The technology for creating of decorative plywood with low formaldehyde emission

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Abstract

The development of new technologies of processing of industrial art products to improve their functional, ergonomic and aesthetic properties is one of the important directions of improvement of product design. The article presents the technology of preliminary contact thermal modification of sheets of veneer in the production of low-toxic decorative plywood and laminated products, which lets significantly improve their water resistance. It has been established that thermal modification of wood material causes a decrease in density with increasing temperature and duration of treatment. A mathematical model describing the process of heat treatment of wood veneer and allowing predicting the degree of thermal modification of wood material depending on the modes of modification has been developed. Several studies to determine the basic properties of plywood made on the basis of heat-treated veneer were conducted in the work. Studies have shown that the thermal effect on veneer in the manufacture of plywood provides improves water-repellent properties of it, while not increasing its toxicity. It has also been found that the alternating of layers of wood with varying degrees of heat treatment when creating laminated products greatly enhances the decorative features of the products.

1. Introduction

The main challenges for improving the technology of plywood production nowadays are aimed at improving the environmental sustainability of the processes, and to receive the finished product with low toxicity, enhanced durability and minimal shape variability in conditions of humidity and temperature influences [1].

Plywood is hygroscopic as well as the solid wood. Its operation in a humid environment leads to the loss of strength, to shape variability and biological damage. Without special treatment plywood production has a limited lifespan.

The resin, which consists of toxic formaldehyde, the selection of which from the material is a serious danger to human health is applied in Russia for the production of plywood of increased water resistance. In this regard there is a prohibition on the use of water-resistant plywood in the conditions of the premises. According to the Russian standard the waterproof plywood can be only used in external conditions.

At the same time it is known that thermal modification – the technology of high-temperature treatment of wood without oxygen access air allows reducing the water absorption and enhancing the resistance to decay.

There are various methods of thermal modification of wood nowadays: in hydrophobic liquids, in the environment of superheated steam, in the environment of flue gases, vacuum contact method [2-5]. Heat treatment of wood significantly reduces swelling, shrinkage, improves the heat insulation qualities. Improvement of these properties of wood raw material is determined by the influence of high temperature on its chemical structure - mainly due to the thermal degradation of hemicelluloses. In addition, the results of the tests have shown [6, 7], that after heat treatment the ordinary tree species acquire the characteristics approaching to the rare and exotic breeds. Thermo wood acquires the intense colour throughout the thickness, more smooth and dense texture.
The researches of the influence of preliminary heat treatment of wood filler on the properties of composites have been conducted by the scientists worldwide in the last 6-7 years.

The technology of thermal pre-treatment of eucalyptus wood using steam at a temperature of 453 K with subsequent production of wood polymer composite is studied in the work [8]. Studies have shown that the thermal effect on wood raw material in the manufacture of WPC reduces the swelling and water absorption of the composite with 80 % and 70 % respectively after 28 days of immersion. In addition, the modulus of elasticity in bending has been reduced to 22 %.

In the work of Matjushenkova the method of oil heat treatment of plywood larch wood for increasing the water resistance is presented. The process of getting this plywood consists of impregnation of veneer by specially prepared tall oil from hardwood with subsequent heat treatment. The water and moisture resistant non-toxic building product is made in this case. But the proposed method of oil heat treatment of plywood is time-consuming on an industrial scale [9].

The work [10] presents the results of investigations of the basic properties of a composite material created on the basis of thermally modified wood and Portland cement grade 400 as a mineral binder. It has been established, that the thermal impact on the filler reduces the water-cement ratio that can be explained by a significant reduction of water absorption of thermally modified wood particles compared to untreated. Studies of the frost resistance of these types of samples allowed establishing the increase of this parameter with increasing of treatment temperature.

The results of the presented studies indicate an increased interest in issues of pre-heat treatment of wood in the manufacture of wood-based composites because of the advantages of using a less hydrophilic wood [2-11]. Despite the fact, that for some types of composites decreased mechanical properties were found, preliminary thermal modification of wood particles allows significantly increasing of the performance characteristics of the composite and, consequently, expanding the sphere of its possible use. Analysis of literature has shown that there are the active researches in the field of composite materials based on thermally modified crushed wood in recent years. While researches, aimed at improving of operational characteristics of the laminated material by heat-treatment of wood veneer has not been carried out.

2. Materials and methods

In this regard the studies on modifying the properties and characteristics of the plywood material, created on the basis of thermally modified veneers and heat-cured glue based on urea-formaldehyde resin have been conducted.

During the experiments birch peeled veneer sheets were used as wood filler. They were thermally treated by the contact method in the temperature range 180-260 °C. For thermal modification the installation, diagram of which is shown in Figure 1 was established. The unit is a sealed heat-insulated heat chamber 1 with the insulated lid 2. The internal space of the chamber 2 through a valve 3 communicates with the pumping system, including the circulator 4, a capacitor 5 and the condensate collector 6. Thermal energy supplies of to the veneer 7 by a contact method using heating plates 8.

To determine the hygroscopic properties of the thermally modified veneers the method of treatment of wood in desiccators with a saturated solution of soda for 30 days was used. The degree of saturation of the medium was 0.75. To determine the water absorption, the samples were kept in distilled water for 50 days. The moisture content of samples was determined by the gravimetric method: by measuring the current mass, followed by final drying to absolutely dry state at a temperature of 105 °C.

To determine the water absorption of plywood the method, according to which the samples were immersed in desiccators containing distilled water and were kept for five days was used. The samples are periodically weighed and measured, and the first weighing and measuring is in a day, counted from the moment of immersion of the samples in water, then through two, three and five days.
Figure 1. The scheme of installation of the vacuum-contact thermal modification of veneer

3. Results
In the process of heat treatment of the veneer on the unit, shown in Fig. 1, the kinetic changes of the density of the veneer sheets is founded (Figure 2).

![Figure 2. Kinetic curves of the change in the density of veneer thickness of 1.5 mm in the process of thermal modification](image)

In this regard the relative value is offered to determine the degree of thermal modification (1)

\[ Q = \frac{\rho_s - \rho_i}{\rho_s - \rho_f} \]

where: \( \rho_s \) – the initial density of the sample, (kg/m\(^3\)); \( \rho_i \) – is the density of the sample after heat treatment, (kg/m\(^3\)); \( \rho_f \) – density for a given wood sample, achieved at the maximum temperature for the process of thermal modification – 260 °C (kg/m\(^3\)).

The proposed method of classification of thermally modified veneers through a change in density allows quantifying the degree of thermal modification.

Using the kinetic curves of the change of density of the veneer in the process of contact thermal treatment (Figure 2) the graphic dependences of the duration of the stage of heat treatment to the required degree of thermal treatment which are presented in Figure 3 were obtained. Received chart allows us to select the mode of the process of thermal treatment by reducing unsustainable options that require significant duration of the process.
Figure 3. The degree of thermal treatment of birch veneer at thickness 1.5 mm

On the basis of experimental design and results of experimental studies of thermal modification of wood sheet material a mathematical model (2) allowing predicting the process of thermal modification of veneer depending on time ($t$), temperature ($T$) and the thickness of the veneer ($\delta$) was developed.

$$Q = -1.35 + 0.0803t + 0.0056T - 0.54\delta + 0.00183T \cdot \delta - 0.00169t^2. \quad (2)$$

As a result of the conducted research the change of colors of thermal veneer depending on the degree of thermal modification has been found. The results are presented in the table.

| Temperature processing | $\delta = 1.5 \text{ mm}$ | The thickness of the veneer | $\delta = 2 \text{ mm}$ |
|------------------------|-------------------------|-----------------------------|-------------------------|
|                        | Processing time 10 min | Processing time 20 min      | Processing time 30 min  |
|                        | Processing time 10 min | Processing time 20 min      | Processing time 30 min  |
| < 210°C                | 0.33                    | 0.48                        | 0.57                    | 0.27                    | 0.44                    | 0.51                    |
| > 230°C                | 0.44                    | 0.65                        | 0.76                    | 0.41                    | 0.60                    | 0.70                    |
| > 260 °C               | 0.75                    | 0.97                        | 0.99                    | 0.71                    | 0.90                    | 0.98                    |

Further the thermal veneer sheets were sorted by texture and color and were bonding. As a result of expert analysis of texture and color when creating the decorative plywood the degree of thermal modification of outer layers in the range of 0.5-0.75 was recommended. In addition, to create the products with high decorative characteristics the alternation of veneer sheets with different degrees of heat treatment that allows you to create curved supporting structures with interesting cross texture and to get Souvenirs by the method of milling was proposed (Figure 4).
Figure 4. Samples of plywood and Souvenirs made of birch veneer with varying degrees of thermal modification

Further samples of plywood created from veneer sheets with the same degree of thermal modification were tested for water absorption.

Figure 5 shows the kinetic curves of the change in the humidity of the samples of plywood in the process of treatment in distilled water. Chart analysis shows that the increase in the degree of thermal processing of raw wood provides a lower water-absorbing ability.

Figure 5. Water absorption of samples of plywood from thermally modified veneers

Analysis of the results of the comparative evaluation of shear strength of plywood in the dry state and after boiling in water for 3 hours (Figure 6) indicates the lower limit of the compressive strength of dry plywood with a higher degree of heat treatment of veneer. Thus, a significant reduction in strength is observed when the veneer with the degree of thermal modification is higher than 0.75. At the same time, for samples of plywood veneer with degree of thermal modification in the range 0.45-0.55 boiling does not almost cause reduction of the strength characteristics.

As the result of studies of the mechanical characteristics of plywood from thermally modified veneers rational degree of heat treatment of wood material in the range of 0.45 to 0.6 for plywood of general purposes, providing high aesthetic characteristics with high moisture and water resistance and maintaining the basic strength parameters is determined.
Figure 6 The change in compressive strength of samples of plywood depending on the degree of thermally modified veneer

4. Conclusions
It has been revealed on the basis of an expert analysis that the thermal modification of veneer sheets in the manufacturing process of plywood allows us to create the products with high decorative features. In addition it has been found that the thermal modification of sheets of veneer can improve the water resistance of plywood without reducing its environmental properties.

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