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OPTIMIZATION OF WOODEN CONSTRUCTIONS WITH BASALT-BASED MATERIALS

Abstract. This study investigated material properties of wood-composite materials made in the form of cellular structures. 5 honeycomb wood honeycomb structures were examined and compared with 3 reference samples, which were made of pure wood. 2 samples were made using the reinforcement scheme, 3 other samples were made using the lamination scheme. As a result, the composite-reinforced specimens were found to have 30% higher strength than the original pure wood specimens. A comparison was made with the finite element calculations of these structures.

Key words: compressive strength, wood-composite structures, basalt fiber, epoxy resins, finite element modeling, monitoring of wooden structures.

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ОПТИМИЗАЦИЯ ДЕРЕВЯННЫХ КОНСТРУКЦИЙ НА ОСНОВЕ БАЗАЛЬТА

Аннотация. Настоящая работа посвящена изучению древесно-композитных материалов, выполненных в виде ячеистых структур. Было исследовано пять ячеистых древесно-композитных структур и сравнены с третьим референтным образцом, который был выполнен из чистого дерева. Два образца были выполнены с использованием схемы армирования, три других образца были выполнены по схеме ламинирования. В результате было получено, что усиленные композитом образцы имеют на 30 % больше прочности, чем исходные чисто деревянные образцы. Было проведено сравнение с конечно-элементными расчётами данных конструкций.

Ключевые слова: прочность на сжатие, дерево-композитные конструкции, базалтовое волокно, эпоксидные смолы, конечно-элементное моделирование, мониторинг деревянных конструкций.

1. Introduction

Currently, a large number of lightly loaded structures are being constructed from metal, for example, summer houses, pavilions, short pedestrian bridges [1]. The loads acting on these structures are noticeably lower than critical for metal, which has a significant for these structures own weight. For such structures, metal can be replaced with wooden structures [2]. Wood is barely light, tensile and ecologic material. But now days it is not very distributed due its poor strength characteristics in compassion with steel and concrete as civil engineering material. By reinforcement it can be made tougher [3]. For example, one way is to reinforce it by using basalt fiber reinforced polymer [4], like the way wood is repaired using epoxy [5]. One approach is to reinforce by combining wood and basalt fiber reinforced polymer. To obtain a strong contact, the reinforcement of basalt fiber is made directly on wood [6-9]. At the same time, wood receives new properties, such as increased tensile strength [10]. Another approach, is to use basalt fabric reinforcement [17-20]. It can be used as lamination material on wood, or other construction material. At the same time, mass, volume and geometric characteristics remain unchanged. Assessing these changes is difficult due to the orthotropicity of wood and the isotropy of basalt fiber reinforced polymer. One of the most relevant methods is mechanical strength testing. But due to the limited size of the test benches, it is possible to test only small parts. For testing finished products and taking into account the maximum number of influencing factors, in any case, we need to use finite element modeling [11-16] with strong results validation. So, we decided to test the maximum possible designs to obtain the most relevant results.

2. Materials and methods

2.1. Sources of materials and mechanical properties

We’d like to introduce our testing constructions. These are wooden frames with different parameters. Frames. T1, T2, T3 are pure wood frames. T1A, T3A – are reinforced T1 and T3 frames. T1L7, T2L4, T3L3 are different type of frames – they are reinforced with basalt fiber lamination. The wood used is coniferous, in this case, first class pine, with a minimum number of knots, exclusively in the center of the canvas. They are shown on figure 1.

Pine wood has density from 487 to 520 kg/m^3. Pine belongs to the genus of conifers. A total of about one hundred and thirty species of pine are known. Pine is an evergreen tree containing a large amount of resin.

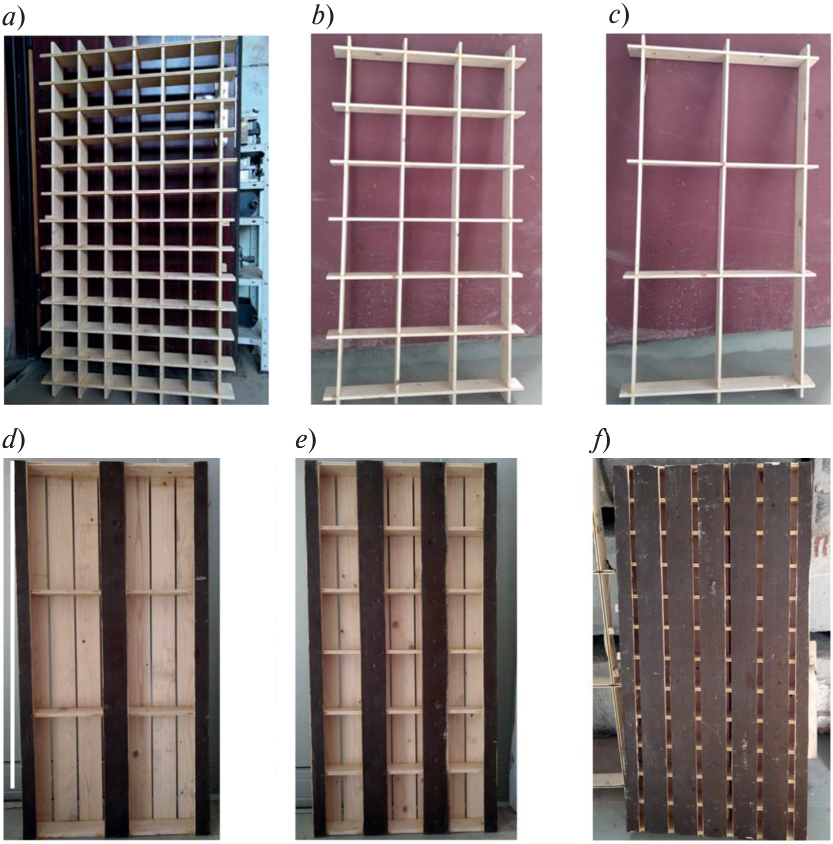


Figure 1. Frame types. (*a*) T1, T1A; (*b*) T2; (*c*) T3, T3A; (*d*) T1L7; (*e*) T2L4; (*f*) T3L3

The most common species in Russia is ordinary pine. Pine is the most used type of wood in Russia. About 30% of all types of wood used in our country is pine. Pine wood is not afraid of the effects of fungi, insect pests, putrefactive damage due to increased resinity. According to this indicator, pine varieties are divided into the first type (with a high resin content) and the second type (reduced resin content). Resin pine is not recommended for use in carpentry, since the resin makes it difficult to saw and plan, sticking to tools. When heated, the varnish coating may rise. If you still need to process pine wood, you must tar it. For this, solvents, acetone, gasoline, alkali solutions, and alcohol substances are used. Also, pine lumber is divided into grades by the presence of defects (in particular, knots). For class 1 lumber, up to 40 mm thick, no more than 3 knots per linear meter are allowed, no more than 1/4 of the size of the lumber.

The reinforcement material for frames T1, T2, T3, T1A, T3A is basalt-fiber rowing reinforced with Epoxy ED-20, a sort of Epoxy-diane Resins.

Density of ED-20 is 1166 kg/m^3 in uncured state. Dynamic viscosity, 13-20 Pa * sec, at (25 ± 0.1) °C. It consists of epoxy groups (20.0-22.5%), chlorine ion (0.001%), saponified chlorine (0.3%), hydroxyl groups (1.7%). Of the distinguishing features of the ED-20, excellent adhesion to wood and does not cause corrosion of materials in contact with them. As a hardener was used Polyethylenepolyamine. Its density is 0.956-1.011 g / cm^3. Bulk prp mixing with epoxy is 10%.

Basalt roving with a fiber thickness of 10 microns and a linear density of 4800 mg/m, Specific density 2.67 g / cm^3. Breaking load is 500-650 mN/Tex.

The result of reinforcement is shown in fig. 2. And the reinforcement material for frames T1L7, T2L4, T3L3 is reinforced with basalt fabric, by lamination. The result of reinforcement is shown in fig. 2. Blueprints of both types of reinforcements are shown on figure 3.

As basalt fabric, was used Basalt fabric TBK-100. The width of the original canvas 1000mm. The surface density of 190-230 g / m^2. Number of threads 9-11 / cm. Breaking load of 780 N. Thickness 0.19 mm.

a) b)

Figure 2. The result of basalt fiber reinforcement (*a*) and the result of basalt fabric reinforcement (*b*)

a) b)

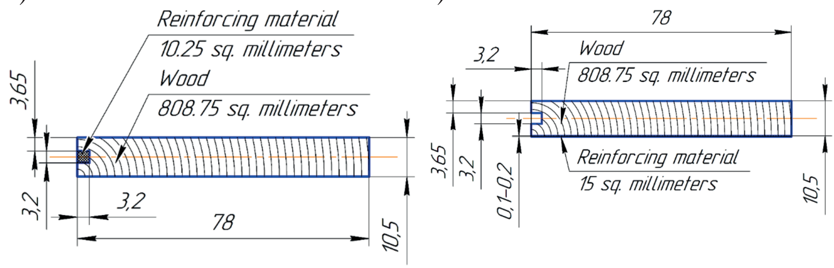


Figure 3. The blueprint of basalt fiber reinforcement (*a*) and the blueprint of basalt fabric reinforcement (*b*)

2.2. Method of research

The research methodology is shown in Figure 4. First of all, the most suitable structural forms for mechanical testing were developed, in this case, the frames. Then, designs were made, representing the frames of various types described earlier, as well as digital 3D models, taking into account the materials used. Then, mechanical tests were carried out, as well as finite element calculations with preliminary tabular character-

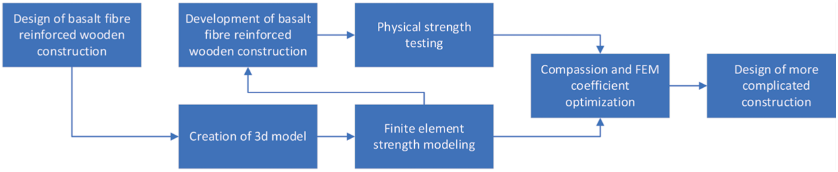


Figure 4. Research methodology

istics of the materials. After that, comparisons and optimization of the coefficients for the calculation model were carried out. And of course, the final design is calculated.

2.3. Mechanical testing

The loading was carried out continuously with a hydraulic jack at a speed of 1 kN/min. The load was measured by an electronic force meter, deflections were measured using dial indicator. Deflections were measured in the middle of the span at three points across the width of the model. Indications were recorded by a camera. The scheme of testing is shown in fig. 5. Camera record of unloaded and loaded frames are shown in fig. 6.

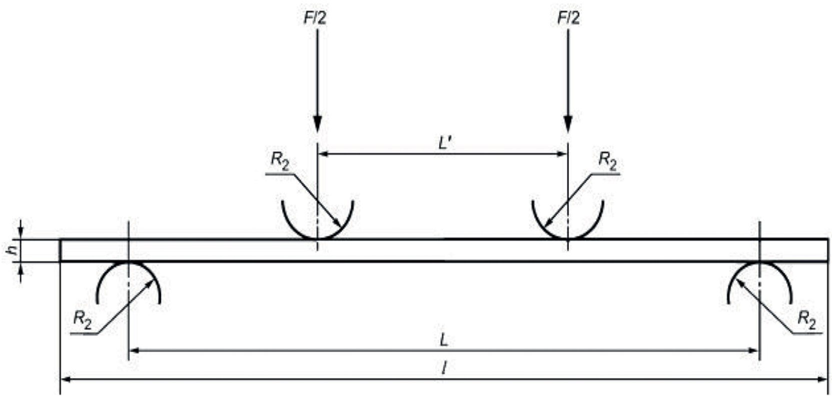


Figure 5. Load scheme (L= 1000 mm; L'= 333 mm; R_2 = 50 mm; h = 78 mm)

a) *b*)

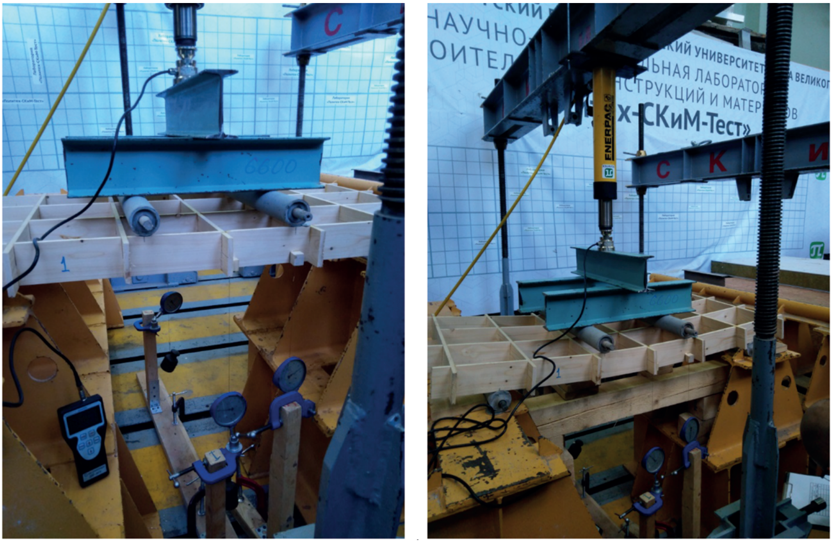


Figure 6. Unloaded frame (*a*) and loaded frame (*b*)

2.4. Finite element testing

Of course, element modeling was carried out in the Ansys software package, and in the calculation module - static structural. The design scheme is shown in Figure 7. The loads were set in accordance with the loads on the test bench.

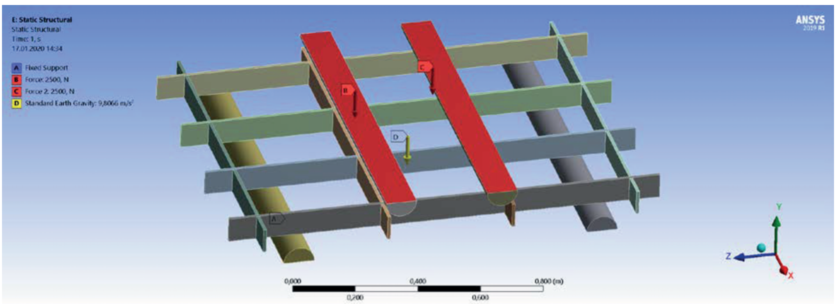


Figure 7. Design scheme and loads for T3A frame

3. Results and discussions

3.1. Testing results

The result of mechanical testing of first type of frames (T1,T3,T1A,-T3A) are provided in figure 8. Results of T2 doesn't provided, because, there wasn't T2A frame. We see that the destruction of the T3 sample occurs at a load of 5.2 kilonewton, with a deformation of 19 mm, while the destruction of the T3A sample occurs at a load of 6.4 kilonewton and a deformation of 24 mm. The destruction of the T1 specimen occurs at a load of 6.8 kilonewton, with a deformation of 22 mm, while the destruction of the T1A specimen occurs at a load of 11.2 kilonewton and a deformation of 25 mm.

The destruction of the reinforcement wooden frame occurs immediately after the tear of the reinforcing fiber. Samples of destruction are shown in Figure 9.

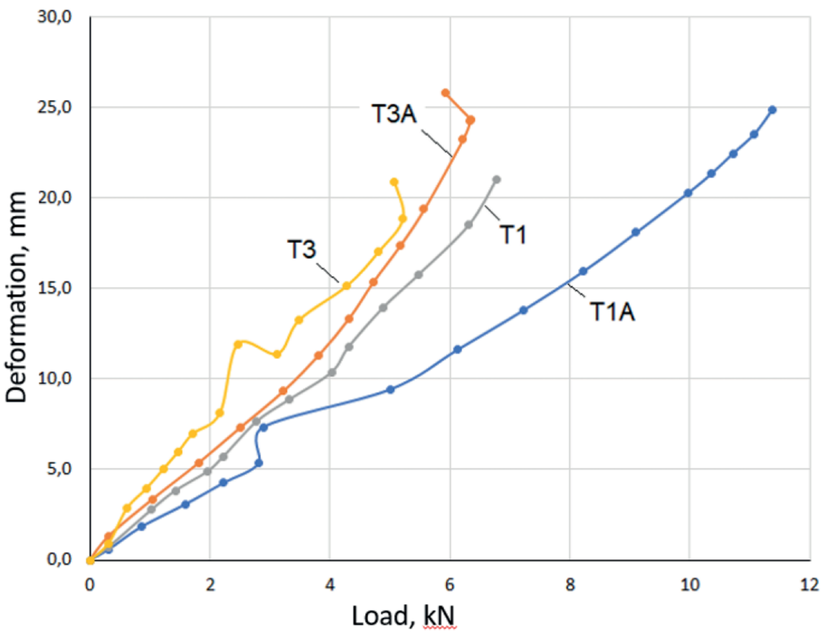


Figure 8. Results of mechanical testing of frames T1,T3,T1A,T3A

a) *b*)

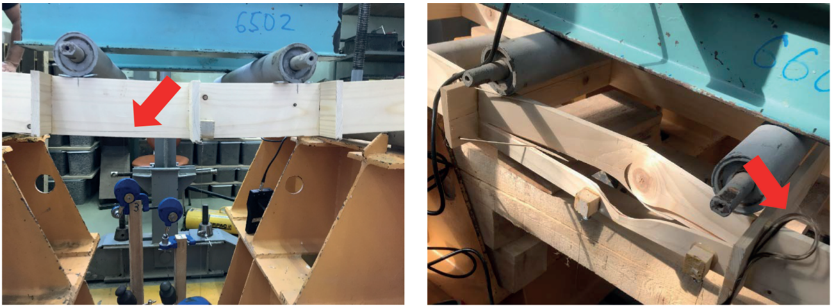


Figure 9. Crack in the bottom of frame (a), and teared reinforcement material (b).

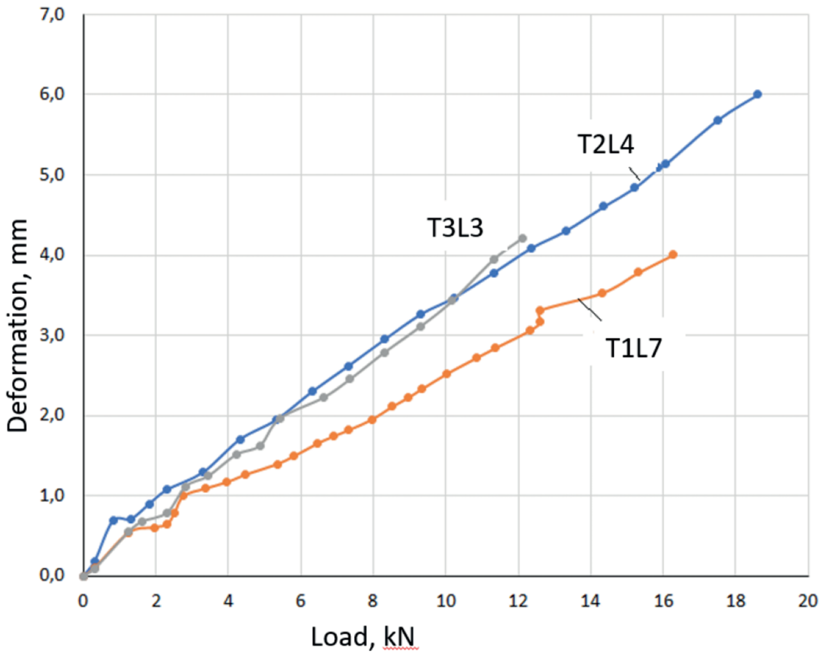


Figure 10. Results of mechanical testing of frames T1L7,T2L4,T3L3

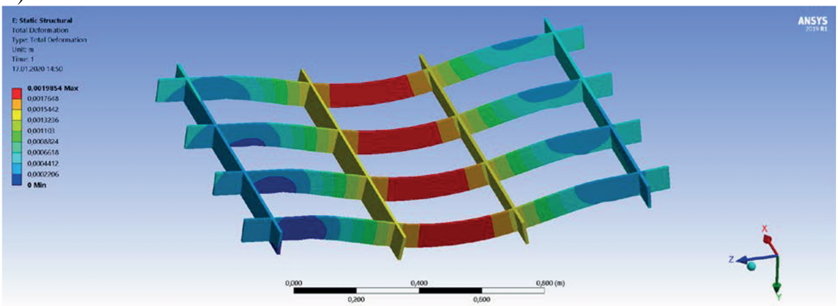
The result of mechanical testing of second type of frames (T1L7,T2L4,T3L3) are provided in figure 10. The destruction of the

T1L7 sample occurs at a load of 16.2 kilonewtons, with a deformation of 4 mm, the destruction of the T2L4 sample occurs at a load of 18.6 kilonewtons and a deformation of 6 mm, the destruction of the T3L3 specimen at a load of 12.0 kilonewtons and a deformation of 4.2 mm.

3.2. FEM

Finite element modeling of samples T3 (Figure 11) and T3A (Figure 12) were carried out with the corresponding materials. We see that the maximum deformations approximately correspond to those obtained during mechanical tests. Deformations 19 and 19.8 for specimen T3, and 17 and 17.1 for specimen T3A at a load of 5 kilonewtons. This corresponds to approximately a tensile yield strength of 20 MPa in the base material (wood).

a)



b)

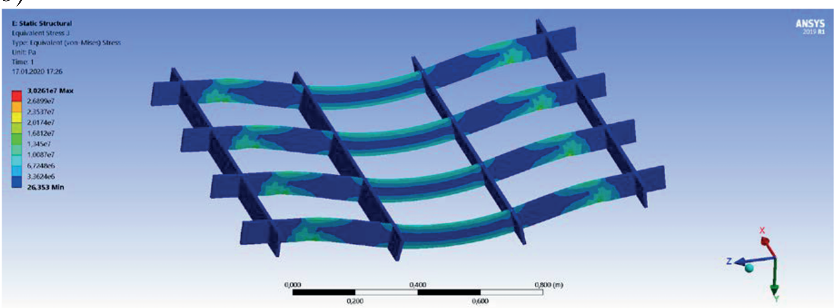


Figure 11. Deformations (*a*) and von-mieses Stress of pure wood frame T3

3.3. Material Consumption

№	Frame name	Frame cell size, mm	Bottom roving reinforcement	Lower laminated planks	Wood Mass, kilograms	Reinforcing material Mass, kilograms	Maximum load, kN	strength, %	Strength per mass
1	T1	100x100	no	no	6,55	0	6,6	100	1,01
2	T2	200x200	no	no	3,64	0	5,6	100	1,54
3	T3	300x400	no	no	2,43	0	5,2	100	2,14
4	T1A	100x100	yes	no	6,55	0,22	11,2	170	1,65
5	T3A	300x400	yes	no	2,43	0,08	6,2	119	2,47
6	T1L7	100x100	no	7	13,34	0,17	16,2	245	1,20
7	T2L4	200x200	no	4	8,98	0,10	18,4	329	2,03
8	T3L3	300x400	no	3	7,28	0,07	12	231	1,63

4. Conclusion

In this article, the results of mathematical and physical modeling of structures using combined materials (wood, basalt roving, basalt canvas, epoxy) were presented. The research results showed that structures made of combined materials show increased strength on the influence of external factors. And thus, we can conclude that the applicability of these materials and structures for the construction of wooden structures.

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