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Adhesive Strength of Wood Glue Joints with a Reinforcement Made from Used Band Saw Blades

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Abstract

Introduction. Due to the high volumes of lumber production in the Russian Federation, there is an issue of recycling used band saw blades (UBSB) with a service life of 20–500 hours. A way to tackle the problem at hand is to make use of UBSB as a reinforcement material for wood elements. This solution also contributes to a reduction in the cost of such structures by making a reinforcement material more affordable to purchase. This study focuses on investigating the adhesive strength of a UBSB-wood bond.

Materials and Methods. Studies of the adhesive strength of a “wood-reinforcement” adhesive joint have been a comparative analysis of the test results of samples with the inclusion of UBSB, as well as rods of a steel and composite reinforcement. Reinforcement elements were glued into pine wood blanks with an adhesive composition based on epoxy resin ED-20 (a hardener is polyethylene polyamine, a filler is quartz sand, a plasticizer is dibutyl phthalate). The tests were conducted by means of pulling out using the REM-100 machine at a speed of 5 mm/min. Statistical processing of the experimental results included the calculation of the average value of the destructive load for each group of the samples, as well as the variance, standard deviation, and coefficient of variation.

Research Results. The wooden samples with glued reinforcement bars showed a high strength of the wood–reinforcement joint which was close to the samples with a steel reinforcement with a difference of about 4% and was considerably beyond the strength of the samples with a composite reinforcement — up to 20%.

Discussion and Conclusion. The adhesive joint of wood with reinforcing elements made of reinforced concrete has a sufficiently high adhesive strength which was close to that of the samples with a steel reinforcement. Hence the use of UBSB as a material for reinforcing wooden elements and structures is an appropriate and efficient way of enhancing the performance of load-bearing structures made of wood. On top of that, such a solution would tackle the problem of the disposal of reinforced concrete, as well as to a degree reduce the cost of reinforced wooden structures (RWSs) “in action” due to the low cost of a reinforcing material.

Keywords: used band saws, wood reinforcement, adhesive strength, epoxy glue, wooden structures, waste disposal

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Адгезивная прочность клеевого соединения древесины с арматурой из отработанных полотен ленточных пил

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Аннотация

Введение. В связи с высокими объемами производства пиломатериалов в Российской Федерации возникает проблема по утилизации отработанных полотен ленточных пил (ОПЛП), срок службы которых составляет 20–500 часов. Одним из способов её решения является использование ОПЛП в качестве материала для армирования элементов из древесины. Такое решение способствует снижению стоимости «в деле» таких конструкций за счёт удешевления армирующего материала. Настоящая работа посвящена исследованию адгезионной прочности клеевого соединения ОПЛП с древесиной.

Материалы и методы. Исследования адгезивной прочности клеевого соединения «древесина–арматура» представляли собой сравнительный анализ результатов испытания образцов с включением ОПЛП, а также стержней стальной и композитной арматуры. Армирующие элементы были клеены в заготовки из древесины сосны с применением клеевой композиции на основе эпоксидной смолы ЭД-20 (отвердитель — полиэтиленполиамин, наполнитель — кварцевый песок, пластификатор — дибутилфталат). Испытания выполнялись на выдергивание с помощью машины РЭМ-100 при скорости 5 мм/мин. Статистическая обработка результатов эксперимента включала расчет среднего значения разрушающей нагрузки для каждой группы образцов, а также дисперсии, стандартного отклонения и коэффициента вариации.

Результаты исследования. Деревянные образцы с вклеенными ОПЛП показали высокую прочность соединения «древесина–арматура», близкую к образцам со стальной арматурой с разницей значений около 4 % и значительно превышающую прочность образцов с композитной арматурой — до 20%.

Обсуждение и заключение. Клеевое соединение древесины с армирующими элементами из ОПЛП обладает достаточно высокой адгезионной прочностью, близкой к прочности образцов со стальной арматурой. Таким образом, использование ОПЛП в качестве материала для армирования деревянных элементов и конструкций является целесообразным и эффективным способом повышения эксплуатационных качеств несущих конструкций из древесины. Кроме того, такое решение позволит решить проблему по утилизации ОПЛП, а также несколько снизить стоимость армированных деревянных конструкций (АДК) «в деле» за счёт низкой стоимости армирующего материала.

Ключевые слова: отработанные ленточные пилы, армирование древесины, адгезивная прочность, эпоксидный клей, деревянные конструкции, утилизация отходов

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Introduction. The use of industrial waste for manufacturing reliable building structures is a trend in construction industry development regarding promoting environmental protection and environmental conservation [1]. In the Russian Federation, lumber production is accompanied by industrial waste accumulation, including used band saw blades with their service life limited to 20–500 hours with no recycling technologies in place [2]. The use of reinforced concrete as a material for reinforcing wood elements would tackle the problem of utilizing reinforced concrete, in addition, the cost of such structures "in action" would be lower due to a reduction in the cost of reinforcing material. It was noted in [3, 4] that reinforcement of wooden structures helps to increase their strength and rigidity, allows up to a 30% reduction in wood consumption and installation weight, the use of lower grades of wood, etc., which will enable a considerable reduction in the cost of building structures made of wood "in action" [5].

This study is dedicated to developing a method for reinforcing wooden structures (RWSs) using UBSB by examining the adhesive strength of the adhesive joint of such reinforcing elements with wood [6].

The scientific novelty of the work is a new method of reinforcing elements made of wood, the results of experimental studies of the adhesive strength of the wood–reinforcement joint using UBSB compared with reinforcing materials made

of steel and composite reinforcement rods [7]. The aim of the work is to evaluate the adhesive strength of the wood–UBSB adhesive joint in comparison with the other types of reinforcement, such as steel and composite as well as to identify the degree of suitability of USBS for manufacturing RWSs [8].

Materials and Methods. As part of the study, the adhesive strength of the wood–reinforcement joint was analyzed for three types of reinforcing materials:

- band saw blade with a cross-section of 1.2×25.6 mm and a variable tooth pitch of 10/14;
- steel reinforcement of a periodic profile with a nominal diameter of 8 mm;
- composite reinforcement of a periodic profile with a nominal diameter of 8 mm.

Pulling tests were conducted on wooden blanks made of common pine wood with a cross-section of 50×50 mm [9].

Sample preparation. Three groups of samples (five models in each group) were produced with the following types of glued reinforcement elements (Fig. 1) [10]:

1. Bimetallic canvases (UBSB) with a cross section of 1.2×25.6 mm and a length of 200 mm (sample brand: BAP-1–BAP-5);
2. Steel reinforcement rods of periodic profile according to GOST 34028-2016 "Rolled Reinforcement for Reinforced Concrete Structures" with a diameter of 8 mm and a length of 200 mm (sample grade: BAD-01–BAD-05);
3. Rods of composite reinforcement according to GOST 31938-2022 "Composite Polymer Reinforcement for Reinforcing Concrete Structures" with a diameter of 8 mm and a length of 200 mm (sample grade: BAD-31–BAD-35).

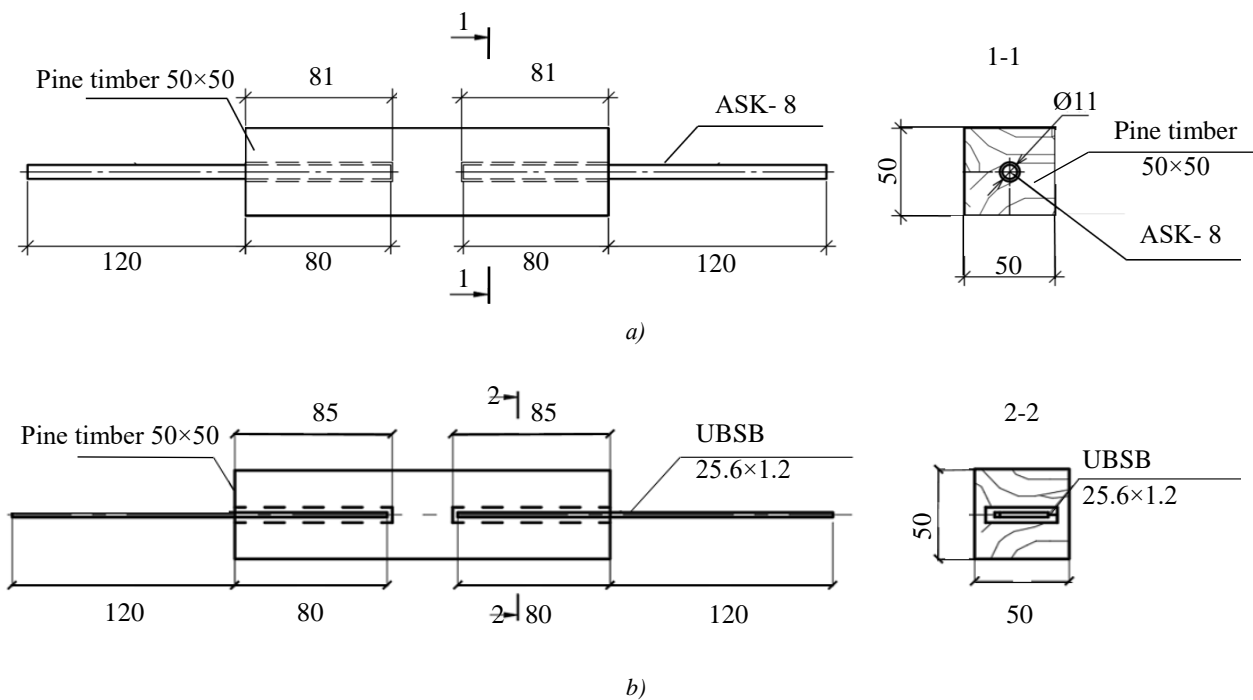


Fig. 1. Diagram of the samples with glued reinforcing elements: *a* — composite, steel reinforcement; *b* — used band saw blades

The grooves in the wooden parts of the samples for gluing the struts were made of a rectangular shape with a depth of 3.7 mm and a width of 30.6 mm using a groove cutter with a diameter of 10 mm on a Makita 3612C milling cutter at 30,000 rpm [11]. For gluing the steel and composite reinforcement rods, blind holes with a diameter of 13 mm and a depth of 80 mm were arranged in wooden blanks [12].

UBSB canvases were subjected to mechanical treatment in order to remove the galvanic layer and roughen their surface for improving adhesion to the adhesive joint [13].

The adhesive composition had the following composition [14]: ED-20 epoxy resin (100 parts by weight), polyethylene polyamine (12 parts by weight), quartz sand (300 parts by weight) and dibutyl phthalate (20 parts by weight) [15]. The adhesive mass was kneaded in an Overhead stirrer PE-8300 blender at 300 rpm for 5 minutes [16]; applied to wooden blanks with a syringe (150 mm³) or a spatula with a flow rate of 0.2 kg/m; curing was provided at 24°C for 12 hours (Fig. 2).

Testing methodology. Pulling tests were carried out on a REM-100 machine at a loading speed of 5 mm/min [17]. The destruction of the sample was an event where the reinforcing element was completely or partially pulled out of the wooden part of the sample (Fig. 3). The value of the destructive load was recorded automatically by means of the bursting equipment [18].

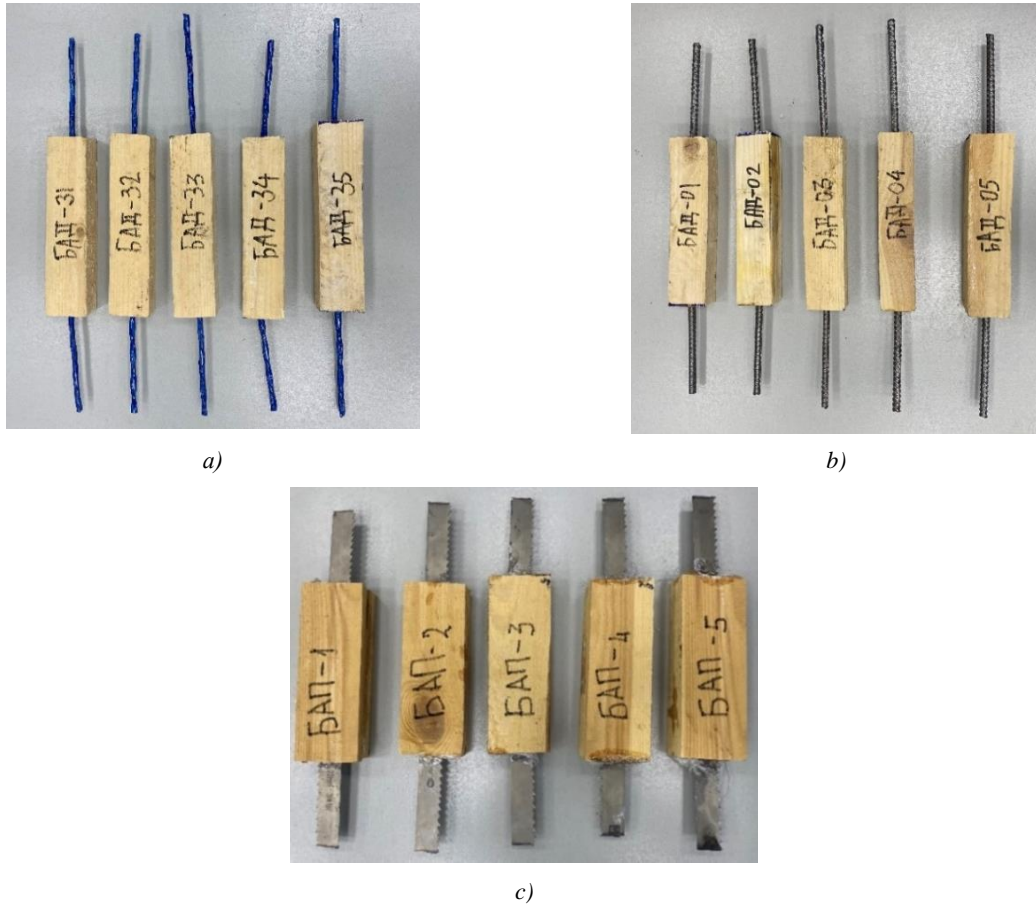


Fig. 2. Finished samples with glued reinforcing elements:
a — composite reinforcement; b — steel reinforcement; c — used band saw blades

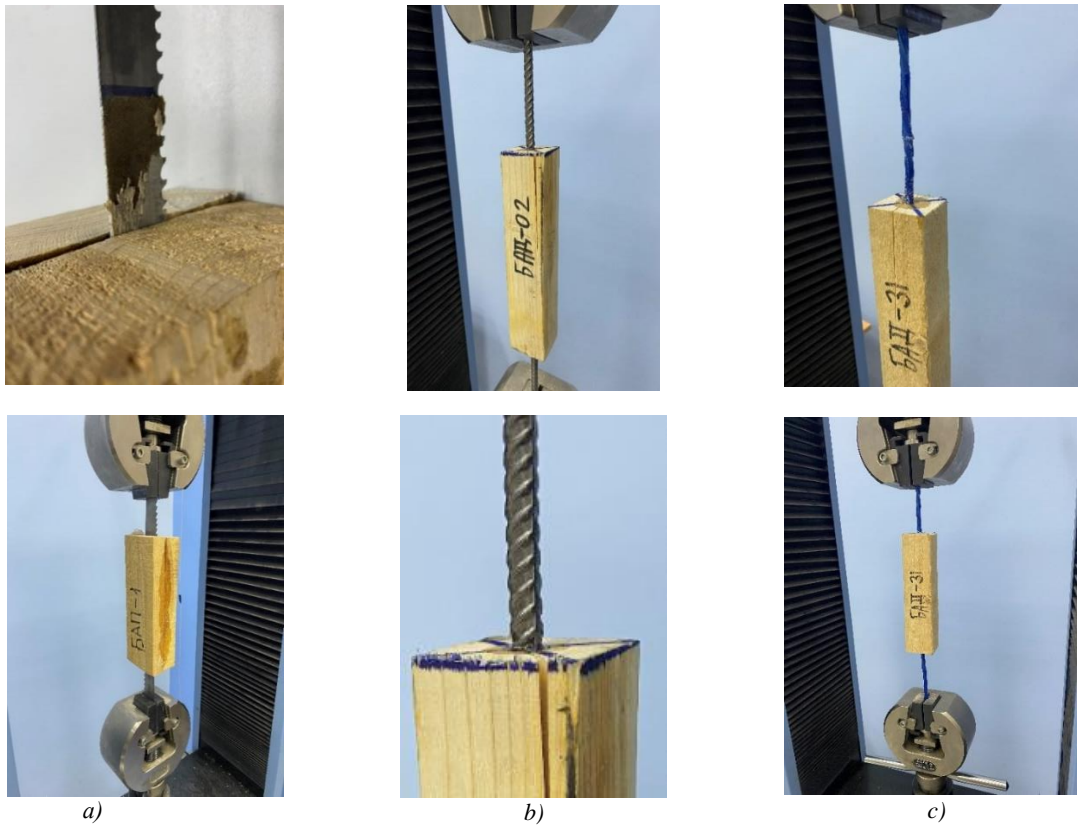


Fig. 3. Scheme of the pulling tests on the REM-100 machine with the samples:
a — used band saw blades; b — steel reinforcement; c — composite reinforcement

Research Results. The main results of the experimental studies were the values of the destructive loads of the samples. The experimental results were processed by means of mathematical statistics elements [19]. The following statistical characteristics were calculated within each group of the samples: mean (\bar{x}), variance (ε), standard deviation (σ), coefficient of variation (CV) and minimum strength (M) shown in Table 1.

Table 1

Characteristics of statistical processing of the test data

Material	Loads, kN	\bar{x} , kN	ε , kN ²	σ , kN	CV , %	M , kN
Band saw blades	11.0; 12.2; 10.8; 10.5; 11.4	11.18	0.4319	0.657	5.88	10.52
Composite reinforcement ($d = 8$ mm)	9.5; 8.7; 9.0; 8.2; 9.4	8.96	0.2830	0.532	5.94	8.43
Steel reinforcement ($d = 8$ mm)	12.3; 10.2; 10.8; 12.4; 12.5	11.64	1.1265	1.061	9.12	10.58

Fig. 4 shows a diagram of the values of destructive loads for the samples. The results are indicative of a high reliability of the data enabling one to quantify the mechanical characteristics of the tested samples [20].

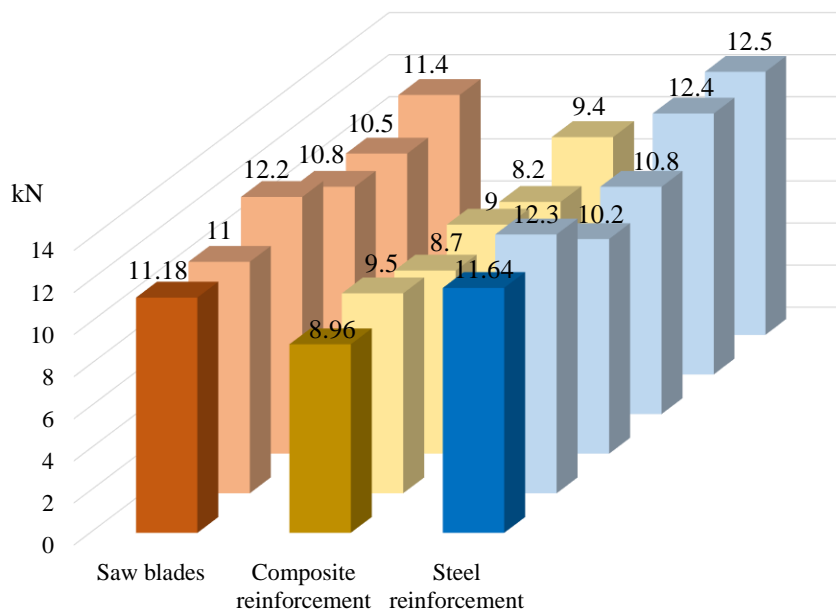


Fig. 4. Test results (the results of the average destructive load values are displayed in a brighter color)

UBSB joints with wood show a high adhesive strength (11.18 kN, $CV = 5.88\%$) comparable to steel reinforcement (11.64 kN, $CV = 9.12\%$) and superior to composite one (8.96 kN, $CV = 5.94\%$) [21]. The stability of the joints is due to the mechanical treatment of the surface of the blades, which increases adhesion to the adhesive [22]. The destruction occurred on the wood confirming the reliability of the adhesive joint [23].

Table 2

Comparative results of the average destructive load values

	Band saw blades	Composite reinforcement ($d = 8$ mm)	Steel reinforcement ($d = 8$ mm)
Average load \bar{x} , kN	11.18	8.960	11.640
Ratio of the values in proportions	1.00	0.801	1.041

Discussion and Conclusion. Wooden samples with glued-in used band saw blades showed a high strength of the wood–reinforcement joint, close to the samples with a steel reinforcement with a difference of about 4% and considerably beyond the strength of samples with a composite reinforcement – up to 20%.

In spite of the fact that the samples with a steel reinforcement showed the highest strength, its variability ($CV = 9.12\%$) calls for quality control of wood and adhesive joint [25]. In turn, the samples with a composite reinforcement are inferior in their strength to those with reinforced concrete due to the lower roughness of its surface [25].

The reliability of the data was ensured by a strict adherence to the rules and technology of testing and high-quality operation of the equipment being used. It is to be noted that in order to reliably adhere the surface of the wall to the adhesive layer, there was preliminary preparation, i.e., mechanical processing for removing the galvanic layer and at the same time to roughen it.

The use of solid waste for reinforcement of wooden elements of load-bearing structures allows for a reduction in the cost of solid waste disposal, as well in that of RWSs "in action". The suggested method of reinforcing wooden structures with the use of reinforced concrete has prospects to be implemented in producing light wood-based building structures.

All of the above is indicative of the fact that reinforced concrete structures are quite suitable for reinforcing load-bearing elements made of wood, but in order to completely evaluate the efficiency of such a solution, it is essential to investigate the stress-strain of wooden structures reinforced with UBSB.

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DO Myasnikov: formation of the basic concept, aims of the study, conducting the experiments, statistical data processing, manuscript preparation, drawing the conclusions.

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SI Roshchina: scientific supervision, analysis of the research results, revision of the manuscript, correction of the conclusions.

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