An issue related to using wood and wood products for building structures is to ensure their stability and durability during operation within wide limits. Therefore, the object of this study was a change in the properties of the polymer shell of powder paint on wood during thermal modification.

It is proved that in the process of thermal modification of wood, its structure changes, and accordingly, during the polymerization of powder paint, degassing occurs, which affects the polymer shell. Namely, during the thermal polymerization of powder paint at a temperature of 180 °C for untreated wood, shallow bubbles and craters are characteristic of the formed polymer shell. Instead, a smooth surface is marked for a sample of thermally modified wood. Thermogravimetric analysis data show thermogravimetric curves characterized by the loss of mass of the sample of the original wood with increasing temperature due to the processes of dehydration, destruction of hemicellulose and lignin. This is dehydration, accompanied by the destruction of the pyranose cycle, and carbonization to form a carbon residue and a complex mixture of volatile products. Due to this, bubbles and craters are formed in the polymer shell of the coating. Based on the obtained results of adhesion of the polymer shell on wood, which is treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 180 °C, the adhesion level is 2.1 MPa. Reducing the polymerization temperature of a mixture of the epoxy polyester system with functional additives to 130 °C increases adhesion by 1.75 times, and the nature of the destruction passes through the polymer shell. For thermally modified wood, the level of adhesion is within 2.1 MPa, and the destruction takes place through the wood. This is due to the increased fragility of the surface after thermal modification of wood

Keywords: wood structure change, powder paints, thermal polymerization, pyrolysis and wood degassing

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DETERMINING PATTERNS IN THE FORMATION OF A POLYMER SHELL BY POWDER PAINT ON WOOD SURFACE

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1. Introduction

Wood is one of the best materials for the construction of buildings, decoration inside residential premises, the manufacture of various interior items and products, etc. Natural wood is an environmentally friendly material, it breathes and has low thermal conductivity. However, it has a number of negative defects, such as anisotropy and hygroscopicity, which leads to uneven swelling, curvature, and cracking of wood products during operation, which encourages the need for additional processing. Therefore , the duration of the service life of wooden structures and surfaces depends on how well and correctly their processing is carried out with special protective paints and varnishes.

For the effective use of paints and varnishes, it is necessary to take into account the type of wood, as well as the possibility of reusing the coating and the operating conditions of wooden products and their compatibility with paint and varnish material, environmental friendliness of the coating. This is due to the fact that the coatings are made on the basis of synthetic solvents, resins, various siccatives, and other chemical additives, which causes a low level of environmental friendliness of paint compositions, and methods of preparation for applying paint.

Thus, the use of effective paints and varnishes requires fundamental research to determine the resistance of products to operating conditions. During the operation of wood under conditions of temperature and humidity fluctuations, individual coatings dissolve in water and degrade from the surface of the wood. In addition, the lack of theoretical ideas about changes in the structure of wood during operation and the impact on the stability of wood of paintwork limit the scale of use of these materials for building structures.

Therefore, studies aimed at determining the compatibility of paintwork and wood and changing their structure during processing, which are necessary to determine the parameters of wood protection, are relevant.

2. Literature review and problem statement

In [1], coloring powder microcapsules coated with urea-formaldehyde resin were made, and their properties were used to study the properties of painted coatings of wooden surfaces. The mechanical and optical properties of water-based paint films containing powder coloring microcapsules have also been tested. The results show that with an increase in the content of microcapsules, the effect of changing the color of the coating gradually becomes obvious, and the magnitude of the change in the parameter *b*, representing a yellow tint, gradually increases. Thus, the content of the microcapsule increased from 1.0 to 13.0 %; respectively, the value of *b* increased from 0.7 to 2.6. The gloss of the film has significantly decreased with an increase in the content of the coloring microcapsules of the powder – the highest gloss index at 1.0 %. The content of microcapsules also affected the impact resistance of the film in the surface layer of the water-based coating. The best impact resistance was 5.0 %, the second level of adhesion at 1.0–5.0 % and 11.0–13.0 %, the first level of adhesion – at 7.0 % and 9.0 %. In terms of mechanical and optical properties, the content of powder coloring microcapsules at the level of 5.0 % is the best for the overall efficiency of surface layers of water-based coatings. Such coloring microcapsules have practical use in furniture production but can change color according to the actual temperature and play a decorative role.

In [2], the possibility of using powder coating on wooden panels, which are non-conductive and sensitive to high temperatures, is given. This expansion is associated with the development of powder coatings that harden at low temperatures, and the production of special-class MDF panels. Solvent-based paints are still the most used coatings in the furniture industry, followed by water-based paints and powder coatings. However, government legislation on toxic chemicals used in solvents, especially in relation to human health, has raised people's consciousness. This forced furniture manufacturers to use modern and environmentally friendly coating systems. There are many advantages to using powder coatings – they are non-toxic, cost-effective, easy to apply, and resistant to weathering. But issues related to the establishment of a change in the structure of wood during the polymerization of the coating remain unresolved.

Powder coating is environmentally friendly and safe from the point of view of human health and is used mainly in household appliances and in the automotive sector [3]. Because of these advantages, recent studies have expanded the work of applying powder coating to non-conductive surfaces. As part of this study, low-temperature curing (from 120 °C to 130 °C) was applied to wood-based MDF composite panels, chipboard, and plywood to facilitate electrical conductivity. Epoxy, polyester, and hybrid (epoxy-polyester) types of powder paint and water-based liquid paint (control group) were applied to the surface of the materials. Powder-coated panels were compared to panels coated with water-soluble acrylic resin. Prepared samples were analyzed for operational properties. The best results for swelling in thickness, water absorption, adhesion strength, abrasion and scratch resistance were obtained for plywood coated with water-based liquid paint. Next in the ranking is MDF coated with powder paint on a polyester basis; plywood coated with hybrid powder paint; chipboard coated with hybrid powder paint, and plywood coated with epoxy powder paint, respectively. However, it is not specified what measures should be applied to improve the properties of processed wood during industrial production.

In study [4], variable phase microcapsules (VPM) were added to water-based paint for application to wooden furniture. Testing the microscopic and thermal properties, it was found that such a powder can undergo phase changes and absorb heat after dispersing in water-based paint. Secondly, fiberboard coated with microencapsulated coatings with different solid content was tested on homemade equipment at room temperature of 27 °C. Results showed that the addition of VPM can significantly change the contact temperature. And as the number of microcapsules added increased, the cooling effect became more obvious. At the same time, the addition of microcapsules can cause the paint film to be matted and affect its hardness. Thus, the cooling effect can be achieved by applying a film of paint to the surface or by controlling the number of microcapsules.

In [5], the effect of fiberglass powder on the properties of water-soluble coatings with thermochromic ink applied to the board of Chinese fir and temperature-sensitive thermochromic water-soluble coatings with thermochromic inks as the basis of paint was investigated. The concentration of fiberglass powder was determined when the microstructure, optical properties, mechanical properties, liquid resistance and heat preservation effect were the best. The results showed that a paint film with a fiberglass powder concentration of 1.0 % to 7.0 % had better discoloration rates. With the increase in the concentration of fiberglass powder, the gloss of the paint film gradually decreased, and when the concentration of fiberglass powder was from 0 % to 5.0 %, the gloss of the paint film was preferable. The concentration of fiberglass powder did not affect adhesion, impact resistance and resistance to liquid. In the first 2.5 minutes, the temperature of the water-based coating with a fiberglass powder content of 3.0 % was higher than without fiberglass powder. There is a certain effect of heat retention. When the fiberglass powder content was 3.0 %, the microstructure of the paint film was the best. The composition of the paint film with different concentrations of fiberglass powder did not differ, and the discoloration performance of the paint film with the effect of heat preservation did not change over time. The analysis showed that water-based coatings with a fiberglass powder content of 3.0 % had the best complex characteristics. However, issues related to the ability to retain color and heat remained unresolved.

In study [6], organic thermochromic pigment powder and water-based wood primer were selected as the basis of the paint. The Chinese fir board was chosen as the basis for the preparation of water-based thermochromic coatings with different concentrations of thermochromic pigment powder. The best concentration of thermochromic pigment powder for aqueous primer on the surface of Chinese fir was investigated. The results of the experiment showed that the property of the primer film to change color was the best when the concentration of pigment powder in the primer film was 5.0–10 %. There was a negative correlation between the primer luster and the concentration of pigment powder. The luster of the primer film was the highest at a pigment powder concentration of 5 %. At the concentration of pigment powder 0–20 % and 25.0–30 %, the adhesion of the coating was at the level of 0 and 1, respectively. Resistance to the effects of the primer film increased with an increase in the concentration of pigment powder, but the resistance to the influence of the primer film with a concentration of thermochromic pigment powder of more than 30 % did not change. Scanning electron microscopy showed that the higher the concentration of thermochromic pigment powder, the more particles and agglomeration. When the concentration of pigment powder was 5 %, the particle distribution was uniform and there was no agglomeration, and the microstructure of the primer film was the best. Infrared spectroscopy showed no difference in the composition of the paint film from 0 % to 30 % of the powder content. The results showed that the property of water-soluble primer on Chinese fir was better when the pigment concentration was 5 %. Water-soluble thermochromic primer film provides potential applications for the development of intelligent furniture in different temperature ranges. But it is not indicated how the film behaves during thermal action and its stability during artificial aging is not determined.

The purpose of study [7] was to evaluate the effectiveness of surface coating using an aqueous base, solvent base, and powder coating on medium-density fiberboard. The coating efficiency was evaluated using adhesion strength, surface hardness, layer thickness – dispersion analysis. The results of the rapid strain test were analyzed using the Kruskal-Wallis method. According to these results, the type of coating was an effective factor in adhesion strength, surface hardness, layer thickness, and quick deformation test. The adhesion strength and resistance to shock deformation when applying water-based painting were higher than those of solvent-based coatings. During powder coating application, although the surface hardness of the coating was higher than that of solvent and water-based coatings, the results of rapid deformation were lower than solvent and water-based coatings. The adequacy of the models was carried out according to the values of the R-square (R2) and the adjusted R-square (Adj-R2). The values of R2 adhesion strength, layer hardness, and film layer thickness were 93.60 %, 95.33 % and 73.90 %, respectively. The Adj-R2 values of strength, layer hardness, and film layer thickness were 93.45 %, 95.23 % and 73.30 %, respectively. But treatment with such substances did not significantly improve the mechanical properties.

Shape-resistant various phase materials (VPMs) have great potential for regulating unbalanced demand and heat supply. However, most VPMs have a powdered, lamellar, or volumetric solid form that is difficult to glue to a heat source or target substrates [8]. The authors developed an VPM coating based on reactive poly (ethylene glycol) (RPEG) for direct exchange and storage of thermal energy. RPEG with highly reactive silanol groups is obtained by PEG reaction with 3-isocyanatopropyltriethoxysylan (IPTS) followed by hydrolysis in a weak acid. Coatings made of sewn VPM are obtained on various substrates, including cotton fabric, wood, wool, and even objects of irregular shape. Coatings demonstrate the obvious properties of the phase transition between a solid and a high energy storage density (142.8 J/g). Multilayer carbon nanotubes (MWCNTs) are additionally doped into coatings using a self-stitching disperser. Composite coatings demonstrate excellent high-temperature shape stability and fast heat transfer properties due to the formation of a cross-linked network between RPEG and MWCNT. But the question of their resistance to destruction remains unresolved.

The surface properties of thermally modified ash wood with powder coating and compared the results with unmodified wood were investigated [9]. Wood samples were sanded with sandpaper with a grain of 80, and then preheated at 80 °C for 5 minutes in an infrared oven. The surface of unmodified and modified wood samples was coated with an epoxy-polyester (1 to 1) hybrid coating using an electrostatic corona sprayer at a pilot plant installed in the laboratory. Coatings on wood samples were strengthened under different curing conditions in an infrared furnace, i.e., 120 °C/15 min., 140 °C/10 min., and 160 °C/10 min. The results showed that the thermal modification (TM) of wood led to a slight decrease in the mechanical characteristics of the surface system (wooden base and coating film). For example, the resistance to scratches and abrasion of unmodified samples at a curing temperature of 120 °C was 3.33 N and 135 revolutions, but 3.12 N and 120 revolutions after TM. However, the average surface roughness (1.26 microns) and contact angle (60.8°) of distilled water on hardened coatings on modified wood were lower than on unmodified wood (1.86 microns and 80.8°, respectively). However, the durability of such a coating is not determined.

The issue of reducing the toxicity of composite materials encourages the use of dry powder adhesive mixtures of polyester resin since its dissolution in organic substances reduces environmental safety. Work [10] presents the results of studies of free surface energy and its components (polar and dispersed) for plywood, which is made on the basis of powdered polyester resin. The sequences of polarity changes and their ratio with the main component of wood after the formation of a plywood slab at high temperature, which are consistent with the structural and functional features of thermally modified wood, have been established. The resulting plywood is characterized by a reduced property to the absorption of water since the free surface energy is reduced by 2.3 times, and the polarity by 2 times, which is associated with the thermal modification of veneer. However, the strength characteristics of the adhesive seam in the environment of variable temperature fields have not been investigated.

The use of electrostatic powder coating technology for wooden panels has increased significantly. In study [11], oriented strand boards (OSB; OSB/2; and OSB/3) were coated with powder paints using an electrostatic corona sprayer. Epoxy/polyester (hybrid:1/1) coating suitable for internal use was applied to the surface of OSB samples (150 g/m^2) at three different curing temperatures: 120 °C for 15 min., 140 °C for 10 min., and 160 °C for 10 min. using an electrostatic crown gun. The surface properties of OSB samples are determined – roughness, wettability, resistance to scratches, abrasion, film thickness. Abrasion and scratch resistance of coated OSB samples improved with an increase in curing temperature from 120 to 160 °C. The highest mechanical surface strength was obtained from OSB/3 samples that were aged in an infrared furnace at 160 °C for 10 minutes. Whereas the lowest strength was found in OSB/2 samples that were aged in an infrared furnace at 120 °C for 15 minutes. However, the contact angle values of coated OSB samples increased with increasing curing time, while surface roughness decreased.

Unlike conventional coating processes, such as varnishing, plasma deposition of powder using a plasma jet of atmospheric pressure on wood is not yet widely used [12]. The key advantage of this process is the absence of volatile organic compounds and organic solvents. Thus, the sapwood of European beech (*Fagussylvatica L.*) and pine (*Pinussylvestris L.*) were coated with particles of polymer (polyester), metal (silver with aluminum coating) or metal oxide (bismuth oxide). In addition, a layer system consisting of polyester and metal or metal oxide was investigated. The layer thickness and topography were analyzed using a laser scanning microscope and a scanning electron microscope, which fixes a thickness of 2–22 microns depending on the coating material. In general, the chemical composition of the layers was determined using measurements of X-ray photoelectron spectroscopy and infrared spectroscopy with the Fourier transform. Coatings consisting of metal and metal oxide showed band gap width and plasmon resonance in the range of 540 and 450 nm. Due to this absorption, wood can be protected from ultraviolet (UV) radiation. In water absorption and release tests, polyester layers showed a decrease in water vapor absorption after 24 hours at 100 % relative humidity (RH) by 53–66 %. Whereas layers of pure metal oxide showed the best desorption efficiency. The combination of metal oxide and polyester in a single-layer system combines the protective properties of individual coatings from water vapor and UV radiation. But there remained questions related to the resistance of these coatings to use in external conditions.

Powder coating of wooden panels, such as medium-density wood fiber boards (MDF), is gaining industrial interest due to the environmental and economic advantages of powder coating technology. Transferring powder coating technology to temperature-sensitive bases such as MDF requires a deep understanding of melting behavior, fluidity, and curing of the low-baking resins used. In [13], thermal analysis was used to characterize the properties of powder coating based on epoxy resin in combination with the analysis of kinetic isoconversion data, as well as rheometry. The resulting polymeric and hardened powder coating films are tested to determine the ideal production window. To do this, it is advisable to apply and process the resin to obtain satisfactory surface characteristics, on the one hand, and without affecting the MDF carrier of too high a temperature, on the other hand. This is necessary in order to prevent deterioration of the mechanical strength of the panel. For the manufacture of powder coated films with a high glossy surface level – a characteristic that has not yet been successfully implemented on powder-coated MDF.

Thus, from literary sources it has been established that when using powder paints for wood, during its polymerization, changes are made in the structures of the substrate components and the polymer shell itself. During polymerization of paint during thermal action, gas bubbles are released from wood and craters remain on the surface of the polymer shell. This reduces the level of adhesion of the paint to the substrate. All this gives grounds for conducting a study on determining parameters that ensure the use of such paint for wood.

3. The aim and objectives of the study

The aim of this work is to establish the patterns of formation of the polymer shell during the polymerization of powder paint on the surface of the wood. This makes it possible to justify the directions of expanding the scope of application of wood products.

To accomplish the aim, the following tasks have been set:

– to study the process of forming the coating shell during polymerization of powder paint on the surface of wood during thermal action;

– to establish the amount of adhesion of the polymer shell during the polymerization of powder paint on wood.

4. Materials and research methods

4. 1. Research hypothesis

The object of our study is the change in the properties of the polymer shell of powder paint on wood during thermal modification.

The research hypothesis is that according to the results of establishing the quality of the formation of a polymer shell from powder paint on wood and determining the adhesion of the polymer shell during the polymerization of powder paint, it becomes possible to use wood coating.

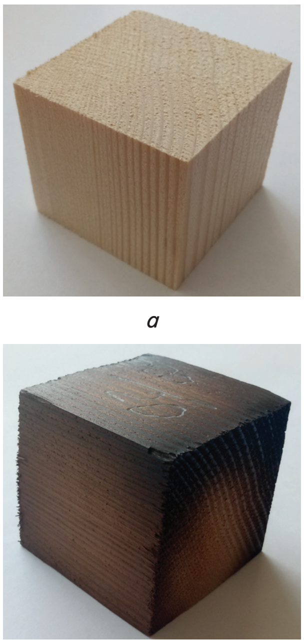
4. 2. Investigated materials and equipment used in the experiment

The studies were carried out both using samples of untreated pine wood with dimensions of about 50×50×50 mm, and thermally modified wood, at a temperature of 200 °C for 6 hours using technology [14] (Fig. 1).

To establish the effectiveness of the polymer shell of powder paint on wood, electrostatic application to wood samples of 180–190 g/m^2 was carried out and thermal polymerization was carried out at a temperature above 100 °C for 20 min. As samples of powder paint, a mixture of epoxy polyester system with functional additives and polymerization temperature of 130–140 °C and 180 °C was used.

Also, a polyester system with a polymerization temperature of 180 °C with a total flow rate of about 183 g/m^2.

After aging for 14 days, wood samples with the resulting protective coating were tested for coating efficiency and adhesion capacity.



a

b

Fig. 1. Samples of materials for research: *a* — pine wood; *b* — thermally modified pine wood

4. 3. Procedure for determining the properties of samples

Determination of the effectiveness of coating with wood samples was carried out according to the working procedure, the essence of which was to experimentally determine the quality of the polymer shell of wood coating [15]. To obtain the efficiency values of the polymer shell of powder coating on wood, the equipment of a scanning electron microscope was used (Fig. 2). The test sample was fixed on the table and the outer surface of the coating was fixed on the wood.

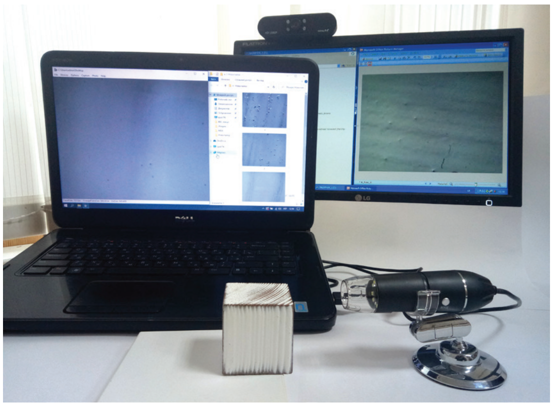


Fig. 2. Determination of the quality of the polymer shell powder coating on wood

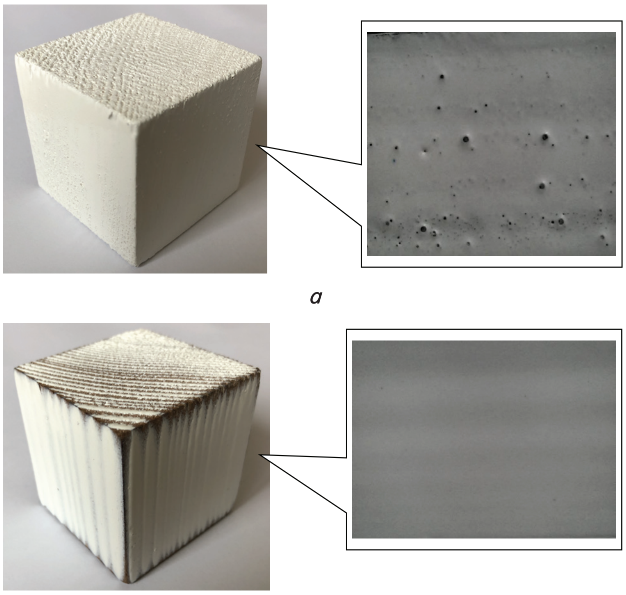
Determination of the adhesion strength of the polymer coating shell to wood was carried out in accordance with ASTM D4541-22 [16]. The essence was to glue the stop to the polymer shell of the coating of the wood sample and, after drying and aging, the stop was loaded on separation with the determination of the force of its level. As an adhesive, an elastic glue-sealant "Fix All" manufactured in Ukraine was used.

To determine the degassing of wood, thermogravimetric analysis was carried out according to [17] and the determination of the temperature range at which the thermal destruction of wood occurs most intensively, in a dynamic mode, was carried out. Thermogravimetric studies were carried out on the Linseis STA 1400 derivatograph (Germany). Samples weighing 10 mg were heated in an air atmosphere from 20 to 250 °C at a rate of 10 °C/min.

5. Results of studying the process of formation of a polymer shell from powder coating on wood during thermal polymerization

5. 1. Investigation of the influence of thermal modification of wood on the polymerization process of the polymer coating shell

At the first stage, the untreated and thermally modified wood sample was stained with an epoxy polyester system (Fig. 3, 4) and a polyester system (Fig. 4) with polymerization of paint at a temperature of 180 °C.



a

b

Fig. 3. Samples of untreated and thermally modified wood coated with a white epoxy polyester powder system with polymerization of paint at a temperature of 180 °C: *a* — untreated; *b* — thermally modified wood

As can be seen from Fig. 3, 4, during thermal polymerization at a temperature of 180 °C on the polymer shell for untreated wood, shallow bubbles and craters are inherent, which are formed during thermal polymerization of a wood sample. Instead, a smooth surface was marked for a sample of thermally modified wood. In this regard, studies were carried out on the formation of a polymer shell on untreated wood at a polymerization temperature of 130 °C and 140 °C (Fig. 5).

From Fig. 5 we found that lowering the polymerization temperature of powder paint to 130 °C does not remove the shortcomings of the polymer shell on untreated wood.

Thus, the similarity of the results of the use of different colors is noted. Analysis of the results of experiments on dyeing wood with powder paint shows that for untreated wood covered with a powdered epoxy polyester system of white color with polymerization of paint at a temperature of 180 °C, shallow bubbles are inherent, which are formed during thermal polymerization. In turn, a smooth surface is marked for samples of thermally modified wood.

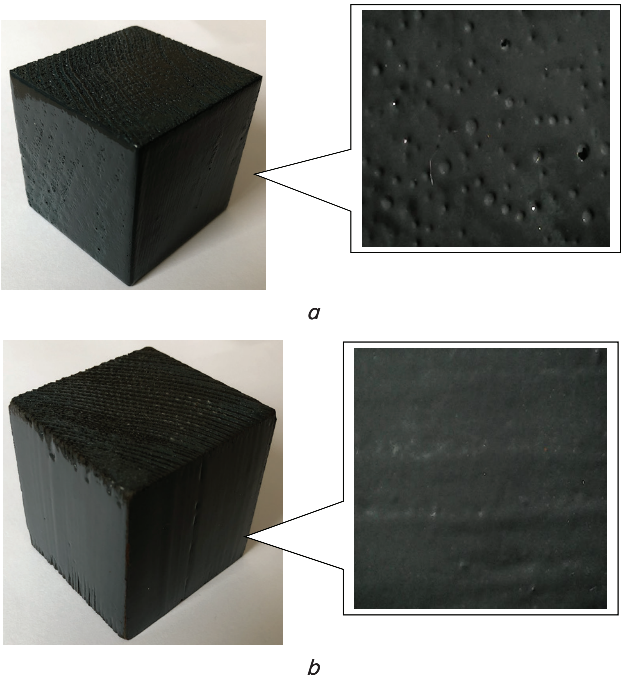


Fig. 4. Samples of untreated and thermally modified wood coated with a gray powder polyester system with polymerization of paint at a temperature of 180 °C: *a* – untreated; *b* – thermally modified wood

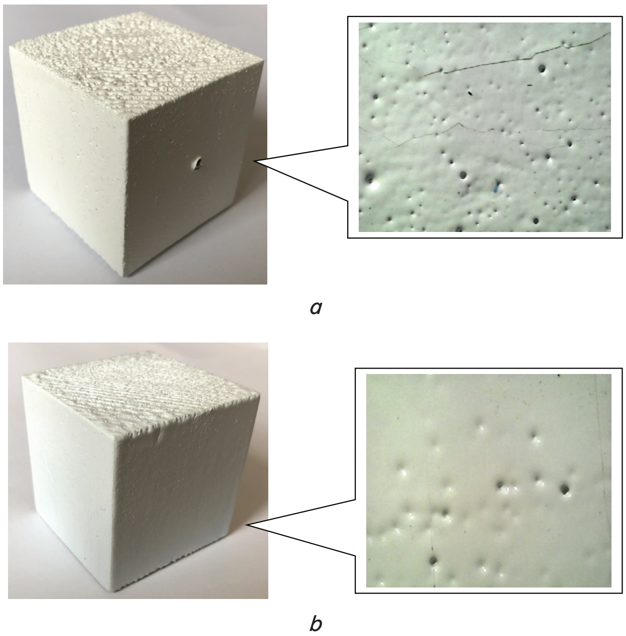


Fig. 5. Samples of untreated and thermally modified wood coated with a white epoxy polyester powder system with polymerization of paint at a temperature: *a* – 140 °C; *b* – 130 °C

5. 2. The results of studies of the adhesion of the polymer shell in the polymerization of powder paint on wood

Fig. 6, 7 and Table 1 demonstrate the results of the study of the adhesion of the polymer shell to wood samples.

As can be seen from Table 1, the level of adhesion of the polymer shell on wood treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 180 °C, the adhesion level is 2.1 MPa. Reducing the polymerization temperature with a mixture of the epoxy polyester system with functional additives up to 130 °C increases adhesion by 1.75 times, and the plane of destruction passes through the polymer shell. For thermally modified wood, the level of adhesion is within 2.1 MPa, and the destruction occurs through the wood. This is due to the increased fragility of the surface after thermal modification of wood at high temperatures. For wood treated with a mixture of a polyester system with a polymerization temperature of 180 °C, the amount of adhesion is almost the same and is about 1.7 MPa. The nature of the destruction for untreated wood is a separation from the polymer shell, and for thermally modified wood – by wood.

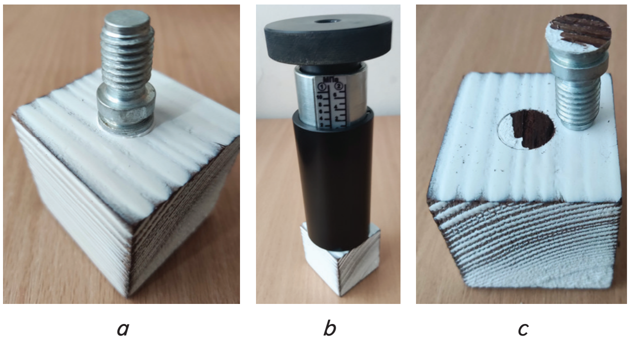


Fig. 6. Results of determination of adhesion for thermally modified wood treated with a mixture of epoxy polyester system: *a* – fungus on the surface of the polymer shell; *b* – the process of separation of the fungus; *c* – the nature of the separation

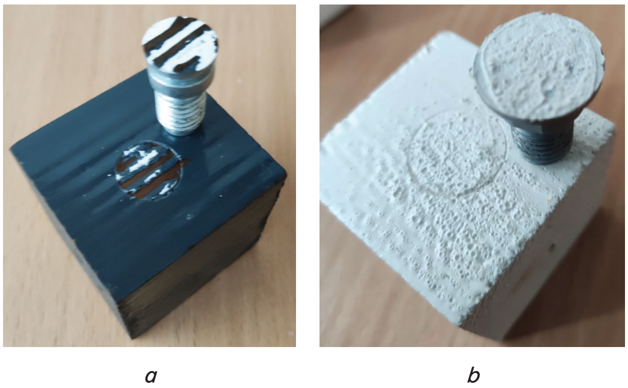


Fig. 7. Results of separation of the fungus from the surface of the polymer shell: *a* – thermally modified wood; *b* – wood treated with a mixture of epoxy polyester system

To determine the features of degassing of untreated wood, its thermal destruction is given by thermogravimetric analysis.

Graphic images of thermogravimetric analysis of wood samples are shown in Fig. 8, 9.

The resulting thermograms for untreated (initial) and heat-treated wood have similar curve contours of measurement of 20–250 °C. In the temperature range from 25 to 100 °C on TG curves, mass loss is observed by samples caused by evaporation of free chemically unbound water concentrated in tracheid – long thin cells with flat or spindle-shaped closed ends and in the interwall space of adjacent cells. Evaporation of water occurs from simple pores, which are located in adjacent cell walls, bordered pores of tracheid and window and pinoid semi-bordered pores. TG curves have minor abrupt oscillations, which can be explained by the shape of the pores and the ability of individual pores to close under the influence of pressure differences, in particular pores having membranes with a torus. Bordered pores in shape have a narrow hole and a large chamber. Therefore, it can be assumed that of certain types of pores, evaporation is not uniform, but abrupt.

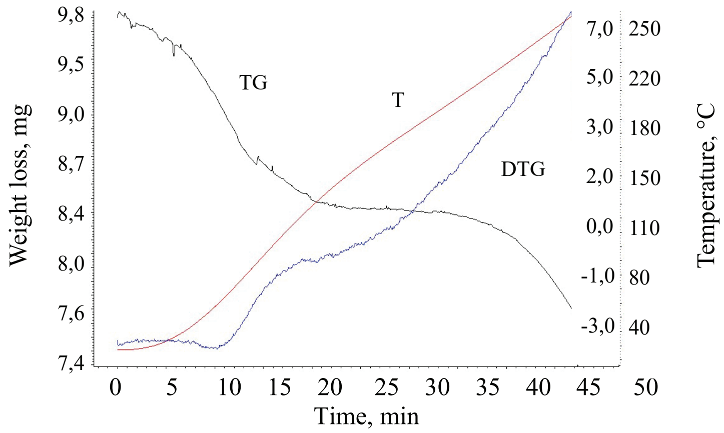


Fig. 8. Thermogravimetric analysis curves for pine wood samples: T — temperature curve; TG — weight loss curve depending on temperature growth; DTG — differentiable TG curve

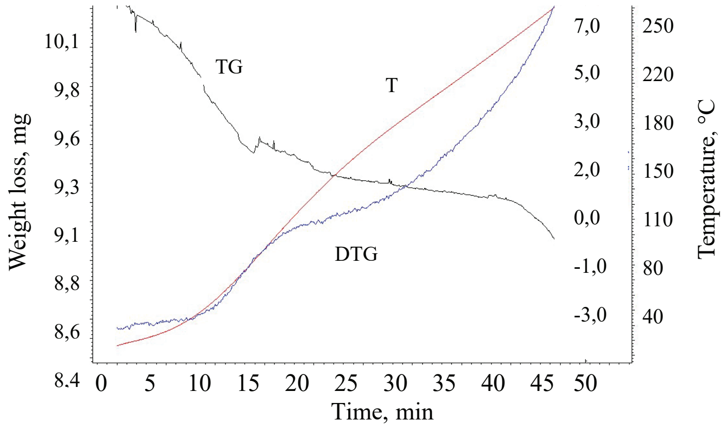


Fig. 9. Thermogravimetric analysis curves for samples of thermally modified wood: T — temperature curve; TG — weight loss curve depending on temperature growth; DTG — differentiated TG curve

On DTA curves from the beginning of heating with a temperature of 25 °C to about 60 °C with a maximum at 50 °C, there are wide-shaped endothermic peaks of moisture evaporation with smooth transitions to exothermic gentle peaks with an end at 100 °C. The latter can be explained by the achievement of the pressure of saturated steam in the bordered pores, the shape of which does not allow evaporation to pass with a sufficient speed, as a result of which partially condensation takes place – an exothermic process.

A further increase in temperature initiates the decomposition of organic substances, and upon reaching 150 °C – structural changes in hemicellulose with a mass loss of 8 % at 170 °C and 100 % decomposition and weight loss of hemicelluloses upon reaching 250 °C. Also, at 150 °C, various structural changes in lignin begin. At 200 °C, the destruction of the pyranose rings of cellulose begins, which takes place only partially under experimental conditions (heating to 250 °C). These processes take place with a slight endothermic slope of the DTA curve, which may indicate dihydroxylation of the wood components, followed by evaporation. This can explain the appearance of bubbles and craters on the polymer shell of paint applied to wood during thermal polymerization.

Table 1

Results of determining the adhesion of the polymer shell on wood

Sample	Adhesion, MPa	The nature of the destruction of the polymer shell
The wood is treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 180 °C in white	2.1	Destruction occurred on a polymer shell
Thermally modified wood treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 180 °C in white	2.0	Destruction occurred on wood
The wood is treated with a mixture of polyester system with a polymerization temperature of 180 °C of gray color	1.70	Destruction occurred on a polymer shell
Thermally modified wood treated with a mixture of polyester system polymerization temperature of 180 °C gray	1.65	Destruction occurred on wood
The wood is treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 140 °C in white	3.1	Destruction occurred on a polymer shell
The wood is treated with a mixture of epoxy polyester system with functional additives and a polymerization temperature of 130 °C in white	3.5	Destruction occurred on a polymer shell

6. Discussion of results of the study of polymer shell from powder coating on wood during thermal polymerization

In the study of the polymer shell formed from powder paint on wood after thermal polymerization, as follows from the results obtained (Fig. 3–5), the process of formation of shallow bubbles and craters on the surface of a sample of natural wood is natural. This is due to a change in the structure of wood during thermal polymerization (Fig. 8), which is confirmed by the data obtained by the method of thermogravimetric analysis about minor structural changes in hemicellulose and lignin. They are associated with the intramolecular restructuring of wood components and the degassing of pyrolysis products. The formation of a protective shell on the surface of the wood during the polymerization of paint is characterized by the processes of release of gases from wood with the formation of bubbles and craters.

It should be noted that thermal modification of wood leads to chemical transformations of wood components capable of inhibiting the degassing process. Obviously, such a mechanism of influence of thermal modification is the factor in regulating the process by which the resistance of the polymer shell on wood to degassing disappears. The presence of a polymer shell of powder paint leads to the formation of an elastic film on the surface of the wood. In this sense, there is an interpretation of the results of determining the quality of the film, namely the absence of defects on the surface. This indicates the absence of degassing through the polymer shell, which can be identified by direct contact with the surface of the painted wood.

This means that taking into account the fact of inhibition of degassing with thermally modified wood opens up an opportunity for effective regulation of wood properties in industrial production conditions.

Analysis of experimental studies on changes in the structure of wood during thermal modification and studies on the determination of thermogravimetric studies indicates changes in thermal effects, since during heat treatment dehydration processes take place with the destruction of wood components (Fig. 9).

This does not diverge from the practical data well known from works [3, 9], the authors of which, by the way, also associate a decrease in the quality of wood coating with a change in structural composition. But, unlike the results of studies published in [7, 18, 19], the obtained data on the effect of thermal modification on the properties of wood, in particular, on degassing, suggest the following:

– the main regulator for reducing the degassing of thermally modified wood is a change in the structure in the components of wood;

– the processes of preliminary thermal modification have a significant impact on the process of protecting wood from the effects of volatile pyrolysis products.

Such conclusions may be considered appropriate from a practical point of view since they allow for a reasonable approach to both thermal modification and the determination of the required amount of protective agent. From a theoretical point of view, this suggests the definition of the mechanism of processes of inhibition of gas permeability, which are certain advantages of this study.

However, it is impossible not to note that the results of determining the adhesion of the polymer shell of wood (Table 1) indicate the ambiguous effect of changes in the structure of wood on thermal decomposition. This is manifested primarily in the nature of the destruction of the polymer shell during the determination of adhesions in tests of thermally modified wood. Such uncertainty imposes certain restrictions on the use of the results obtained, which cannot be interpreted as the shortcomings of this study. Since the disadvantage for the thermal polymerization of powder paint on ordinary wood is the high temperature, which must be reduced much lower than 100 °C. The inability to remove these restrictions in the framework of this study gives rise to a potentially interesting direction for further research. In particular, tests can be focused on identifying the moment in time from which an intensive decrease in the adhesion of the polymer coating to wood begins. Such a detection will make it possible to investigate the structural transformations of wood that begin to occur at this time, and to determine the input variables of the process that significantly affect the beginning of such a transformation.

7. Conclusions

1. During the formation of the coating shell during thermal polymerization of powder paint at a temperature of 180 °C, shallow bubbles and craters are characteristic of untreated wood while a smooth surface is marked for a sample of thermally modified wood. Reducing the polymerization temperature of powder paint to 130 °C does not remove the disadvantages of the polymer shell on untreated wood. This is due to the fact that with increasing temperature, due to the processes of dehydration and destruction of wood components, mixtures of volatile products come to the surface and form bubbles and craters in the polymer shell of the coating.

2. Based on the obtained results of adhesion of the polymer shell on wood formed by powder paint at a polymerization temperature of 180 °C, the adhesion level is 1.7–2.1 MPa. Reducing the polymerization temperature to 130 °C increases adhesion by 1.75 times, and the nature of the destruction of the polymer shell passes through the paint itself. For thermally modified wood, the level of adhesion is within the same limits, and the nature of the destruction passes through the wood. This is due to increased plasticity of surfaces after thermal modification of wood.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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