Effects of Guayule Resin on Structural Performance and Durability of Wood Strand-Based Composites

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Effects of guayule resin on mechanical, physical, and biological performance of wood strand-based panels were evaluated. Southern yellow pine (*Pinus* spp. L) wood strands were mixed with phenol formaldehyde (PF) resin to a target resin content of 5% and hot-pressed to manufacture wood strand-based panels. A guayule resin solution was prepared and sprayed on the wood strands immediately after PF resin to different guayule resin contents of 0.5% and 1.0%. Specimens cut from treated panels and control panels were subjected to tensile, internal bond, water absorption and thickness swelling, and fungi soil block tests. Guayule resin had a positive effect on tensile strength, as specimens showed 8.0% and 9.5% increase compared to control specimens. However, the internal bond strength decreased 5.3% and 6.4%, respectively. Water absorption and thickness swelling for the treated specimens with guayule resin decreased as compared to control specimens. The fungal decay resistance test indicated little differences in the average percent mass loss across the untreated and treated wood strand-based composite materials. Regardless of increase or decrease, the effects of guayule resin on mechanical, physical, and biological performances of wood strand-based panels were not statistically significant.

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Keywords: Internal bond; Water absorption and thickness swelling; Tensile; Decay resistance; Wood strand-based panels; Guayule resin

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INTRODUCTION

Wood is a natural renewable resource and carbon storage material that has been used as one of the major building construction materials and has become very important in many other industries due to its high strength per weight ratio, workability, relatively low cost, low thermal conductivity, aesthetic value, and sustainability (Panshin and de Zeeuw 1980; Hoadley 1990; Forest Products Laboratory (FPL) 2021). The major drawback of wood as a building material is its vulnerability to biological degradation under certain conditions. Although weathering, wood-boring insects, termites, and marine organisms can cause deterioration of wood, fungi are the major wood decomposers (Hunt and Garratt 1953; Zabel and Morrell 1992). There is, therefore, a need to use natural anti-microbial and anti-fungal compounds that will increase the use life of wood and wood-based products.

For over 100 years, chemical, biocides, pesticides, and preservative treatments have been developed for wood and wood-based products to have long-term protection from wood destroying fungi and insects (Groenier and Lebow 2006; North American Wood Pole Council 2023; U.S. EPA 2023). Creosote, pentachlorophenol (Penta/PCP), chromated copper arsenate (CCA), copper naphthenate (CuN), 4,5-dichloro-2-N-octyl-4-isothiazolin-

3-one (DCOI), micronized copper azole (MCA), acid copper chromate (ACC), 2-n-octyl-4-isothiazolin-3-one (OIT), borates, disodium octaborate tetrahydrate (DOT), and recent bio-based natural chemicals are some of these preservatives (Groenier and Lebow 2006; North American Wood Pole Council 2023; U.S. EPA 2023). Today many wood preservative treatments include pesticides that are classified as having moderate acute toxicity by the United States Department of Agriculture (USDA) Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA) (Burt 2004). There is increasing pressure and a greater need to be environmentally friendly and to reduce, restrict, and/or eliminate the use of chemical wood preservatives because of the concern that toxic constituents may leach from the treated wood (Groenier and Lebow 2006).

Guayule (*Parthenium argentatum* A. Gray) is a low perennial desert shrub, native to southwestern United States and throughout the northeastern parts of the Chihuahuan Desert in Mexico, that accumulates large amounts of natural latex rubber in its stems (Evancho and Dial 2020). Guayule fields are established with genetically diverse seeds and are harvested mechanically for rubber production (Rasutis *et al*. 2015; Evancho and Dial 2020). The harvested woody materials are ground into bagasse, and then solid latex rubber is chemically extracted from its cells (Rasutis *et al*. 2015). After the latex rubber is extracted, a guayule resin byproduct residual is left over (Thames *et al*. 1996; Nakayama 2005). The guayule resin compounds have potential as low-toxicity components of coatings, tackifiers, adhesives, additives, composite components, emulsifiers, bio-control agents, insecticides, anti-microbials, and anti-fungal agents (Belmares *et al*. 1980; Bultman *et al*. 1991; Greenfield 1992; Ash *et al*. 2010; Dehghanizadeh and Brewer 2020). Guayule resin has been proven as an effective natural biocide with termiticidal and fungicidal properties that can be used in lumber and engineered wood products and it has the potential to provide longevity and protection to wood and forest products (Bultman *et al*. 1991; Thames and Kaleem 1991; Thames and Wagner 1991; Bultman *et al*. 1998; Nakayama *et al*. 2001; Nakayama *et al*. 2003; Entsminger *et al*. 2022).

Despite what has been reported in the literature, there remains a gap in the research in using guayule resin as an additive to wood strand-based products to enhance their mechanical and physical performances and promote durability against termite and fungal attack. Therefore, this novel bio-based preservative (guayule resin) was applied to southern yellow pine wood strand-based panels during the manufacturing process as an additive and experiments were conducted to evaluate its effects on mechanical, physical, and biological performances of wood strand-based panels.

EXPERIMENTAL

Materials

Commercial southern yellow pine (*Pinus* spp. L) wood strands were obtained from West Fraser (Guntown, Mississippi, USA). The pine wood strands had a dimension of 10.16 cm long by 2.54 to 5.08 cm wide with an average thickness of 0.0715 cm. Wood strands were dried in a high temperature oven for at least 24 h at 88 °C to reach an average of 3% moisture content (MC) and mixed with phenol formaldehyde (PF) resin in a drum blender to a target resin content of 5% of the oven-dry weight of the wood strands. The industrial wood composite adhesive used in this study was phenol formaldehyde (PF) resin polymer, from Hexion Inc. (Columbus, Ohio, USA). The industrial PF resin was a liquid having a reddish-brown color, slight aromatic odor, had a solid content of 55.5%, dynamic viscosity of 120 to 300 cP at 25 °C, pH of 9.5 to 10.5 at 25 °C, and a relative density of 1.2233-1.2473.

Even though it has been reported that guayule resin can be applied using pressure treatments, impregnation, spraying with a hot gun, dipping, mixed additive into resins, and in many other applications to protect lumber and engineered wood products (Bultman and Schloman 1993; Nakayama *et al*. 2001), it is quite difficult to work with guayule resin due to its very high viscosity – above 70 °C it is liquid, between 50 and 70 °C it becomes tacky and gum-like, and at room temperature it is a firm hard solid black product with a sweet honey-like odor (Fig. 1a) (Schloman and Wagner 1991; Dehghanizadeh and Brewer 2020; Entsminger *et al*. 2022). Therefore, the guayule resin was kept in a laboratory conventional oven above 70 °C to reduce the viscosity for subsequent processing (Fig. 1a). To further decrease the viscosity of guayule resin and improve its workability, a guayule resin-acetone solution was prepared by mixing a 1:1 weight ratio of guayule resin to pure acetone ($((CH_3)_2CO)$) (Fig. 1b). This was based on previous research conducted by Nakayama *et al.* 2001; Stratton 2019; and Entsminger *et al.* 2022. The solid content of guayule resin was 100%. The guayule resin-acetone solution had a solid content of ~57%. However, it is difficult to find the viscosity of guayule resin as it is dependent on temperature and speed.

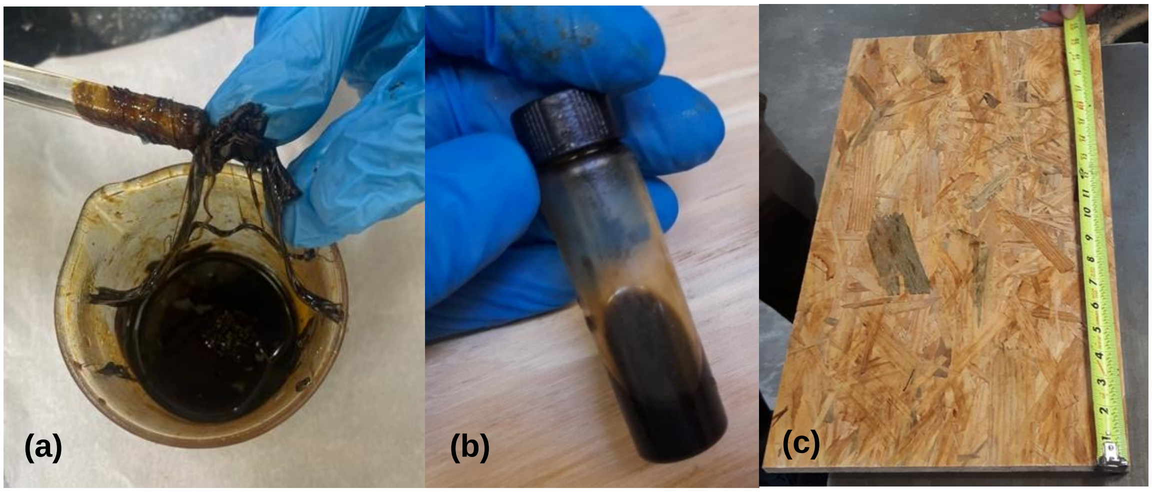

Fig. 1. (a) Guayule resin tackiness within min of being below 70 °C, (b) liquid guayule resin-acetone solution, and (c) wood strand-based panel after hot pressing and edges trimmed

Panel Manufacturing

To fabricate untreated (control) panels, wood strands mixed with PF resin were oriented uniaxially and hot pressed to the target thickness of 12.7 mm and target density of 673 kg/m^3 (42.0 lb./ft^3 (pcf)). For treated panels, guayule resin-acetone solution was immediately sprayed on the wood strands after the PF resin was applied using the same gravity feed air spray gun that was used for PF resin. Two different levels of treatments were considered; hence the solution was sprayed to a target guayule resin content of 0.5% and 1.0% of the oven-dry weight of wood strands. The drum blender used had a 12 revolutions per min (RPM) speed. A Clifton Hydraulic Hot Press (Clifton, New Jersey, USA) was used to hot press each wood strand-based panel for 5 min at 176.7 °C temperature, and an average of 12.75 MPa of pressure. Each of the nine wood strand-based panels were 66.04 x 31.75 x 1.27 cm^3 in size, which was based on the target density, platen size, and maximum applied pressure. The final wood strand-based panel after hot pressing and edges trimmed is shown in Fig. 1c.

Material Characterization

To evaluate the effects of the guayule resin treatment on structural and biological performance of wood strand-based panels, ASTM D1037 (sections 10, 11, and 23) and AWPA E-10 were followed, and specimens cut from these panels were subjected to different experiment testing (ASTM 2020; AWPA 2022). Those tests were tension parallel to the surface, known as tensile strength (ASTM 2020), tension perpendicular to the surface, known as internal bond (ASTM 2020), and water absorption and thickness swelling (WA and TS) (ASTM 2020). The number and dimensions of specimens can be found in Table 1. Tensile specimens were dog-bone shaped, and detailed dimensions can be found in ASTM D1037, section 10 (ASTM 2020). Specimens were all conditioned in an environmental chamber for a minimum of 4 weeks at approximately 25 °C and a relative humidity (RH) of 65% before testing.

Table 1. Specific Dimensions and Number of Test Specimens per Treatment for Each Structural and Biological Test Performed on Wood Strand-Based Panels.

Tests Performed	Specimens Per Treatment	Length (cm)	Width (cm)	Thickness (cm)
Internal Bond (IB)	12	5.08	5.08	1.27
Water Absorption and Thickness Swelling	9	15.24	15.24	1.27
Tensile	9	25.40	5.08	1.27
Fungal Decay Resistance	15	2.54	2.54	1.27

The laboratory method for evaluating the decay resistance of wood strand-based materials against pure basidiomycete cultures soil block test was applied from the American Wood Protection Association standards, commonly known as the Soil Block Test (AWPA 2022). Five blocks of each treatment were conditioned to a constant weight at recommended conditions (20 to 30 °C; 25 to 75% relative humidity). Five blocks of untreated southern yellow pine (1.905 x 1.905 x 1.905 cm^3) remained untreated as controls. These blocks were placed onto southern yellow pine softwood feeder strips in containers into which sterilized soil, deionized water, and decay fungi had been placed. The brown-rot decay fungi, *Gloeophyllum trabeum,* was introduced and allowed to grow onto the feeder strips, which were maintained in an incubator set at 27 °C, with no internal light. Based on recommendations in AWPA E-10 standard, since the material was a wood strand-based composite, a minimum of 12 weeks was allotted for the test (AWPA 2022).

RESULTS AND DISCUSSION

The effects of guayule resin on mechanical properties (tensile strength and internal bond), water resistance (water absorption and thickness swelling), and fungal decay resistance of strand-based specimens is discussed in the following subsections. Statistical analyses were used to compare the results for each of the individual test properties separately. Statistical analysis was conducted using Microsoft Office Excel and SAS 9.4 software for mean value comparisons and to determine any statistical differences among treatments and for robust statistical analyses each test was performed at $p \leq 0.05$ at an α level of 0.05 (SAS Institute 2013).

Mechanical Properties

Tensile strength and internal bond strength of untreated specimens (control) compared to those treated with guayule resin are shown in Figs. 2a and b, respectively. Guayule resin had a positive effect on tensile strength. Specimens having 0.5% and 1.0% guayule, respectively, showed 8.0% and 9.5% increase in tensile strength compared to control specimens, as shown in Fig. 2a. However, guayule resin had a negative effect on internal bond strength. For specimens with 0.5% and 1.0% guayule resin, internal bond strength decreased 5.3% and 6.4%, respectively, compared to that of control specimens. Such trends make it difficult to reach a conclusion on the effects of guayule resin on mechanical properties of wood strand-based products. Therefore, other factors such as density and variation in mechanical properties of wood-based products are discussed.

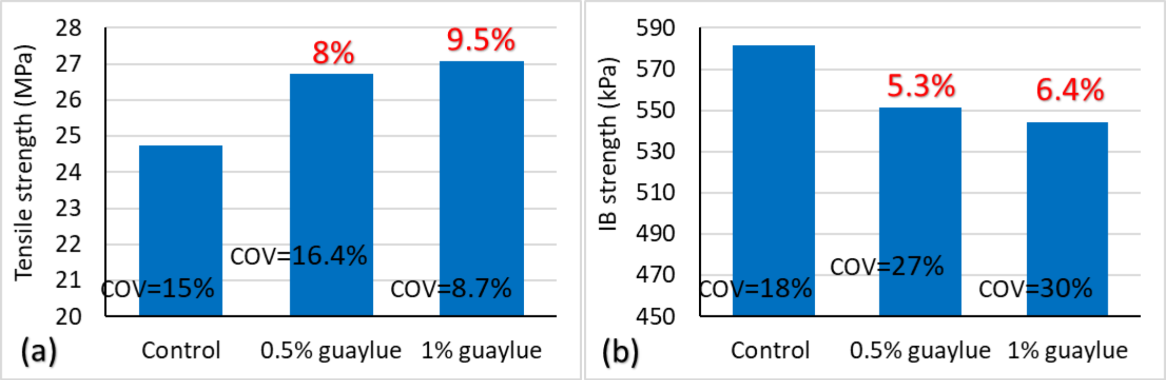

Fig. 2. Comparison between (a) tensile strength and (b) internal bond strength of wood strand-based composite material untreated and treated specimens with guayule resin. Note: COV = coefficient of variation of the mean

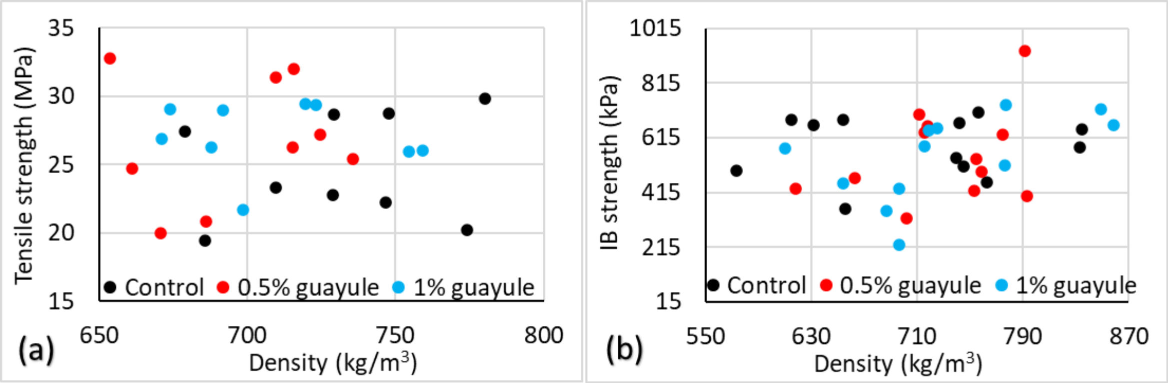

Fig. 3. Effects of density on (a) tensile strength and (b) internal bond (IB) strength of wood strand-based composite material untreated and treated specimens with guayule resin

Density is one of the factors that significantly affects the mechanical properties of both solid wood and wood-based products. Since the difference between tensile and internal bond strengths of treated specimens with those of control ones can be because of different densities, these properties versus density are shown in Figs. 3a and b for each specimen. The difference between untreated and treated specimens and higher and lower properties cannot be fully explained due to different densities.

Variation in wood properties is another factor that should be considered. Wood is a natural material, and several factors such as moisture, soil content, and growing space all affect wood properties. Mechanical properties vary from species to species, from one tree to another tree of the same species, and from earlywood to latewood within a tree. Therefore, there is a significant coefficient of variation (COV) in wood mechanical properties. An average coefficient of variation of 25% has been reported for tension parallel to grain of clear wood (Forest Products Laboratory (FPL) 2021). In wood composites such as strand-based products discussed in this study, variations in manufacturing process such as spraying PF and guayule resins and making the strand mat before pressing, intensify the variability. Coefficient of variation results for tensile and internal bond strengths of untreated and treated specimens are given in Fig. 2. It should be highlighted that the difference between mechanical properties of untreated specimens with those of treated ones with guayule resin is less than the coefficient of variation within each group. Therefore, it can be concluded that the difference between mechanical properties of untreated and treated specimens could be due to the inherent variation in wood strand-based products, as there was a standardized manufacturing process (*i.e.*, raw material contents, mixing time, hot press pressure, hot press temperature, *etc.*). In addition, the differences were not due to the presence of guayule resin product. Further studies are required to capture the effects of guayule resin on mechanical properties of wood strand-based products.

Water Absorption and Thickness Swelling

The water absorption and thickness swelling of untreated specimens and treated ones with guayule resin are shown in Figs. 4a and b, respectively. The water absorption and thickness swelling for all specimens significantly happened during the first 24 h of immersion. Water absorption for the treated specimens with guayule resin decreased compared to control specimens. However, this decrease was higher for those treated with 0.5% guayule resin (7.2% decrease after 24 h immersion) compared to those treated with 1.0% (1.9% decrease after 24 h immersion). Such a decrease cannot be tied to the presence of guayule resin as it was lower for specimens with higher content of guayule, 1.0%.

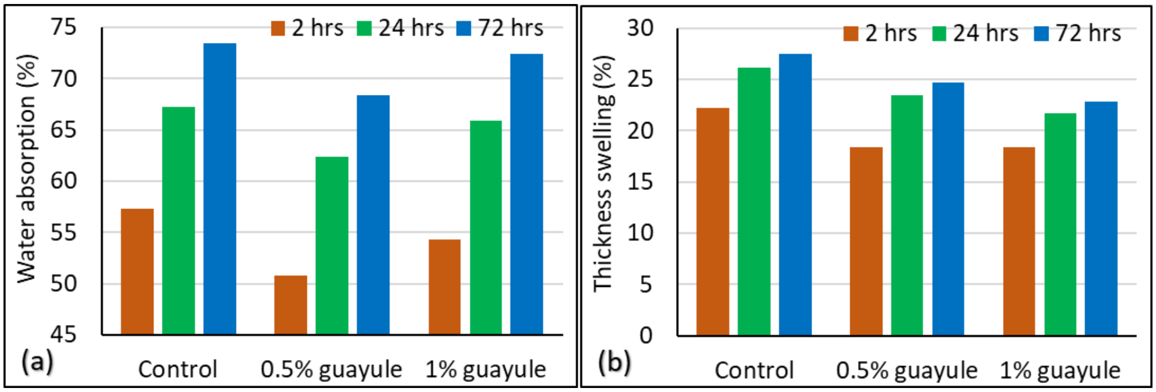

Fig. 4. (a) Water absorption and (b) thickness swelling of wood strand-based composite material untreated and treated specimens with guayule resin

Thickness swelling for the treated specimens with guayule resin decreased compared to control specimens. After 24 h immersion, thickness swelling of specimens treated with 0.5% guayule resin decreased by 10% compared to control specimens, while it was decreased 17% for those treated with 1.0% guayule resin. It can be concluded that the presence of guayule resin decreases thickness swelling (Fig. 4b) even though it does not increase internal bonding as shown in Fig. 2b. Further study is required to verify these conclusions.

Fungal Decay Resistance

Results of the decay resistance test indicated little differences in the average percent mass loss across the untreated and treated wood strand-based composite materials. The group of southern yellow pine control blocks averaged a percent mass loss of 36.1%, indicating that the decay fungi was actively degrading the control blocks (Fig. 5). The wood strand composite control specimens had an average mass loss of 6.6%, the composites treated with 0.5% guayule resin had an average mass loss of 7.2%, and those treated with 1.0% guayule resin had an average mass loss of 7.3% (Fig. 5). Across the individual specimen treatments, the lowest mass loss was 5.7% and the highest was 8.8%. The pine control group was statistically different from the treated and treated composite groups. However, across the wood strand-based composite groups, the average mass loss proved to be statistically the same (Fig. 5). There was very little mass loss, and very little physical damage to the wood strand-based composite material from the decay fungi. Whether or not this indicates a protection from decay provided by the inclusion of guayule resin, it will require further testing and longer exposure times beyond the AWPA E-10 minimum standard requirements of 12 weeks.

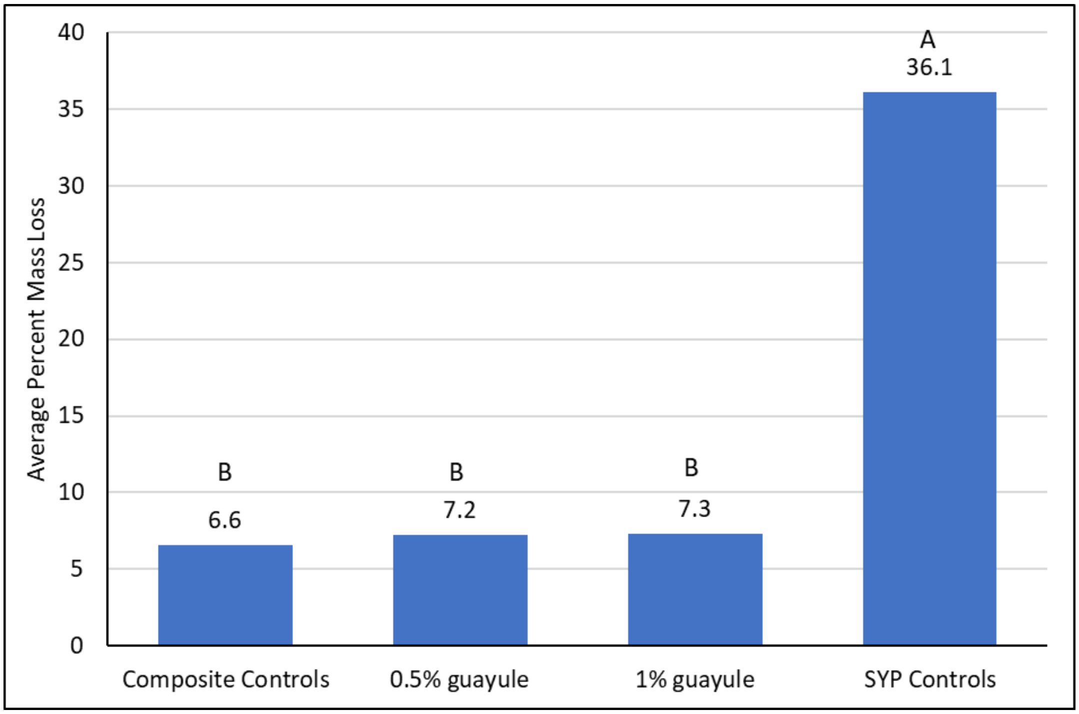

Fig. 5. Average percent mass loss for untreated wood strand-based composites and treated specimens with 0.5 and 1.0% of guayule resin compared to southern yellow pine (SYP) control blocks. Each different letter (A and B) represents statistical differences between various treatments. Plots with Letter B are statistically the same between those treatments.

CONCLUSIONS

1. The effects of novel bio-based preservative, guayule resin, on structural and biological performance of wood strand-based panels was evaluated. This preservative was applied during the manufacturing process at two different levels, 0.5% and 1.0% of the oven-dry weight of the wood strands.
2. The effects of guayule resin on mechanical properties of wood strand-based panels were not clear, as it had a positive effect of tensile strength, while a negative effect on internal bond strength.
3. Water absorption of treated specimens with guayule resin was lower than that of control specimens. However, it was difficult to attribute this decrease to the guayule resin, as specimens treated with 0.5% guayule resin content had a lower water absorption than those treated with 1.0% guayule resin content.
4. Thickness swelling of treated specimens with guayule resin was lower than that of control specimens. There was a 10% and 17% decrease compared to control specimens for those treated with 0.5% and 1.0% guayule resin content, respectively.
5. The use of guayule resin cannot be pinpointed as the reason for average lower mass loss due to fungal degradation in wood strand-based panels at 0.5% and 1.0% concentrations.
6. Considering these results, it was difficult to reach a conclusion about the effects of guayule resin on structural, water resistance, and biological performance of wood strand-based panels, as larger sample sizes might have been used to gain a clearer statistical conclusion.

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