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Ultra-light hybrid composite wood-polymer structural materials in construction

Сверхлегкие гибридные композитные древесно-полимерные конструкционные элементы в строительстве

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Ключевые слова: гибридные древесно-полимерные композиты; пропитка; градиентное упрочнение; внешне армирование; сульфоаддукты нанокластеров углерода

Abstract. In the 21st century, wood construction is again widespread. Industrial wood ceased to be perceived as a material for household buildings and low-rise rural houses and began to be used in the construction of large-span, high-rise and unique buildings and structures. The paper analyzes the use of wood for the construction of large-span, high-rise and unique buildings and structures. The results of experimental studies of hollow wooden parts, developed by the authors, impregnated with epoxy compositions, modified by sulfoadducts of nanoclusters of carbon ("Ugleron C") are given. The possibility of external reinforcement of wood with high-strength carbon fiber grids is considered. The technology of additional strengthening of wooden parts by an external membrane from a multifunctional composite water compatible coating "EpoxyPAN" has also been proven. The results of physical and mechanical tests of samples of ultralight hybrid wood-polymer components are presented. The spheres of their application in park construction, wooden bridge construction, construction of wooden high-rise, large-span and unique buildings and structures are analyzed.

Аннотация. В 21-ом веке строительство с использованием древесины вновь обрело массовый характер. Древесина перестала восприниматься как материал для хозяйственных построек и малоэтажных домов и стала применяться при строительстве большепролетных, высотных, уникальных зданий и сооружений. В статье проведен анализ сфер использования древесины при строительстве большепролетных, высотных, уникальных зданий и сооружений. Приводятся результаты экспериментальных исследований полых деревянных деталей, пропитанных эпоксидиановыми композициями, модифицированными сульфоаддуктами нанокластеров углерода («Углерон С»). Рассматривается возможность внешнего армирования древесины сетками из высокопрочного углеродного волокна. Отработана технология дополнительного усиления деревянных деталей внешней мембраной из многофункцинального композиционного водосовместимого покрытия «ЭпоксиПАН». Приводятся результаты физико-механических испытаний образцов сверхлегких гибридных древесно-полимерных деталей. Проанализированы сферы их применения в парковом строительстве, деревянном мостостроении, строительстве деревянных высотных, большепролетных, уникальных зданий и сооружений.

1. Introduction

Since ancient times, in geographic forest-rich areas, wood has been used as the main building material due to its availability, good strength characteristics, ease of processing and low price. Solid

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wood and sawn timber were used in construction, ranging from simple farm buildings to unique structures, such as wooden fortresses in towns and temples, some of which are extant at the present and overcame the mark of 300 years [1].

But in the 19th century, due to the development of industrial technologies, brick and steel structures became more accessible, and concrete also reinforced. The concrete became the most common material in the construction industry in the 20th century. As a result, the wood fell by the wayside and began to be considered a finishing material, a material for household outbuildings and cottage housing construction

But by the end of the 20th century, due to the rapid development of chemical technology of woodworking, the scope of the use of wood in load-bearing building structures has significantly expanded. In addition, the construction has reached a new level, as more attention was paid to the issues of ecology, resource saving and comfort of human habitation. Wood is one of the most environmentally friendly materials, as it creates a useful indoor microclimate for humans and is a renewable natural resource.

Laminated wood structures came into common use in the construction [2–5]. Their history began with glued beams from individual slats (Glulam) [2, 3]. At the moment, a veneer beam (LVL) [3], as well as panels and veneer blocks (CLT) [4–8] are already widely used.

Due to the development of wooden architecture technologies, as well as the improvement of legislation, which in many countries has previously banned the building of multistore blocks from wood, pilot constructions have been built that show the applicability of wood for the construction of large-span, high-rise and unique buildings and structures.

In 2015 the first multistore (8 floors) apartment block using CLT technology, which is operated without any complaints, was built in Finland.

Among the large-span laminated wood structures, Zenith Concert Hall (France), Bern railway station (Switzerland), the Arena in Salzburg (Austria) should be mentioned.

Also, high efficiency of wood structures in the construction regions with high seismic activity is known [9–11].

The widespread introduction of structures with load-bearing elements on the basis of wood is hampered by the established belief about fragility, increased fire hazard of timber-based structures, as well as its low bearing capacity. This makes actual the work on improving the properties of wood structures. Different aspects of this issue were covered by researchers around the world. The issues of impregnation are covered in the publications [11–14], protective coatings are analyzed in the publications [13, 16–20], external and interlayer reinforcement and the issues of glued laminated wood is covered in the publications [2–5, 21–43].

Based on the analysis, it can be concluded that construction requires lightweight, high-strength construction materials based on wood with equally high fire and technical characteristics for the construction of large-span, high-rise and unique buildings and structures.

2. Materials and methods

In order to carry out research on the physical and mechanical characteristics of HWPC, hollow test samples from coniferous wood veneer with humidity no more than 10% have been developed and manufactured. The test samples were in the form of hexahedrons inscribed in a circle of 185 mm and 1200 mm long.

The wood hexahedrons were assembled from a 10 mm thick veneer with preliminary impregnation. For the impregnation, a composition based on 75.53 % mass. of alcohol-acetone mixture (with a weight ratio of alcohol to acetone 1:1), 20 % mass. of epoxy resin SR 8100 from Sicomin (France), 4.47 % mass. of amine hardener SD 8824 from Sicomin (France). The hardener was modified with sulfoadducts of the carbon nanoclusters ("Ugleron C") in an amount of 1.6 % by weight of the amount of hardener. The efficiency of the modified epoxy compositions with sulfoadducts of the carbon nanoclusters ("Ugleron C") [42], as well as their optimal concentrations, have been specified in the previous work of the authors [13].

The impregnation was made in the sleeve of vacuum film PO180, air evacuation was provided by a two-stage plate-rotor vacuum pump with an oil seal Ulvac GLD-137A.

After the impregnation, the drying of the preparations was continued for 7 days in a room with heated floors without access of damp air. Additional drying was necessary to ensure uniformity in temperature moisture-induced deformations after gluing.

As glue structure the composition from 53 % mass. of epoxy resin ED-20 (Russian State Standard GOST 10587-84), 47 % mass. of water soluble amine hardener was used. The water soluble amine hardener has been modified by carbon nanoporous microfibers (CNPMF) in number of 0.8 % of mass. relatively the mass of the hardener. The efficiency of the modification of epoxy compositions with carbon nanoporous microfibers (CNPMF) [43], as well as their optimal concentrations, have been specified in the previous work of the authors [13].

After the polymerization of the glued joint of the wood sample, under normal conditions, external reinforcement in the form of a grid of carbon fiber UKN-M-12K according to Russian Specification TU 1916 -146-05763346-96 produced by LLC Argon (Russia) was made. As a binder, a composition consisting of SR 8100 epoxy resin from Sicomin (France) and SD 8824 amine hardener of Sicomin (France) in a ratio of 25:6, respectively, was used. The composition was modified with sulfoadducts of the carbon nanoclusters ("Ugleron C") in an amount of 1.6 % by weight of the amount of hardener. Photo of a wood sample with a carbon fiber grid external reinforcement is given in Figure 1.

Figure 1. HWPC sample with external reinforcement in the form of a carbon fiber grid

Upon completion of polymerization process of glue connection, the continuous membrane from polymer nanocomposite material EpoxyPAN was applied on an external surface of preparations for additional strengthening of HWPC and protection against possible action of hostile environment, water and fire (Fire technical characteristics of EpoxyPAN, according to the existing certificate: G1, If1, Sp1, Fo2, T1). Drawing was made by a pneumatic method by means of the textural sprayer the LC-02 brand PRAKTIKA Ltd company.

Measurements of durability on a tension strength of samples of HWPC on a four-dot bend in accordance with Russian State Standard 16483.12-72 have been taken. Tests were carried out at the stand with the hydraulic test BISS MAGNUM UT-05-3000 module. For a possibility of carrying out tests of samples of the above-stated sizes the industrial technological equipment which drawing is given in Figure 2 has been developed and has been made.

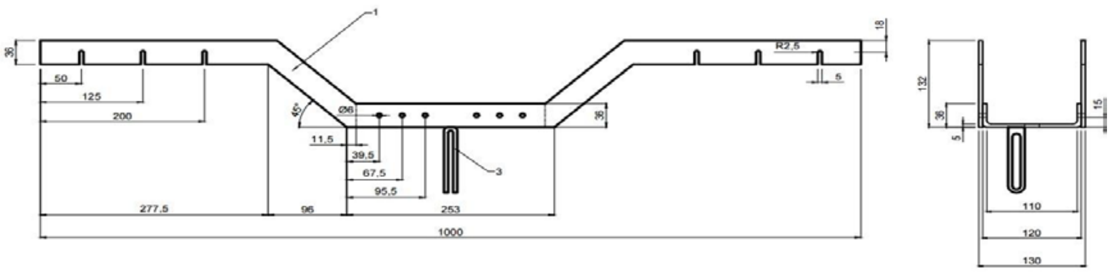

Figure 2. Drawing of the industrial technological equipment

The loading scheme of the test samples is shown in Figure 3.

Axial compression tests were carried out on a universal electromechanical machine Instron 5982 with a maximum force of 100 kN and a test space of 1930 mm. A photo of the process of testing for axial compression is given in Figure 4.

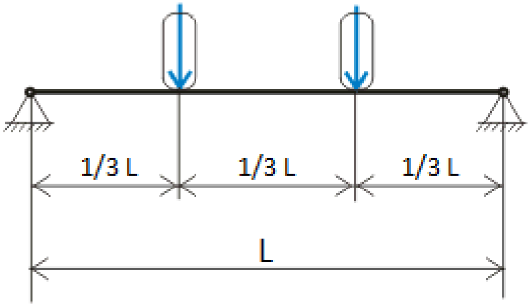

Figure 3. Loading scheme

Figure 4. Compression tests of a HWPC sample on Instron 5982 test machine

3. Results and Discussion

The results of physical and mechanical tests of ultralight hybrid wood-polymer components are given in Figures 5 and 6.

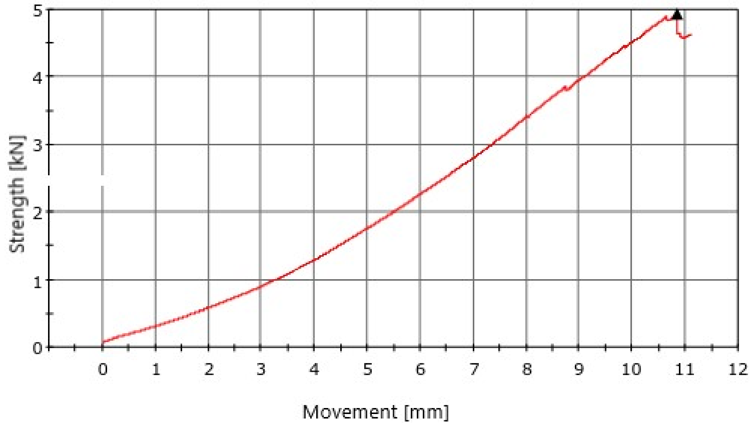

Figure 5. Results of HWPC samples bending tests

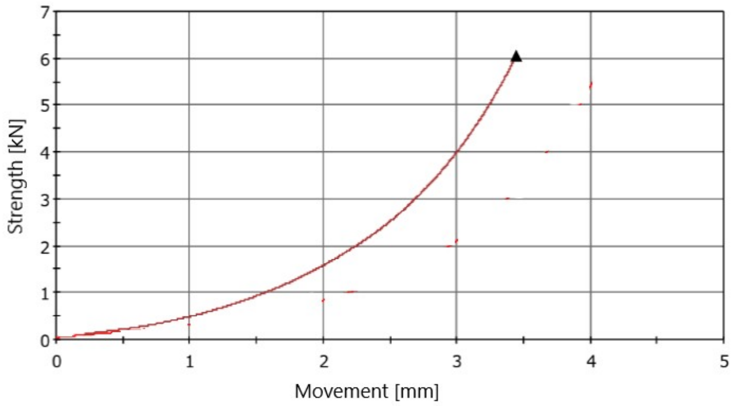

Figure 6. Results of HWPC samples compression tests

Analysis of the results of physical and mechanical tests of the HWPC samples says for their high load-bearing capacity, despite the fact that the weight of 1 linear meter of the HWPC is a hexagonal hollow structure inscribed in a circle with a diameter of 185 mm is 3.2 kg, which is 4 times lighter than a pine with 10 % humidity and equal volume. It is essential decrease in mass of a structural element of rather previous work of authors [13].

These structures could be used as elements of the frame, rafter systems, columns of wood structures, which would significantly reduce the overall weight of the structure and, consequently, the load on the foundation.

As the construction industry is quite conservative and the legislation is imperfect, ultralight HWPCs will not be able to get a toehold in the housing construction industry fast, it will take some time. But already at the current stage, ultralight HWPCs are able to replace wood, concrete and metal supports of power lines, communications and lighting. This is particularly relevant to hard-to-reach, mountain, marshy places, as well as the extreme north, since the installation of traditional wood, concrete and metal supports requires a lot of labor, special equipment, burial or foundation. HWPC is many times lighter and several of its components can be assembled directly on site.

Impregnation and a protective layer of "EpoxyPAN" provide a greater durability than wood and metal, especially in corrosive environments, and external reinforcement allows to achieve high mechanical characteristics.

Low relative density, high load-bearing capacity, durability, resistance to aggressive environmentы, ease of assembly at the construction site opens the possibility of constructing towers, masts, antennas from HWPC.

HWPC can also be used as vertical elements of the bearing structures of small pedestrian bridges and transitions. Schematic diagrams are given in Figures 7 and 8.

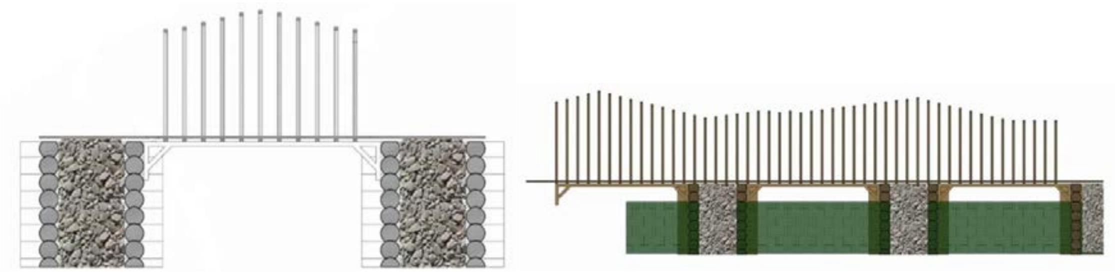

Figure 7. Schemes of park pedestrian bridges, developed by the architect S.I. Gareyev

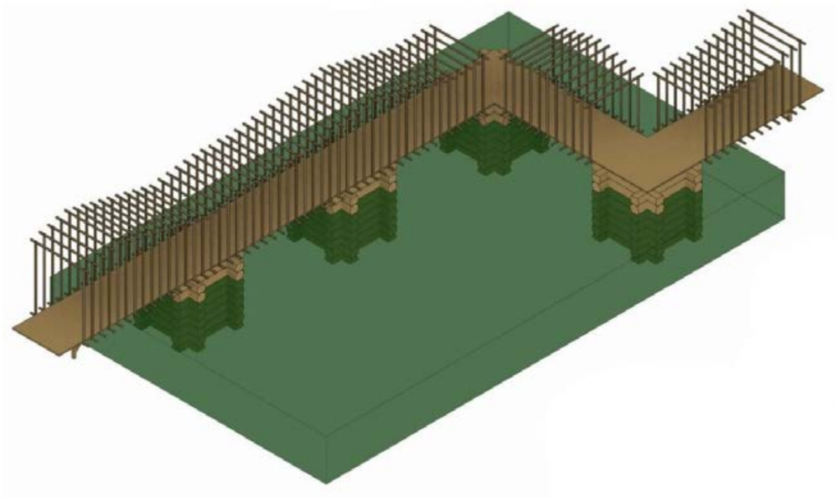

Figure 8. Scheme of the pedestrian bridge across the marshy / mountainous areas, developed by the architect S.I. Gareyev

4. Conclusions

1. The performed data analysis shows an increased interest in wood as a building material, even for high-rise, large-span, unique buildings and structures.

2. The efficiency of impregnation of wood with compositions on the basis of epoxy compositions by evacuation is specified.
3. The efficiency of external reinforcement of wood by carbon fiber grids is specified.
4. An ultra-light hybrid composite wood-polymer structural element for the construction of high-rise, large-span, unique buildings and structures, lighting poles, power lines, communications, towers and communication towers, etc is developed.
5. Volume density has gone down by 4 times of rather previous work of authors [13].
6. Use of the hollow structural element expands scope of the HWPC as the structural element become more transportable and easily mounted.

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