Change of linear dimensions, [%] | | | | | |
|---|---|---|---|---|---|---|---|
| | | chipboard | | | MDF | | |
| Ambient temperature (-15 °C) | D3 | -0.02 | -0.60 | -0.13 | -0.03 | -0.60 | -0.03 |
| | D4 | +0.02 | -0.55 | -0.02 | -0.07 | -0.79 | -0.15 |
| | WR | +0.08 | -0.74 | -0.08 | -0.03 | -0.69 | -0.03 |
| Combination of environment parameters | D3 | +0.01 | -0.56 | -0.10 | -0.16 | -2.31 | -0.02 |
| | D4 | -0.06 | -0.61 | 0.00 | -0.19 | -2.07 | -0.10 |
| | WR | -0.12 | -1.36 | -0.27 | +0.08 | -2.02 | -0.07 |

**Source:** compiled by the authors

In a wet environment there is an increase in the linear dimensions of samples for all types of glue and materials. The largest increase was noted in samples with a chipboard base with D3 glue (up to 5.25% along the length). At an elevated temperature, the size of the samples decreases for all variants of the samples. The largest decrease is observed for MDF with D4 glue (up to 2.07% in width). At low temperatures, changes in size are insignificant – they range from 0-0.08%. Under the conditions of combined influence (humidity and different temperature values), slight changes in dimensions are observed, mainly a decrease in the range of 0-0.27%.

In general, samples glued with WR are more stable. And samples with a chipboard base show greater sensitivity to changing conditions than with MDF. The largest change in linear dimensions occurs in the thickness of the samples, because the inner layer of sheet materials is usually less dense than the outer ones. At the same time, the amount of changes in the bases is different, which is due to the difference in the structure of the materials. Namely, the size of the chip fraction used in the inner layers of chipboard and the more uniform fibre structure of MDF.

With regard to the main experiment (determination of the destructive pressure on the adhesive joint after exposure of the samples in different climatic conditions using a tearing machine) – a visual assessment of the fracture surface after loading is shown in Figure 4.



a b

**Figure 4.** Pressure of samples in the tearing machine during determination of the strength limit of the adhesive joint

**Note:** a – MDF base; b – the base of chipboard

**Source:** compiled by the authors

The nature of the destruction for samples with different bases is slightly different. In samples with a chipboard base, veneer destruction is observed under a certain pressure, while in samples with MDF, the veneer remains intact. This is explained by the different density of these materials.

On the peeled veneer, the base material remains over the entire area, which indicates strong adhesive connections regardless of the conditions before the experimental exposure of the samples. The nature of the destruction of the samples mainly occurred along the material of the base, with separation of the outer layer of the base to the veneer. Only in some cases was veneer destruction observed.

The indicators of the destructive pressure on all groups of samples are shown in Figure 5 in the form of diagrams for visual comparison.

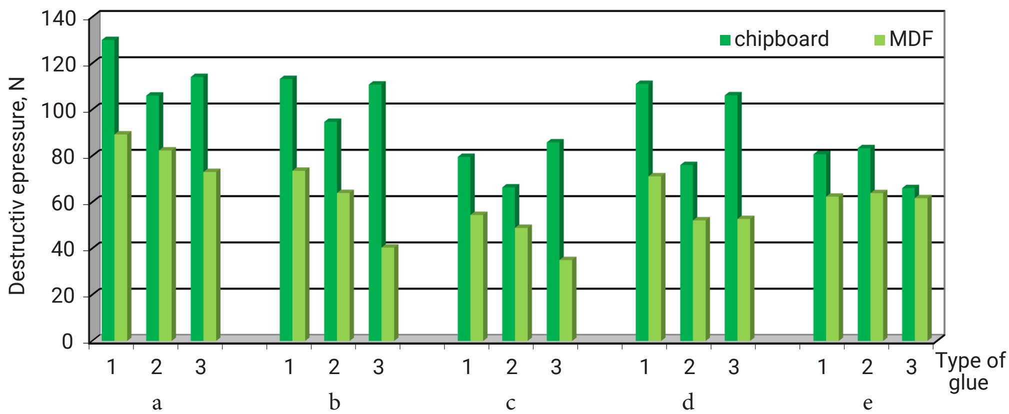



**Figure 5.** The maximum breaking load of test samples

**Note:** 1 – glue D3; 2 – glue D4; 3 – glue WR; a – control; b – after exposure in a humid environment; c – after exposure to elevated temperature; d – after exposure in a freezer; e – a combination of temperature and humidity conditions

**Source:** compiled by the authors

Analysing the obtained results, it was established that for the control samples, the highest destructive pressure was recorded for chipboard with D3 glue (130.03 N), and the lowest for MDF with WR glue (72.99 N). In conditions of high humidity, the pressure on the adhesive joint decreased for all samples, except for chipboard with WR. The biggest decrease in MDF with WR glue is 45%. At elevated temperature, a decrease in the value of the destructive pressure is also observed for all samples. The biggest decrease – 34% – in samples with a chipboard base with D3 glue. In conditions of low temperature, the pressure decreased not so significantly, by a maximum of 18% for chipboard with D4 glue. With the combined effect of the factors, the largest load reduction in chipboard with WR glue is by 42%. Stability coefficients were calculated to determine the influence of environmental factors (Table 4).

**Table 4.** Indicators of stability of the adhesive seam depending on the operating environment

| Research samples | | The influence of environmental conditions on the stability of the adhesive joint | | | |
|---|---|---|---|---|---|
| **Basis** | **Type of glue** | **humidity** | **high temperature** | **low temperature** | **combination of parameters** |
| Chipboard | D3 | 0.87 | 0.61 | 0.85 | 0.62 |
| | D4 | 0.73 | 0.51 | 0.58 | 0.64 |
| | WR | 0.85 | 0.66 | 0.82 | 0.51 |
| MDF | D3 | 0.82 | 0.61 | 0.80 | 0.70 |
| | D4 | 0.72 | 0.55 | 0.58 | 0.72 |
| | WR | 0.45 | 0.39 | 0.59 | 0.69 |

**Source:** compiled by the authors

If the glue is not heat- stable enough, the glued joint may fail to maintain its adhesion. J. Vaněrek *et al.* (2024) studied the behaviour of glued joints based on phenol-resorcinol-formaldehyde (PRF), polyurethane (PUR) and emulsion polyisocyanate (EPI) under the influence of long-term and short-term elevated temperatures. Calorimetric analysis revealed that the onset of thermal degradation occurred at 135°C for EPI and around 160°C for both PRF and PUR.

Therefore, the toughness of the adhesive joint is negatively affected by both increased humidity and the temperature of the environment, especially the combination of temperature and humidity conditions. The combination of MDF base and WR glue turned out to be the least stable. Instead, the best stability was demonstrated by combining the chipboard base with D3 glue.

The applications of wooden structures are quite varied, as they are utilized in the construction of external walls and roofs, window frames, and doors, suitable for both dry and wet environments. Research conducted by S. Dabin & K. Keonho (2022) on the impact of the production environment on the effectiveness of bonding cross-laminated timber (CLT) with polyurethane (PUR) adhesive demonstrated that adjusting the pressing time based on the adhesive's open time significantly enhances adhesive strength under production conditions. The peeling tests performed under consistent relative humidity and adhesive conditions revealed that the temperature of the production environment affects the reliability of the glue.

Strengthening structural elements with the help of reinforcing tapes is a widely adopted technique of increasing the durability of buildings. Here, the most important element is the adhesive layer, which is involved in the stresses transfer between the aggravated element and the reinforcing tape. Studies A. Szewczak (2021) show the possibility of changing the adhesive's bonding strength by changing composition and application surface of the adhesive. The results obtained from the tests suggest that the method of surface modification, along with the outlined adjustments, can be tailored to the specific conditions of adhesive application. Similar reinforcement was carried out by İ. Yalçın & R. Esen (2023) with industrial wood species. Was found that the type of glue and the process of lamination have a positive influence on the mechanical properties of the material. The essence of this method is to first compress the wooden boards for 10 minutes and then perform lamination. Fiberglass and carbon fibre are suitable as reinforcing elements.

Also, increasing the adhesion strength and water resistance of wood glue can be achieved by varying the SPI concentration, pressing temperature, and pressing time. D. Vnučec *et al.* (2016) thermally modified commercial SPI in a vacuum chamber at 50°C. Distilled water dispersions with SPI mass fractions of 9.09, 9.91, 10.71, 11.50, and 12.28% were prepared. The effective penetration (EP) and tensile shear strength of beech wood samples jointed under the same gluing conditions (in accordance with European standards EN 204 and EN 205) were evaluated. It has been found that the viscosity of the glue increased with increasing SPI concentration. EP rose with increasing viscosity and SPI mass fraction up to 11.50%, after which it started to decline. The optimal pressing temperature determined for this glue was 110°C, with an optimal pressing time of 10 minutes.

In the course of the experiment, it was established (Fig. 5, Table 4) that, regardless of the glue, samples with MDF as a base withstand less pressure than samples with chipboard (the reason for this effect is discussed above), in general, this difference is 35.38%. Based on the results, it became possible to evaluate the influence of different environmental parameters on the change in the linear dimensions of samples with different materials and adhesives (Table 3). The combination of MDF and WR glue turned out to be the most stable.

In order to reduce water absorption, thermal modification of curd is widely practiced today. In particular, the possibility of using various cellulose-containing materials for the manufacture of furniture panels is being investigated. Therefore D.P. Ribeiro *et al.* (2020) evaluated the effect of different levels of heat treatment (170, 200 and 230°C) on the properties of plates made from sugar cane. The experimental panels were evaluated according to their physical (density, degree of compression, moisture, water absorption and swelling) and mechanical (internal connection, tensile strength modulus, flexural modulus) properties. Thermal treatment of cane at 230°C contributed to a significant improvement in the quality of plates. A decrease in water absorption and swelling of the panels in thickness and an increase in the values of the modulus of elasticity were observed. This result confirms the great potential of using 230°C processing for the production of sugarcane slabs.

In accelerated climate aging tests, components are often subjected to multifactor loading. An example of such climatic stress is ripening at high temperatures and humidity (Yang *et al.*, 2021). During the experiment, the connections are subjected to climatic loads from thermal shocks and the influence of high temperature and humidity. As a result, it was found that the dominant aging factor depends on the type of glue.

The humidity of the environment has a significant effect on the strength of the adhesive connection. In all cases, there is a decrease in strength compared to the control samples. The biggest decrease is for MDF with WR glue (by 55%).

Indeed, wood-based products typically face significant limitations regarding water exposure. In their work, R. Magalhães *et al.* (2021) investigated the influence of the plate humidity on its physical and mechanical properties. Medium-density fibreboard (MDF) from different European manufacturers were stored for 9 weeks under specific conditions (approximate temperature range 15-20°C and 50-85% RH). A notable correlation between the moisture content of MDF and the internal strength of the glue joint was identified, revealing a decreasing linear relationship. It was also observed that this effect is reversible – upon drying, the strength of the internal joint increases again.

Interesting in this direction are the studies of various modifications of oriented strand board (OSB). T. Pipíška *et al.* (2020) acetylated spruce (*Picea abies L. Karst*) fibers using acetic anhydride or thermally modified at 180°C. It was established that the equilibrium moisture content of boards with a modified outer layer did not differ from reference boards. Acetylated chipboard and cork particle board had a significant increase in water resistance. Acetylation increased the strength of the internal joint. The results provide a comparison between different chipboard modifications and show a new opportunity to reduce the impact of water on chipboard.

Thus, the analysis of adhesives of different degrees of moisture resistance and experimental studies to determine the effects of temperature and humidity fluctuations on the glued layer and the maximum destructive force indicate changes in the characteristics of the adhesive joint. The following studies will allow to investigate the transformation of the surface of the adhesive contact of wood and wood materials, which is destroyed under the affect of temperature and humidity instability. It is also advisable to determine those parameters that significantly influence the beginning of the conversion process of the destruction of the adhesive layer. A promising research direction is establishing the processes of interrelation between the constituent components of glues and their properties of glues, as well as their influence on processes of adhesion with wooden materials and the long life of the product.

## Conclusions

The largest percentage increase in mass occurs in chipboard samples (6.25% versus 4.3%). At the same time, the action of frost showed the least impact (the weight of the samples decreased by 0.77% on average).

Likewise, the influence of humidity on linear dimensions was significantly greater than the influence of temperature or their combination (3.96% on thickness and 0.13% on planar dimensions A change in size in terms of thickness was noted, while the indicators for chipboard and MDF are slightly different This is due to the difference in the structures of these materials.

Elevated temperature also leads to a noticeable weakening of the strength of the adhesive joint. The greatest decrease in the stability factor is observed for MDF with WR glue (by 61%). The effect of low temperatures is less noticeable, but also leads to a reduction in the fastness of the seam by 15-42%, depending on the base material and glue. The combined action of humidity and temperature changes has a strong negative impact. The greatest reduction in the stability factor is observed for chipboard with WR glue (by 49%).

Therefore, the comprehensive research carried out in the work made it possible to assess the degree of influence of typical operating conditions of furniture in the kitchen on the strength of the adhesive joint and justify the optimal choice of base materials and glue to ensure the necessary strength and durability of the products. In future studies, it is worth expanding the list of researched wood composite materials that were not included in this work. It is also advisable to modify the coating material using various methods and determine the positive or negative impact of the measures taken on the durability of the finished product.

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## Conflict of Interest

None.

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# Вплив умов середовища експлуатації деревних композитів на міцність адгезійного з’єднання

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**Анотація**. Для забезпечення довговічності та безпечної експлуатації виробів із деревних композитів необхідно чітко розуміти, як умови експлуатації впливають на адгезійні властивості матеріалів. Метою роботи було експериментально дослідити вплив умов експлуатації на зміну маси та розмірів зразків в основі яких деревностружкова (ДСП) та середньої щільності (MDF) плита, шпонованих дубом з використанням клеїв різного ступеню вологостійкості. Встановлено закономірності впливу даних факторів на матеріали та міцність клейового з’єднання. Виявлено, що збільшення маси у зразків з основою ДСП на рівні 6,25 %. Для MDF значення дещо відрізнялося і становило 4,3 %. При поєднанні впливу умов середовища на зразки ДСП і MDF показники зменшувалися до 3,72 та 2,99 % відповідно. Також встановлено, що найстійкішим був клей «Rakoll Express D3». Тоді як найгірші показники продемонстрував клей «Woodmax WR 13.50M». Максимальне збільшення лінійних розмірів зафіксовано у зразків ДСП з клеєм D3 – 5,25 %. Розраховано коефіцієнти стійкості, що свідчать про значне зниження міцності особливо під впливом вологості та температури одночасно.

Найменш стійким було поєднання MDF та клею WR 13.50M. Натомість комбінація ДСП і клею D3 виявилася найкращою. Виявлено, що на лінійні розміри більш вагомим фактором впливу була вологість середовища. Використання деревних композитів у конструкціях, де матеріали піддаються впливу змін температури, вологості та ультрафіолетового випромінювання, є важливим для забезпечення тривалої служби та надійності таких виробів

**Ключові слова**: деревні матеріали; умови експлуатації; стабільність геометричних розмірів; вологе середовище; коливання температури та вологості; руйнівне навантаження