

Climatic influences on the building materials properties based on wood-polymer compositions (WPC)

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Abstract. The work is devoted to the assessment of the influence of climatic influences on wood-polymer composites (WPC), which are actively used for the production of building materials. In particular, terraced boards and other construction materials are made from them. Since terraced boards are often used outdoors, it is necessary to study in detail the effect of moisture on the change in color of products, their water permeability, the ability to withstand UV radiation, etc. In the work, terraced boards produced by the domestic company Savewood are investigated. The matrix polymer was polyvinyl chloride (PVC). The studies were accompanied by theoretic studies of water permeability. The relationships describing water permeability of polymers are given. These ratios include the parameters of the chemical structure of polymers. Experiments on the influence of climatic effects are performed with the help of modern instruments at positive and negative temperatures

1. Introduction

Currently, the application of polymer composites filled with wood (WPC) is developing rapidly. WPC are used mainly for outdoor work. In particular, such boards to produce the floors of terrace rooms are used, siding, decorative fences, fence systems, steps, universal profiles, various accessories and components. In this regard, the issues of climate impact on the properties of products from WPC are of particular importance. In the literature there are quite limited information on the WPC products and the dependences of their physical and chemical properties on the composition of the polymer matrix [1-6]. These studies examine a variety of wood-polymer composites and their properties, such as limiting mechanical and rheological properties. The works cycle is devoted to the study of WPC based on polyvinylchloride (PVC) [7-11], which is the main matrix polymer in the production of these kind products. PVC serves as a polymer matrix mainly in the form of primary material. This material is described in both foreign and domestic literature. Methods of manufacturing WPC set out in detail in the work [12]. WPC materials are widely used in construction [1, 13-14]. Important characteristics are the modulus of elasticity in tension and compression, impact strength, resistance to cracking, bending and tensile strength, hardness. In the analysis of thermal effects, the most important characteristics are relaxation transitions in the material during heating, associated with the glass transition of polymers, changes in the crystallinity degree, the melting point of the crystal phase, the coefficient of thermal expansion and changes in the size of products with an increase in temperature.

The problem of control over the nanocomposites permeability was attracted careful attention from specialists over the last several decades. Special attention was given to nanocomposites containing long planar nanoparticles, because they created "tortuous" paths for the motion of liquid molecules, thereby significantly decreasing the diffusion rate and permeability. The water permeability of polylactic acid series (PLA)-based nanocomposites containing up to 6 wt % phyllosilicate, i.e., montmorillonite (nanoclay), have been studied [15]. The measured values of permeability were found to decrease with an increase in the nanoclay content up to 5 wt %, a result that agrees well with the predictions of Nielsen's

model [16]. The penetration of gases through nanocomposites was reviewed in [17]. A geometrical model for the prognosis of efficient diffusion through composite membranes with impermeable anisotropic domains as depending on their orientations and volume fractions was described in [18]. The predictions of the model were compared with the experimental data. The works [19–28] were dedicated to different models for the permeability description of the composites containing layered fillers in the polymer matrix. The experimental properties of nanocomposites containing nanoclays were studied in [25–28].

The studies performed in [21, 23], where the prediction theory of the barrier membranes properties was verified. They are the closest in regards to the topics of this paper. The permeability was predicted to change with the concentration changes and the ratio of planar particles sides used to fill composite materials. The polymer films with parallel-packed planar impermeable particles of filler were shown in [23] to possess permeability 2–3 orders of magnitude lower than those of the same-size films containing no filler. However, if the planar particles of filler have a size distribution, the decrease in permeability can result from a compromise between the shorter diffusion paths in any region containing fine particles and the particle concentration. The theoretical and experimental data show that the diffusion resistance of films containing 3 vol. % planar particles is 20% higher than films containing 6 vol % of such particles. A geometrical model for prediction of efficient diffusion through nanocomposites as depending on the orientation and volume fraction of the polymer nanoclay, as well as on its interaction with the polymer matrix, was proposed in [21]. Good agreement between the predictions of the model and the numerical-simulation data was observed. In regards to the already existing theoretical models, the authors believe that the proposed model is more adequate for description of the diffusion in conventional nanocomposites. In the case, the inorganic lamellas agglomerate into clusters, the model ceases to work. Summarizing the available data, we can conclude the task of developing models that allow to take into account the chemical structure of polymers and nanoparticles at the quantitative level was been raised to date.

2. Materials and methods

The objects of the study were terraced boards produced by the company Savewood. Matrix polymer is polyvinyl chloride. To measure the specific impact strength, the device Dinstat (Germany) was used. Determination of softening point and coefficient of thermal expansion were carried out on a TMA Q400 (TAInstruments) device (USA). The studies of resistance to climate impacts were carried out with the help of a light chamber (q-Sun Xe-2 HS model), as well as a climate chamber VLK 07/90-2. For the analytical description the procedure CIELAB-76 was used. Test of resistance to climatic influences is carried out with the following Standards: 9.708 Requirements-83 "Plastics. Test methods for aging in the process of it exposed to natural and artificial climatic factors"; 583-74: "Polymer materials, construction, finishing materials. Methods for the resistance determination to the influence of light, uniformity of coloring and lightness"; 19111-2001: "Products molded PVC profile for interior design". The investigations were carried out using the light camera (Q-Sun model XE-2 HS weathermeter) when it irradiated from one external side with a xenon lamp with $\lambda > 290$ nm and an UV irradiation intensity of 65 W/m²; air temperature 35±2°C, the temperature of the black panel is 60±2°C. The measurements were carried out at different relative humidity. The irrigation was carried out for 18 minutes; the dry period was 102 minutes. For the analysis, the climate chamber VLK 07/90-2 was also used; the temperature was -40±2°C, the time of one cycle was 1.5 hours.

3. The results of the study

Experiments to measure the specific impact strength at positive and negative temperatures of materials based on polyvinyl chloride (PVC) were carried out in this work. The specific impact strength values at -21 and -60°C possess a value of 6 kJ/m², which is typical for many other polymeric materials. Therefore, even with such severe climate impacts, there is no fragile destruction, which is important for the climatic conditions of Russia. The softening temperature of WPC investigated, where the matrix polymer is PVC, is 70°C. The coefficient of thermal expansion in the temperature range -30÷50°C is in the range 59÷76·10⁻⁶ K⁻¹. This indicates the thermal stability of WPC products.

The studies of water absorption and water permeability of WPC were carried out. The influence of the chemical structure of matrix polymers on these characteristics, as well as the degree of crystallinity, the shape of the filler particles and other parameters is analyzed. The water permeability was described by the following equation:

$$\ln P_0^* = \frac{\left(\sum_i \Delta E_i^{**} \right)}{N_A \sum_i \Delta V_i}, \quad (1)$$

where $\left(\sum_i \Delta E_i^{**} \right)$ is the reduced energy of intermolecular interaction, N_A is the Avogadro's number, and $\sum_i \Delta V_i$ is the van der Waals volume of the repeating unit of the linear polymer or the repeating fragment of the network.

The experiments regarding resistance to climate impacts were carried out on the basis of cooperation agreements with the Institute of RAS organoelement compounds and the Institute of chemical physics of RAS. The influence of wood components chemical structure in thermal and energy lignin properties of different types as well as hemicellulose was analyzed. It was found that decking company Savewood has a sufficiently high stability to climatic influences. The method is proposed for preserving the color. When the product is aged in the external environment under UV irradiation and moisture, there is a chemical interaction of wood filler with PVC macromolecules. The main product of wood is lignin (its composition depends on the wood type, but in all cases lignin contains a strong polar group, aromatic and aliphatic cycles). The basic chemical structure of spruce lignin is shown below (Fig. 1), although it contains a number of other structures [29]. Each of these structures contains OH-groups, possessing the hydrogen bonds. These groups can also chemically interact with PVC, resulting in a change in color over time. In addition, the polar functional groups themselves undergo chemical changes over time during operation in an open environment, resulting in color changes.

The chemical structures of the spruce major fragments and beech lignin contain the aromatic rings, OH-groups, ether bonds, CH_3O -groups, and aliphatic cycles. Naturally, such groups can be exposed to UV radiation, humidity, and the results of such actions depend not only on the chemical structure of the components, but also on the degree of grinding, concentration, particle shape (sawdust, fibers, etc.).

Small color differences were analyzed, CIELAB-76 system was used to quantify these differences, described in detail in monographs [30, 31]. According to the recommendations of the International Council on Illumination, the space $L^* a^* b^*$ is defined by the following rectangular coordinates (see Figure 2). The following notation is introduced: $f(X/X_n) = (X/X_n)^{1/3}$ for $X/X_n > 0.008856$ or $f(X/X_n) = 7.787(X/X_n) + 16/116$ for $X/X_n \leq 0.008856$; $f(Y/Y_n) = (Y/Y_n)^{1/3}$ for $Y/Y_n > 0.008856$ or $f(Y/Y_n) = 7.787(Y/Y_n) + 16/116$ for $Y/Y_n \leq 0.008856$; $f(Z/Z_n) = (Z/Z_n)^{1/3}$ for $Z/Z_n > 0.008856$ or $f(Z/Z_n) = 7.787(Z/Z_n) + 16/116$ for $Z/Z_n \leq 0.008856$. Here X, Y, Z are the coordinates of the color of the sample; X_n, Y_n, Z_n are the color coordinates of the selected white standard when illuminated with the standard MCE radiation.

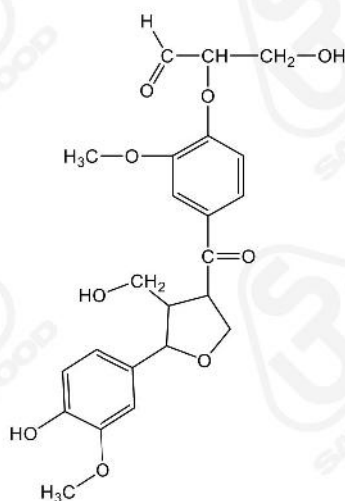


Fig. 1. Fragment of the structure of spruce lignin

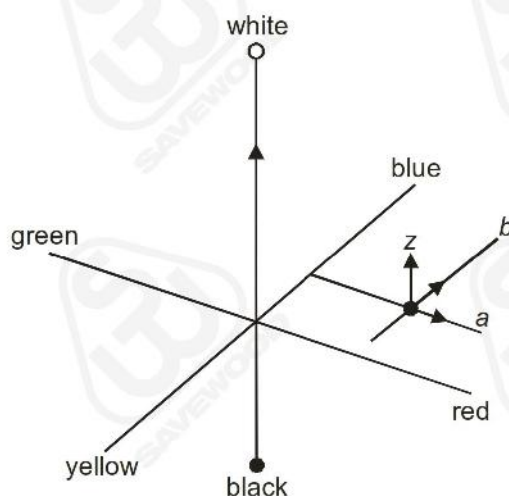


Fig. 2. Geometric space model of color perception [3].

The color differences ΔE are defined as the distances between two colors stimuli in Euclidean space by the formula

$$\Delta E(\text{CIELAB} - 76) = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} . \quad (2)$$

The results of the tests are shown in Table 1.

Table 1. Test results of the material WPC for the terrace boards SAVEWOOD.

№	The name of the indicator and unit of measure	Indicator value	Test methods
1	Change in appearance after testing during - 5 cycles - 10 cycles - 15 cycles	There are no cracks, delaminations, blisters, shells and other defects	GOST 9.708-83
2	Color coordinates: - before the test and after testing for - 5 cycles - 10 cycles - 15 cycles	$L^* = 29,27 \quad a^* = 2,83 \quad b^* = 3,67$ $L^* = 31,82 \quad a^* = 3,01 \quad b^* = 3,95$ $\Delta L^* = -2,55 \quad \Delta a^* = -0,18 \quad \Delta b^* = -0,28$ $\Delta E = 2,57$ $L^* = 32,12 \quad a^* = 3,06 \quad b^* = 4,11$ $\Delta L^* = -2,85 \quad \Delta a^* = 0,23 \quad \Delta b^* = 0,44$ $\Delta E = 2,89$ $L^* = 32,34 \quad a^* = 3,24 \quad b^* = 4,09$ $\Delta L^* = -3,07 \quad \Delta a^* = -0,41 \quad \Delta b^* = -0,42$ $\Delta E = 3,13$	GOST 9.708-83 GOST 11583-74
3	Resistance to impact at + 23°C	None of the tested samples is destroyed	GOST 19111-2001
4	Resistance to impact at -23°C	None of the tested samples is destroyed	GOST 19111-2001

The data presented in Table 1 indicate a high resistance of the material to the action of climatic factors. The main changes occurring under the influence of light and water occur at the initial stages and are manifested as an increase in the number of light points (wood filler) on the surface, leading to a slight clarification of the samples. The intensity of the total (integrated) radiation in the range 0.29 – 10 μm (2380 W/m²) was selected. For a moderate climate, the total dose of light is about 4.5 GJ/m² per year. The irradiation time corresponding to an annual dose under natural conditions is 1.89×10^6 , i.e. ~ 525 hours. It must also be taken into account that the tests were carried out at elevated temperature, and the light intensity exceeded the maximum daily intensity in natural conditions. Therefore, the surface temperature of the samples is approximately 25 degrees higher than the average temperature of the samples under natural conditions. The activation energy of the degradation process of polyvinylchloride is > 50 kJ/mol. Consequently, in the range of 10–60°C, an increase in temperature of 25°C leads to an increase in the rate of aging by almost 5 times (the exact value is 4.9 times). Thus, the accelerated tests' results for 5 cycles (550 hours of irradiation in the artificial light) correspond to aging of at least 5 years in natural conditions.

4. Conclusion

The study of changes in WPC color products in the form of terrace boards produced by Savewood has been carried out. Matrix polymer was polyvinyl chloride. The influence of wood components in chemical structure thermal and energy properties of different types' lignin as well as hemicellulose was analyzed. It was found the decking company Savewood has a sufficiently high stability to climatic influences. The method is proposed for preserving the color. The intensity of color change depends not only on the humidity of the environment, but also on the temperature, the composition of the material, and the chemical structure of the components. All this is true for WPC products used for outdoor work. Hence,

we can conclude that products that use the terraced boards of the Savewood Company can also find application in the construction industry.

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