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Assessment of the Impact of Boron Treatment by Impregnation Method on Finger-Jointed Pine (*Pinus caribaea*) Wood

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Abstract. Wood is a leading environmentally friendly construction material due to its renewability, carbon sequestration, and energy-efficient production. Sourced sustainably, it has a lower carbon footprint than concrete and steel while offering natural insulation for energy-efficient buildings. Wood stores as much as 15 times CO_2 released during its manufacture whereas aluminum and steel store negligible amounts. Finger joint is a sustainable technique used to ensure sustainable utilization of small pieces of wood removed as waste. Chemical protection of wood is performed with preservatives, such as insecticides, fungicides and UV protective finishes that are used for wooden materials. Softwood species are highly susceptible to deterioration caused by wood-destroying agents such as fungi, insects, and moisture. Without proper protection, their structural integrity and lifespan can be significantly reduced. Therefore, preservation treatments are essential to enhance durability, improve resistance to decay, and extend the usability of softwood in various applications. The objective of this study has been to evaluate the impact of boron treatment for finger-jointed pine wood samples on enhancing the durability of pine wood planks. Samples of pine wood with 19 mm-long fingers have been used for this study. Average tensile strength values of treated and untreated finger-jointed pine wood samples are higher than the recommended minimum requirement of tensile strength value (≥10 N/mm^2). Failure modes of treated and untreated finger-jointed pine wood samples have also been described. Boron-treated, finger-jointed pine wood planks with 19 mm-long fingers offer improved durability and resistance to decay, making them well-suited for industrial applications. The treatment enhances the wood's structural integrity, extending its lifespan and performance in demanding environments.

Keywords: boron treatment, durability of wooden materials, finger joint, impregnation, pine, pine boards

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Научная статья

Защитная обработка клеевых шиповых соединений заготовок из древесины сосны (*Pinus caribaea*) борсодержащим водным раствором

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Аннотация. Древесина является ведущим экологически чистым строительным материалом, что обусловлено ее возобновляемостью, способностью к связыванию углерода и энергоемкостью процесса получения такого материала. Производство древесины оставляет меньший углеродный след по сравнению с производствами бетона и стали: древесина поглощает в 15 раз больше CO_2, чем выделяется при ее изготовлении, тогда как про алюминий и сталь этого сказать нельзя. При этом древесные материалы обеспечивают естественную энергоэффективную изоляцию для зданий. Шиповое соединение – устойчивая технология, позволяющая рационально использовать небольшие куски древесины, которые обычно классифицируются как отходы. Химическая защита древесины осуществляется с помощью консервантов, таких как инсектициды, фунгициды, а также УФ-защитные покрытия. Древесина хвойных пород сильно подвержена износу, вызванному грибками, насекомыми и влажностью. В отсутствие надлежащей защиты структурная целостность древесного материала может нарушиться, а срок службы – ощутимо сократиться. Следовательно, пропитки имеют важное значение для повышения долговечности и устойчивости древесины к гниению, а также расширения возможностей применения древесины хвойных пород в различных областях. Целью данного исследования стала оценка влияния воздействия бором на шиповые соединения материала из древесины сосны на долговечность досок из этого сырья. Использовались образцы древесины сосны с шиповым соединением длиной 19 мм. Средний предел прочности при растяжении обработанных и необработанных образцов древесины сосны с шиповым соединением превышает рекомендуемую минимальную прочность при растяжении (≥10 Н/мм²). Также описаны виды разрушения обработанных и необработанных образцов сосны с шиповым соединением. Бор способствует повышению прочности и устойчивости досок к гниению, что делает их пригодными для промышленного применения. Такая обработка увеличивает структурную целостность древесины, продлевая срок ее службы и обеспечивая рост эксплуатационных характеристик в сложных условиях.

Ключевые слова: обработка бором, долговечность древесных материалов, шиповое соединение, пропитка, сосна, сосновые доски

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Introduction

Wood is considered the most valuable renewable natural resource. The strength properties of solid wood and the natural durability of certain species offer a material which can be used in a wide range of applications such as building and construction, tools, utensils and furniture production, as well as providing a source of extractive for industrial, domestic and pharmaceutical purposes. In addition, wood is the basic raw material in paper making and textile industry and is also used in the manufacture of wood composites and panel products [1]. In fact, wood is considered to be the first structural material for mankind and today it becomes a more important product than any other material [21].

Climate change is one of the most pressing and burning issues facing the society in the next century. Mitigation of greenhouse gas emissions is an important contribution to minimize the effect on climate change [13]. For every kilogram of wood, 1.5 kg of CO_2 is removed from the atmosphere [12]. Storing CO_2 in wood materials is to be considered as an effective action to mitigate climate change [3].

Wood residues such as saw dust, offcuts, outside slabs are typically viewed as a burdensome disposal problem [17]. However, this material has a potential to be used in a sustainable way. Wood offcuts, sawdust, wooden pallets, wood shavings and similar kind of materials are considered as wastes [8]. 4 types of wood wastes are usually generated in furniture industry: offcuts of solid wood, offcuts of engineered wood products, sawdust and shavings [18].

Short length of sawn wood is considered to be the main issue in timber industry, though a few of them are already being used in fuel kiln-drying boilers. Another means of utilization of wastes is applying a jointing system through the finger joint technique. Finger joint technology ensures maximum utilization of wood wastes for minimizing the pressure on forest plantations [15]. Finger joint is an interlocking end joint formed by machining a number of similar tapered symmetrical fingers in the ends of timber members and then connected together by bonding material (BS EN, 15497). Finger joint is a sustainable and economically viable concept in furniture industry [10].

Wood can be deteriorated by wood destroying agents such as insects, fungi, marine borers and some other biological agents. Chemical protection of wood is performed with preservatives, such as fungicides, insecticides, fire retardants and UV protective finishes that are applied on the wood surface. The chemical protection of wood is performed with chemical protective agents called "wood preservatives". Fungicides used for wood protection are classified into 2 groups (organic and inorganic) according to their chemical structure [2].

Treatment processes such as drying, impregnation and surface treatments are applied to enhance the durability of wooden materials and the most effectively applied protection method for wooden materials is to treat them with an appropriate chemical [19]. Boron chemical compounds are the wood preservatives possessing both insecticide and fungicide properties. They are responsible for lower levels of environmental damage, no more toxic than common salt to humans and are accepted as one of the safest chemicals utilized as a preservative impregnation substance without heavy metals [9]. Although it is important that boron conserves a certain mobility to maintain the preservative action and, at the same time, decreasing its leach ability [6].

Pine (*Pinus caribaea*), a major softwood species grown in Sri Lanka, is used in furniture production and other light construction works. Pine wood is an important source of raw material in sawmilling and paper industry [5]. Softwood species are easily susceptible to deterioration by wood destroying agents. Thus, preservation is needed to enhance the durability of such wood. The aim of this research has been to assess the impact of borax and boric acid treatment by impregnation method on treated and untreated finger-jointed pine wood.

Research Objects and Methods

Materials. Pine wood samples have been taken from breast height of the first logs available at the State Timber Corporation, Galle, Sri Lanka (Latitude and longitude coordinates are: 6.053519, 80.220978). All the samples have been made of heartwood after preservation and seasoning processes (moisture content 12–14 %). Borax and boric acid mixture has been blended with water (23 kg of borax and 15 kg of boric acid per 1000 l of water) and used for the treatment solution with strength of 8 %. Impregnation process has been started with initial vacuum at 635 mmHg for 30 min and then impregnation treatment has been performed by borax and boric acid mixture at a temperature of 60 °C and pressure of 200–210 psi for 45 min. After that, the final vacuum has been done at 635 mmHg for 45 min (Fig. 1).

Fig. 1. The vacuum pressure impregnation plant

Manufacture of Finger Joints. All the samples have been made in accordance with the finger joint geometry shown in Fig. 2 and the samples have been prepared at the finger joint factory of the State Timber Corporation, Galle, Sri Lanka. Wooden planks with 19 mm-long fingers which are horizontally oriented to be used in finger joint applications have been made from softwood species like pine [14]. Polyvinyl acetate (PVA, P-SWR) D3 adhesive has been used at an assembling pressure of 6 MPa for making finger joint samples [14]. Sawn wood planks which have been placed under room temperature for 7 days have shown good structural performance compared to those placed under hot and wet conditions [4].

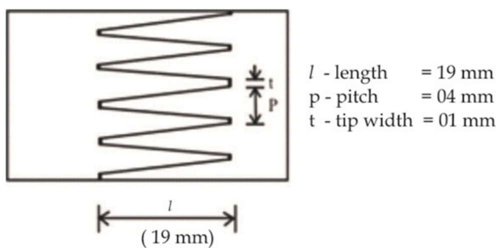

Fig. 2. The geometric parameters of a finger joint

Tensile Testing. Testing of the finger-jointed samples have been conducted in accordance with BS 373:1957 [20]. Dimensions of the sample and experimental setup are shown in Fig. 3. 10 finger-jointed wood samples without boron treatment have been tested and 10 boron-treated samples of pine wood have been used as control.

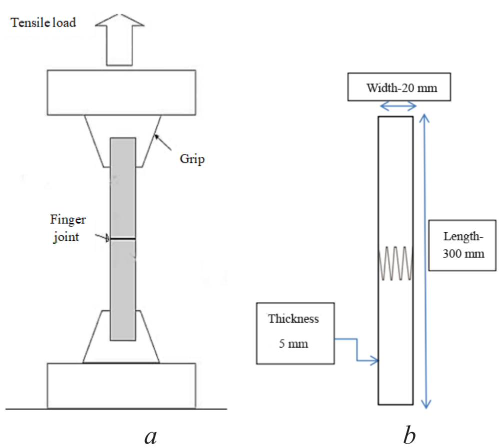

Fig. 3. The experimental setup dimensions (*a*) and the sample prepared for tensile testing (*b*)

Tensile strength has been calculated using the following equation:

$$\text{Tensile strength} = \frac{\text{Maximum load (N)}}{\text{Area of cross-section of test length (mm}^2\text{)}}$$

Failure modes have also been identified for both treated and untreated samples under tensile testing.

Calculation of Wood Density. Density values have been calculated using the equation below. Dry weight of the wood samples has been measured after placing the samples in an oven at 105 °C for 48 h [7].

$$\text{Density} = \frac{\text{Dry weight of oven-dried wood (kg)}}{\text{Wood volume (m}^3\text{)}}$$

Identification of Chemical Penetration. The process of the preservative infiltration into wood is known as penetration. Prior to adding colorants, a sample has been cut in the middle away from the end to prevent longitudinal penetration. After that, turmeric treatment has been applied to the cut wood surface. The indicator used to gauge boron penetration has been a shift in colour to red. After that, the penetration depth has been observed by naked eye.

Determination of Chemical Retention. Retention is the amount of chemical preservatives that are kept in a unit volume of wood, which is measured in kg/m³. Chemical retention has been calculated using the equation:

$$\text{Chemical Retention (kg/m}^3) = \frac{GC}{V} \cdot 10^3,$$

where G – amount of solution absorbed by wood that is calculated by $T2–T1$; $T1$, $T2$ – wood weight before and after impregnation, correspondently (g); C – solution concentration (%); V – sample volume (cm³).

Results and Discussion

By contrasting untreated and treated pine wood samples, the effects of borax and boric acid treatment on finger-jointed samples have been examined. The average density of pine samples has been found to range from 645 to 650 kg/m³. The purpose of this study has been to evaluate the effects of treatment on the wood mechanical strength, durability, resistance to biological deterioration and dimensional stability, among other aspects.

The application of borax and boric acid treatment is well recognized for giving wood products fire retardancy and resistance to insect and fungal attacks. Researchers have put finger-jointed pine wood samples through this procedure in an attempt to see if the treated wood has performed better than the untreated sections. To determine the effectiveness of treatment, parameters like flexural strength, compressive strength, moisture content, and dimensional changes have been evaluated.

The results of this study may have an impact on the way that the woodworking industry operates, especially with regard to improving the durability and quality of finger-jointed pine products by using efficient treatment techniques. Furthermore, by extending the lifespan of wood products and lowering the need for frequent replacements due to degradation, knowledge of the effects of borax and boric acid treatment on commonly used wood species like pine can support sustainable forestry practices.

Fig. 4 shows how finger-jointed samples have performed in tensile testing. The findings have revealed that the finger-jointed samples have failed after tensile testing in every instance examined. This implies that the samples have been subjected to enough stress during tensile testing to result in failure.

a *b*

Fig. 4. The untreated (*a*) and treated (*b*) failure finger-jointed samples

In the course of the research, T-tests have also been conducted in order to assess the statistical significance of the test results. The table above, containing a summary of the T-test results, provides pertinent statistical information and the results of comparison between the treated and untreated samples.

The T-test results and failure modes of boron-treated and untreated samples

Untreated / treated wood sample	Glue line failure (%)	Wood grain failure (%)	Finger break failure (%)	Average tensile strength (N/mm²)	Standard deviation	Standard mean
Untreated	–	20	80	35.46	9.23	3.1
Treated	70	–	30	12.96	4.72	1.6

Note: T-value = 6.51, P-value = 0.000, DF = 11.

Moreover, the samples' failures throughout the testing are explained by the failure modes listed in the table, providing information about the type of mechanical failure, such as shear failure, tensile rupture, or another type of failure. In order to evaluate the finger-jointed samples' structural integrity and performance characteristics under particular testing conditions used in the research, it is essential to comprehend these failure types.

The research has revealed that the average tensile strength of boron-treated pine wood samples (12.96 N/mm²) has been significantly lower than that of the untreated ones (35.46 N/mm²), with a T-value of 6.51 and a P-value of 0. This indicates that the bonding of finger-jointed samples has been adversely affected by the boron preservative.

The investigation has found multiple mechanisms of tensile failure in the examined samples, being glue line, finger break, and wood grain failures. More specifically, when it came to the treated samples, the finger-jointed connection points have been where most failures happened (Fig. 5). The glue line failures have accounted for a considerable majority (70 %) of these failures, suggesting that the boron preservative has had an adverse effect on the finger-jointed wood bonding. On the other hand, almost 30 % of the treated samples have had finger break failures which highlight the difficulties with bonding integrity in the treated samples.

a *b*

Fig. 5. The failure modes of the treated samples: *a* – glue failure; *b* – finger break failure

On the contrary, the untreated samples have shown a distinct pattern of failure mechanisms. Fig. 6 illustrates that finger break failures have accounted for around 80 % of the failures in the untreated samples. This implies that failures have occurred more often in the finger joints of the untreated samples than at the glue lines. Overall, the results highlight how the boron preservative negatively affects the adhesive bond strength of finger-jointed wood, showing a discernible shift in treated samples toward glue line failures rather than the more common finger break failures seen in the untreated samples.

a *b*

Fig. 6. The failure modes of the untreated samples: *a* – finger break failure; *b* – wood grain failure

The strength ratings of all the finger-jointed samples have exceeded those of the DIN/EN 204-D3 test. Prabhu et al. [16] have found that after 7 days of dry storage, the minimum tensile strength value required for the DIN/EN 204-D3 test should be ≥10 N/mm^2 (EN 204, 2001). This analysis has found that all finger-jointed samples bonded with SWR-D3 glue have had tensile strength values greater than ≥10 N/mm^2, indicating compliance with this value. According to Jayawardhane and Gunaratne [11], the mean carbon stock (t/ha) of Sri Lanka's pine monoculture forest plantations is 130.19 t/ha, a substantial increase above the 42.7 t/ha of teak monoculture forest plantations. For this reason, the use of pine in commercial replanting programs and its wood in make finger-jointed wood products could be regarded as an environmentally sound sustainable solution. Average retention amount of the boron chemical preservative has been 25 kg/m^3.

Conclusion

With regard to the impact of borax and boric acid wood preservatives, the results have confirmed that the average strength value of the boron-treated finger-jointed samples has been lower than that of the untreated ones. But the average tensile strength values of the treated finger-jointed pine samples have been higher than the recommended minimum requirement for tensile strength value (≥ 10 N/mm^2) after 7 days. Hence, boron-treated finger-jointed pine wood planks with 19 mm-long fingers can be recommended for effective use in industrial applications with enhancing the durability of wood. Lesser durability of the untreated pine wood is a major disadvantage for its maximum utilization. Therefore, preservation of pine wood is vital and the boron treatment with the mixture of borax and boric acid is an effective method to increase its durability.

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