ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 67(1): 89−100, 2025
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2025.67.1.08

DEFORMATION OF WOOD – RESIN PHASE BOUNDARY BY MOISTURE CONTENT CHANGES IN WOOD

Barbora Slováčková – Radek Kovařík

ABSTRACT

In recent years, casting epoxy resins have been on the rise among wood furniture manufacturers. Epoxy resins can be applied to wood of various qualities, including those with defects and textures. A range of problems arise during the production of wood-epoxy resin products. These problems stem from the different characteristics and properties of these materials. The focus of this article is on studying the dimensional changes of openings in beech wood filled with casting epoxy resin during changes in wood moisture content. The stability of the wood-epoxy resin phase boundary during moisture and mechanical stress was also studied. Experimental results confirmed that the dimensions of the openings in wood enlarged proportionately with wood swelling. This resulted in a disruption of the wood-epoxy resin phase boundary stability. The epoxy resin separated from the sides of the openings in wood. During the shrinking process, a limited shrinkage was observed in the vicinity of the openings. This can lead to the formation of cracks in wood. Swelling of the beech wood samples resulted in a significant height difference between the beech wood and the epoxy resin. On the other hand, the shrinking of the samples showed a more tapered height difference between the beech wood and the epoxy resin. The shear strength test did not indicate an adhesive failure but rather a cohesive failure of the epoxy resin. The failure occurred in the epoxy resin, close to the wood-resin phase boundary. This finding confirmed that epoxy resin has a good adhesion to beech wood.

Keywords: epoxy resin; beech; adhesion; moisture stress; mechanical stress; phase boundary.

INTRODUCTION

In comparison to other materials, wood, as a natural, organic composite material, is very specific. Wood has a wide range of positive properties, especially its mechanical properties, which determine its use in the construction and furniture industry. On the other hand, there are some negative properties of wood, such as heterogeneity, hydrophilicity, and dimensional instability during moisture content changes, to name a few. These properties pose a significant obstacle to the optimization of various technological processes, including surface treatment, gluing, and modification, among others. Therefore, modification of wood has been the focus of research for a long time to enhance some of its properties. Currently, there is a wide variety of physicochemical methods for wood modification (Hill, 2006; Reinprecht, 2016; Sandberg *et al.*, 2021; Spear *et al.*, 2021).

One of the first chemical modification methods is the modification of wood with resins. This method was first used in the first half of the 20th century (Stamm and Seborg, 1943, Stamm and Seborg, 1944). Pores in wood, especially lumens of cell elements, were filled out with these modifying substances. The goal of this modification was to enhance the mechanical properties of the modified wood, as well as its dimensional stability during changes in moisture content (Kurjatko *et al*., 1987; Liptáková *et al*., 1991; Deka and Saikia, 2000; Homan and Jorissen, 2004; Dieste *et al*., 2008). Resins are also used in the preservation of archaeological wood (Rowell and Barbour, 1990).

In recent years, the use of casting resins by small furniture enterprises has been on the rise. The manufacturers applied casting resins on solid wood with various textures and even on damaged wood (cracks, openings left after knots fall out, wood decay cavities, etc.). This method of wood modification has gradually gained traction in medium and large enterprises within the furniture industry. The furniture and items produced are mainly tabletops, decorative items, and jewellery (Pacas *et al*., 2023, Kovařík and Tesařová, 2022). Epoxy resins are the main resin kind used for these products. From a designer's perspective, the combination of wood and resin yields new, visually appealing, and intriguing products.

The use of casting epoxy resins in combination with wood revealed several issues arising from the distinct properties of wood and casting resins, particularly in their differing behavior under varying conditions. These problems need to be solved. The research by Kovařík and Tesařová (2022) and Kovařík *et al*. (2023) indicates that one of the problems is the phase boundary stability of wood and casting epoxy resins under mechanical, moisture, and heat stress. According to Guo *et al*. (2022), Wondmagegnehu and Legesse (2023), and Zhou *et al*. (2025), the phase boundary between wood and epoxy resin is the most susceptible to mechanical load, moisture, and heat stress.

Epoxy resins are synthetic materials consisting of mono- or oligomers in the raw state. During the polymerization of the resin, mono- and oligomers chemically crosslink to form a three-dimensional polymer structure. Epoxy resins are widely used in adhesives, paints, coatings, medical implants, and electrical devices (Bilyeu *et al*., 1999, Frihart, 2005, Kumosa, 2006). Epoxy adhesives and coatings are widely used due to their excellent environmental resistance and ability to bond to a wide variety of surfaces. Properties that are important in the processing of uncured epoxy resins, such as viscosity, as well as the final properties of cured epoxies, can be optimized by the appropriate selection of the epoxy monomer and the curing agent or catalyst (Bilyeu *et al*., 1999). The processing of epoxy resins is simplified by their low shrinkage, good adhesion to wood, and lack of volatile by-products (Kovařík and Tesařová, 2022). According to the last cited authors, epoxy resins exhibit greater dimensional stability than wood under varying moisture conditions. The ability of epoxy resins to absorb water is almost null (Vanlandingham *et al*., 1999).

As mentioned earlier, casting resins are often used to fill various cavities and openings in wood. Research by Kúdela and Dubovský (1986) concluded that an opening in wood swells and shrinks proportionally to the swelling and shrinking of solid wood. Therefore, the phase boundary of wood and resin in these products needs to be studied in detail.

The primary focus of this work was to investigate the dimensional changes of an opening in wood filled with casting resin during changes in wood moisture content. Additionally, deformations on the wood-resin phase boundary, adhesion, and overall stability of the wood–epoxy resin system were studied.

MATERIALS AND METHODS

Sample material

Beech wood (*Fagus sylvatica* L.) was used in the experiment; it is a wood species characterized by extensive swelling and shrinkage (Kúdela and Čunderlík, 2012). Five trunks were felled in January 2021 in the locality of Opavské vrchy (the Opava mountains, Czech Republic). The logs were cut approximately at a height of 1.3 m off the ground. The length of the logs was 2 m, and their diameters ranged from 0.4 to 0.5 meters. The logs were sawn into mid-radial and mid-tangential-plane planks. These planks were dried to a moisture content of approximately 16 %. One plank was selected from each log for the experiment. Two sets of samples, each with dimensions of 620 mm × 120 mm × 24 mm (length × width × thickness), were produced. The average density of the beech wood in oven-dried state was 673 $kg \times m^{-3}$.

The casting resin used in this experiment was an epoxy bisphenol-A type resin (Epilox 19-00, Leuna-Harze, Leuna, Germany), and Itamine CA60 (DDCHEM, Oppeano, Italy) was used as the hardener. The epoxy resin was mixed according to the manufacturer's instructions.

Sample preparation for studying dimensional changes during wood moisture content change

Two sets of samples were produced for this experiment. The first set was designed to study the swelling of wood, and the second set was created to investigate the shrinkage of wood.

The first set of samples was oven-dried and then conditioned at an air temperature (t) of 20 °C and relative air humidity (φ) of 40%. The moisture content of these samples was 6±2 %. After drying, five openings with a depth of 22 mm and a diameter of 60 mm were cut into the planks (Fig. 1). The holes were milled on a CNC machining center. The walls and the bottoms of the openings were impregnated with a two-part epoxy-based penetrating coating. According to the manufacturer, this penetrating coating is supposed to stop the resin from penetrating into the wood structure. It should also prevent the air from the wood from passing into the unpolymerized resin; thus, later-formed air bubbles are trapped inside the cured resin. Three coats of the penetrating coating were applied in 30-minute intervals, each coat being gradually applied.

Regarding the maximum thickness of one casting epoxy resin layer poured at once and the depth of the opening in the sample, the casting resin was poured in two layers. This way, any gaps between the resin and wood caused by resin contraction were eliminated. The resin was left to polymerize at a t = 20 °C and a φ = 40%. After a full epoxy resin polymerization (approximately 5 days), the planks were milled on a thickness planer on both sides. The wood on the backside of the plank was worked until the resin layer was exposed, and the opening was open on both sides of the plank. The samples were then placed in a climate chamber for 26 days at a temperature of 20 °C and a relative air humidity of 93%.

Fig. 1 On the left – sample plank with cut openings. On the right – opening after application of the penetrating coating.

The second set of samples was conditioned for 26 days at a temperature of 20 °C and a relative humidity of 93%. After conditioning, five openings were cut into these planks in the same way and with the exact dimensions as for the first set of samples (Fig. 1). The penetrating coating, resin casting, and thickness milling were performed in the same way as for the first set of samples. The resin in these samples was left to polymerize at a temperature of 20 °C and a relative humidity of 93% for 5 days. After polymerization, it was found that the epoxy resin had penetrated deeply into the wood structure. The penetration prevailed significantly in the longitudinal direction of the beech wood, approximately 20 to 30 mm deep (Fig. 2, marked with a red square). It was not possible to determine whether this penetration was caused by the penetrating coating or by the epoxy resin itself.

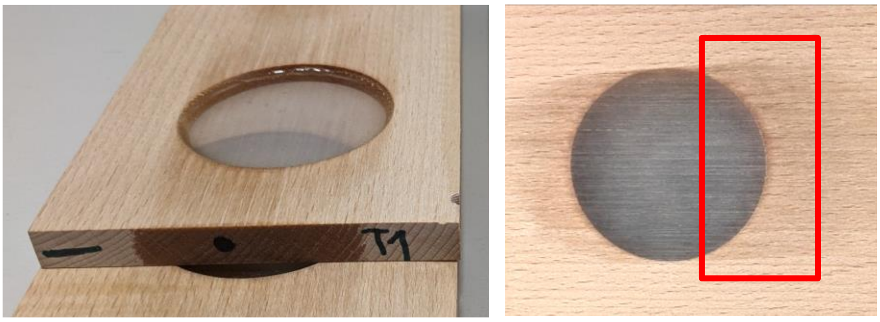

Fig. 2 Epoxy resin poured into the opening in the beech plank and view on the sample from the top.

The planks were then milled on a thickness planer on both sides, following the same process as the first set of samples. The wood on the backside of the plank was worked until the resin layer was exposed, and the opening was open on both sides of the plank. The samples were then oven-dried at 65 °C for 6 hours.

Studying dimensional changes of width and thickness of the samples and openings in the samples filled out with casting resin

The dimensions (width and thickness) of the oven-dried samples from the first set were measured at five locations on the plank, always across the opening, with an accuracy of 0.01 mm. The dimensions of the openings were also measured with the same accuracy. The measurements were repeated after the sorption process. Swelling of widths and thicknesses of the samples was calculated from the measurements according to Eq. (1):

$$\beta_{\Delta w(r,t)} = \frac{x_{w2} - x_{w1}}{x_0} \qquad (1)$$

Where: x_0 is the width (thickness) measurement of the sample at 0 % moisture content 0 % moisture content, x_{w1} is the width (thickness) measurement of the sample at the initial moisture content and x_{w2} is the width (thickness) measurement of the sample after sorption.

The same way of measuring dimensions was applied to the second set of samples. The measurements were taken after conditioning the samples prior to resin pouring and then after drying them at 65 °C for 6 hours. Shrinkage of the widths and thicknesses of the samples was calculated from the measured dimensions according to Eq. (2):

$$\alpha_{\Delta w(r,t)} = \frac{x_{w1} - x_{w2}}{x_{w1}} \tag{2}$$

Where: x_{w1} is the width (thickness) of the samples after conditioning, x_{w2} is the width (thickness) after drying to a certain moisture content.

The swelling extent of the openings $\beta_{w'}$ was calculated according to Eq. 1 and the shrinkage of the openings $\alpha_{w'}$ was calculated according to Eq. 2.

Changes in the wood-epoxy resin phase boundary after swelling and shrinking of the samples were observed on a Keyence digital microscope.

Testing of epoxy resin adhesion to wood by shear strength test

Radial plane samples with dimensions of 630 mm × 180 mm × 24 mm (length × width × thickness) were used for testing the adhesion of epoxy resin to wood. The samples were conditioned to a moisture content (MC) of 8% at a temperature (t) of 20 °C and a relative humidity (φ) of 40 ± 5%. Rectangular openings with a depth of 12 mm were cut into the planks. The epoxy resin was poured into these openings (Fig. 3) according to the procedure described in *Sample preparation for studying dimensional changes during wood moisture content change*.

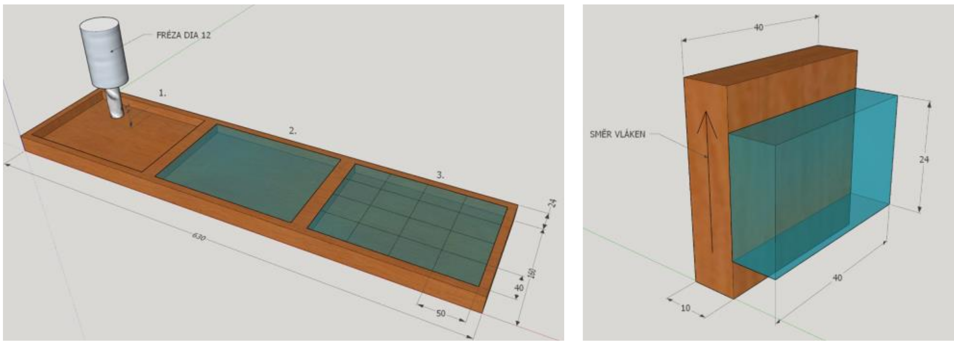

Fig. 3 On the left – sample preparation for the shear strength adhesion test. On the right – the shape of the shear strength sample.

One set of samples was then left to polymerize at a t = 20 °C and a relative humidity φ = 40 ± 5%, and a second set of samples was left to polymerize at a t = 20 °C and a relative humidity φ = 93 ± 5%. The resin was left to polymerize for 5 days. After the resin polymerized, the samples were conditioned again at a t = 20 °C and a relative humidity φ = 40 ± 5%. The samples were then cut on a thickness planer and sawn into samples with dimensions of 40 mm × 50 mm (width × height; radial × longitudinal wood grain direction). Parts of the epoxy resin casting were removed to achieve the final shape of samples (Fig. 3). The area of the resin casting on the wood was measured prior to the shear test. The force was applied parallel to the wood grain. The shear strength was calculated according to Eq. (3):

$$\tau = \frac{F_{max}}{A} \tag{3}$$

Where: F_{max} is the maximum force needed to damage the adhesion of epoxy resin to wood, and A is the area of the epoxy resin casting and wood surface phase boundary (Fig. 3). The shear strength test was considered successful when the epoxy resin separated from the wood in one piece without shattering.

RESULTS AND DISCUSSION

Dimensional changes of openings filled out with casting resin

The moisture content in the beech samples of the first set increased by 14% after the sorption. The widths and heights of the samples swelled proportionally with the change in moisture content. According to Dubovský and Kúdela (1988), the openings in the wood should swell proportionally to the swelling of solid wood. The adhesive bonds between the epoxy resin and the wood were broken; therefore, the opening swelled as if there was no epoxy resin inside it. The openings swelled on average 0.36% more than the widths of the samples. However, a linear regression statistical test revealed no significant difference between the swelling of the opening and the swelling of the widths of the samples (Dubovský and Kúdela, 1988). The results of the beech wood samples swelling and shrinkage extent are presented in Tab. 1.

Tab. 1 Basic statistical characteristics of the swelling and shrinkage of the beech wood samples and the dimensional change of the openings in the samples.

Place and the anatomical direction of the dimensional change measurements		Basic statistical characteristics	Swelling	Shrinking
Beech wood sample	Width	$\bar{x}$ [%] s [%]	2.94 0.94	4.06 0.62
	Thickness	$\bar{x}$ [%] s [%]	4.72 0.84	4.41 0.49
Opening	Width of the sample	$\bar{x}$ [%] s [%]	3.30 0.90	–

Note: The measurement of swelling was performed 20 times and the measurement of shrinking was performed 16 times.

The openings in wood were filled out with a dimensionally stable epoxy resin. Due to the swelling of the beech wood, stress developed at the wood-epoxy resin phase boundary. This stress disrupted the phase boundary stability, resulting in the separation of the epoxy resin inside the opening. The separation of epoxy resin from beech wood after swelling of the sample is presented in Fig. 4. It has a similar character to the patterns observed by Liptáková *et al*., (1991) in wood modified with polystyrene. However, the causes of the phase boundary disruption were different.

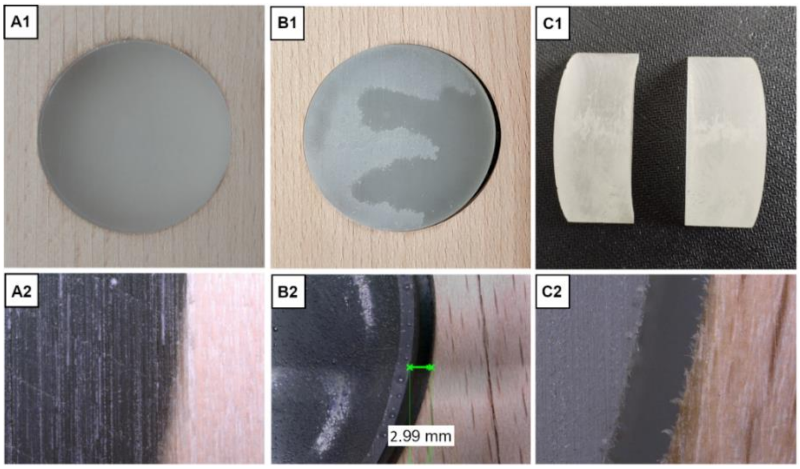

Fig. 4 The opening in the beech wood, with the epoxy resin casting. Figures A1 and A2 show the sample prior to swelling, figures B1 and B2 show the sample after swelling. Figures C1 and C2 show the failure of adhesion.

The most striking separation of the epoxy resin from wood was observed in the cross direction of samples (Fig. 4). The widths of the gaps between the epoxy resin and the beech wood ranged from 1.5 to 3mm in the widest dimension of the opening. The examination of the gap between the epoxy resin and beech wood revealed that the failure of adhesion occurred at the phase boundary between the casting epoxy resin and the epoxy resin layer applied to the openings prior to casting (Fig. 4).

Because the adhesion between the epoxy resin and the beech wood failed, the samples were able to swell evenly throughout their whole size. The samples swelled even in the vicinity of the resin-wood phase boundary along their thickness. This swelling caused a significant height difference between the surface of the epoxy resin and the surface of the swelled beech wood (Fig. 5). This height difference between the resin and the wood was easily noticeable - it was visible to the naked eye and could be felt by touch. The height difference between the resin surface and the wood surface reached up to 1.6mm. Such height differences are significant faults of any product.

According to Zhou *et al*., (2025), the differences in dimensional and chemical stabilities of wood and epoxy resin are the cause of stresses in the phase boundary. This leads to a gradual disruption of the bonds between the wood and the epoxy resin.

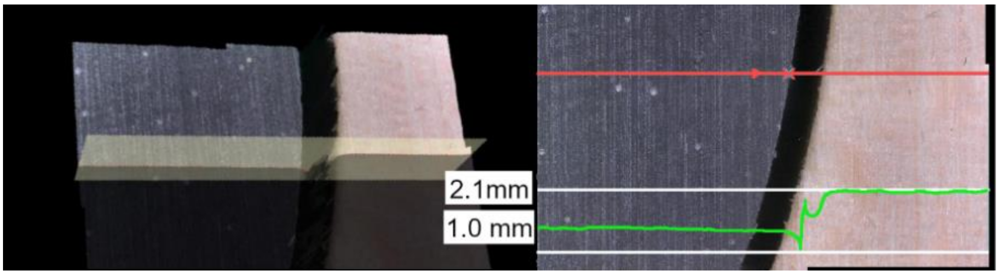

Fig. 5 Height difference between the surfaces of epoxy resin and beech wood after swelling. The red line denotes the measurement area of the height profile; the green line presents the height profile.

The second set of samples, where the resin was cast into wood with a high moisture content, was dried. These samples shrunk. Since the openings were filled tightly with epoxy resin, the fully polymerized resin prevented the openings from shrinking. This caused a limited shrinkage in the vicinity of the openings. Parts of the samples (denoted with a red square in Fig. 2) developed a tension stress perpendicular to the grain. Nonetheless, these stress values did not exceed the ultimate tensile strength of beech wood perpendicular to the grain. There were no indications of failure in the beech wood parts of the samples. However, it is necessary to note that the strength in the parts of the samples was increased due to the penetration of resin into the samples.

In comparison to the first set of samples, the height difference between the resin and wood in the second set of samples was tapered (Fig. 6). This was the result of good adhesion of the epoxy resin to the beech wood and it was amplified by the compression on the phase boundary caused by shrinkage. The height profile in the second set of samples is presented in Fig. 6.

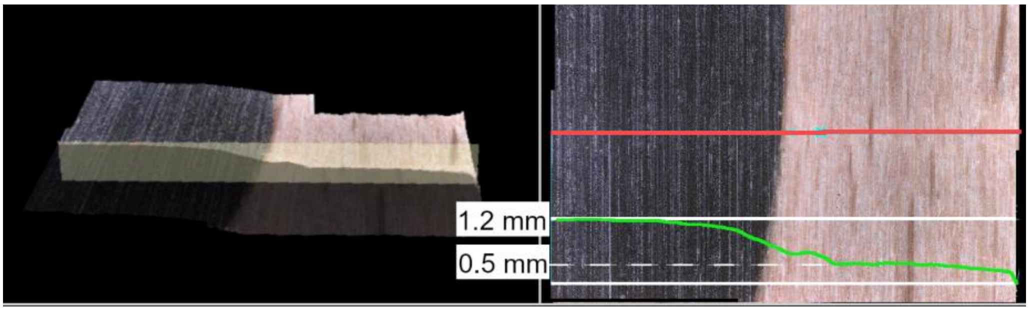

Fig. 6 Height difference between the thickness of epoxy resin layer and the thickness of beech wood after shrinking. The red line denotes the measurement area of the height profile; the green line presents the height profile.

The results of this experiment suggest that to ensure the high quality and longevity of wood-epoxy resin products, the dimensional stability of wood in these products needs to be improved. To avoid the above-mentioned unfavorable effects, the hydrophobicity and, ultimately, the dimensional stability of wood should be improved prior to epoxy resin application. A suitable modification is the thermal modification of wood (Sandberg *et al.,* 2021; Lagaňa *et al*., 2021; Kačíková *et al*., 2025). Another possibility is surface modification of wood-epoxy resin-based products with suitable transparent coatings. These coatings also homogenize the surface and enhance the color stability of the final product (Kúdela *et al.,* 2024, Slabejová *et al*., 2023).

Testing adhesion of epoxy resin to wood by shear strength test parallel to the grain

The results of the shear strength test are presented in Tab. 2. Even though the samples for the shear strength test were conditioned to an MC = 8% and the test was carried out at this MC, the sample sets displayed different shear strengths. The first set of samples, where the epoxy resin was cured at φ = 45%, showed higher shear strength values than the second set of samples, where the epoxy resin was cured at φ = 93%. In comparison to the first sample set, the shear strength of the second sample set was, on average, 23% lower.

Tab. 2 Results of the shear strength test.

Basic statistical characteristics	Shear strength τ [MPa]	
	Sample set 1	Sample set 2
$\bar{x}$	8.67	6.67
s	2.53	1.43
n	14	14

Note: The epoxy resin was cured at φ = 45% and at φ = 93% in the first and second sample sets, respectively.

The beech wood and the epoxy resin blocks were analyzed after the shear strength test. Based on the analysis, it was found that most samples showed a cohesive type of failure. The failure occurred in the resin layer close to the phase boundary (Fig. 7). This type of failure was dominant in the second set of samples. In the first set of samples, wood fibers were present in the epoxy resin block (Fig. 8). These fibers were torn off from the beech wood during the shear strength test. The type of failure in the first set of samples was determined to be non-cohesive. This type of failure was caused by the mechanical working of the wood samples. Some fibers were partially loosened during the sample production. These fibers were then more thoroughly impregnated with the epoxy resin, which was easier to tear off during the shear strength test. According to Kúdela and Liptáková (2006), this type of failure cannot be considered as a cohesive type of failure in the substrate. A cohesive failure in the beech wood was ruled out according to the data of shear strength parallel to the grain of beech wood presented by (Požgaj *et al.*, 1997, Kúdela and Čunderlík, 2012). The aforementioned authors reported significantly higher shear strength values than those presented in this paper.

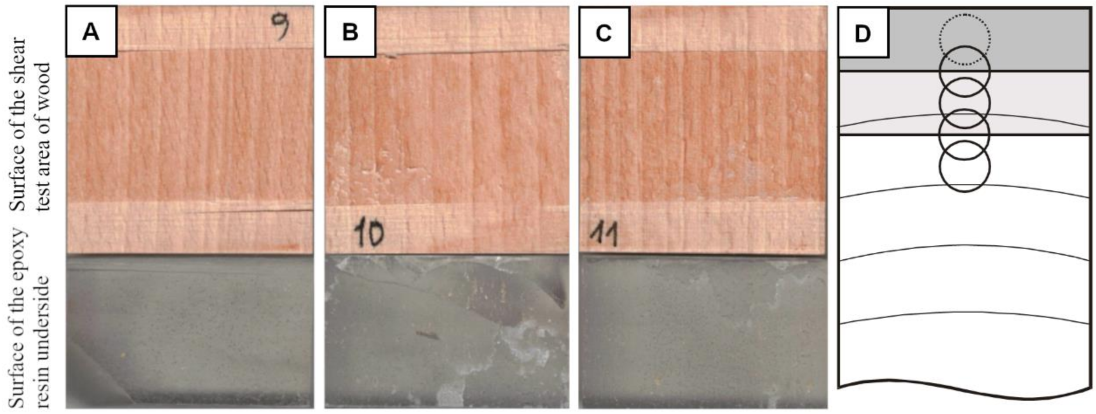

Fig. 7 A – C Examples of the cohesive failure in the epoxy resin, D is the schematic illustration of the weakest spot in the wood-epoxy resin system.

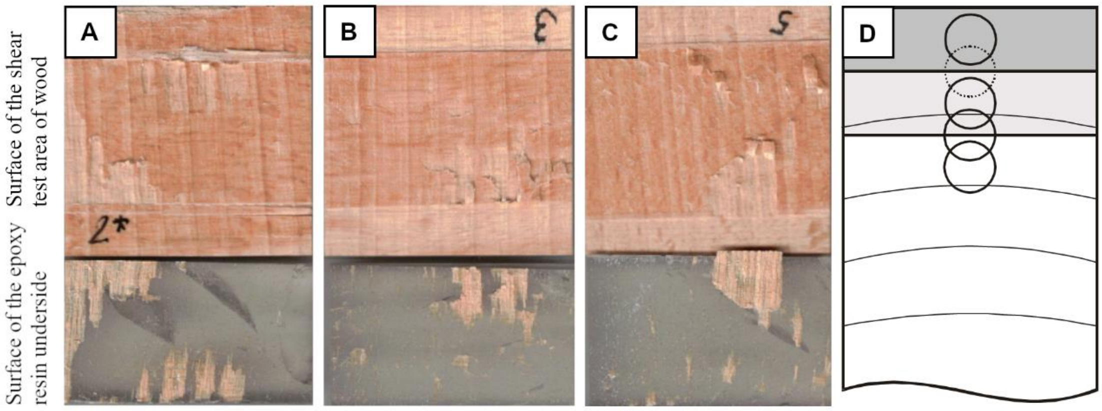

Fig. 8 A – C Examples of a cohesive failure in the epoxy resin and in the resin-impregnated layer of beech wood. D is a schematic illustration of the weakest spot in the wood-epoxy resin system.

The experimental results confirmed that, in most samples, the weakest point of the wood-epoxy resin layer was the epoxy resin itself. This is illustrated by the series of circles in Fig. 7, where the lowest spot is denoted by the circle with a dotted outline. These failures are often mistaken for adhesive failures, especially during free examinations of transparent coatings. The appearance of wood fibres in the epoxy resin layer means that the weakest point was the phase boundary of the resin with the impregnated beech wood layer (Fig. 8). None of the samples in the experiment exhibited a typical adhesive failure. This confirms that the epoxy resin has a good adhesion to beech wood. Since the failure was located in the epoxy resin, the question arises as to why the shear strength was lower in the second sample set. During the curing of the second sample set, the samples were placed in a $\varphi = 93\%$, and they were then conditioned back to an MC = 8% after the resin was cured. Even such a short increase in air humidity caused stresses to form at the wood–resin phase boundary; these were described in the previous chapter. These stresses caused the lower shear strength.

Hydrophilicity and porosity of wood are important during wood modification by resins (Stefanowski *et al.*, 2018). According to these authors, the type of resin has a significant influence on wood modification. Resins that react with hydroxyl groups in the wood also react with water. Therefore, the moisture content of wood is significant during the reaction of epoxy resin with hydroxyl groups. The moisture content of wood, together with relative air humidity, influence the polymerization of epoxy resin (Bilyeu *et al*., 1999, Rowell, 2012). The negative results of humidity changes in the environment during the mechanical tests of wood-resin systems were also presented in the works of Kovařík and Tesařová (2022) and Kovařík *et al*., (2023).

CONCLUSION

Based on the results, the following conclusions can be stated.
Studying the dimensional changes of openings in wood filled with casting epoxy resin revealed that the openings swelled proportionally with the swelling of the wood. The swelling caused the epoxy resin to separate from the beech wood. The stability of the beech wood–epoxy resin phase boundary was disrupted.
A steep height difference between the epoxy resin and the thickness of the beech wood was observed after the swelling. This is considered a significant fault in a product.
During the shrinking of the beech wood samples with epoxy resin, limited shrinkage was observed in the vicinity of the openings, which may have caused cracks in the wood. The height difference between the epoxy resin and beech wood in the vicinity of the phase boundary was tapered.
The adhesion of the epoxy resin to wood was tested using a shear strength test parallel to the grain. This test demonstrated that the resin exhibited good adhesion to the beech wood. The samples did not exhibit adhesive failure; instead, cohesive failure in the epoxy resin near the phase boundary was observed.

REFERENCES

Bilyeu, B., Brostow, W., Menard, K. P., 1999. Epoxy Thermosets and Their Applications I: Chemical Structures and Applications**.** Journal of Materials Education Vol. 21(5&6): 281-286.

Deka, M., Saikia, C. N., 2000. Chemical modification of wood with thermosetting resin: effect on dimensional stability and strength property. Bioresource Technology 73, 179–181. https://doi.org/10.1016/s0960-8524(99)00167-4

Dieste, A., Krause, A., Bollmus, S., Militz, H., 2008. Physical and mechanical properties of plywood produced with 1.3-dimethylol-4.5-dihydroxyethyleneurea (DMDHEU)-modified veneers of *Betula* sp. and *Fagus sylvatica*. Holz Als Roh- Werkstoff 66, p. 281. https://doi.org/10.1007/s00107-008-0247-3

Dubovský, J., Kúdela, J., 1988. Vplyv cyklických zmien vlhkosti na rozmerové zmeny otvorov v dreve a dreva v okolí otvoru [The effect of cyclic changes in humidity on dimensional changes in holes in wood and the wood around the hole]. Drevo, 43, 323–325.

Frihart, C. R., 2005. Wood adhesion and adhesives. Handbook of wood chemistry and wood composites. Boca Raton, Florida: CRC Press, 2005, pp. 215-278.

Guo, D., Guo, N., Fu, F., Yang, S., Li, G., Chu, F., 2022. Preparation and mechanical failure analysis of wood–epoxy polymer composites with excellent mechanical performances. Composites Part B: Engineering, 235, 109748. https://doi.org/10.1016/j.compositesb.2022.109748

Hill, C., 2006. Wood Modification: Chemical, Thermal and Other Processes. John Wiley & Sons 2006. https://doi.org/10.1002/0470021748

Homan, W. J., Jorissen, A. J. M., 2004. Wood modification developments. Heron 49(4): 361 – 385.

Kačík, F., Kúdela, J., Výbohová, E., Jurczyková, T., Čabalová, I., Adamčík, L., Kmeťová, E., Kačíková, D., 2025. Impact of Thermal Treatment and Accelerated Aging on the Chemical

Composition, Morphology, and Properties of Spruce Wood. Forests, Vol 16 (1) https://doi.org/10.3390/f16010180

Kovařík R., Tesařová D., 2022. Surface treatment of composite materials based on epoxy casting resins and solid wood. XV. Konference pigmenty a pojiva: sborník/Conference Proceedings. Pardubice: Chemagazín, 2022, pp.71-79.

Kovařík, R., Tesařová, D. Kúdela J., 2023. Analysis of durability characteristics of composite material based on epoxy casting resins and solid wood with focus on surface finish. XVI. Konference pigmenty a pojiva: sborník/conference proceedings. Pardubice: Chemagazín, 2023, pp. 66-74.

Kúdela, J., Čunderlík, I., 2012. Bukové drevo – štruktúra, vlastnosti, použitie. Technická univerzita vo Zvolene, Zvolen [Beech wood – structure, properties, use. Technical University in Zvolen, Zvolen].

Kúdela, J., Dubovský, J., 1986. Rozmerové zmeny otvorov v dreve a dreva v okolí otvoru vplyvom zmien vlhkosti [Dimensional changes in holes in wood and the wood around the hole due to changes in humidity]. Drevo, 41, 361 – 364.

Kúdela, J., Hrčka, R., Svocák, J., Molčanová, S., 2024. Transparent Coating Systems Applied on Spruce Wood and Their Colour Stability on Exposure to an Accelerated Ageing Process. Forests, Vol. 15 (1) https://doi.org/10.3390/f15111865

Kúdela, J., Liptáková, E., 2006. Adhesion of coating materials to wood. Journal of Adhesion Science and Technology, vol. 20,(8), pp. 875–895. https://doi.org/10.1163/156856106777638725

Kumosa, M. S., 2006. Damage Mechanisms in Polymer Matrix Composites in Extreme Environments. Key Engineering Materials. Vol. 324–325, pp. 663–666. Trans Tech Publications, Ltd. https://doi.org/10.4028/0-87849-413-8.663

Kurjatko, S., Kúdela, J., Lawniczak, M., Lübke, H., 1987. Modifikácia imisného smrekového dreva metylmetakrylátom a styrénom [Modification of polluted spruce wood with methyl methacrylate and styrene] Modyfikacja drewna '87. Rydzyna, AR Poznań, pp. 156–166.

Lagaňa, R., Janeka, A., Andor, T., 2021. Selected elastic properties of thermally treated beech wood. In: 9th Hardwood Proceedings, Vol. 9 – PT II: An Underutilized Resource – Hardwood Oriented Research, 56 – 60.

Liptáková, E., Kúdela, J., Paprzycki, O., 1991. The adhesion of polystyrene to wood. Holz als Roh und Werkstoff, 49, vol. 1, 31–37. https://doi.org/10.1007/bf02627548

Pacas P., Tesařová D., Kovařík R., Paul D., 2023. Study of the Effect of Alternating Climatic Conditions and Mechanical Loading on the Strength Properties of Joints Between Cast Epoxy Resin and Solid Wood. XVI. Konference pigmenty a pojiva: sborník/conference proceedings. Pardubice: Chemagazín, 2023, pp. 66-74.

Požgaj, A., Kurjatko, S., Chovanec, D., Babiak, M., 1997. Štruktúra a vlastnosti dreva [Structure and properties of wood] Bratislava: Príroda, 487 p.

Reinprecht, L., 2016. Wood Deterioration, Protection and Maintenance. John Wiley & Sons, p. 357.

Rowell, R.M., 2012. Handbook of Wood Chemistry and wood composites. 2nd Ed. CRC Press, Taylor and Francis group, Boca Raton, Florida, USA p. 703.

Rowell, R. M., Barbour, R. J., 1990. Archaeological wood: Properties, chemistry, and preservation. Washington, DC: American Chemical Society. 472 p.

Sandberg, D., Kutnar, A., Karlsson, O., Jones, D., 2021. Wood Modification Technologies: Principles, Sustainability, and the Need for Innovation, 1st ed.; CRC Press: Boca Raton, FL, USA. https://doi.org/10.1201/9781351028226-1

Slabejová, G., Vidholdová, Z., Šmidriaková, M., 2023. Change in the Colour of Transparent Surface Finish on Hydrothermally Treated Wood. Acta Facultatis Xylologiae Zvolen. Vol. 65 (1), p. 45 – 56. https://doi.org/10.17423/afx.2023.65.1.04

Spear, M. J., Curling, S. F., Dimitriou, A., Ormondroyd, G. A., 2021. Review of Functional Treatments for Modified Wood. Coatings, 11, 327. https://doi.org/10.3390/coatings11030327

Stamm, A. J., Seborg, R. M., 1943. Resin treated wood (Impreg). USDA Forest Service Forest Products Laboratory Report No. 1380. Madison, WI.
Stamm, A. J., Seborg, R. M., 1944. Resin treated laminated compressed wood (Compreg). USDA Forest Serv. Forest Prod. Lab. Rep. No. 1381, Madison, WI.
Stefanowski, B., Spear, M., Pitman, A., 2018. Review of the use of PF and related resins for modification of solid wood. In: M. Spear (Ed.), Timber, pp. 165-179.
Vanlandingham, M., R., Eduljee, R., F., Gillespie, J. R., 1999. Moisture diffusion in Epoxy Systems. Journal of Applied Polymer Science 71 (5): 787 – 798, https://doi.org/10.1002/(SICI)1097-4628(19990131)71:5<787::AID-APP12>3.0.CO;2-A
Wondmagegnehu, B. T., Legesse, A. A., 2023. Experimental Investigation of Mechanical and Physical Properties on Epoxy Resin with Wood Timber for Furniture Application. Journal of Natural Fibers, 20(2), 2286327. https://doi.org/10.1080/15440478.2023.2286327
Zhou, A., Li, K., Yang, G., Liu, T., Qin, R., & Zou, D., 2025. Effect of temperature and humidity on the mechanical behavior of basalt FRP bonded wood under sustained load: An experimental and atomistic study. Journal of Building Engineering, 104, 112325. https://doi.org/10.1016/j.jobe.2025.112325

ACKNOWLEDGMENT

The authors would like to thank Ing. Stanislav Vágner for his help with sample production and execution of the experiments.
This research was supported by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic, VEGA contract number 1/0656/23 "Stabilizácia vlastností modifikovaných povrchov dreva a systému drevo – filmotvorná látka v procese starnutia" (Stabilization of modified wood surface properties and the wood-coating material system in the process of aging).

AUTHORS' ADDRESSES

Ing. Barbora Slováčková, PhD.
Ing. Radek Kovařík
Department of Wood Science
Faculty of Wood Science and Technology
Technical University in Zvolen
T. G. Masaryka 24
960 01 Zvolen
Slovakia
xslovackova@tuzvo.sk
xkovarik@is.tuzvo.sk