Investigation of the Bending Bearing Capacity for Wood Modified with Polymers with Nanoparticle Filler

Svetlana Roschina, Mikhail Sergeev, and Danila Chibrikin

Abstract The issues of resource conservation are relevant in our time as never before. The study suggests a way to modify wood by vacuum infusion methods using a polymer composition. This method is relevant in the manufacture of new types of wooden structures, reinforcement of nodes and interfaces. Of the greatest interest are structural elements and manufacturing technologies of wooden structures using modern composite polymer materials with the inclusion of carbon nano-tubes (CNTs) in their composition, which leads to increased strength and rigidity, reduced mate-rial consumption and mounting weight of structures, reduces the effect of anisotropy of proper-ties and defects of wood on the bearing capacity.

The wood was impregnated with a polymer composition based on dimethacrylic polyester with a nanostructured filler. At the stage of destruction of samples, during bending tests, the stress level in wood is equal to 25–26% of the temporary bending strength for wood modified with compo-site, and 36–37% - with the addition of carbon nanotube filler to the composite. Experiments on samples have shown the prospects of using a polymer composition to modify wood in order to increase its strength properties.

Keywords Bending · Testing · Polyester · Modification · Carbon nanotubes

1 Introduction

Wood is an environmentally friendly material, it resists static and dynamic loads well, it is very light and at the same time durable. Wood, as a product of plant origin, is a layered-fibrous porous material in its structure and consists of numerous fused elementary cells, diverse in shape, size, and elongated mainly along the trunk. All of them are strongly connected with each other. The cell cavities can be filled with resins, gums (resinous secretions), tiles, and water. Vessels, core rays, and wood pulp

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are formed from the cells. Each cell has its own shell (wall). The cell walls are 99% com-posed of organic compounds: carbohydrates (70–80%) and lignin (about 30%). The carbohydrate part of wood includes cellulose, glucose, sugar, hemicellulose. Carbo-hydrates and lignin are natural high-molecular compounds (polymers).

The location of wood fibers along the axis of the tree causes a sharp difference in the mechanical properties of wood along and across the trunk. The elastic modulus of pine for the direction along the fibers is almost 40 times greater than across, and the compressive strength is 10 times, and the tensile strength is 20–30 times [1–7].

One of the ways to improve the physical and mechanical properties of wood is its modification. Modification of wood should be considered as a process of directed change of physico-mechanical, thermophysical, tribotechnical, biochemical properties of wood in relation to the operating conditions of products made of it [8–10].

Thermochemical modification is based on the impregnation of wood with synthetic monomers and oligomers, followed by polymerization and curing by a thermocatalytic method [11–13]. The technological process of impregnating wood with a modifier based on monomers, oligomers or polycondensation resins is carried out according to the vacuum-pressure or vacuum-pressure-vacuum method at a temper-ature of 20–30 °C. The amount of absorbed impregnation composition is assumed to be equal to 30–80% of the mass of the original wood. Phenol alcohols, furan-, ace-tate, methyl methacrylate, styrene methylmethacrylate, styrene vinyl acetate, polyes-ter resins, styrene polyester resins, phenol-formaldehyde, epoxy, furan, urea-formaldehyde, etc. are used as modifiers, the conditional viscosity of which accord-ing to the VZ-4 viscometer should be 11–14 c at a temperature of 20 °C [14–17]. The viability of the modifier should ensure a complete technological cycle of wood impregnation. The composition can be cured by radiation and thermocatalytic meth-od [18–20].

The study is carried out in order to study the strength properties of wood impregnated with a polymer composition when working on bending standard samples.

2 Methods

The impregnation composition for wood modification is a polymer composition based on dimethacrylic polyester with a nanostructured filler. The main components that make up the polymer composition are: liquid resin, dry hardener (0.25 mass parts), surfactant (OP–10) in an amount (0.5 mass parts), carbon nanotubes (CNTs of the Taunit-M series) (0.5 mass parts). Mixing of the components was carried out using a PE-8300 top-drive agitator equipped with a built-in control unit [20–23].

The modification was carried out in the following order:

1. Drying of workpieces to a humidity of 5–7% for 2 h at (110 + 5) °C in a standard drying cabinet (SHS-100–01) at atmospheric pressure.
2. Checking the moisture content of each workpiece with a wood moisture meter (Testo-616). If the tests are not breaded immediately after drying, then they should

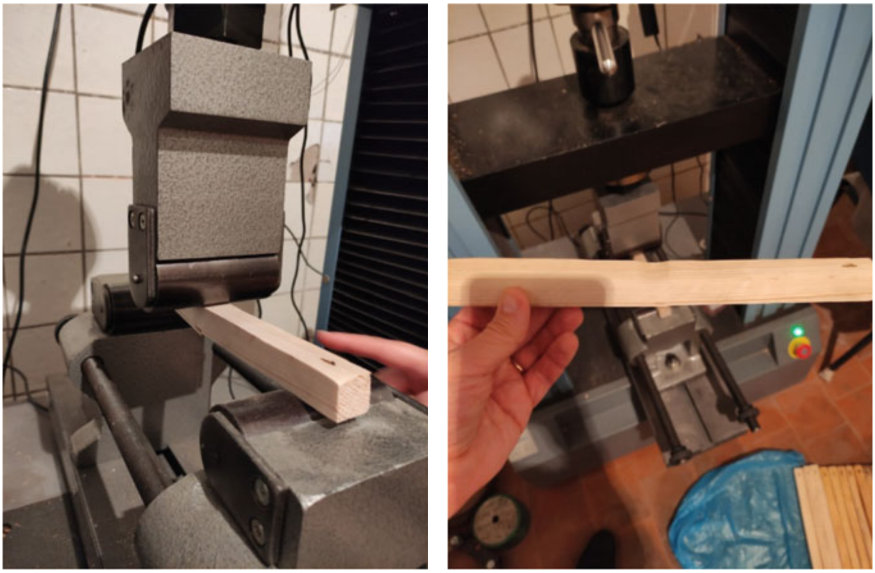
be stored for no more than 3 days in a tightly closed container, for example, in a desiccator) at a temperature of (18–25) °C and humidity control.

3. The blanks are placed in a container for impregnation, fixed with a plate from floating the blanks and filled with an impregnating compound 5 cm above the plate. The container is transferred to a mobile unit for vacuum infusion MVS-20 (−01). Slowly, preventing rapid foaming of the impregnating composition from the air available in the blanks, the air is pumped out to a residual pressure of minus (0.8–0.9) atm. The blanks are kept under vacuum until there is no visible release of even the smallest air bubbles in the layer of the impregnation composition above the blanks, then the vacuum is discharged (see Fig. 1a).
4. To achieve the effect of modification for full volume impregnation, it is recommended to carry out additional exposure (soaking) already impregnated billets in the impregnating composition for up to 15 days.
5. Visually control the degree of filling with the composition of the workpiece. At the end of impregnation, the workpiece should sink in the impregnating composition, and not float. The completeness of the impregnation of the workpiece is controlled visually by a cross-section.
6. The samples are wrapped in aluminum foil and placed at atmospheric pressure in a drying cabinet with forced internal ventilation. The curing temperature is (95–105) °C. The holding time is determined by the type of wood, it is selected for the dimensions of the workpiece and is usually at least 1 h (see Fig. 1b).

The research was carried out on a RM-50 M bursting machine. The bursting machine with a pulsator is equipped with an electrohydraulic automated control system for the loading process based on a computer, which provides static and dynamic

a) b)

Fig. 1 Technology of wood modification: a) vacuuming of samples; b) samples before testing



a) b)

Fig. 2 Testing of modified wood samples for bending. a) a sample during the test in the press; b) samples after destruction

tensile tests of metal and alloy samples, concrete samples, wood and polymer materials in manual and semi-automatic modes. Loading of standard samples was carried out uniformly with a constant speed of movement of the loading head of the ma-chine - 4 mm/min [24–31].

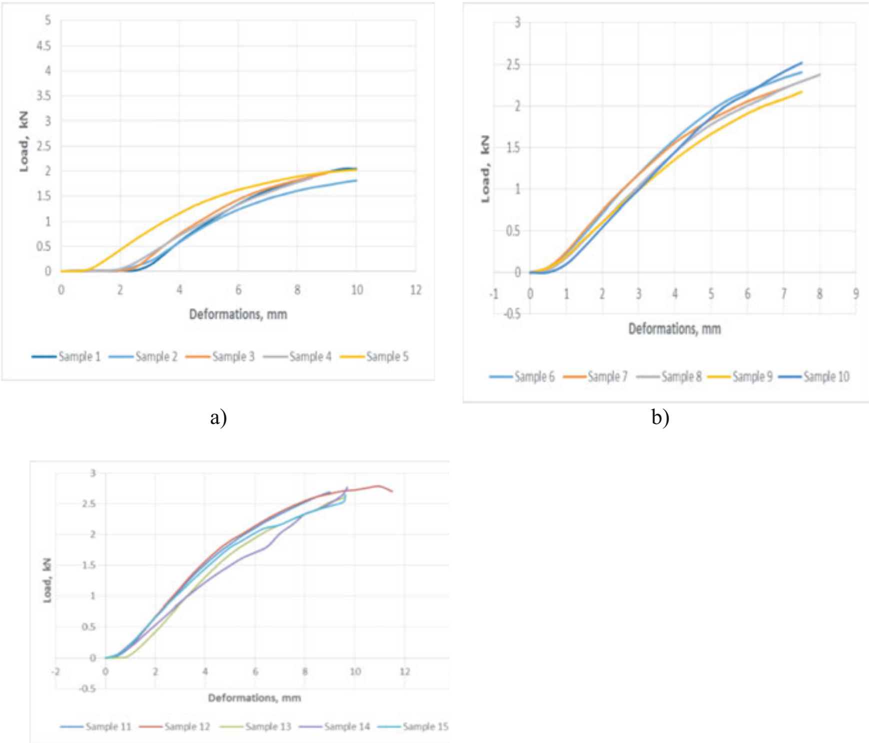
15 samples were subjected to the radial cleavage test - 3 series of samples of 5 pieces each. 1 series - samples without modification, 2 series - images with modification by polymer composite and 3 series with modification by polymer composition with nanostructured filler. According to the test results, statistical processing of experimental data was carried out.

Cleavage tests were performed on standard samples (Fig. 2).

3 Results and Discussions

Figure 3a shows the results of mechanical bending tests of standard wood samples without polymerization, Fig. 3b – wood samples with a modified polymer composition, Fig. 3b - wood samples with a modified polymer composition with a nanostructured filler.

The bending strength of the samples was determined by the formula:



a) b)

c)

Fig.3 Load –strain diagram for tensile wood samples: a) samples without modification; b) samples with modified polymer composition; c) samples modified with a polymer composition with a nanostructured filler

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

where P_{max} - is the maximum load, kN; a,b - 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 σ - is the average strength value; x – is the standard deviation.

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

Table 1 Comparative data on the mechanical properties of samples during radial cleavage

Type of test samples Indicators	Without modification	With modification by polymer composition	With modification by polymer composition with nanostructured filler
Destructive load P_{max},kN / Accuracy index P,%	2.03 / ±4.7	2.31 / ±3.58	2.74 / ±4.63
Voltage σ,MPa / Strength gain, %	34.96 / –	43.56 / 25.7	47.58 / 36.1

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

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

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

4 Conclusions

Based on the conducted studies of prismatic bending wood samples modified with a polymer composition with a carbon nanotube filler, the following conclusions can be drawn:

1. Modification of wood by means of its impregnation with polymer compositions has prospects and is relevant for further use. This solution makes it possible to significantly increase the efficiency of the use of various structures and compositions made of wood.
2. At the stage of destruction of samples, during bending tests, the stress level in wood is equal to 25–26% of the temporary bending strength for wood modified with composite, and 36–37% - with the addition of carbon nanotube filler to the compo-site. The limiting state occurs at the moment of rupture of the stretched fibers or by weakening in the form of various defects of the stretched zone.
3. As a modifier, in the above series of tests, a polymer composition based on di-methacrylic polyester with a nanostructured filler was used. The main components that make up the polymer composition are: liquid resin, dry hardener (0.25 mass parts), surfactant (OP–10) in an amount (0.5 mass parts), carbon nanotubes (CNTs of the Taunit-M series) (0.5 mass parts).
4. The conducted research contributes to the knowledge base on the use of polymer composites with CNTs for thermochemical modification of wood, which will give development to composite building structures.

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