Received: 23.02.2022, Revised: 27.06.2022, Accepted: 11.08.2022

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 13(3), 22-31

UDC 674.04:544.7
DOI: 10.31548/forest.13(3).2022.22-31

Mobile technology of thermal modification of wood

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Abstract. Wood as a structural material has some disadvantages, which include a short service life, relatively low form resistance, considerable volumetric deformations under moisture, pronounced anisotropy, and water absorption. Thermal modification slightly improves the physical and mechanical properties. However, a problem of changing surface characteristics occurs, specifically adhesion. To determine the technological characteristics of thermally modified wood and develop possible measures to improve the technology of applying protective coatings, the surface energy and compressive strength along the fibres were determined. A comprehensive approach was applied to analyse the surface state of thermally modified wood through the investigation of surface energy characteristics based on the Fowkes method, which considers dispersion, hydrogen, and dipole-dipole interactions at the solid-liquid interfacial boundary. According to the marginal angle of wetting, it was found that the thermal modification of wood helps increase the resistance of its surface to wetting by reducing the polarity by 1.68 times with an increase in the duration of modification to 30 min. Therewith, the surface free energy for samples modified at 300°C for 5 min is 64.5 mJ/m^2, for 30 min – 24.1 mJ/m^2. Regarding compressive strength, thermal modification reduces the strength limit by 1.46 times. Thus, at 300°C and a time of 5 min and 15 min, the indicator stays at the level of ordinary wood – 42 MPa. Processing for 30 minutes reduces the strength limit to 29 MPa, the wood loses its plasticity. The obtained results allow effectively choosing stable coatings for such wood for high-quality surface treatment with paint and varnish materials. Knowing the moment of time from which the reduction of the strength limit begins, thermal modification becomes more controlled and allows predicting the characteristics of the future material

Keywords: wood material, technological parameters, thermal modification process, wetting angle, surface free energy, compression along the fibres, strength limit, brittleness

Introduction

Wood is widely used in construction due to its mechanical and operational properties. However, it tends to collapse under atmospheric factors. Still, it is possible to increase the level of operation of building structures made of wood by thermal modification. The essence of this modification method is to give wood new improved properties – to resist the influence of moisture, biological factors, and prevent wood destruction.

But during thermal modification of wood, there are certain difficulties associated with technological parameters, specifically time and temperature. This is because in effective thermal modification of wood, it is necessary to season it for several days at temperatures above 200°C. Therewith, there may be a difference in the structure of wood and modification is not always achieved. Knowledge of the physical and mechanical properties of thermally modified wood and quality indicators allows choosing a technology considering economic indicators and the safety of technology application, environmental aspects.

Therefore, the development of the mode of mobile technology of thermal modification of wood, the study of thermophysical transformations for this process is an unresolved component of the production of sustainable building materials from wood. This determines the need

Suggested Citation:
Horbachova, O., Tsapko, Yu., Mazurchuk, S., & Tsapko, O. (2022). Mobile technology of thermal modification of wood. *Ukrainian Journal of Forest and Wood Science*, 13(3), 22-31.

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to establish the technological parameters of such thermal modification.

The purpose of this study is to investigate the technological characteristics of thermally modified wood to determine the surface energy and justify the compressive strength along the fibres.

To fulfil the purpose of this study, the tasks were set as follows:

– to establish the features of changing the surface energy of wood depending on the time of thermal modification of wood.

– to find the limits of strength during compression along the fibres, depending on the time of thermal modification of wood.

The scientific originality lies in the creation of a mobile technology for thermal modification of wood, characterized by a decrease in the time of thermal modification at elevated temperatures.

Literature Review

A review [1] summarizes recent advances and provides a perspective on the choice of wood modification method, i.e., the currently commercialized methods (acetylation, furfurylation, and thermal modification). An ancient practice (charring) has been rediscovered, certain types of polymerization modifications have now reached pilot scale, and samples of new functional wood-based materials are being explored at laboratory scale. And in paper [2] it is stated that wood modification is an excellent and increasingly popular method of expanding the use of wood materials. Conventional methods, such as chemical or thermal, have been developed to purposefully improve some selected wood properties, unfortunately usually at the expense of other parameters. These methods, as a rule, change the composition of wood, and therefore its mechanical properties, increase dimensional stability, water resistance, or reduce its sensitivity to microorganisms. Although conventional methods achieve the desired properties, they require the use of a lot of energy or chemicals. Therefore, research is more often shifting towards the development of more ecological processes. The advantage of modern methods is that in most cases they only modify the surface and do not affect the structure and mechanical properties of wood, while the use of chemicals is minimized. Cold plasma surface treatment is one of the cheapest and simplest technologies with limited environmental impact.

Compared to other building materials, wood has many advantages [3], such as thermal insulation, high strength-to-weight ratio, easy to process and has an attractive aesthetic appearance. But, as a valuable building and industrial material, it needs protection from biodegradation, especially when structures are exposed to harsh environmental conditions during operation. The durability of wood can be increased with wood preservatives and modification systems. Wood protection must be safe to use, reliable and long-lasting, cost-effective, and must not corrode metal or damage wood components. Presently, the scientific literature holds numerous reports on wood protection, but so far, the combination of wood preservation and modification has not been considered. Notably, the latest wood protection research projects in academia do not always reflect the most current developments in the field due to exclusive rights. The obtained results and conclusions, which are reported in scientific publications, contribute to the safe use of preservatives, the improvement of wood modification methods, as well as the processing and disposal of treated material. Thus, this paper discusses the latest research and advances in wood protection, including a general summary of the latest developments in wood preservatives, several types of preservatives, natural preservatives, and modification technologies. Therefore, it is desirable to use natural materials in the future.

Wood used outdoors is exposed to several biotic and abiotic factors, and for this reason, it needs protection to extend its life [4]. Some wood protection technologies are already being used commercially. One such technology is thermal modification, which refers to the structural, mechanical, and chemical transformations that occur in lignocellulosic material when gradually heated to certain temperature ranges. Over the past few years, researchers have evaluated weather resistance for distinct types of wood. Some experiments looked at natural radiation in different countries with distinct climatic conditions, while others focused on artificial radiation during UV and xenon tests. Most of the studies evaluated the effect of weathering on chemical, mechanical, and physical and anatomical changes compared to the initial characteristics of the material. A review of the scientific literature revealed a significant lack of research focused on abiotic impact factors, such as industrial and marine environments, or even individual climate factors, such as salt spray (simulated marine environment) or polluting gases (simulated industrial environment). This lack of information may be an opportunity for future work. This can provide understanding whether thermally modified wood is sensitive to pollutant gases or salinity, or a combination of the two. Knowing the mechanisms of degradation caused by these factors, it will be possible to investigate other forms of protection.

The greatest interest of researchers is caused by heat treatment of wood occurring in an airless environment at 180-250°C, since heat treatment of wood can increase its moisture resistance, reduce hygroscopicity and increase resistance to rot [5]. However, a decrease in the hygroscopicity of wood adversely affects the process of obtaining glued materials due to a decrease in surface wettability of thermally modified wood and, as a result, a decrease in adhesive characteristics. This paper investigates the effect of ozone on the surface of thermally modified wood to improve the adhesive properties during bonding. It was established that ozonation contributes to an increase in the surface wettability of thermally modified wood by over 15% due to the reactivity of ozone to oxidize and degrade lignin-containing wood products. It was found that the modification of wood, which includes preliminary volume heat treatment followed by surface treatment with ozone, causes an increase in the strength of the adhesive layer during operation in conditions of elevated humidity. In connection with the obtained results, an improved technology to produce glued support structures for wooden house construction is proposed.

The study [6] examines the results of hygroscopic and dimensional behaviour of thermally modified wood, modified in dry (the cell wall has almost zero moisture content) and wet (the cell wall contains moisture) conditions.

The literature on the thermal degradation of polysaccharide and lignin components of the cell wall, as well as the role of extractives, is also examined. Properties of wood modified in wet and dry conditions are compared, including mass loss, hygroscopic behaviour, and dimensional stability. The role of hydroxyl groups in determining hygroscopicity is discussed, as well as the importance of considering the mobility of cell wall polymers and crosslinking when interpreting sorption behaviour. The behaviour of thermally modified wood produced under wet conditions changes when the wood is further treated with water leaching, which includes further weight loss, changes in sorption behaviour and dimensional stability, but without any further adjustments in available hydroxyl (OH) content. This raises fundamental questions about the role played by OH groups in the sorption behaviour.

The paper [7] reviews systems that combine established wood modification procedures with secondary techniques or modifications to develop innovative technologies with multiple functionalities. These include UV stabilization, fire resistance or increased suitability for the application of paints and protective coatings. Thus, wood can become a multifunctional material through a series of modifications, treatments, or reactions to create a high-performance material with previously impossible properties. New applications targeting this extra functionality are diverse and range from enhancing electrical conductivity, creating sensors or responsive materials, improving well-being in the architectural environment, and improving fire and flame protection. Two parallel and related topics are identified: the functionality of modified wood and the modification of wood for multifunctionality. The new generation of wood modifications and wood processing uses a wide range of nanotechnology concepts. As this industry is expanding rapidly, current research trends are also included in the review to estimate the current status, but the likely direction of the industry is unknown.

Alternative and environmentally friendly technologies, such as thermal modification, can improve the durability and dimensional stability of wood, as reported in [8]. The effect of thermal modification on increasing the resistance of *Corymbia citriodora* and *Pinus taeda* wood against brown and white rot fungi in laboratory conditions was evaluated. Wood samples were exposed to temperatures of 160°C, 180°C, 200°C, 220°C, and 240°C in a laboratory electric furnace in a dynamic nitrogen atmosphere. For *P. taeda*, a processing temperature of 260°C was additionally used. Seven boards with dimensions of 6 cm×16 cm×56 cm (thickness × width × length) were used for each temperature. The thermally modified boards were transformed into prismatic test specimens with dimensions of 1.9 cm×1.9 cm×1.9 cm. Bottles of inoculated cultures containing test blocks were stored in the incubation room for 12 weeks. It was found that temperatures of thermal modification at the level of 160°C and 180°C reduced the biological stability of *C. citriodora* wood. Treatment temperatures of 200°C, 220°C and 240°C showed a satisfactory increase in rot resistance for both breeds.

In the study [9], pine (*Pinus massoniana* Lamb.) samples were thermally treated at different temperatures (150°C, 170°C, and 190°C), and the nanomechanical properties of the cell wall of the wood, which was coated with a water-based polyacrylic lacquer product, were determined and compared. The modulus and cell wall hardness of the wood and coating were measured and characterized by nanoindentation, and the factors influencing the mechanical properties during thermal modification were investigated by chemical composition analysis, contact angle analysis, and colorimetric analysis. The results showed that as the heat treatment temperature increased, the contact angle of water with the wood surface and the colorimetric difference increased, while the content of cellulose and hemicellulose decreased. After thermal modification at 190°C, the modulus of elasticity and hardness of the wood cell wall increased by 13.9% and 17.6%, respectively, and the modulus of elasticity and hardness of the polyacrylic coating applied to the wood decreased by 12.1% and 22.2%. The modulus of elasticity and hardness of the interface between the coating and the wood were lower than near the surface of the coating. The modulus of elasticity and the hardness of the cell wall at the interface between the coating and the wood were lower than those at a distance from the coating. The necessity and improvement of wood materials processing technology after thermal modification is not shown.

Due to environmental problems, the use of wood materials is becoming increasingly widespread and causes a shortage of wood [10], so the use of *Populus* wood as a fast-maturing wood is vital. *Populus* wood has several disadvantages: it is not durable, has a low density and is hygroscopic. Thermal modification is a technology that can be used to improve the situation. Therefore, in the study, aspen (*Populus tremula* L.) was thermally treated for 50 minutes at 160°C, and poplar (*Populus* x *canadensis* Moench) was processed in a vacuum environment for 120 min at 204°C, 120 min at 214°C, 180 min at 217°C, and 30 min at 218°C. Mass loss, colour change, density, tensile strength along the fibres, moisture removal efficiency and weight loss after the action of the brown rot fungus *Coniophora puteana* were determined, and light microscopy images were taken. The aspen veneer lost 5.3% weight between the 120-214 (6.2%) and 30-218 (4.6%) treatments in vacuum, which was consistent with the results in the scientific literature. The highest rate of mass loss was 8.7% in samples of wood modified with parameters of 180 min at 217°C in a vacuum, while the lowest – 2.9% – was obtained at 204°C for 120 min. The total colour change ΔE was 44 c.u., with the lightness parameter L providing the largest effect, which was halved after modification. Tensile strength decreased by 47% after modification for 50 min at 160°C and had a decrease of 29% during vacuum treatment. The weight loss of wood after exposure to the fungus *C. puteana* was 33% for 50 min at 160°C. After vacuum modification – 0-2.4%. The most suitable to produce plywood was poplar veneer thermally modified with the following operating parameters – 120 min at 214°C and 180 min at 217°C, vacuum environment.

Mozambique's abundance of tropical hardwoods is hindered by the predominance of low-grade wood species, as well as the lack of cost-effective treatment technologies to improve wood properties. *Brachystegia spiciformis* and *Julbernadia globiflora* are the most common wood species in terms of volume in the country, but with limited use due to poor wood quality. Therefore, in [11] thermal modification of wood of both species at three different temperatures (215°C,

230°C, and 245°C) for 2 hours was investigated with subsequent measurement of physical and mechanical properties of the material. The results indicate that the initially light sapwood of both types of wood gradually darkened with increasing intensity of thermal modification. Furthermore, from untreated samples to the highest level of heat treatment, *B. spiciformis* wood experienced a maximum weight loss of 27%, while the dry wood density decreased from 0.65 to 0.56 g/cm^3 and the equilibrium moisture content changed from 7 to 3%. *J. globiflora* wood had a 23% mass loss after the highest treatment level, a decrease in density from 0.81 to 0.74 g/cm^3 and a decrease in equilibrium moisture content from 8 to 3%. The changes in mechanical properties from the control samples to the highest level of heat treatment were also significant. For *B. spiciformis*, the modulus of elasticity decreased by 10.2%, the tensile strength – by 50.8%, the compressive strength along the fibre – by 29.2%, and the Brinell hardness – by 23.5%. The wood of *J. globiflora* follows the same trend of decreasing parameters – 6.9%, 53.2%. and 21.9%, respectively. All tested wood properties showed a considerable response to thermal modification after applying the most intensive treatment level. Despite the deterioration of the mechanical properties of both species, it is possible to achieve an optimal combination of temperature and processing time. The registered changes in the examined properties of wood of both species can expand the range of applications. Furthermore, the acquired colour resembled the colour of deciduous tropical species, which is very much in demand.

The research presented in [12] investigates the effect of thermal modification on the physical and mechanical properties of wood. To this aim, the experimental part was focused on the selected influencing parameters, namely temperature, residence time and density, while the four-point flexural strength was obtained as an output parameter. The obtained experimental data are stochastically modelled and compared with the model created by the method of genetic programming. Classical mathematical analysis provided processing parameters for the maximum bending strength – T = 187°C, t = 125 min, ρ = 0.780 g/cm^3) and compared with the results obtained by the genetic algorithm – T = 208°C, t = 122 min, ρ = 0.728 g/cm^3). Using stochastic modelling and evolutionary algorithms, it is possible to obtain models that aptly describe the experimental results. But the weatherproof properties of the material are not known.

Thermal modification of wood in a nitrogen atmosphere [13] allows increasing its suitability for use. Black poplar was thermally modified in a nitrogen atmosphere in the temperature within 160-220°C, duration of exposure from 2 to 8 hours. Wood colour parameters were measured according to the CIE L*a*b* colour space model. The changes in a* and b * had a non-linear profile. The maximum value of a* for black poplar wood was achieved after modification at 200°C, while the maximum value of b* was achieved after modification at 190°C. Changes in colour ΔE of black poplar after modification at 160°C and 170°C were similar, and the dynamics of changes increased after modification at 180°C. The highest value of ΔE, about 40 conditional units, was observed after modification at 220°C and over 8 hours. There were no statistically significant differences between ΔE for the radial and tangential cross-sections. Statistical analysis indicated that the modification temperature has a more significant influence on the variability of the L* value by 90%, and for changes in parameters a* and b* – about 70%. The effect of modification time on colour parameters was insignificant – less than 4%. The effect of the combined interaction between modification temperature and time on colour parameters was less than 10%. As a result, in case of ΔE of black poplar wood, the influence of temperature was at the level of about 80%. On the other hand, the effect of time and the interaction between temperature and modification time were below 3%.

In the study [14], wood was modified by a combined pre-compression treatment and post-vacuum thermal modification to simultaneously improve its mechanical strength and dimensional stability. The law of changes in the mechanical properties of wood with the degree of compression was investigated, as well as the effect of improving the dimensional stability of wood treated in this way. The results indicate that the optimal temperature and time of vacuum-thermal modification were 190°C and 10 h, respectively. Under these conditions, the structure of pre-pressed and post-vacuum thermally modified wood is gradually densified with an increase in the compression degree, which leads to a constant improvement in mechanical properties. Meanwhile, the anti-swelling performance after water absorption is correspondingly better than that of pressed wood before thermal modification. This indicates that the dimensional stability of compressed wood was improved by thermal modification. When the compression ratio was 70%, the modulus of rupture and impact toughness of the wood were 176 MPa and 63 kJ/m^2, which were 125% and 59% higher than those of untreated wood. The swelling index was also 26% higher than that of wood after compression. Thus, this method improves the mechanical strength and dimensional stability of the wood at the same time. This fact provides a scientific basis for optimizing the reinforcement modification of fast-growing wood. But the issue related to the resistance of the material to leaching stays unresolved.

The paper [15] analysed the change in colour, morphology, and wetting of beech wood thermally modified at 200°C during three periods of heating – 1, 3, and 5 h. The results show that with increasing heating time, the lightness parameter L* decreased significantly, while the a* and b* coordinates increased during three hours. Subsequently, there was a moderate decline. Immediately after the one-hour thermal modification, the total colour difference ΔE was much higher than 12. This means that as a result of heat treatment, which lasted only one hour, an entirely new colour was obtained. Further modification caused a further increase in ΔE, but more moderate. Increased surface roughness was detected during the examination of changes in the surface morphology of beech wood. But this fact was not confirmed unambiguously in all three processing periods. The results indicate that the heat treatment of beech wood led to a considerable improvement in the wetting resistance of the beech wood surface. It is confirmed by the values of the wetting contact angle – θ > 90°. Furthermore, the time required for complete absorption of the drop by the material increased by one or two orders of magnitude. The wettability changed mainly due to the change in the processing temperature. The importance of the duration of the modification has not been unequivocally confirmed. A decrease in the wetting of the wood surface substantially

affected the decrease in the free energy of the wood surface, which was mainly caused by a decrease in the polar component of this energy. This can adversely affect the process and the quality of the surface treatment, if coating materials are applied to wood modified in this way.

Thus, it has been established from literary sources that thermal modification of wood can provide it with the ability to resist decay. However, the high schedule parameters of thermal modification, namely temperature and time, encourage the search for more effective technologies. Therefore, research in this area is an unresolved component of thermal modification of wood and necessitated more in-depth research.

Materials and Methods

To investigate the technological characteristics of thermally modified wood to determine the surface energy and substantiate the compressive strength along the fibres, samples of pine wood with dimensions of about 50×50×50 mm were used (Fig. 1).

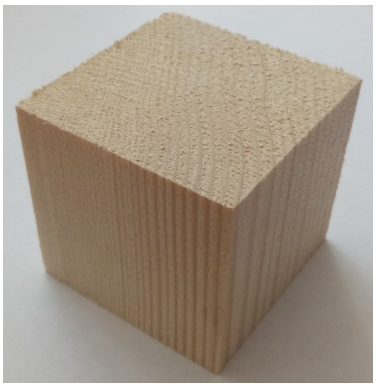

Figure 1. Samples of research materials: pine wood

Thermal modification of pine wood samples was carried out in a convective chamber. In general, the material was seasoned at 300°C for 5, 10, 15, 20, 25, and 30 min (Fig. 2). To analyse the surface energy characteristics of wood, the marginal angle of wetting on samples of thermal pine wood was determined (Fig. 3). Testing: a drop of coating was applied to the sample using a pipette [16]. After the drop reached an equilibrium state, its height and diameter were determined using a microscope with a certain degree of magnification.

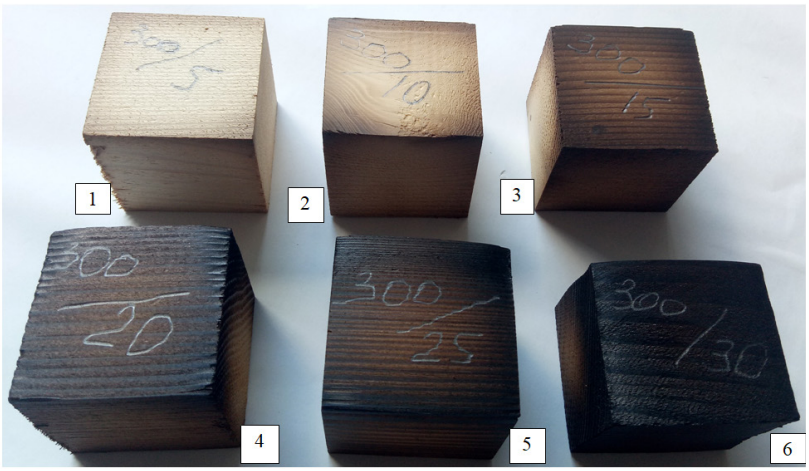

Figure 2. Pine wood samples after thermal modification at 300°C for contrasting times: 1 – 5 min, 2 – 10 min, 3 – 15 min, 4 – 20 min, 5 – 25 min, 6 – 30 min.

The marginal wetting angle θ was determined through the tangent of the angle θ, which was calculated according to the formula:

$$tg\theta = \frac{4dh}{d^2-4h^2}, \quad (1)$$

where d, h are the diameter and height of the drop, mm.

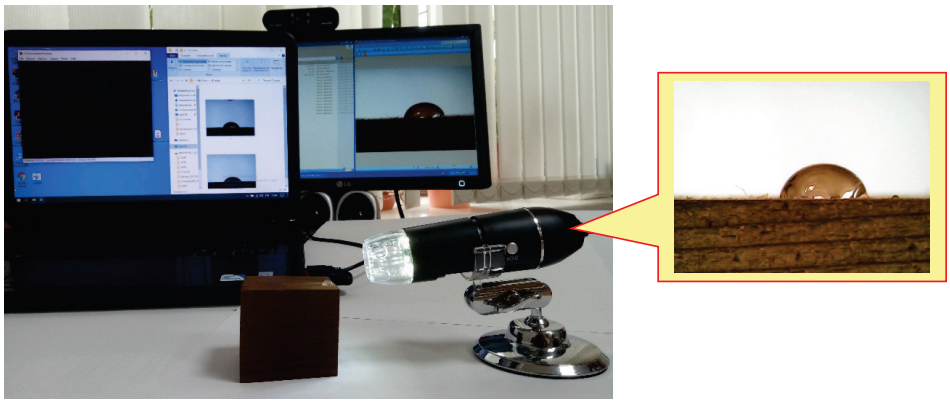

Figure 3. Determination of the edge wetting angle of the coating

To estimate the surface energy of thermally modified wood, the Fowkes method was used [17], which allows considering dispersion, hydrogen, and dipole-dipole interactions at the solid-liquid interface:

$$(1 + cos\theta)\sigma_l = 2\left(\sigma_s^d \cdot \sigma_l^d\right)^{0,5} + 2\left(\sigma_s^p \cdot \sigma_l^p\right)^{0.5}, \quad (2)$$

where θ is the marginal wetting angle; σ_s, σ_l are the surface energy of solid and liquid, respectively; index p is the component of the total surface energy due to hydrogen and dipole-dipole interactions; index d is due to dispersion interactions.

This equation has two unknown values σ_s^d and σ_s^p, and for practical use, contact angle data for two different liquids with known surface tensions σ_l^d and σ_l^p are required (Table 1).

Table 1. Surface tension and dispersed and polar components for test liquids

Liquid	σ_l^d	σ_l^p	σ_l
water	21.8	50.8	72.6
ethylene glycol	29.3	19.0	48.3

The compressive strength along the fibres of pine wood was determined according to ISO 13061-3:2014 [18].

Results and Discussion

Conducting the test: a drop of coating was applied to the sample using a pipette (Fig. 4). After the drop reached an equilibrium state, its height and diameter were determined using a microscope.

As Figure 4 shows, water creates an almost straight angle of the drop during wetting, which increases along with the level of modification, while ethylene glycol creates a sharp angle, which in turn decreases.

The results of determining the marginal angle of wetting by test liquids and determining the corresponding components of the free energy of the plywood surface are presented in Table 2.

Table 2. Marginal angle of wetting and free energy component of the wood surface

Thermally modified pine wood	Marginal angle of wetting, θ, °		Surface free energy, mJ/m²			Polarity
	Water	Ethylene glycol	General	Polar	Dispersed	
at 300°C and for 5 min	78.1	40.1	64.5	37.3	27.2	57.9
at 300°C and for 10 min	81.1	38.8	54.2	27.7	26.5	51.1
at 300°C and for 15 min	84.0	33.3	43.3	20.6	22.7	47.6
at 300°C and for 20 min	86.1	29.2	38.1	17.2	20.4	45.1
at 300°C and for 25 min	87.4	26.4	32.2	13.6	18.6	42.2
at 300°C and for 30 min	88.3	20.1	24.1	8.3	15.8	34.4

As a result (Table 2), it was established that thermal modification of wood led to an increase in resistance to wetting and a decrease in the surface free energy of wood.

Thus, an increase in the active component in the modifier leads to a decrease in the surface free energy and the polarity of the wood surface. As a result of a complex approach to the study of wettability, polarity, interphase tension, it is possible to choose stable coatings for wood. The results of determining the compressive strength of wood along the fibres are presented in Figure 5.

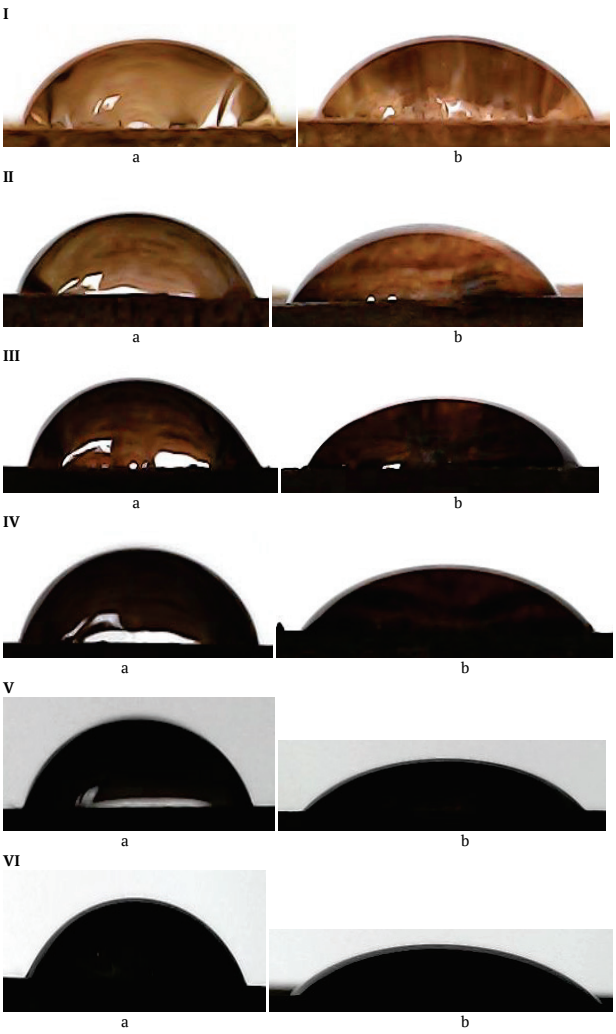

Figure 4. A drop of liquid on pine wood after thermal modification during: I – 5 min, II – 10 min, III – 15 min, IV – 20 min, V – 25 min, VI – 30 min, a – water, b – ethylene glycol

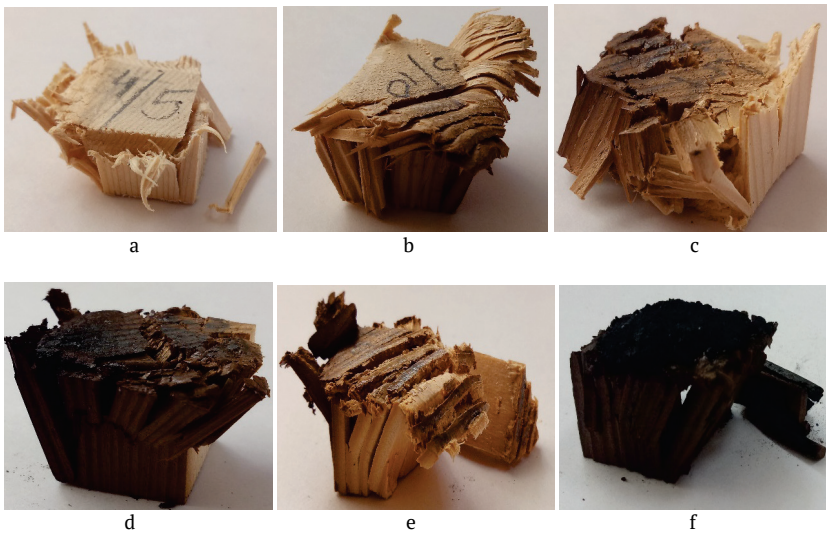

Figure 5. Determination of the compressive strength of thermally modified wood for contrasting times: a – 5 min, b – 10 min, c – 15 min, d – 20 min, e – 25 min, f – 30 min

For wood samples with a modification time of up to 20 minutes, crumpling of the fibres at the load point with minor chipping is characteristic (Fig. 5). In the samples with a modification time of 25 and 30 min, complete destruction under load is observed. The results of determining the resistance of pine wood to compression depending on the level of thermal modification are presented in Table 3.

Table 3. Compressive strength of wood samples

Thermally modified pine wood	Sample dimensions, mm			Maximum pressure, N	Compressive strength, MPa
	width	thickness	length		
at 300°C and for 5 min	20.00	19.90	30.50	16,828.9	42.3
at 300°C and for 10 min	20.00	20.00	30.00	16,448.2	41.1
at 300°C and for 15 min	20.20	20.10	29.90	17,064.8	42.2
at 300°C and for 20 min	20.00	19.70	30.20	15,275.6	38.9
at 300°C and for 25 min	19.80	19.80	30.10	20,507.2	52.3
at 300°C and for 30 min	20.90	19.80	30.40	12,009.2	29.0

As a result of research, it was established that during thermal modification for 10 minutes, pine wood withstands compression at 41.1 MPa. With an increase in the time of thermal modification to 25 min, the compressive strength increases to 52.3 MPa. Over time, the wood becomes brittle, less plastic, while the compressive strength decreases by 1.46 times.

During the thermal modification of wood, as evidenced by the research results, the chemical transformations of pine wood is natural. This is manifested in a change in colour under temperature and, accordingly, in a change in structure, which can lead to a change in certain properties, e.g., water absorption. Thermal modification of wood leads to an increase in resistance to wetting [19], which is characterized by an increase in the water wetting angle. Therewith, the calculated components of the free energy of the wood surface showed a decrease in both polar and dispersive components. Thermally modified wood is obtained at the same exposure temperature, but for a longer time, characterized by a larger wetting angle with water and a decrease in surface energy (Fig. 4, Table 2). Obviously, such a mechanism of thermal modification of wood is a factor in regulating the degree of formation of weather-resistant material. This agrees with data known from studies [8; 15], the authors of which also link the effectiveness of protection against the influence of water during thermal modification of wood. Unlike the results of studies [4; 7], the obtained results regarding the change in compression of thermally modified wood and changes in its surface properties suggest the following:

– the main regulator of resistance to wetting is not only the formation of the surface, but also the chemical transformations of wood components, which provide resistance to moisture penetration.

– a substantial impact on reducing the wettability of the surface of thermal wood is carried out towards the formation of water-resistant capillary porous elements, as a result, the reduction of the adhesive characteristics of the material.

Such conclusions can be considered appropriate from a practical standpoint because they allow a reasonable approach to the definition of the necessary technology of thermal modification of wood. From a theoretical standpoint, they allow stating the determination of the mechanism of wood thermal transformation processes [20], which constitute certain advantages of this study. The results of determining the compressive strength after thermal modification of wood (Table 3) indicate an ambiguous effect of the nature of the change in strength on the compression of thermally modified wood. This assumes the availability of data sufficient for qualitatively performing thermal modification and identifying, on its basis, the time at which the drop in strength begins. Such detection allows investigating the transformation of wood moving towards reduced resistance to destruction and to determine those variables that substantially affect the beginning of the transformation of this process.

Conclusions

The results of determining the strength on the compression of pine wood show that the compressive strength decreases depending on the degree of thermal modification. Specifically, at 300°C and for 5 min and 15 min of thermal modification, the compressive strength is equal to ordinary wood, at 300°C and a time of 10÷20 min, the compressive strength is reduced to 1.1 times. At a modification temperature of 300°C and a time of 25÷30 min, the wood becomes brittle, less plastic, while the compressive strength decreases by 1.46 times. Therewith, for samples of pine wood thermally modified for up to 20 min, crumpling of fibres at the point of pressure with minor splitting is characteristic, and for samples of pine wood thermally modified for more than 20 min, complete destruction under the pressure with discolouration of the outer layers is observed.

Thermal modification of wood leads to an increase in resistance to wetting, which is characterized by an increase in the angle of wetting. Therewith, the calculated components of the free energy of the wood surface showed a decrease in both the polar and dispersive components. A decrease in the free surface energy of wood can adversely impact the effectiveness of surface treatment of the material with paint and varnish coatings.

In the future, it is planned to develop equipment and work out this technology of thermal modification of wood and to investigate the technological properties of the obtained materials.

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Мобільна технологія термічного модифікування деревини

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Анотація. Деревина як конструкційний матеріал має ряд недоліків, до яких відносяться малий термін служби, відносно низька формостійкість, значні об'ємні деформації під впливом вологи, виражена анізотропія та водопоглинання. Термомодифікування дещо покращує фізико-механічні властивості, але постає проблема зміни поверхневих характеристик, зокрема адгезії. З метою визначення технологічних характеристик термічно модифікованої деревини та розроблення можливих заходів покращення технології нанесення захисних покриттів визначено поверхневу енергію та межу міцності на стиск вздовж волокон. Застосовано комплексний підхід для аналізу стану поверхні термічно модифікованої деревини через вивчення поверхневих енергетичних характеристик на основі методу Фоукса, який враховує дисперсійні, водневі та диполь-дипольні взаємодії на міжфазній границі «тверде тіло-рідина». За крайовим кутом змочування встановлено, що процес термічного модифікування деревини сприяє збільшенню стійкості її поверхні до змочування за рахунок зменшення полярності в 1,68 рази із збільшенням тривалості модифікування до 30 хв. При цьому вільна енергія поверхні для зразків модифікованих за 300 °С упродовж 5 хв. становить 64,5 мДж/м^2, упродовж 30 хв. – 24,1 мДж/м^2. Щодо стійкості на стиск – термічне модифікування знижує межу міцності у 1,46 рази. Так, за температури 300 °С і часу 5 хв. та 15 хв. показник залишається на рівні звичайної деревини – 42 МПа. Оброблення упродовж 30 хв. зменшує межу міцності до 29 МПа, деревина втрачає пластичність. Отримані результати дають можливість ефективно підібрати стабільні покриття для такої деревини для якісної обробки поверхні лакофарбовими матеріалами. Знаючи момент часу, з якого починається зменшення межі міцності, ведення процесу термічного модифікування стає більш контрольованим і дає можливість передбачити характеристики майбутнього матеріалу

Ключові слова: деревинний матеріал, технологічні параметри, процес термічного модифікування, кут змочування, вільна поверхнева енергія, стиск вздовж волокон, межа міцності, крихкість