Modeling of light propagation in a wood polymer-sand composite

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Abstract. The subject of the research is wood polymer-sand composite (WPSC) and study of its physical and mechanical properties. In this case it is propagation of light in the material using simulation and development of a computer program to simulate the propagation of UV radiation in WPSC block. A separate computer program in the Object Pascal language was compiled to study the model. The program is designed to simulate two-dimensional approximation of infrared, visible, ultraviolet radiation propagation in wood polymer-sand composite. The program is applicable in a wide range of concentrations of the composite components, for different optical absorption coefficients of the components, depending on the wavelength of the radiation. Concentrations, optical properties of the components, and lighting conditions can be specified in the text of the program. The results of the program are the structure of the composite as a random uniform distribution of wood and sand fragments in a polymer matrix, a cartogram and a graph of the intensity distribution in the composite specimen. The result has been obtained: penetration depth of destructive UV radiation is about 1.5 mm at an optimal concentration of the components C_W =45%, C_P =35%, C_S = 20%.

1. Introduction

Many polymers used in consumer goods are degraded by UV light. It is necessary to use simulation programs to assess the effect of the intensity and duration of UV irradiation on the physical and mechanical properties of specimens. The structure and mechanical properties of composite materials are extremely difficult to model. It is due to the following: several components in the model and all types of mechanical connection between them, the shape and mutual arrangement of the particles of the components in the material and external load distributed in space must be taken into account. The task of this paper is to develop a mathematical model of structure and mechanical properties of wood polymer-sand composite. It enables to study the dependence of strength and damping properties on the parameters of the initial components, production technology and external influences. The principles of object discretization and high spatial resolution are used when building a model. In addition, the computational capabilities of modern computers are used [1, 2].

As practice and experiments show, the most dangerous effect on composites is exerted by ultraviolet radiation. The destructive effect of ultraviolet radiation occurs due to the destruction of...
bonds between atoms in polymers under the influence of rays of this spectrum. Various coatings are used to protect composites from UV radiation.

However, the problems of operational stability and resistance to climatic influences of polymer composite materials are discussed by many foreign and domestic authors. In the papers UV radiation is used to simulate the effect of solar radiation.

The authors of a number of literary sources show that the results of accelerated tests in special climatic chambers often differ from the results of field experiments due to differences in aging. In a number of works it is noted that the intensity of solar radiation and other climatic factors are not additive [3-5].

The data on the study of the influence of UV radiation, electromagnetic fields on the polymerization processes, and the possibility of modifying wood-polymer composites with a thermoplastic polymer matrix using ultraviolet radiation have been analyzed and summarized. The relevance of further research in this direction is noted. Their results are necessary for solving problems arising in the creation of new materials [6-8].

2. Task statement
One of the most significant destructive factors is the effect of ultraviolet component of solar radiation on WPSC building blocks. Due to some transparency of WPSC material, not only the surface of the block, but also the near-surface layer of a certain depth is a subject of destructive impact. Therefore, the study of UV radiation propagation into WPSC block and the influence of the composition of the surface area on the penetration depth of UV radiation is an extremely important research.

3. Methods and materials
Considered wood polymer-sand composite, consisting of a polymer binder, wood and sand, is intended for building products (building blocks).

The features of modeling of UV radiation propagation in a block made of wood polymer-sand composite are as follows: a modeling technique has been developed to simulate the propagation of light (of arbitrary nature) into WPSC specimen. The technique differs from the modeling technique for mechanical behavior of WPSC specimens. Within the framework of the model, the space, wrapping WPSC block is divided by a square grid (size 200×200) into many nodes [9, 10]. Optical properties of WPSC components are attached to the nodes. Further, a gradual decrease in the intensity of light from the node to the node is calculated, taking into account the fact that the radiation source is located at the boundary nodes of the left grid boundary:

\[ I_{ij} = I_{i-1,j} \cdot \alpha, \]

where \( I \) – light intensity in the node; \( i \) and \( j \) – horizontal and vertical node indexes; \( \alpha \) – transparency coefficient given to the inter-node distance.

The model calculates not only the propagation of light from left to right, but also the processes of light re-emission by the nodes to which the radiation has reached. For this, a multiple iterative calculation (about 1000 cycles) of the map of propagation intensity has been performed.

Despite the simplicity of the basic principles of the model, it has high scientific value due to the detailed accounting of structure and high spatial resolution. It enables to test options for the propagation of light for which it is difficult to predict the results in advance (figure 1).

3.1. A computer program to simulate the propagation of UV radiation in WPSC block
The separate computer program in the Object Pascal language was compiled to study the developed model [9, 10].

The program is designed to simulate two-dimensional approximation of infrared, visible, ultraviolet radiation propagation in a specimen of wood polymer-sand composite.
The program is applicable in a wide range of component concentrations, for different optical absorption coefficients of the components, depending on the wavelength of the radiation. Concentrations, optical properties of the components, and lighting conditions can be specified in the text of the program. The results of the program are the structures of the composite as a random uniform distribution of wood and sand fragments in a polymer matrix [11, 12], a cartogram and a graph of the intensity distribution in the composite specimen (figure 1).

![Program to simulate the propagation of UV radiation in wood polymer-sand composite](image)

**Figure 1.** Representation of simulation results on the screen: composite structures (left), cartograms of light intensity distribution (upper right), logarithm distribution graph of light intensity into the specimen (bottom right).

### 4. Results and discussion

Since only the polymer (among all the WPSC components) is relatively transparent to UV radiation, an increase in the concentration of wood and sand in the near-surface area of the building blocks can significantly reduce the penetration depth of the damaging UV radiation. A series of computer experiments was carried out to study the effect of the component concentrations on the penetration depth. During the experiments the polymer concentration was changed at the levels of 30, 40, 50, 60, 70, 80, 90, and 100%, while the ratio of sand and wood concentrations was $C_{sa} : C_{w} = 1:1$ (figures 2 and 3).

The dependence of intensity on the penetration depth $I(x)$ has an exponentially decreasing character (figure 4). The addition of an insignificant amount (10%) of sand and wood into the polymer leads to a sharp decrease in the UV transparency of the material (figure 4, curves of 100% and 90%).
Figure 2. The distribution of light intensity in the near-surface area of WPSC specimen: $C_{Pl} = 90\%$.

Figure 3. The distribution of light intensity in the near-surface area of WPSC specimen: $C_{Pl} = 30\%$. 
Figure 4. The dependence of the intensity $I(x)$ of UV radiation on the penetration depth $x$ at different polymer concentrations $C_{Pl}$ (with equal concentrations of the other components – sand and wood).

5. Conclusion
The dependence of the penetration depth $h$ of UV radiation into WPSC building block on $C_{Pl}$ concentration has been constructed (figure 5) after processing the dependences, $I(x)$ for a number of $C_{Pl}$ concentrations.

Figure 5. The dependence of the penetration depth $h$ of UV radiation (the distance at which the intensity decreases by 10 times) on the polymer concentration $C_{Pl}$ with the same concentration of sand and wood.

The depth of penetration decreases significantly with increasing concentrations of sand and wood.

With a wood concentration of 45% and sand concentration of 20% (which is optimal for the volume physical properties discussed above) we get a penetration depth of about 1.5 mm. It is quite small and comparable to the surface.

Thus, for the optimal concentration of the components $C_{w} = 45\%, C_{Pl} = 35\%, C_{sa} = 20\%$, the penetration depth of the destructive UV radiation is about 1.5 mm.
This is comparable to the surface roughness of the building block. It is not advisable to change the component concentration in the surface layer during the production phase intentionally. However, additional protection against UV radiation may be provided by coating or surface modification, for example, painting.

In conclusion, we present a quote from Professor Viktor Kisly, director of the Dom Company: “Constant study of wood properties and improvement of technologies for its processing is the basis for expanding the range of timber products. The world scientific community believes that the age of wood is not in the past, but in the future. Timber products will be replenished with wood composites, which are fundamentally important for the integrated, full use of wood raw materials as a valuable natural material”.

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