

# Use of Thermo-Modified Wood Massif in Making Parametric Exterior Furniture

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## Abstract

This paper proposes the use of an array of heat-treated wood of various species to make parametric furniture for the purpose of operation in the exterior, and on objects in conditions of high humidity. The dependence of change in the color range of thermowoods depending on the temperature and duration of treatment is presented. Experiments were carried out to study the biological stability of thermally modified wood treated by various technologies including: vacuum-convective thermal modification in superheated steam, convective thermal modification in high-pressure saturated steam, as well as in hydrophobic liquids, in flue gas and vacuum-conductive thermal-modifying. The degree of resistance of wood was determined, which allows to conclude that the mass losses of heat-treated specimens caused by the destructive action of fungi are significantly lower compared to untreated ones. The research was conducted to determine the numerical characteristics of microroughness of the polished surface of wood, thermally modified at different temperatures.

**Keywords:** Engineering, Design, Wood, CNC

## 1. Introduction

In recent times, parametric furniture, which is being made using certain editable parameters and variables, is becoming more and more popular, representing products on rigid supports of unusual streamlined shapes resembling a carcass of a boat or the skeleton of a large animal that turned inside out. Parametric models are a fresh direction in the design of the architectural environment, impressing with their forms: the lack of sharp corners, pleasant ergonomics, smooth flow of composing systems into each other, creating interesting and unique 3D effects.

The most important thing in this direction is the ability to create architectural elements and volumes that previously seemed unattainable to us due to the complexity of performing unusual geometric shapes, and, in the case of finding the methods of execution, were insanely expensive.

In addition to the design, another feature of parametric models is the validity of the approach to the manufacture of models associated with installation site and functions of future products, depending on what the designers choose the individual form of furniture.

The main idea in the manufacture of parametric furniture is to create a safe design of architectural environment that does not adversely affect people's health. That is why, most often, this furniture is made of natural materials, such as wood and stone. Also to create parametric furniture using plywood, MDF, chipboard, plexiglass.

There are many projects on the use of parametric models including: benches, coffee tables, hammocks, rocking chairs. Using parametric, they create open shelves of the original form for storing books and other decorative elements. Parametric furniture options are also made for pools, saunas, terraces, street parks and gardens. They can combine a variety of products on which several people can comfortably sit at the same time. However, a short

service life, low resistance of wood to external influences and natural biodegradation becomes a serious obstacle to the use of such furniture in the exterior and in conditions of high humidity.



Fig. 1: Parametric rocking chair



Fig. 2: Parametric leisure furniture

One way to solve this problem is modern technologies of thermal modification of wood of coniferous and hardwood [1], during which chemical changes occur at the molecular level [2,3], which improves the physical and mechanical [4], aesthetic and operational properties of any wood species. Thermotree furniture is almost immune to changes in temperature, changes in humidity and exposure to ultraviolet rays. After heat treatment in wood, the equilibrium moisture content decreases to 4–8%, the hemicellulose content is significantly reduced, as a result of which the volume of material sensitive to the fungus is significantly reduced, and, consequently, the indices of biostability, durability, hardness [5], and also stability sizes that allows to use a thermotree in the open air. Regular processing of thermowood varnishes or linseed oil is not required, which means that it is environmentally friendly and extremely neutral to the person material, which will create a feeling of comfort and help you relax from the city rush. Thermally modified wood combines natural beauty and naturalness with impressive technical characteristics and a wide range of applications. Against the background of the list of advantages, the most significant disadvantage of a thermotree is its high cost, but if we take into account the almost infinite durability and the given properties, this minus loses its significance.

## 2. Research method

One of the advantages of a thermotree over ordinary wood is an intense color that is uniform over the entire cross section of the material — from light brown to dark brown, while preserving the natural texture of the wood (Fig. 3). To determine the dependence of the thermal wood color range on the temperature and duration of treatment, oak samples were tested using energy-saving technology for thermally modifying wood in a saturated pair without pre-drying, in which freshly chopped wood with a moisture content of 60% was processed. The technological process consisted of the following main stages: raising the temperature in the apparatus to 180 - 220 ° C by supplying saturated steam from the steam generator, holding the wood at high temperature and medium pressure for 4-8 hours in order to change the chemical and physicochemical properties at the molecular level wood, vacuuming treated wood.



Fig. 3: Thermowood obtained at different processing temperatures

To study the resistance to biological damage and decay, which is a fundamental factor when using furniture made of thermowood in the external environment, samples of sapwood of pine and oak, sized 500x50x20 mm, previously heat-treated according to

technologies known in Russia were taken: vacuum-proof convective thermal modification in superheated steam [6], convective thermal modification in high-pressure saturated steam [7], in liquids [8], in flue gas s [6] and vacuum-conductive thermomodifitsirovaniyu [4]. A characteristic that unites these methods of heat treatment of wood is the treatment temperature in the range of 180 to 240 ° C, which is explained by the physicochemical changes that occur in the wood at a given temperature range. In all methods, the duration of the stage of sample processing in a high-temperature environment was determined by the completion of the thermal modification process, which is characterized by a change in sample mass between two measurements of less than 1% [9]. Samples were measured every 30 min. At the same time with thermomodified samples, untreated pine and oak wood of similar dimensions of the room-dry state was taken, having no knots, cracks, signs of decay, insect damage, or other obvious defects. Thermally modified and untreated wood samples were immersed in water for 24 hours to equalize moisture and create favorable initial conditions for wood-destroying microorganisms. After exposure, the samples were weighed and at a distance of 15 cm from each other were buried in different soil substrates to a depth of 20 cm. The first soil substrate contained a large number of the most common and considered the most dangerous fungi *Coniophora puteana*, and the second *Poria placenta*. The incubation period was 360 days. Every 30 days, samples were taken, weighed, visually inspected for the presence of rot, then placed back into the ground. After 360 days, they were finally removed, weighed and dried in a vacuum chamber at a temperature of 50 ° C to constant humidity, after which the durability of the material was evaluated. To this end, according to EN 350-1 (Table 1), the mass loss coefficient for thermally modified and untreated samples was calculated as the quotient from dividing the mass loss of heat-treated materials by the mass loss of control samples.

Table 1: Classes of resistance according to EN 350-1.

Resistance class	Definition	EN 350-1 standard
1	very resistant	
2	persistent	$x \leq 0.15$
3	moderately resistant	$0.15 \leq x \leq 0.30$
4	weak	$0.30 \leq x \leq 0.60$
5	unstable	$0.60 \leq x \leq 0.90$

An important parameter that must be considered in the manufacture of furniture from wood materials, for which protective and decorative coatings are not provided, is the parameter of the surface roughness of the parts (not more than 63  $\mu\text{m}$  according to GOST 7016). This requirement also applies to thermowood due to the fact that one of its advantages is the absence of the need for treatment with impregnating and paintwork materials. In this regard, in order to study the quality of treatment of the surface of thermal wood, studies have been conducted to determine the numerical characteristics of the microroughness of the polished surface of wood of various species, thermally modified at different temperatures. The size of the studied samples was 40 x 150 x 500 mm. Grinding of samples was carried out on a grinding stand using Red Wood tape (Bosch) with grinding grain sizes of 40, 60, 100, 120 microns. Determination of the surface roughness of thermowood was performed by a profilograph after five times passing the sample through the grinding stand.

## 3. Results and analysis

As a result of studies to determine the dependence of the color range of thermally treated wood on the temperature and duration of treatment, the color range of oak thermowood 25 mm thick was obtained (Table 2).

**Table 2:** The dependence of the color gamut of oak thermowood on the temperature and duration of treatment and temperature

		Duration of treatment, hour		
Processing temperature, 0C		4	6	8
180				
Natural color				
				
Processing temperature, 0C				
103	160	180	200	220
				



**g. 4:** Parametric bench made of thermowood

During the experiment, it was revealed that to accelerate the process of heating, and, accordingly, darkening of the material, it is necessary to use high temperature [9], the choice of the range of which should be determined taking into account the physico-mechanical properties of wood changing under the influence of high temperatures. It is important to take into account that the improvement of some characteristics may lead to the deterioration of others. For example, a significant increase in temperature improves the biostability of the material, but leads to an increase in brittleness and a decrease in strength in general. The simultaneous increase in temperature and duration of treatment increases the rigidity and dimensional stability, but reduces the mechanical indicators of the strength of the wood, which limits the use of the material treated in this way as a structural material. On the other hand, prolonged thermal modification at very low temperatures does not cause the necessary changes in the wood, and a multi-step change as compared to a single-stage one can have a significantly smaller effect on the formation of the given material properties. Accordingly, it can be concluded that the thermal modification of wood is, first of all, a compromise between the main and secondary properties of wood, which play a crucial role in the production of the final product. Thus, along with improved aesthetic, physico-mechanical and performance

characteristics of thermowood, an important advantage of this material over plywood, MDF or untreated wood is the ability to create unique interior items of rich shades and with different color gradation, without using artificial dyes (Fig. four).

As a result of the studies on the determination of biostability, it was determined that all thermally modified samples had a smaller mass loss caused by fungi than untreated ones (Table 3). Both thermally treated rocks (pine, oak) showed a slight lesion (from 3.4% to 31%) after 360 days in two different substrates. At the same time, the samples processed in oil showed the smallest percentage of mass loss, possessing the resistance class 1, while the samples processed in a saturated high-pressure steam received a resistance class 4, having significant weight and strength losses with signs of rotting. This result is caused by a low processing temperature of 180 ° C, which, at the same time, is the maximum permissible with this technology due to the high pressure in the apparatus and the cost of the processing.

**Table 3:** Compliance with the resistance class of thermally treated wood according to EN 350-1 using field test results after soaking in the ground for 360 days.

Processing technology	Resistance Coefficient - Pine	Resistance class	Resistance Coefficient - oak	Resistance class
in saturated steam (T - 180 0C)	0,90	4	0,65	4
in superheated steam (T - 220 0C)	0,45	3	0,32	3
in oil (T - 240 0C)	0,14	1	0,10	1
in flue gases (T - 220 0C)	0,50	3	0,40	3
vacuum conductive (T - 220 0C)	0,55	3	0,45	3

With regard to the action of fungi, heat-treated wood showed the following results (Table 4). *Poria placentia* caused the highest mass loss in modified materials, ranging from 7.4 to 31%, while due to the fungus *Coniophora puteana*, the heat-treated specimens lost from 3.4% to 16.3%, which indicates that thermally modified pine and oak have significantly improved natural resistance after

prolonged contact with soil containing the fungi *Poria placentia* and *Coniophora puteana*, compared to untreated wood. In this regard, we can conclude that a higher temperature treatment of wood is needed in order to achieve maximum resistance to the effects of the fungus *Poria placentia* compared with resistance to the effects of *Coniophora puteana*.

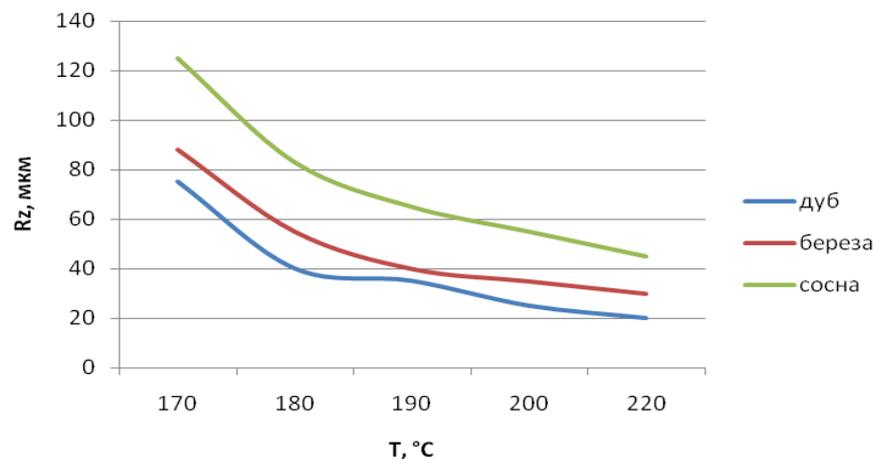
**Table 4:** The average weight loss of pine and oak (%), after 360 days of aging in two different soil substrates.

Processing technology	<i>Poria placentia</i>		<i>Coniophora puteana</i>	
	pine	oak	pine	oak
in saturated steam (T - 180 0C)	31.0	25,2	16.3	12,4
in superheated steam (T - 220 0C)	10.0	6,9	3.7	1,8
in oil (T - 240 0C)	7.4	5,2	3.4	1,5
in flue gases (T - 220 0C)	12.7	8,7	5.1	3,2
vacuum conductive (T - 220 0C)	13.8	10,3	5.7	3,5

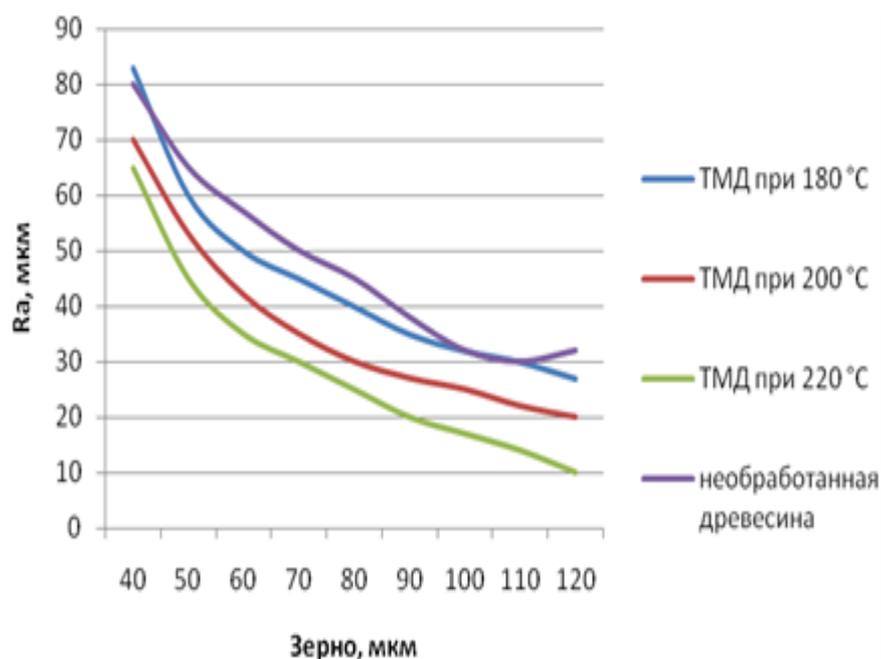
At the same time, the technology of thermal modification is important, according to which the material is processed. So, of all

the materials, the most thermally modified samples turned out to be the most resistant, which was caused by the additional impregnation of wood with a treating agent. The samples that were processed in a saturated steam environment at a lower temperature of 180 ° C proved to be the least resistant to decay, which allows us to conclude that this technology is unsuitable for the manufacture of furniture items that involve operation in saunas, parks and garden plots. Thus, for processing wood for compliance with the requirements of class 1 (high durability) a temperature in excess of 220 ° C is required with a dwell time of at least 3 hours. As for fungi, it has been determined that a higher treatment temperature is required for maximum resistance to the effects of the fungus *Poria placentia* compared to resistance to the effects of *Coniophora puteana*.

As a result of studies to determine the quality of treatment of the surface of thermal wood, it was found that thermal modification at a temperature of 180 ° C causes a slight decrease in roughness, while thermal modification of sawn timber at a temperature above 180 ° C leads to a significant improvement in the quality of processing and reduction in roughness by more than 2 times . 5, 6).



**Fig. 5.** Change of the roughness parameter Rz for the surface of thermowood of various species depending on the heat treatment temperature



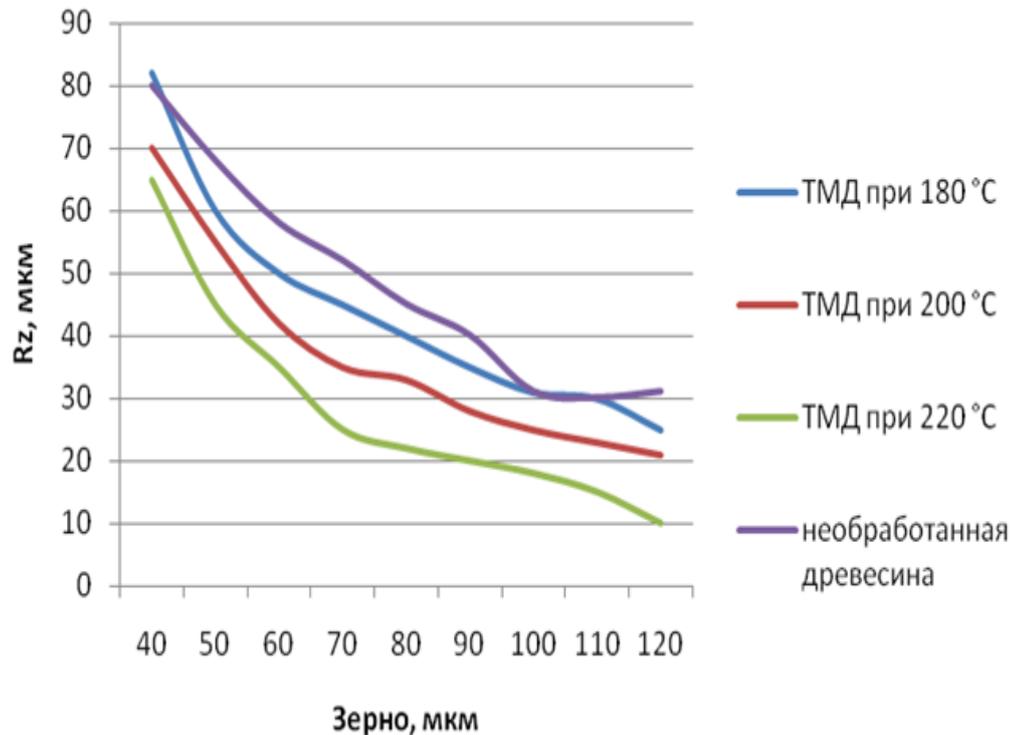


Fig. 6: Change of surface roughness parameter Rz thermowoods of various breeds depending on heat treatment temperature

#### 4. Conclusion

The present article discusses the possibility of using an array of thermo-modified wood when making parametric furniture used in the external environment or on objects in conditions of high humidity. The effect of temperature and duration of thermal modification on the change in the color range of oak wood is presented. The results of experiments on the study of the biological stability of thermowood processed by various technologies are presented. The degree of resistance of wood was determined, which allows to conclude that the mass losses of heat-treated specimens caused by the destructive action of fungi are significantly lower compared to untreated ones. The optimal technologies and regime parameters of the process of thermomodification for use of thermowood in the design of the architectural environment are identified. The paper presents the results of a study to determine the roughness parameters of wood of various species, thermally modified at different temperatures. Thus, on the basis of the presented work and the revealed improved characteristics of thermowood, the use in the production of street parametric furniture of an array of thermotree with specified properties and meeting the highest demands is appropriate.

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