Polymer compositions for restoration of destructed wooden structures

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Abstract. Under changing temperature and humidity conditions, organic material is biodegraded by microorganisms, rot appears, and wood is destroyed, which leads to a loss of operational reliability of wooden structure elements as a whole. To maintain the working condition of wooden structures, extend their life cycle, and ensure operational reliability, it becomes necessary to carry out work to strengthen and repair the surfaces of wooden elements. The article's authors have developed polymer compositions that can be used to restore the bearing capacity. The first composition was developed based on epoxy resin, and the second was based on dimethacrylic polyester. Conducted tests to determine the compressive strength and shearing along the fibers and the adhesive strength in shear and bending of the wood-composite element. It has been established that the compressive and chipping strengths of impregnated samples are comparable to the strengths of "healthy" wood. The developed composition, based on epoxy resin, showed high adhesive-cohesive properties. It is shown that both materials equally provide the restoration of destructed elements and increase their bearing capacity. Science-based technical solutions for the restoration of local areas of destructed wooden structures can be used in projects to reconstruct, repair, and restore wooden buildings and structures.

1 Introduction

The wood used in constructing wooden housing is often exposed to adverse operational impacts. Various methods of restoring and strengthening wooden structures are used, based mainly on the selective replacement of affected structures with solid wood or metal [1,2,3].

For many years, life cycle research and restoration of the bearing capacity of building structures made of conventional building materials (e.g., reinforced concrete and metal structures) have been widely studied [4…8]. However, very little literature can be found on strengthening wooden structures in operation, which determines the relevance of this study.

With the advent of high-strength polymeric materials, it became possible to restore the affected areas of load-bearing wooden structures [9…14]. Such polymers make it possible to provide sufficient thermal, fire, and frost resistance to reinforced wood elements and increase their biostability [15].

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The main criterion for weakening the section is the degree of destruction of the element in percent [16,17]. The characteristic types of sections of the destructed support zones of wooden beams for which a restoration method has been developed are shown in Fig.1.

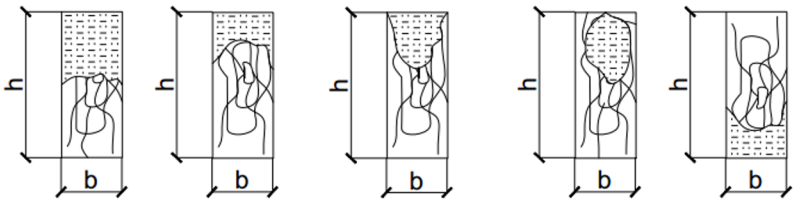


Fig. 1. Typical destructed damage to support zones wooden beams: a) 0 ... 50%; b) 0… 25%; c) 0 ... 30%; d) 0 ... 20%; e) 0… 25%;

The technology of reinforcement and local modification proposed in the framework of the study will allow restoring the strength and operational parameters of a damaged structural wooden element, for example, a wooden beam.

2 Methods

Restoration of destructed sections of wooden beam structures, including support zones, is supposed to impregnate the polymer composition into local areas of destructed wood [18].

Figure 2 shows how to restore damaged support areas using a wooden beam as an example.

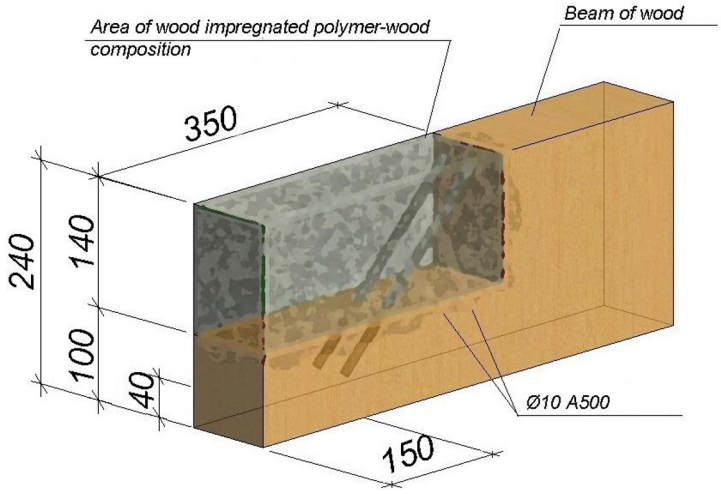


Fig. 2. Method for restoring destructed supporting sections on example of wooden beam

The task was to obtain a component composition (modifier) for wood modification that meets the requirements of high penetrating power, low viscosity, cold hardening, acceptable viability, good wettability, and the possibility of interaction with the structural elements of wood.

To achieve this goal, the authors of this paper have developed two types of polymer composition.

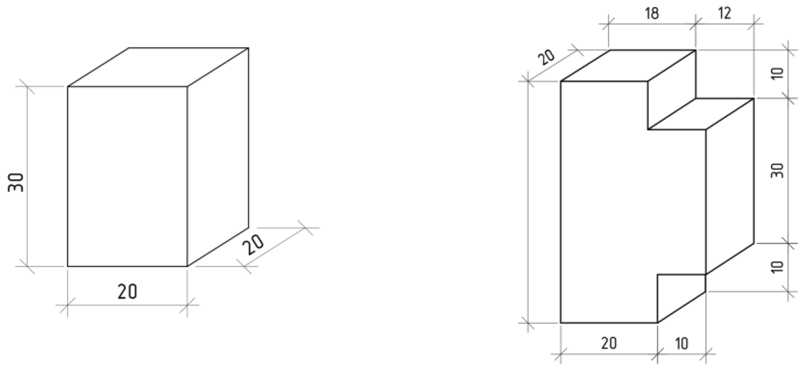
The first composition was developed based on epoxy resin for three cases (Fig. 1 b, c, d) when the degree of destruction of the element reaches 30% of the cross-sectional area. Epoxy resin, in its cured form, is characterized by high tensile and compressive strengths and high hardness [19]. Epoxy resin ED-20 is a two-component resin. Hardeners for epoxy resins (PEPA, TETA) are required for its curing. These resins' curing process can occur at normal room temperature up to 20°C. Cured epoxy resins have valuable technological properties and high physical and mechanical properties. Plasticization significantly improves the mechanical properties of polymers. Plasticizers reduce brittleness, increase flexibility, elasticity, and relative elongation, and increase the material's frost resistance. Dibutyl phthalate was used as a plasticizer. A diluent (acetone) was introduced into the composition to reduce the viscosity.

Sometime later, a second composition based on dimethacrylic polyester was developed. Dimethacrylic polyester is an inexpensive, non-toxic, widely used polymer on the Russian market. Based on the results of the tests, it was decided to use the composition of dimethacrylic polyester with a curing accelerator in the form of cobalt octoate, a hardener of methyl ethyl ketone peroxide, a surfactant emulsifier and with the addition of carboxylated carbon nanotubes. Carbon nanostructured materials improve the mechanical properties of the polymer composition as a whole [20, 21]. To reduce the viscosity, distilled water was introduced into the polymer composition.

Tests of polymer compositions were carried out in two stages: first, the strength of the impregnated wood was checked for compression and shearing along the fibers, and then the adhesive strength of the modifiers was tested.

2.1 Determination of shear strength along the fibers

To test wood for shearing along the fibers, samples were taken from the same exploited wooden floor beam as for compression tests along the fibers. The tests for chipping along the fibers were performed on the samples (Fig. 3, b). The test conditions and apparatus are similar to those for determining the compressive strength along the fibers.



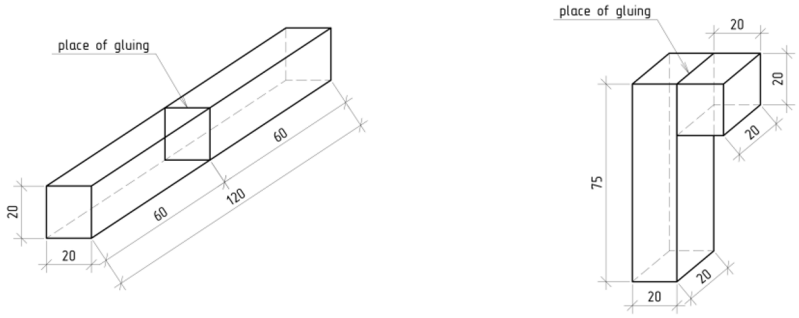
a) b)

Fig. 3. Impregnated wood test: a) compression along the fibers; b) chipping along the fibers.

The temperature and humidity of the environment were determined by an alcohol psychrometer. The air temperature in the room was within 18–22°C, and the relative humidity was 50–60% [22]. The tests were carried out on a universal testing machine, REM-600-A1. The loading occurred evenly at a speed of movement of the loading head of the testing machine of 4 mm/min. The destruction of the sample occurred 1 min after the start of loading [23].

2.2 Adhesion strength tests

Tests of adhesive strength of polymer compositions with wood were determined by shear and transverse bending tests [24]. The shape and dimensions of the test specimens are shown in Fig. 4.



a) b)

Fig. 4. The shape and dimensions of samples for testing adhesive strength: a) adhesive strength in bending; b) adhesive shear strength.

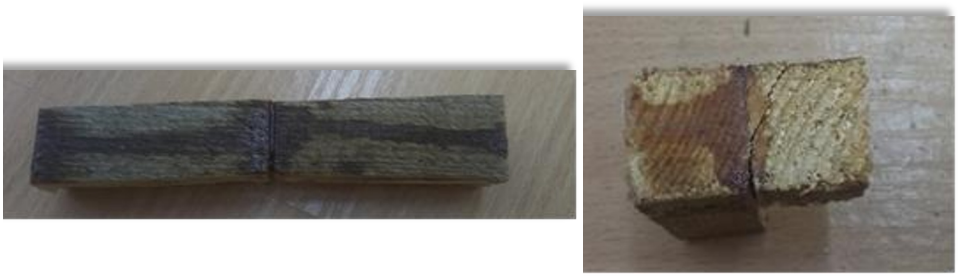
Shear adhesion strength is determined by the formula:

$$\sigma = \frac{P}{A_0} \tag{1}$$

where P is the breaking load, N; A_o is the adhesive joint area, mm^2.
The adhesive strength in transverse bending is determined by the formula:

$$\sigma_u = \frac{3P_i \cdot L_v}{2b \cdot h^2} \tag{2}$$

where P is the breaking load, N; L_v is the distance between the supports, equal to 100 mm.



a) b)

Fig. 5. Testing wood for adhesive strength of a polymer composition based on epoxy resin:
a) in bending; b) in shear

3 Results and Discussion

A comparative analysis of the compressive strength along the fibers (Table 1) of two polymer compositions relative to "healthy" wood showed that the strength of wood impregnated with an epoxy resin composition increased by 23%, and the strength of wood impregnated with a composition based on dimethacrylic polyester was 19% higher.

Table 1. Comparison of experimental results of wood when compressed along the fibers

Name	Breaking load, kN	Tensile strength, kN/cm^2
Destructive wood	7.33	1.75
Undamaged wood	15.94	3.15
Wood impregnated with epoxy resin	20.8	4.16
Wood impregnated with a polymer based on dimethacrylic polyester	19.7	3.94

According to the test results, the diagram "Fracture load – relative deformations" was built (Fig. 6).

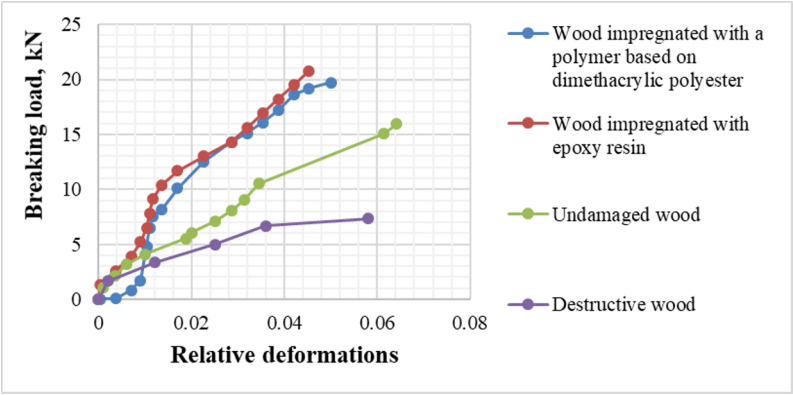


Fig. 6. Diagram "Fracture load – relative deformations" during compression tests along fibers.

A comparative analysis of the shear strength indicators along the fibers (Table 2) of two polymer compositions relative to "healthy" wood showed that the strength of the composition based on the epoxy resin is 23% higher, and the strength of impregnated wood with a composition based on dimethacrylic polyester increased by 20%.

Table 2. Comparison of experimental results of wood when shearing along fibers

Name	Breaking load, kN	Tensile strength, kN/cm^2
Destructive wood	3.2	0.59
Undamaged wood	5.5	0.89
Wood impregnated with epoxy resin	7.2	1.05
Wood impregnated with a polymer based on dimethacrylic polyester	6.9	1.01

According to the test results, the diagram "Fracture load – relative deformations" was built (Fig. 7).

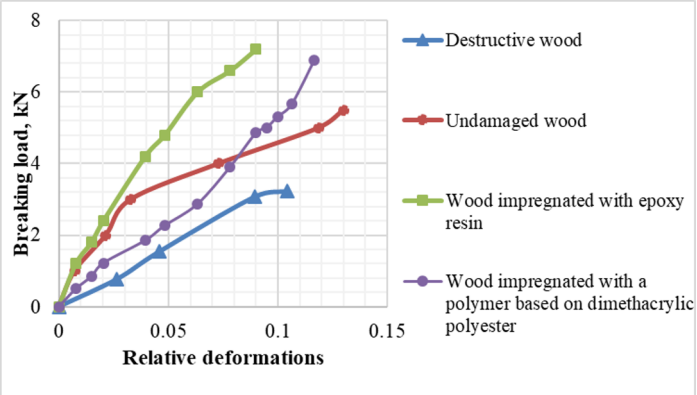


Fig. 7. Breaking load-relative deformations diagram during shearing tests along fibers

When tested for compression and tension along the fibers, elastic-plastic destruction of the samples is characteristic. Up to about half of the tensile strength, the growth of deformations occurs according to a law close to linear, and wood works as an elastic material. With an increase in the load, the increase in deformations more and more outstrips the increase in stresses, indicating the elastic-plastic nature of wood work [25, 26].

Thus, when determining the values of compressive strength and shearing along the fibers, it was determined that both compositions could be used to reinforce degraded wooden beams in the supporting part of the structure. The strength characteristics of impregnated wood increase by 20–23% relative to undamaged wood.

Both of these compositions showed satisfactory strength values for impregnated wood. Therefore, both proposed polymer compositions can be recommended for strengthening destructed wooden structures.

However, wood impregnated with a composition based on dimethacrylic polyester changes its original color and stains the wood black because it contains carbon nanotubes. The composition based on the epoxy resin is devoid of such a disadvantage.

While testing the adhesive strength of wood, the results were obtained, which are presented in Tables 3 and 4.

Table 3. Results of tests of polymer composition on adhesive strength of polymer composition based on epoxy resin in shear and bending

Solid wood		Destructed wood	
shear, kN/cm^2	bending, kN/cm^2	shear, kN/cm^2	bending, kN/cm^2
0.37	2.062	0.451	2.619

Table 4. Strength characteristics of polymer composition based on epoxy resin

Compressive failure load, kN	Compressive strength, kN/cm^2	Shear adhesion strength[1], kN/cm^2	Flexural adhesion strength[1], kN/cm^2
58.021	14.58	0.37/0.451	2.062/2.619

Note: [1] The numerator indicates the value for "healthy" wood and the denominator for degraded wood, respectively.

Wood samples were destroyed during the adhesion test of the polymer composition based on epoxy resin. Different values of the adhesive strength of healthy wood and wood weakened by destruction are explained by the change in wood structure during operation. Destructed wood is "looser" and more porous, which increases the absorption capacity of the polymer composition. The polymer composition flows into the wood's pores, forming

the so-called glue locks [27–30]. Thus, one can judge the cohesive nature of the destruction: the rupture occurs along the substrate array, which indicates a high quality of bonding.

The strength characteristics of the adhesive strength of the polymer composition based on dimethacrylic polyester were low, so they were not included in Tables 3 and 4. This modifier showed poor adhesion because destruction occurred along the adhesive seam. It should be noted that the modifier based on dimethacrylic polyester has a low viscosity. It is very liquid, so the adhesive line was not formed as such. During adhesive failure, the external forces applied to the sample were stronger than the modifier.

An epoxy resin-based polymer composition can be used in damaged elements where degradation is up to 30% of the cross-sectional area. In addition, high adhesive strength allows the use of such a modifier in the support zones of the beam, where there is a high concentration of shear stresses.

4 Conclusions

Developed and scientifically substantiated formulations of a polymer composition based on epoxy resin and dimethacrylic polyester, rational in terms of component composition, for the restoration of damaged areas of the supporting zones of wooden structures, which allows modifying the capillary-porous structure of destructed wood.

The main strength characteristics of the polymer composition are experimentally determined: breaking load, ultimate strength, and adhesive strength in shear and bending. The nature of the destruction of polymer compositions during compression tests with a short-term load is revealed. Plastic destruction occurs when a plasticizer is introduced into the polymer composition.

Experimental substantiation of the possible restoration of the health of destructed wood using its impregnation is given. It has been established that the strength characteristics of impregnated wood with a polymer composition based on epoxy resin and dimethacrylic polyester are comparable to those of "healthy" wood. The strength characteristics of impregnated wood increase by 20-23% relative to undamaged wood. The developed compositions should be used in damaged wooden elements, where destruction is up to 30% of the cross-sectional area. If the destruction exceeds 30%, then this method of restoring the bearing capacity is ineffective because strongly destructed wood cannot form adhesive locks.

The polymer composition based on dimethacrylic polyester has a very low viscosity and, therefore, a high penetrating power. However, the obtained low adhesive strength values limit the use of such material. The polymer composition can be used for local modification of wooden elements with little degradation.

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