Mechanical Properties of Polymer Composition Based on Dimethacrylic Polyester with Nanostructured Filler for Wood Modification

Mikhail Lukin, Roschina Svetlana, and Vladimir Rimshin

Abstract Polymer materials are used in a variety of sectors of the national economy, including in construction. Due to the development of science and technology, higher and higher requirements are being imposed on them, which conventional polymers no longer satisfy. Significantly improve the performance properties of polymers allows the creation of polymer composite materials based on them. One of the promising areas of research in the field of composite materials is the creation of polymer composites based on carbon nanotubes (CNTs). The effectiveness of the use of wooden structures can be increased by modifying wood. Modification is proposed to be carried out using a polymer composition based on dimethacrylic polyester with a nanostructured filler. The solution of this problem will allow, with an increase in strength and rigidity, to reduce the material consumption and installation weight of structures, to reduce the influence of anisotropy of properties and defects of wood on the bearing capacity. In order to establish the mechanical properties of wood, experimental tests were carried out with a polymer composition without filler and with a nanostructured filler. The increase in strength properties with the introduction of filler was 27.7% in compression tests and 23.49% in tensile tests. Studies have proved the promising possibility of using a polymer composition for wood modification.

Keywords Polymer composition · Modification · Strength · Microstructure · Nanotubes

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1 Introduction

Wood, as a material used in construction, along with its advantages, has major disadvantages [1]. Improving the properties of natural wood not only increases the time and reliability of its service in buildings, products, but also expands the scope of its application and allows more extensive use of wood [2, 3].

One of the methods that comprehensively improves the properties of wood is its modification with synthetic resins [4, 5].

Modification of wood in a broad sense should be understood as directed improvement of its properties, giving it new positive qualities, elimination of natural disadvantages for wider and full use in construction [6–8].

A very promising method of wood modification is its impregnation with polymers, followed by their curing in wood under the influence of heat treatment [9–12].

An important issue is the definition of the scientific principles of the choice of monomers and oligomers for the modification of wood and the action of various additives (catalysts, plasticizers) and the choice of optimal different ratios of resin components at different stages of their polymerization and condensation [13–16].

It was found that resins with low viscosity and polarity, easily penetrating into wood and curing at temperatures up to 100–150 °C are most suitable for modification purposes [17–19]. Resins that give wood high water and moisture resistance and good dimensional stability and shape of products should have a relatively low molecular weight and be located in the intermolecular spaces of cell walls. High-molecular and relatively more viscous resins are placed mainly in the cavities of cells and do not impart significant hydrophobicity to wood.

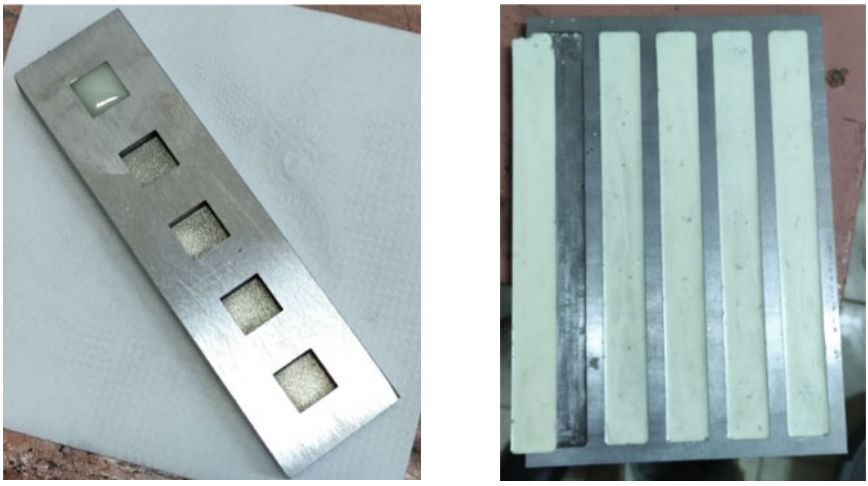
The polymer protects wood from internal and external destruction and is chemically resistant to the operational effects of petroleum products, gas and fuel–air mixtures, water and steam, organic solvents, acid and alkali solutions. The operating temperature of cured sealants is from minus 70 °C to plus 220 °C and up to plus 250 °C for (1–4) h without oxygen access [20, 21].

Impregnation compositions are mobile liquids with high capillary fluidity based on methacrylic monomers and oligomers that do not contain solvents and plasticizers [22, 23].

The aim of the study is to experimentally substantiate the mechanical characteristics of the impregnation composition for wood modification based on methacrylic monomers and oligomers that do not contain solvents and plasticizers.

2 Methods

Impregnation formulations are supplied with a set of two components: liquid resin and dry hardener, which are mixed together before use in a ratio of 0.25 g of hardener per 100 g of resin.



a) b)

Fig. 1 Special molds for casting polymer samples: **a** compression; **b** tensile

Special steel molds with specified geometric dimensions were developed for casting samples (Fig. 1).

Compression test samples had dimensions of 10 × 10 × 4 mm, tensile 250 × 25 × 2 mm. The tests were carried out on a series of 5 samples each. Destructive testing methods were adopted as a method of studying the physical and mechanical properties of a polymer composition. To fully study the strength properties of the composition, it is necessary to conduct compression and tensile tests [24, 25].

As an additive, carbon nanotubes (CNTs) of the Taunit-M series were adopted, which are quasi-one-dimensional, nanoscale, filamentous formations of polycrystalline graphite, mainly cylindrical in shape with an internal channel in the amount of 0.5%.

In order to exclude the settling of nanotubes, surfactants (surfactants) were added to the liquid phase of the polymer composite. The OP-10 wetting agent was used as a surfactant in an amount of 0.5%. The introduction of surfactants also contributed to an increase in the adhesive strength of the composition with wood. OP-10 wetting agents are a product of processing a mixture of mono- and dialkylphenols with ethylene oxide, have a slightly alkaline or slightly acidic reaction and are well soluble in water.

The introduction of additives was carried out in the following sequence: a hardener is introduced into the resin, then a surfactant and only then CNT [26, 27]. Mixing was carried out using a PE-8300 top-drive agitator equipped with a built-in control unit (see Fig. 2).

For curing, the samples were wrapped in aluminum foil and placed at atmospheric pressure in a drying cabinet with forced internal ventilation. Smoothly, in (5–10) min,

Fig. 2 Mixing of the solution for the preparation of the polymer composition

the temperature reached (95–105) °C. The exposure time was usually at least 1 h (see Fig. 3).

The strength properties of a polymer composite depend on the microscopic structure of the material. In order to clarify and confirm the results of mechanical tests, optical microscopy of samples was carried out [28, 29].

Optical microscopy was performed on a Raztek MRX9-D digital optical microscope (Russia), which allows visual observation of the microstructure of opaque objects. Microscopic studies were carried out on samples that were selected for mechanical testing prior to their compression experiment.

Before the start of the tests, the samples were weighed and their density was determined. The average density value for the samples of the polymer composition is 1030 kg/m^3, and the polymer composition with a nanostructured filler is

Fig. 3 Curing of the composition in the drying cabinet

a) b)

Fig. 4 Destruction of polymer composition samples: **a** for compression; **b** for stretching

1080 kg/m^3. This fact can also be explained by the change in the structure of the polymer matrix itself under the influence of CNT.

The research was carried out on the REM-100-A-1 testing machine. The universal testing machine REM-100-A-1 meets the requirements and is designed for mechanical tests in the mode of stretching, compression and bending of samples and products made of materials for which the destructive load does not exceed 100 kN. Loading of samples uniformly with a constant speed of movement of the loading head of the machine. The speed of movement of the loading head of the test machine was 4 mm/min.

Compression and tensile tests were performed on standard samples (Fig. 4).

According to the test results, statistical processing of experimental data was carried out.

3 Results and Discussions

Figure 5 shows the results of mechanical tests of samples for compression and stretching of standard samples of a polymer composition, Fig. 6 shows samples of a composition with a nanostructured filler.

The compressive and tensile strength of the samples was determined by the formula:

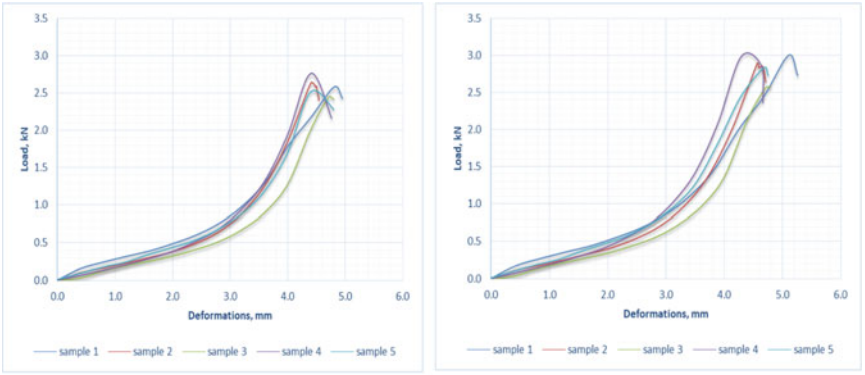


Fig. 5 Load–strain diagram for compression samples: **a** polymer composition **b** polymer composition with nanostructured filler

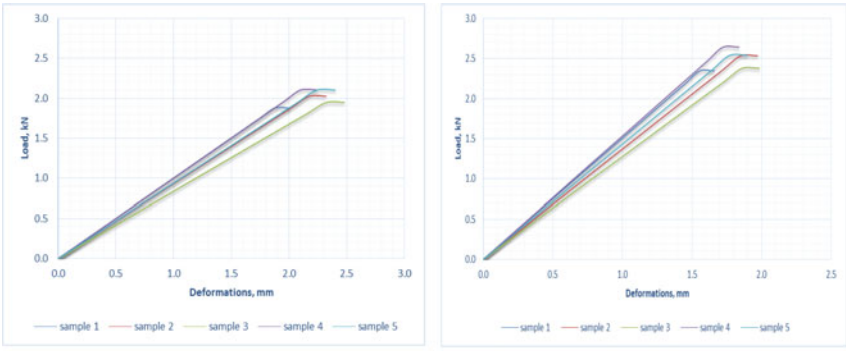


Fig. 6 Load–strain diagram for tensile samples: **a** polymer composition **b** polymer composition with nano-structural filler

$$\sigma_w = \frac{P_{max}}{a \cdot b} \tag{1}$$

where P_{max}—is the maximum load, kN; $a \cdot b$—re the cross-sectional dimensions of the working part of the sample, mm.

According to the test results, statistical processing of experimental data was carried out.

The lowest strength value was determined by the formula:

$$R_s = \overline{x} - \sigma \tag{2}$$

where $\overline{x}$—is the average strength value; σ—is the standard deviation.

The accuracy index of the obtained average value is determined by the formula:

$$\xi = \sigma_x / \overline{x} \tag{3}$$

where σ_x—is the average error of the average value.

To summarize the test results obtained, Table 1 has been compiled.

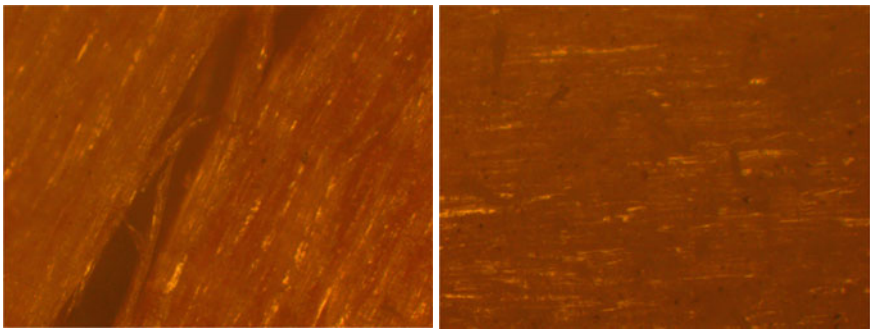
Figure 7 shows the results of studies of samples by optical microscopy in the longitudinal section.

Optical microscopy illustrates the distribution of nanostructured filler in a polymer composition.

Nanotubes, being distributed in the volume of the polymer matrix, cause the processes of molecular ordering in the amorphous phase of the polymer [30–34]. The resulting local ordering regions cause the effect of compaction of the composite structure [35–38]. It was found that an increase in the concentration of CNTs of more than 0.5% practically does not affect the size of their clusters, but only the number of these sites.

Table 1 Comparative data on the mechanical properties of a polymer composition and a composition with a nanostructured filler

Type of tests	Destructive load P_{max},kN / Accuracy index P,%		Voltage σ,MPa / Strength gain,%	
	Polymer composition	Polymer composition with nanostructured filler	Polymer composition	Polymer composition with nanostructured filler
Compression	2.19 / +3.89	2.54 / +4,99	49.86 / –	63,68 / 27,72
Stretching	1.83 / +3.95	2.26 / +4.10	36,65 / –	45.26 / 23.49



a) b)

Fig. 7 Examination of samples by optical microscopy: **a** polymer composition; **b** polymer composition with nanostructured filler

The micrographs shown in Fig. 7 can be interpreted as follows: samples with a content of 0.05 CNT mass fraction in the polymer composition in the polymer composition are characterized by the greatest uniformity of structure; carbon nanotubes form clusters of individual bundles that are differently oriented in the matrix. At a concentration of 0.05 of the mass part of CNT, clusters obviously fill the free space. At lower concentrations of CNTs, the concentration of bundles is insufficient to fill the free volume, therefore, they are mainly located on the surface.

All these factors make it possible to explain the changes in the macro properties of composites, namely the greatest value of density and strength at concentrations of 0.05 mass fraction.

4 Conclusions

Thus, based on the results of studies of the mechanical properties of a polymer composition based on dimethacrylic polyester with a nanostructured filler for wood modification, the following conclusions can be drawn:

1. A polymer composition based on dimethacrylic polyester with a nanostructured filler for wood modification was obtained. Carbon nanotubes (CNTs) of the Taunit-M series were adopted as an additive.
2. The optimal amount of filler, established as a result of strength experimental studies, as well as optical microscopy, is 0.05 mass parts.
3. In order to exclude the settling of nanotubes, surfactants (surfactants) must be added to the liquid phase of the polymer composition, for example, OP–10 in an amount of 0.05 mass parts.
4. The strength of the thermally cured polymer composition according to the test results is 49.86 and 36.65 MPa, respectively, for compression and tensile samples.
5. The strength of the composition when carbon nanotubes are introduced into its composition increases by 27.72 and 23.49%, respectively, during compression and tensile tests.
6. Taking into account the strength properties of the polymer compositions under study, allows us to conclude that they can be used for thermochemical modification of wood.
7. This study substantiates the theoretical possibility of using a composition with CNT for thermochemical modification of wood, which ultimately contributes to the development of composite building structures.

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