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Study of wood deformation indicators after exposure to acidic environments

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Abstract

Experimental studies were conducted on the deformation indicators of structural birch and pine wood under the influence of various acidic environments with different impregnation times. The deformation parameters of all studied wood species were determined experimentally, in particular the critical $u_{c,0,d,agr}$ and residual deformations $u_{c,fin,agr}$. It has been established that exposure to an acidic environment increases the deformation characteristics of structural timber.. Specifically, the relative critical deformations of the studied species increased within the range of 1.12 to 1.17 times after 28 days of impregnation compared to the samples tested at the standard moisture content of 12%, and within the range of 1.14 to 1.19 times after 180 days. Residual deformations increased 1.1 to 1.25 times after 28 days of impregnation, and after 180 days, they remained practically the same. Over the following five months, the strength and deformability characteristics changed insignificantly, they stabilized. This is explained by the fact that after 28 days of impregnation, the wood is almost completely saturated with moisture and subsequently hardly absorbs any more.

Keywords: solid wood, acidic environment, impregnation duration, critical deformation, residual deformation.

1. Introduction

Wood has long served humanity as a natural material and is now used in a wide range of industrial sectors (Green and Kretschmann (1992); Gomon et al. (2022); Patton-Mallory and Cramer (1987); Pavluk et al. (2024); Bojok and Vintoniv (1992); Hua et al. (2025)). It is applied in shipbuilding, mechanical engineering, the fuel and energy sector, the chemical, mining, aviation, and woodworking industries (Homon et al. (2024); Landis et al. (2002); Aleksiievets et al. (2024); Yasniy et al. (2022); Galicki and Czech (2005); Pinchevska and Zavialov (2020)), as well as in the pulp and paper, furniture, and construction industries (Pavluk et al. (2023); Nsouami et al. (2022); Gomon et al. (2022); Shams Huq et al. (2025); Ivaniuk et al. (2025); Anshari et al. (2017)).

When designing, manufacturing and repairing wooden structures, it is essential to know the physical and mechanical characteristics of the material in both precritical and postcritical modes of behavior (Gomon et al. (2024); Zakic (1974); Sobczak-Piastka et al. (2023); Homon et al. (2024); Gong et al. (2019)). This makes it possible to evaluate performance under operational conditions and as the structure approaches its limit states (Lamichhane et al. (2025); Wang et al. (2025); Albrektas et al. (2020); Pavluk et al. (2025); Mykhailovskyi and Komar (2024); Gomon et al. (2023)). Such parameters can be determined only through

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modern testing machines that ensure rigid loading conditions (Yasniy et al. (2022); Moya and Bano (2017); Homon et al. (2025); Datsiuk et al. (2024)).

The influence of aggressive environments on the physical and mechanical properties of wood is mentioned relatively rarely in the literature (Matviiuk et al. (2025); Homon et al. (2023)). The results of experimental studies vary significantly. Because of this, it remains unclear how the deformability parameters of hardwood and softwood species change under different aggressive factors.

On the other hand, we have studied in considerable detail the influence of aqueous environments on the strength and deformation parameters of such materials (Homon et al. (2023); Fojtik (2019); Janiak et al. (2023); Huang et al. (2006); Thygesen et al. (2010); Roshchuk et al. (2024)). Normative documents also provide virtually no data regarding changes in the strength and deformation parameters of wood caused by exposure to various environments (Eurocode 5:2004; NDS (2018); DBN V.2.6-161:2017)). This raises the question of how to design components, elements, and structures under such conditions.

Therefore, in this work, we present the results of our experimental studies on the variation of deformation parameters depending on the type of aggressive environment.

Nomenclature

$u_{c,0,d,agr}$	critical deformation
$u_{c,fin,agr}$	residual deformation
T	impregnation duration

2. Methods of experimental research

To achieve the stated objective, the experimental program required preparing a series of grade I wood specimens in the form of test prisms corresponding to strength classes C30 and D35 (DBN V.2.6-161:2017). Specimens with a cross-section of 30×30×120 mm were manufactured in a carpentry workshop. For the experimental study, birch and pine wood aged 60±5 years were selected, as these are among the most widespread hardwood and softwood species.

The wood tested prior to impregnation with various liquids had a standard moisture content of 12%. The wood blanks were dried in specialized drying chambers to reach this moisture level. At each stage of the study, the moisture content of the test prisms was monitored using a LASERLINER DampFinder Home moisture meter. The specimens were cut from pre-prepared long timber sections. Impregnation of the specimens was carried out using the following acids: acetic acid (9%), lactic acid (40%) and hydrochloric acid (15%). The wood was impregnated naturally without additional stimulation for 7, 14, 28, and 180 days.

The penetration of liquids into the specimens was performed in a container, with the prisms placed horizontally and fully submerged in the respective solutions. This ensured the contact of each solution with all sides of the prisms. The total number of tested prisms was 78. For the axial compression tests along the grain under short-term single loading in a rigid loading regime, using both impregnated and non-impregnated birch and pine specimens, a STM-100 servohydraulic testing machine was used. The loading of the specimens was carried out and controlled directly through a computer equipped with dedicated software.

Initially, birch and pine specimens with a standard moisture content of 12% were tested, followed by the impregnated specimens. The wood prisms were grouped according to impregnation duration: 7, 14, 28, and 180 days. The deformation rate of the specimens was set at 1.5 mm per minute. All tests of the examined prisms were performed with displacement-controlled loading of the testing machine's platen. Before each experiment, the cross section and height of the specimens were measured, since the impregnation process leads to an increase in the volume of the wood.

3. Results and discussion

As a result of the experimental studies, the deformation parameters of the examined wood species were determined after exposure to various acidic environments with different impregnation durations, specifically the critical deformation $u_{c,0,d,agr}$ (the upper point of the deformation diagram) and the residual deformation $u_{c,fin,agr}$ (the lowest point of the deformation diagram on the descending branch). Accordingly, the following values of the critical deformation $u_{c,0,d,agr}$, were obtained experimentally and are presented in Table 1.

Table 1. Critical deformations of wood $u_{c,0,d,agr}$ after exposure to various acidic environments

№	Wood species	Critical deformations $u_{c,0,d,agr}$				
			Impregnation, days			
		Unimpregnated	7	14	28	180
		Acetic acid CH_3COOH (9%)				
1	Birch	0.00521	0.00568	0.00589	0.00597	0.00606
2	Pine	0.00491	0.00559	0.00578	0.00582	0.00584
		Lactic acid $C_3H_6O_3$ (40%)				
1	Birch	0.00521	0.00572	0.00584	0.00611	0.00620
2	Pine	0.00491	0.00493	0.00531	0.00558	0.00564
		Hydrochloric acid HCl (15%)				
1	Birch	0.00521	0.00551	0.00569	0.00581	0.00594
2	Pine	0.00491	0.0054	0.00561	0.00574	0.00578

Based on the obtained experimental results (Table 1), graphs were constructed to illustrate the variation of the critical deformation of wood $u_{c,0,d,agr}$ after exposure to acidic environments as a function of impregnation duration, shown as «$u_{c,0,d,agr}$ – T». Relationships were also established describing the change in critical deformation (dependent variable y) of birch and pine after exposure to different acidic environments $u_{c,0,d,agr}$ from the impregnation duration T (independent variable x) (Fig.1a, Fig.1b, Fig.1c):

- after exposure to acetic acid for birch wood

$$y = -1{,}36\cdot10^{-11}\cdot x^4 + 5{,}65\cdot10^{-9}\cdot x^3 - 7{,}85\cdot10^{-7}\cdot x^2 + 4{,}19\cdot10^{-5}\cdot x + 5{,}35\cdot10^{-3}; \tag{1}$$

- after exposure to acetic acid for pine wood

$$y = -1{,}89\cdot10^{-11}\cdot x^4 + 7{,}73\cdot10^{-9}\cdot x^3 - 1{,}05\cdot10^{-6}\cdot x^2 + 5{,}36\cdot10^{-5}\cdot x + 5{,}09\cdot10^{-3}; \tag{2}$$

- after the action of lactic acid on birch wood

$$y = -1{,}37\cdot10^{-11}\cdot x^4 + 5{,}76\cdot10^{-9}\cdot x^3 - 8{,}27\cdot10^{-7}\cdot x^2 + 4{,}66\cdot10^{-5}\cdot x + 5{,}33\cdot10^{-3}; \tag{3}$$

- after the action of lactic acid on pine wood

$$y = -9{,}30\cdot10^{-12}\cdot x^4 + 4{,}10\cdot10^{-9}\cdot x^3 - 6{,}26\cdot10^{-7}\cdot x^2 + 3{,}83\cdot10^{-5}\cdot x + 4{,}84\cdot10^{-3}; \tag{4}$$

- after exposure to hydrochloric acid for birch wood

$$y = -9{,}38\cdot10^{-12}\cdot x^4 + 3{,}92\cdot10^{-9}\cdot x^3 - 5{,}55\cdot10^{-7}\cdot x^2 + 3{,}14\cdot10^{-5}\cdot x + 5{,}29\cdot10^{-3}; \tag{5}$$

- after exposure to hydrochloric acid for pine wood

$$y = -1{,}57\cdot10^{-11}\cdot x^4 + 6{,}49\cdot10^{-9}\cdot x^3 - 9{,}04\cdot10^{-7}\cdot x^2 + 4{,}79\cdot10^{-5}\cdot x + 5{,}01\cdot10^{-3}. \tag{6}$$

Formulas (1-6) can be used to determine the critical deformations of the wood species studied after exposure to various acidic environments with a soaking period ranging from 1 to 180 days inclusive.

Analysis of the graphs (Fig.1a, Fig.1b, Fig.1c) and Table 1 indicates that acidic environments significantly increase the deformation parameters of birch and pine wood. In particular, after exposure to hydrochloric acid (15%) for 28 days, the critical deformation of birch increases by a factor of 1.15 compared to the critical deformation at standard moisture content, and pine increases by a factor of 1.17. Exposure to acetic acid (9%) results in an increase of 1.15 for birch and 1.19 for pine, while exposure to lactic acid (40%) leads to an increase of 1.17 for birch and 1.14 for pine. After 180 days of impregnation in the acidic solutions, these values remained practically unchanged.

The experimental results also made it possible to determine the residual deformation $u_{c,fin,agr}$ of the wood after exposure to acidic environments with different impregnation durations (the lowest point of the descending branch of the deformation diagrams) (Table 2).

Table 2. Residual deformations of wood $u_{c,fin,agr}$ after exposure to various acidic environments

№	Wood species	Residual deformations $u_{c,fin,agr}$				
			Impregnation, days			
		Unimpregnated	7	14	28	180
		Acetic acid CH_3COOH (9%)				
1	Birch	0.3349	0.4046	0.4142	0.4180	0.4193
2	Pine	0.3526	0.3681	0.3703	0.3867	0.3928
		Lactic acid $C_3H_6O_3$ (40%)				
1	Birch	0.3349	0.3796	0.3940	0.3972	0.4022
2	Pine	0.3526	0.3859	0.4025	0.4317	0.4362
		Hydrochloric acid HCl (15%)				
1	Birch	0.3349	0.3903	0.3916	0.4068	0.4200
2	Pine	0.3526	0.3870	0.4023	0.4325	0.4376

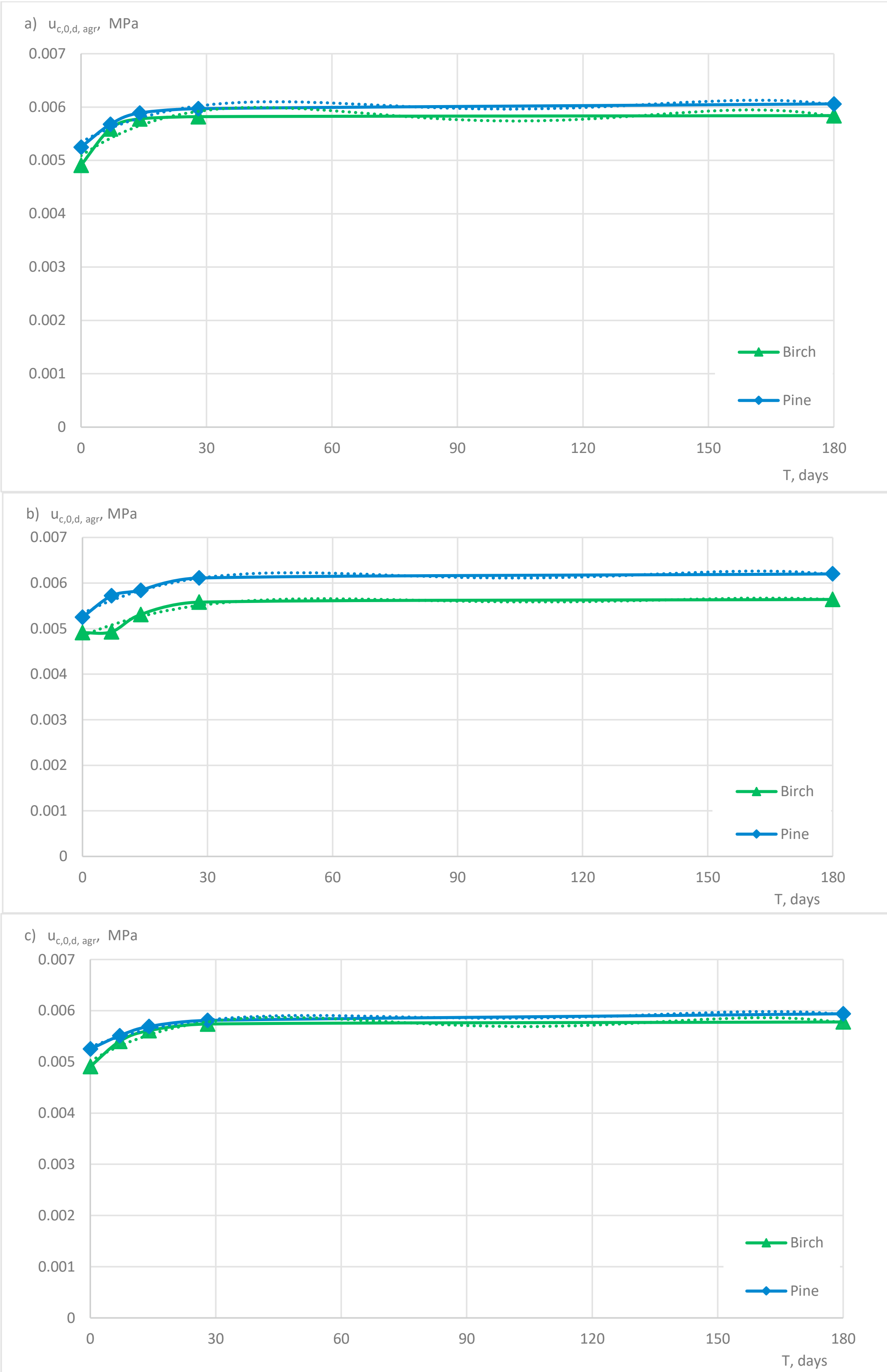

Fig. 1. Graphs showing changes in critical deformations of pine and birch wood with different impregnation times after exposure to various acids: a) acetic (9%), b) lactic (40%), c) hydrochloric (15%)

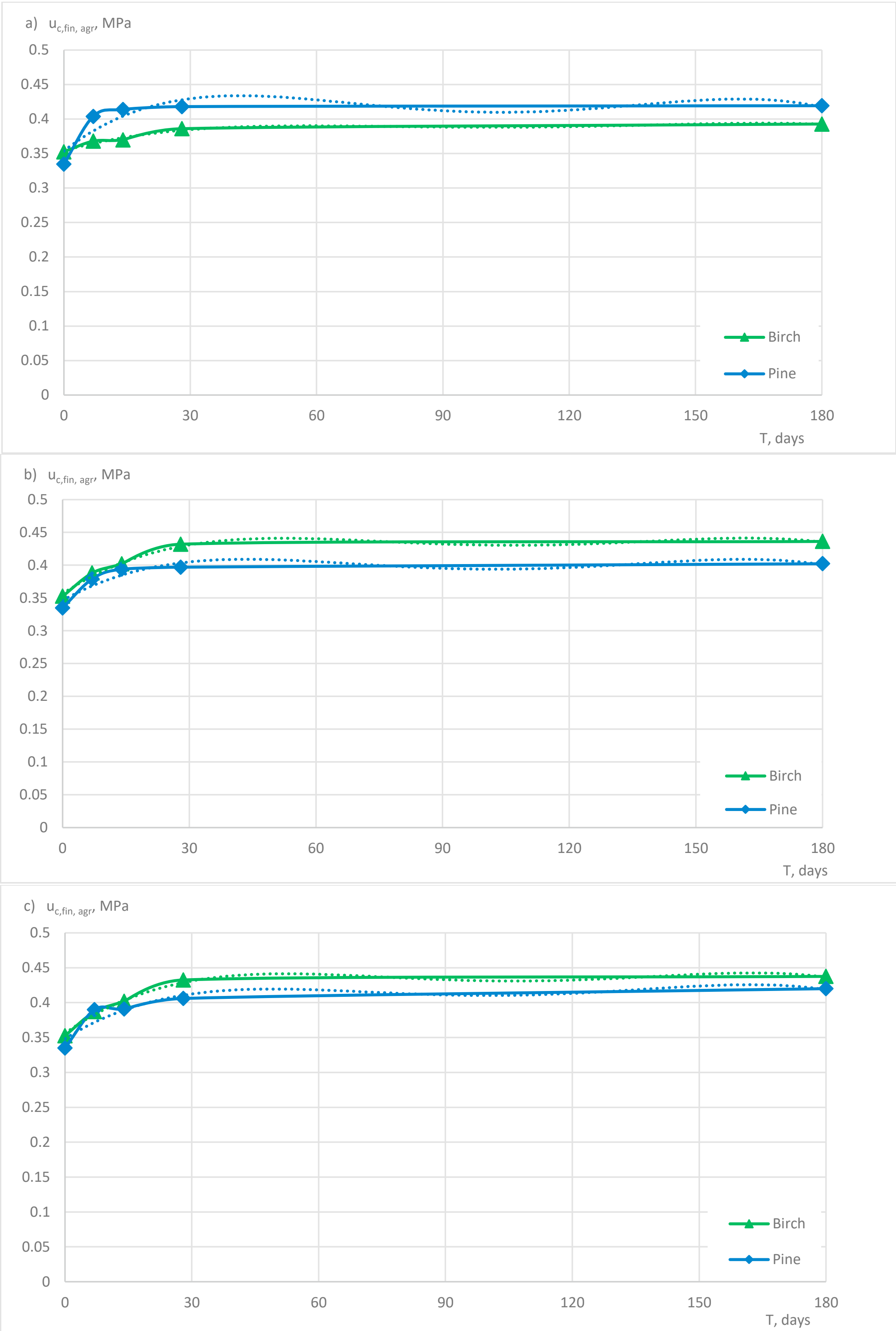

Fig. 2. Graphs showing changes in residual deformations of pine and birch wood with different impregnation times after exposure to various acids: a) acetic (9%), b) lactic (40%), c) hydrochloric (15%)

Based on the obtained experimental results (Table 2), graphs were constructed to illustrate the variation of the residual deformation $u_{c,fin,agr}$ after exposure to acidic environments as a function of impregnation duration, shown as « $u_{c,fin,agr}$ – T». Relationships were also established describing the change in residual deformation (dependent variable y) of birch and pine after exposure to different acidic environments $u_{c,fin,agr}$ from the impregnation duration T (independent variable x) (Fig.2a, Fig.2b, Fig.2c):

- after exposure to acetic acid for birch wood

$$y = -1{,}73\cdot10^{-9}\cdot x^4 + 7{,}06\cdot10^{-7}\cdot x^3 - 9{,}58\cdot10^{-5}\cdot x^2 + 4{,}82\cdot10^{-3}\cdot x + 3{,}54\cdot10^{-1}; \quad (7)$$

- after exposure to acetic acid for pine wood

$$y = -4{,}35\cdot10^{-10}\cdot x^4 + 1{,}89\cdot10^{-7}\cdot x^3 - 2{,}82\cdot10^{-5}\cdot x^2 + 1{,}71\cdot10^{-3}\cdot x + 3{,}54\cdot10^{-1}; \quad (8)$$

- after the action of lactic acid on birch wood

$$y = -1{,}27\cdot10^{-9}\cdot x^4 + 5{,}19\cdot10^{-7}\cdot x^3 - 7{,}10\cdot10^{-5}\cdot x^2 + 3{,}66\cdot10^{-3}\cdot x + 3{,}46\cdot10^{-1}; \quad (9)$$

- after the action of lactic acid on pine wood

$$y = -1{,}18\cdot10^{-9}\cdot x^4 + 5{,}06\cdot10^{-7}\cdot x^3 - 7{,}42\cdot10^{-5}\cdot x^2 + 4{,}28\cdot10^{-3}\cdot x + 3{,}57\cdot10^{-1}; \quad (10)$$

- after exposure to hydrochloric acid for birch wood

$$y = -1{,}19\cdot10^{-9}\cdot x^4 + 4{,}95\cdot10^{-7}\cdot x^3 - 6{,}95\cdot10^{-5}\cdot x^2 + 3{,}81\cdot10^{-3}\cdot x + 3{,}48\cdot10^{-1}; \quad (11)$$

- after exposure to hydrochloric acid for pine wood

$$y = -1{,}19\cdot10^{-9}\cdot x^4 + 5{,}09\cdot10^{-7}\cdot x^3 - 7{,}46\cdot10^{-5}\cdot x^2 + 4{,}31\cdot10^{-3}\cdot x + 3{,}56\cdot10^{-1}. \quad (12)$$

Formulas (7-12) can be used to determine the residual deformations of the studied wood species after exposure to various acidic environments with a soaking period ranging from 1 to 180 days inclusive.

A detailed analysis of Fig.2a, Fig.2b, Fig.2c and Table 2 shows that exposure to acidic environments increases the residual deformation of the examined wood species compared to prisms tested at the standard moisture content of 12%. In particular, after exposure to hydrochloric acid for 28 days, residual deformation increases by a factor of 1.22 for birch and 1.23 for pine. Exposure to acetic acid results in an increase of 1.25 for birch and 1.10 for pine, while exposure to lactic acid leads to an increase of 1.19 for birch and 1.22 for pine. Over the following 5 months of impregnation, these values changed only slightly, similar to the trends observed for the critical deformation parameters.

4. Conclusions

1. New experimental data were obtained on the variation of the deformation parameters of solid pine and birch wood under the influence of aggressive environments, namely acetic, lactic, and hydrochloric acids.
2. It was established that the deformation parameters of solid pine and birch wood increase depending on the impregnation duration in various aggressive environments.
3. It was found that the deformation parameters, including critical and residual deformation, of the examined wood species change significantly only during the first month of impregnation in acidic solutions. Over the subsequent five months, the deformation parameters remain almost unchanged.

References

Albrektas, D., Juciene, M., Dobilaite, V., 2020. The influence of thermal modification on the resistance to water impact properties and strength of wood used in outdoor conditions. Wood research 65(3), 353-364.

Aleksiievets, V., Gomon, S., Aleksiievets, I., Homon, S., Ivaniuk, A., Zadorozhnikova, I., Bandura, I., 2024. Influence of thicknesses of outer and middle elements on the performance of nail connections. Procedia Structural Integrity 59, 710-717.

Anshari, B., Guan, Z. W., Wang, Q. Y., 2017. Modelling of Glulam beams pre-stressed by compressed wood. Composite Structures 165, 160–170.

Bojok, O., Vintoniv, I., 1992. Wood science with the basics of forest commodity science. Kyiv: Publishing by Scientific thought.

DBN B.2.6-161, 2017. Constructions of houses and buildings. Wooden constructions. Main provisions. Kyiv: Ukrarchbudinform.

Datsiuk, V., Homon, S., Gomon, S., Dovbenko, V., Petrenko, O., Parfentyeva, I., Romaniuk, M., 2024. Effect of long-term operation on the strength properties of pine wood. Procedia Structural Integrity 59, 583-587.

Eurocode 5, 2004. Design of timber structures. Part 1.1. General rules and rules for buildings, 124.

Fojtik, R., 2019. Moisture content analysis of wooden bridges. Wood research 64(3), 529-536.

Galicki, J., Czech, M., 2005. Tensile strength of softwood in LR orthotropy plane. Mechanics of Materials 37(6), 667–686.

Gomon, P., Gomon, S.S., Pavluk, A., Homon, S., Chapiuk, O., Melnyk, Yu., 2023. Innovative method for calculating deflections of wooden beams based on the moment-curvature graph. Procedia Structural Integrity 48, 195-200.

Gomon, S., Gomon, P., Korniychuck, O., Homon, S., Dovbenko, T., Kulakovskyi, L., Boyarska, I., 2022. Fundamentals of calculation of elements from solid and glued timber with repeated oblique transverse bending, taking into account the criterion of deformation. Acta Facultatis Xylologiae Zvolen 64(2), 37-47.

Gomon, S.S., Gomon, P., Homon, S., Polishchuk, M., Dovbenko, T., Kulakovskyi, L., 2022. Improving the strength of bending elements of glued wood. Procedia Structural Integrity 36, 217-222.

Gomon, S., Homon, S., Pavluk, A., Matviiuk, O., Sasiuk, Z., Puhach, Yu., Svyrydiuk, O., 2024. Hypotheses and prerequisites for modelling the stress-strain state of wooden element normal cross-section using the deformation calculation method. Procedia Structural Integrity 59, 559-565.

Gong, L., Zhang, Q., Liang, H., Ren, S., Wang, G., 2019. Mechanical properties and microstructure of Zabelia biflora. Wood research 64(3), 423-436.

Green, D.W., Kretschmann, D.E., 1992. Properties and grading of Southern Pine Woods. Forest Products Journal 47 (9), 78–85.

Homon, S., Dovbenko, T., Savitskiy, V., Khoruzhyi, M., Petrenko, O., Sunak, P., Kysliuk, D.Y., 2024. Influence of natural composite materials on mechanical properties of wood. Procedia Structural Integrity 59, P. 595-600.

Homon, S., Gomon, P., Gomon, S., Litnitskyi, S., Boyarska, I., Chapiuk, O., Chornomaz, N., 2024. Study of the mechanical properties of coniferous wood of different ages at standard humidity. Procedia Structural Integrity 59, 545-550.

Homon, S., Gomon, P., Gomon, S., Pavluk, A., Karavan, B., Petrenko, O., Homon, O., Chapiuk, O., 2025. Determination of main strength and deformation parameters of complete diagrams of glue-laminated wood deformation. Procedia Structural Integrity 72, 301-307.

Homon, S., Gomon, P., Gomon, S., Vereshko, O., Boyarska, I., Uzhegova, O., 2023. Study of change strength and deformation properties of wood under the action of active acid environment. Procedia Structural Integrity 48, 201-206.

Homon, S., Litnitskyi, S., Gomon, P., Kulakovskyi, L., Kutsyna, I., 2023. Methods for determining the critical deformations of wood at various moisture. Scientific Horizons 26(1), 73-86.

Huang, S.-H., Cortes, P., Cantwell, W.J., 2006. The influence of moisture on the mechanical properties of wood polymer composites. Journal of Material Science 41, 5386-5390.

Hua, Z., Ding, M., Lin, Y., Wei, Y., 2025. Experimental analysis and theoretical study on the short-term bending performance of prestressed glued laminated bamboo string beams. Structures 82, 110556.

Ivaniuk, A., Aleksiievets, V., Matviiuk, O., Aleksiievets, I., Homon, S., Litnitskyi, S., Ilchuk, N., Kysliuk, D.Y., 2025. Results of research of wooden beams with cracks located neutral axis: an experimental study. *Procedia Structural Integrity* 72, 323-329.

Janiak, T., Homon, S., Karavan, V., Gomon, P., Gomon, S.S., Kulakovskyi, L., Famulyak, Y., 2023. Mechanical properties of solid deciduous species wood at different moisture content. AIP Conference Proceedings 2949, article number 020009.

Lamichhane, A., Vasudevan, A.K., Mohammadabadi, M., 2025. Enhancing bending performance of engineered wood cellular beams: Insights from compressive strength. Structures 82, 110564.

Landis, E.N., Vasic, S., Davids, W.G., Parrod, P., 2002. Coupled experiments and simulations of microstructural damage in wood. Experimental Mechanics 42, 389–394.

Matviiuk, O., Homon, S., Petrenko, O., Vikhot, S., 2025. Operation of silor-modified wood in acidic environments: an experimental study. Lecture Notes in Civil Engineering 781, 237-244.

Moya, L., Bano, V., 2017. Elastic behavior of east-growth uruguayan pine determined from compression and bending tests. BioResources 12(3), 5896-5912.

Mykhailovskyi, D., Komar, M., 2024. Definition of the stress-strain state of a glued laminated timber beam reinforced with composite strips using experimental method. Strength of Materials and Theory of Structure 112, 43-51.

NDS. National design specification for wood construction, 2018. American Forest and Paper Association.

Nsouami, V., Manfoumbi Boussougou, N., Bastidas-Arteaga, E., Moutou Pitti, R., 2022. Effects of long-term loading on Moabi wood beams in the tropical environment of Gabon: variability in properties and effects of exposure conditions on mechanical properties in 3-point bending tests. Procedia Structural Integrity 37, 576-581.

Pavluk A., Gomon S., Gomon P., Homon S., Drobyshynets S., Sunak P., Uzhehov S., Protsiuk V., 2025. Experimental and theoretical studies of the rigidity of gluminun beams under direct and oblique bending. *Procedia Structural Integrity* 72, 330-337.

Pavluk, A., Gomon, S., Khoruzhyi, M., Homon, S., Dejneka, O., Smal, M., Dziubynska, O., 2024. Peculiarities of calculation of wooden beams for oblique bending using the deformation model. Procedia Structural Integrity 59, 566-574.

Pavluk, A., Gomon, S., Ziatiuk Y., Gomon, P., Homon, S., Kulakovskyi, L., Iasnii, V., Yasniy, O., Imbirovych, N., 2023. Stiiffness of solid wood beams under direct and oblique bending conditions. Acta Facultatis Xylologiae Zvolen 65(2), 109-121.

Patton-Mallory, M., Cramer, S., 1987. Fracture mechanics: a tool for predicting wood component strength. Forest Products Journal 37 (7/8), 39–47.

Pinchevska, O.O., Zavialov, D.L., 2020. Properties of new thermal insulation from low quality pine wood. Ukrainian Journal of Forest and Wood Science 11(2), 91–100.

Roshchuk, M., Homon, S., Pavluk, A., Gomon, S., Drobyshynets, S., Romaniuk, M., Smal, M., Dziubynska, O., 2024. Effect of long-term moisture on the mechanical properties of wood: an experimental study. Procedia Structural Integrity 59, 718-723.

Shams Huq, R., Heal, T., Tannert, T., 2025. Load-carrying capacity of housings in solid timber beams. Maderas. Ciencia Y Tecnología 27, e4125.

Sobczak-Piastka, J., Pavluk A., Gomon, S.S., Gomon, P., Homon, S., Lynnyk, I., 2023. Changing the position of the neutral line of beams made of glued wood in conditions of oblique bending. AIP Conference Proceedings 2928, article number 080007.

Thygesen, L.G., Tang Engelund, E., Hofmeyer, P., 2010. Water sorption in wood and modifed wood at high values of relative humidity. Part I: Results for untreated, acetylated, and furfurylated Norway spruce. Holzforsch 64, 315-323.

Wang, Y., Lam, F., He, M., 2025. Long-term performance of eccentrically prestressed glulam beams under variable temperature and humidity. Journal of Building Engineering 116, 114674.

Yasniy, P., Homon, S., Iasnii, V, Gomon, S.S., Gomon, P., Savitskiy, V., 2022. Strength properties of chemically modified solid woods. Procedia Structural Integrity 36, 211-216.

Zakic, B.D., 1974. Inelastic bending of wood beams. Journal of the Structural Division 99(10), 2079-2092.