Study of resistance of thermomodified wood to the influence of natural conditions

Y Tsapko1, O Horbachova2, S Mazurchuk3 and O Bondarenko4

1Scientific Research Institute for Binders and Materials, Kyiv National University of Construction and Architecture, Povitroflotskyj ave., 31, Kyiv, Ukraine, 03037 and Department of Technology and Design of Wood Products, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
2Department of Technology and Design of Wood Products, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
3Department of Technology and Design of Wood Products, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
4Department of Building Materials, Scientific Research Institute for Binders and Materials, Kyiv National University of Construction and Architecture, Povitroflotskyj ave., 31, Kyiv, Ukraine, 03037

E-mail: mazurchuk.s.m@ukr.net

Abstract. It is established that thermal modification provides a decrease in the hydrophobicity of wood. Additional wood surface treatment reduces water absorption factor of 2 and modified sample at a temperature of 220°C – 3 times. Geometric and dimensional stability is improved by 2 times. The effect of heat treatment on the water absorption of wood is slightly smaller for samples modified at 190 and 220°C for more than 10 hours – 20 %. Additionally, a 20 % deterioration in water absorption can be achieved by applying oil-wax or azure. With increasing temperature modification improves color stability to UV-rays. If the wood after termomodyfikuvannya 160°C color difference ΔE 2 times larger, 190 and 220°C – does not change. Protection after applying azure to the surface is slightly better compared to oil-wax. Thermal modification and finishing paint and varnish materials increases resistance to surface weathering. Therefore, such treatment is appropriate for the protection and aesthetic appeal of wood products.

1. Introduction

Unique technical properties (durability, low water absorption and dimensional stability) Thermomodified wood enable its application in various areas [1].

The material is often used by designers for interior decoration due to the acquired color under the action of high temperature. The stability of the geometric dimensions and resistance to environmental facilitates its use in furniture, window frames, doors, wood flooring. It is possible to use as external facing of facades, in the form of a terrace board and garden paths. The material is excellent for cladding saunas and baths [2].

The resistance of heat-treated wood to atmospheric influences (UV rays, wetting) is slightly better in comparison with untreated wood, but additional surface treatment with coatings is required. There are many substances on the market for external wood treatment [3-6]. For horizontal surfaces (deck, terrace cover, garden paths) recommended penetrating finish, which can provide oil [7]. In the market there are many oils that keep the "natural" look and resistant to atmospheric influences. In this work we wanted to study the effectiveness of such oils.

Therefore, the aim of this study was to study the effectiveness of such oils in comparison with film-forming substances to protect the surface of thermally modified and unmodified wood during weathering. These results allow to provide reliable indicator of efficiency heat treated wood in environmental conditions and develop measures to extend the life of the products.
2. Analysis of recent research and publications

Wood treated at high temperatures eventually turns gray. It is established that the brown color of thermally modified wood is not resistant to light. Transparent coatings and oils do not protect the surface from discoloration during weathering, and they are only recommended for the treatment of thermally modified wood products that are operated away from direct sunlight and rain [8]. Recently, more and more attention is paid to the effects of sunlight on the surface of heat-treated wood. A new approach to stabilizing the dark color of thermodified wood, combining visible light screens with organic UV light absorbers, has been developed.

In [9] determined the discoloration is not covered and transparent coatings thermally modified beech, ash and hornbeam and found that the modified wood samples slowly fade in comparison with the unmodified samples. Accordingly, the FTIR spectra of samples of wood ash, beech and hornbeam exposed to UV light, showed similar chemical changes as unmodified wood samples that were exposed to UV light, but less pronounced.

Finishing heat-treated wood is similar to processing dried wood, but you should take into account changes in some of its properties. Thermally treated wood is more hydrophobic; absorbs moisture gradually; less prone to swelling and drying, but still requires elastic coatings; has a dark color, which is prone to fading due to the influence of light [10, 11].

Notice [12], which is a result of improved dimensional stability of wood cracking Thermomodified much less compared to natural. Cracking spruce and pine wood thermofinished after entering the external conditions without protective coating cracking was equivalent to untreated wood with uncoated surfaces. The application of oil did not prevent the appearance of cracks on thermodified wood after exposure to natural conditions [13].

In [7], it was reported that samples of three wood species (oak, ash and beech) without a protective surface coating had fewer surface cracks than heat-treated samples also without coating during accelerated weathering. Cracking of samples of heat-treated wood was reduced by oil treatment.

Heat treated beech wood also showed better color stability compared to untreated samples after three months of natural weathering winter. Natural weathering effect on thermally modified beech wood samples less than unmodified in terms of loss of gloss and surface roughness. In addition, higher temperature and duration of thermal modifications give better surface properties after natural weathering [14].

Compatibility studied nine different coatings of thermally modified wood pine scottish [15]. Coating applied to the thermally modified timber showed a better performance than the unmodified coating on wood. This can be explained by the changed characteristics of thermally modified timber, such as a lower equilibrium moisture content lower permeability, increased dimensional stability, better resistance to UV radiation and resistance to fungal blue stain compared with unmodified wood. It was also demonstrated better penetration of modified wood coatings and better wetting of thermally modified wood protective substances. In addition, solvent-based paints showed better results after one year of external weathering compared to water-based coatings.

Drying oils provide the best protection for wood products, but their use is limited by their long-term polymerization. During the study [16] of the drying behavior of linseed oil, tung oil and their mixture 1:1 repeated measurements of the angle of contact with water coatings applied to beech and oak wood, showed clear differences in wetting. Tung oil gave hydrophobicity to all wood samples soon after application, even when used without a dryer. Flaxseed oil required a longer drying time and was more susceptible to substrate exposure, but eventually reached the highest contact angles after forced drying.

Unfortunately, the problem of discoloration of wood in the room under a transparent coating exists today and most paint coatings with UV protection work at an insufficient level. The market constantly appear new products that position as a defense of color of wood in the interior and to prevent graying, yellowing and darkening surfaces. To date, the amount of scientific information on the effectiveness of these products is insignificant.
Thus, from the literature it is established that thermal modification of wood has a positive effect on resistance to temperature and humidity factors. Additional surface treatment with protective substances contributes to the stability of the size of the product and protects against rapid weathering of the surface in open air conditions. This indicates the feasibility of this study to determine the effectiveness of protection of wood products with paints and varnishes, which will increase the service life of building structures in the environment.

3. The purpose of this work
The purpose of this work is to evaluate the effectiveness of surface treatment with paints and varnishes of different types on the resistance of thermo-modified wood products to temperature, humidity and light.

4. Materials and methods of research
To determine the moisture absorption were used randomly selected 90 samples of hornbeam wood of radial cross section, pre-dried. The samples had dimensions of 20×10×10 mm. Next, the samples were thermomodified at temperatures of 160, 190 and 220°C, exposure in the chamber for 1, 10, 20 hours. According to the mode parameters of thermomodification, all samples were divided into 9 groups and a group of control samples (unmodified wood) in Figure 1.

The samples were then treated with oil-wax and hydrophobic substance (azure) by immersion with re-treatment after drying the first layer for 24 hours. After drying, the samples were placed in a desiccator for 1 day. Then the dimensions and weight of each sample were recorded. The procedure was repeated for 2, 3, 6, 9, 13, 20, 30, 40 days.

To determine the water absorption, 90 samples similar to the previous experiment were used. After 2 hours in water, the samples were weighed and measured. The procedure was repeated for 1, 2, 3, 6, 9, 13, 20, 30, 40, 50 days.

The value and volume swelling $\alpha V$ amount of moisture absorbed $W$ determined according to the equations:
\[ \alpha_r = \frac{L_{r_{\text{max}}} \cdot L_{r_{\text{max}}} - L_{r_{\text{min}}} \cdot L_{r_{\text{min}}}}{L_{r_{\text{min}}} \cdot L_{r_{\text{min}}}} \cdot 100, \]  

where \( L_{r_{\text{max}}}, L_{r_{\text{max}}}, L_{a_{\text{max}}} \) – size samples after aging in a humid environment in the radial, plain areas and along the fiber, mm; \( L_{r_{\text{min}}}, L_{r_{\text{min}}}, L_{a_{\text{min}}} \) – size samples in a completely dry radially, and plain areas along the fiber, mm;

\[ W = \frac{m_n - m}{m} \cdot 100, \]

where \( m_n \) – the mass of the sample on the \( n \)-th day of aging in a humid environment, g; \( m \) – is the mass of the sample in the dry state, g.

Also aware that the surface treatment of oil-wax product helps preserve the color and improves resistance to UV light. To establish the validity of this statement, studies were conducted to determine the effect of sunlight on similarly treated groups of samples of thermmodified hornbeam wood size 20×20×10mm in vivo (Figure 2).

\[ \Delta L^* = L^* \text{treated} - L^* \text{control}, \]  

\[ \Delta a^* = a^* \text{treated} - a^* \text{control}, \]  

\[ \Delta b^* = b^* \text{treated} - b^* \text{control}. \]

The total color difference \( \Delta E^* \) was determined for each group of samples as follows:

\[ \Delta E^* = \left[ (\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2 \right]^{\frac{1}{2}}. \]

5. Research results

From the graph comparing the amount of moisture absorption (Figure 3) of thermmodified wood in different modes (described above) it is seen that oil-wax and azure much better protect wood from moisture absorption from the air in all modes. In the first, the amount of moisture absorbed is 2 times less, and in the tenth mode, the difference was 2.7 times. In the first seven modes, the azure proved to be a little better, but from the eighth to the tenth mode, the wax proved to be better.
Figure 3. The results of determining the moisture absorption of samples of thermmodified wood.

It was experimentally established that on the fortieth day of keeping the samples in a humid environment, the best result was shown by the samples of thermmodified hornbeam wood additionally protected with oil-wax. They gained the lowest amount of moisture – 3.62 %, compared to thermmodified wood under similar conditions (11.73 %) and additionally treated azure (3.76 %). However, the samples with additional azure treatment showed the best result in terms of volume edema, changing the size by 3.39 %. If we compare with untreated wood from this group of samples, the figure is 3.4 times higher and is 11.68 %.

Analyzing Figure 4 we see that in the conditions of exposure of samples in contact with water (water absorption) in terms of volume edema, the best result was shown by samples treated with azure – 11.85 %. In comparison with untreated wood from this group, the value is 2 times higher and is 24.85 %. In terms of the amount of water absorbed, the samples treated with azure performed better – 43.40 %, compared to the samples treated with oil-wax – 45.99 %.

Figure 4. Water absorption and swelling of thermmodified wood samples.

Also on the 6th day of keeping the samples in water, partial exfoliation was observed in the samples additionally treated with azure (Figure 5).

It was also found that the readings of water and moisture absorption are more influenced by the processing time than the temperature. Because in a short time in one hour the wood does not have time to evaporate extractives – terpenes, wax, phenol, fats. They prevent the adhesion of the paint material. The best result was shown by samples with a heat treatment time of 10 hours.

In the Table 1-6 show the results of measurement and calculation of color parameters of samples in the CIELAB coordinate system.
Figure 5. Exfoliation of protective material (azure) on samples: a – untreated wood; b – modified at 160°C for 1 hours; c – modified at 160°C for 10 hours; d – modified at 160°C for 20 hours; e – modified at 190°C for 1 hours; f – modified at 190°C for 10 hours; g – modified at 190°C for 20 hours; h – modified at 220°C for 1 hours; i – modified at 220°C for 10 hours; j – modified at 220°C for 20 hours.

Table 1. Changing the color of the end surface of samples of thermomodified wood without additional protection.

| Thermomodification mode | Control 1 h | 160°C 10 h | 190°C 10 h | 220°C 10 h | Color options | Initial | 1 month | 5 month |
|-------------------------|------------|-------------|------------|------------|----------------|--------|---------|---------|
| T, °С                  | L* a* b* ΔE | L* a* b* ΔE | L* a* b* ΔE | L* a* b* ΔE |                |        |         |         |
| Control                | 70 7 11 0  | 47 5 10 23.1 | 29 2 3 42.1 |
| 160                    | 70 7 11 0  | 51 4 11 18.9 | 28 0 2 43.9 |
| 190                    | 10 51 10 13 | 54 7 13 16.1 | 31 2 3 40.6 |
| 220                    | 20 47 10 12 | 50 8 13 20.1 | 30 3 3 41.3 |

Table 2. Change in the color of the formation surface of the samples of thermomodified wood without additional protection.

| Thermomodification mode | Control 1 h | 160°C 10 h | 190°C 10 h | 220°C 10 h | Color options | Initial | 1 month | 5 month |
|-------------------------|------------|-------------|------------|------------|----------------|--------|---------|---------|
| T, °С                  | L* a* b* ΔE | L* a* b* ΔE | L* a* b* ΔE | L* a* b* ΔE |                |        |         |         |
| Control                | 78 7 14 0  | 58 6 13 20.1 | 33 2 4 46.3 |
| 160                    | 10 68 10 15 | 55 7 13 23.3 | 30 3 4 49.5 |
| 190                    | 20 55 10 14 | 50 8 13 28.0 | 35 3 23 44.4 |
| 220                    | 1 55 10 14  | 48 7 10 30.2 | 36 4 6 43.6 |
| 200                    | 10 35 9 17  | 44.2 7 9 40.6 | 30 4 5 49.0 |
| 210                    | 20 30 8 17  | 48.5 9 10 41.2 | 31 4 5 48.6 |
| 220                    | 1 54 11 14  | 24.2 5 14 23.1 | 36 4 6 42.9 |

ΔE – change in color; L* – lightness; a* – redness; b* – yellowness; T, °С – temperature; τ, hours – duration of treatment.
Research shows that wood modification significantly improves the resistance of wood to ultraviolet light. Thermally modified wood treated at a temperature of 190°C, 220°C for 1, 10, 20 hours is not additionally treated with protective substances and has a stable resistance to fading and color leaching.

Unmodified samples and samples modified at a temperature of 160°C lost half of the color in the first month of the experiment and for 5 months as much.

**Table 3.** Changing the color of the end surface of the samples of thermodified wood additionally treated with wax.

| Thermomodification mode | Control | 160 | 190 | 220 |
|-------------------------|---------|-----|-----|-----|
| **T, °C**               |         |     |     |     |
| 1                      | 19.1    | 21.6| 25.1| 23.0|
| 10                     | 48      | 27  | 23  | 27  |
| 20                     | 19      | 28  | 23  | 27  |
| 1                      | 22.1    | 20  | 23  | 27  |
| **τ, hours**            | 50      | 48  | 50  | 48  |

**Table 4.** Changing the color of the end surface of samples of thermodified wood additionally treated with azure.

| Thermomodification mode | Control | 160 | 190 | 220 |
|-------------------------|---------|-----|-----|-----|
| **T, °C**               |         |     |     |     |
| 1                      | 26.2    | 28.4| 53.6| 54.1|
| 10                     | 26      | 28  | 51.3| 51.1|
| 20                     | 25      | 27  | 51.8| 51.1|
| 1                      | 25      | 23  | 51.8| 51.1|
| **τ, hours**            | 22.2    | 6   | 6   | 6   |

The application of oil-wax and azure improved the color fastness by about 20% compared to untreated samples. Samples of thermodified wood have a strong resistance to ultraviolet light. Unmodified samples almost did not lose their color in the first month, but lost 50% of the color in the next 4 months.

Layer samples treated with oil-wax and azure unmodified have less resistance to ultraviolet light than end samples. Exceptions are samples treated with azure at a temperature of 190°C for 10, 20 hours, which have the best resistance to ultraviolet light among all samples.
6. Conclusions
Thermally modified wood is increasingly used in outdoor conditions, but its surface is also subject to degradation due to weathering as well as unmodified wood. Paints and varnishes are largely used to protect the surface of wood in outdoor conditions, as they are easy to maintain in good condition and re-apply. They also improve the appearance of the wood surface. Protective substances for thermally modified wood provided similar protection of exposed thermally modified wood surfaces from water and ultraviolet radiation. The positive effect of thermal modification on reducing the level of water absorption has been established. Temperature has a significant influence on such changes. The geometric dimensional stability also improves. As the modification temperature increases, the color fastness to UV rays improves. The application of oil-wax and azure improved the color fastness by about 20 % compared to untreated samples. As the protective coating is also prone to photochemical degradation, timely restoration according to the manufacturer's instructions is very important for the pleasant appearance of wooden surfaces during outdoor use.

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Table 5. Change in the color of the formation surface of the samples of thermomodified wood additionally treated with wax.

| Thermomodification mode | Color options | Initial | In 1 month | In 5 month |
|-------------------------|---------------|---------|------------|------------|
| T, °C  | α*  | b*  | ΔE  | α*  | b*  | ΔE  | α*  | b*  | ΔE  |
| Control | 68 | 19 | 11.9 | 58 | 17 | 21.0 | 27 | 1 | 2 | 52.6 |
| 160    | 1 | 54 | 13 | 18 | 25.0 | 51 | 10 | 15 | 27.9 | 29 | 2 | 3 | 50.4 |
| 10     | 1 | 36 | 11 | 10 | 42.7 | 41 | 9 | 10 | 37.5 | 28 | 2 | 3 | 52.1 |
| 20     | 34 | 10 | 8 | 44.4 | 39 | 8 | 9 | 40.0 | 30 | 4 | 4 | 49.4 |
| 190    | 1 | 39 | 13 | 12 | 40.1 | 45 | 9 | 11 | 33.8 | 28 | 3 | 3 | 51.2 |
| 220    | 1 | 41 | 13 | 13 | 37.8 | 47 | 9 | 12 | 31.4 | 30 | 3 | 4 | 49.8 |

Table 6. Change in the color of the formation surface of samples of thermomodified wood additionally treated with azure.

| Thermomodification mode | Color options | Initial | In 1 month | In 5 month |
|-------------------------|---------------|---------|------------|------------|
| T, °C  | α*  | b*  | ΔE  | α*  | b*  | ΔE  | α*  | b*  | ΔE  |
| Control | 68 | 11 | 20 | 13.0 | 68 | 12 | 23 | 14.6 | 50 | 11 | 18 | 28.5 |
| 160    | 1 | 53 | 14 | 21 | 27.3 | 57 | 15 | 22 | 23.9 | 39 | 11 | 15 | 39.2 |
| 10     | 1 | 31 | 14 | 14 | 47.5 | 37 | 16 | 15 | 41.9 | 31 | 8 | 8 | 47.4 |
| 20     | 34 | 15 | 15 | 45.0 | 42 | 16 | 18 | 37.4 | 32 | 8 | 8 | 46.4 |
| 190    | 1 | 43 | 15 | 18 | 36.2 | 48 | 15 | 19 | 31.4 | 38 | 10 | 12 | 40.5 |
| 220    | 10 | 20 | 2 | 1 | 60.3 | 21 | 3 | 0 | 58.7 | 25 | 2 | 1 | 55.4 |
| 20     | 19 | 3 | 1 | 61.2 | 21 | 4 | 1 | 58.6 | 23 | 4 | 2 | 57.0 |
| 190    | 1 | 37 | 16 | 18 | 42.4 | 43 | 15 | 17 | 36.7 | 33 | 9 | 9 | 45.6 |
| 220    | 10 | 18 | -1 | -1 | 62.8 | 19 | 0 | -1 | 61.2 | 20 | 1 | 0 | 60.7 |
| 20     | 17 | 0 | 0 | 62.9 | 20 | 0 | -1 | 60.9 | 20 | 1 | 0 | 60.4 |
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Acknowledgements
Authors express their gratitude to the Ministry of Education and Science of Ukraine for financial support of the research, that was performed in the framework of budget funding No. 0121U001007, as well as for the development of the theme of research according to the program of scientific cooperation COST Action FP 1407 "Understanding the modification of wood through an integrated scientific and environmental approach" of the European Union’s framework program HORIZON 2020.