Innovative particleboards made of chemically modified sugarcane bagasse. Biological durability evaluation

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Context and objectives

Wood is an anisotropic material, mainly consisting of cellulose, hemicellulose and lignin (Zhang et al. 2022) and as a result, wood is susceptible to dimensional changes caused by moisture in service situation, which severely limits its usage in various applications (Sargent 2019). Wood-based composites are manufactured in desirable sizes that offer increased dimensional stability and homogeneity, making them viable substitutes for solid wood in end-uses. Wood composites reduce some of the difficulties associated with water absorption and dimensional instability in wood and do not have the drawbacks of solid wood (Baileys et al. 2003). Since the implementation of the "Forest breathing plan" prohibiting wood exploitation in Iran, difficulties in supplying for particleboard production have pushed producers to investigate for alternatives (Gilanipoor et al. 2021). Meanwhile, waste sugarcane bagasse, widely available in Iran, offers a sustainable and environmentally friendly way to supply this vast need (Berndt and Hodzic 2007). Most of this lignocellulosic waste is either burned as fuel or sent to landfills (Kiatkittipong et al. 2009). Using bagasse as a raw material for particleboard is an affordable way to repurpose this resource while compensating for the panel industry's scarcity of wood. Nevertheless, the problems related to durability and disadvantages related to moisture absorption remain (Kusumah et al. 2016), especially when the composite consists of species with low inherent natural durability, such as bagasse. Therefore, in order to upgrade their performance, protection systems that will not reduce the mechanico-physical properties and will comply with gluing abilities are required (Reinprecht 2016). Furfurylation is an environmentally friendly method that has attracted much attention today, notably as a wood protection method (Lande et al. 2008). The purpose of this research was (i) to impregnate bagasse particles with suitable tannin-furfural resins (TFu), (ii) to bind modified bagasse with tannin-based adhesives to produce environmentally friendly bagasse particleboards. In the first phase, a natural resin based on tannin and furfural was synthesized under different conditions and proportions of furfural according to Ahmadi et al (2022). In the second phase, particleboards were produced from the treated bagasse particles, and their biological properties were evaluated.

Material and methods

Pre-treatment of tannin and furfural

Quebracho tannin (Persianchimi Company) was dissolved in a 10% w/w NaOH (Neutron Pharmaceutical Chemistry Company) solution to obtain a 20% w/w tannin solution. The tannin solution was heated to 80°C for 30 minutes before adding 8% NaSO (Neutron Pharmaceutical Chemistry Company) (w/w based on the dry tannin weight). The solution was stirred at 80°C for 30 minutes. The pretreatment for furfural (Behran Oil Company) was done by adding 5% v/v H_2SO_4 (Neutron Pharmaceutical Chemistry Company) (at 20% v/v) to the furfural and stirring for 20 minutes at 21°C (Yi et al 2016).

Resin synthesis

The previously obtained tannin aqueous solutions (20% w/w) were prepared under vigorous stirring to add furfural. Subsequently, 50% of furfural (based on tannin dry weight) was added to the solution. The resin pH was adjusted to 4.5 with NaOH (33% w/w) according to Ahmadi et al (2022).

Bagasse treatment

Anhydrous sugarcane bagasse were treated using an impregnation method with various tannin/furfural resin (TFu) concentrations. Impregnation was done with 5, 10, and 15% w/w formulations of tannin/furfural resin. As a reference, 0.5 % Boric Acid (BA) (Lactan) (based on the dry weight of the resin) was added to the initial treatment solution in some treatments (Efhamisisi et al 2017). Resin curing operation was carried out by heating at 120°C. Resin uptake was reported in Ahmadi et al (2022).

Particleboard manufacturing

Tannin-Formaldehyde (TF), Tannin-Formaldehyde modified by Furfural (TFFu), Tannin Hexamine (TH) (all synthesized in the laboratory according to Tondi (2017), and Melamine-urea-formal (MUF) (Samad Manufacturing and Industrial Company) were used to bond the treated bagasse. After the curing of resin and drying of bagasse, particleboards were prepared with the dimensions of 400×400×10 mm and a target density of 0.650 g/cm^3. Each adhesive type was added at 12% (based on the dry weight bagasse) in a rotary blending machine. The bagasse mixtures were hot-pressed at 160°C for MUF and 190°C for tannin-based adhesive (TF, TFFu, TH) with 40 kg/cm^2 pressure for an 8–12-minutes press closing time (depending on the adhesive). Three boards were produced from each treatment.

Biological properties

Decay tests were performed strictly according to EN113-3 (2023). Bagasse particleboards samples of size 50×50×10 mm^3 (L×l×Thickness) (12 replicates per modality) were exposed to *Coniophora puteana* for 16 weeks at 22°C, 70% Relative Humidity (RH). Solid pine (*Pinus sylvestris*) sapwood was used as controls: (i) 12 samples with the same dimensions as the particleboard specimens 50×50×10 mm^3 (L×R×T) as size controls, (ii) 10 samples of dimensions 50×25×15 mm^3 (L×R×T) as virulence controls. The mass loss (ML%) of the samples due to the fungal degradation was calculated according to:

$$WL\ \% = \frac{(W_1 - W_2)}{W_1} \times 100 \quad (1)$$

where W_1 and W_2 are the anhydrous mass losses of the samples before and after fungal exposure, respectively.

Termite non-choice tests were performed strictly according to EN117 (2013). Bagasse particleboards samples of size 50×25×10 mm3 (L×l×Thickness) (6 replicates per modality) were exposed to 250 termite workers, 5 soldiers and 5 nymphs of *Reticulitermes flavipes* for 8 weeks at 27°C, 75% RH. Virulence controls were conducted the same way, using six untreated pine sapwood samples of dimensions 50×25×15 mm^3 (L× R× T). At the end of the test, the termite survival rate was calculated and a visual rating was attributed to the samples.

Data analysis was performed by the two-way ANOVA method in SPSS software. The effect of adhesive, and the effect of resin concentration, were investigated.

Results and discussion

Decay resistance

The results of the decay resistance tests towards the brown rot *Coniophora puteana* are depicted in Fig. 1. The mass losses of both virulence controls and size controls (above 30%) allow to validate the test (EN113-3, 2023).
For all particleboards, whatever the adhesive used, the treatment of bagasse with TFu resin led to a reduced mass loss, compared to untreated bagasse. Particleboards treated with resin containing BA, had significantly higher resistance to fungal degradation. BA is responsible for the granted durability to the particleboards, due to its fungistatic action, and has already been reported as an additive increasing panel product biological resistance (Reinprecht et al 2018, Pizzi 2016).
However, the MUF+Tfu $_{(15\%)}$ boards presented the lowest mass loss rates of 3.56%. After being exposed to the brown-rot fungus, the boards bonded with MUF adhesive demonstrated greater resistance than the boards bonded with tannin base adhesive. The boards bonded with MUF lost the least amount of weight in both treated and untreated conditions. It is possible that the fungus is prevented from getting into the particleboard due to the density and cohesion of the boards. The type of adhesive has an influence on the biological resistance of particleboards (Shalbafan et al. 2016). Boards, on the other hand, emit formaldehyde, which can affect biological resistance (Mohamad Amini et al. 2018).

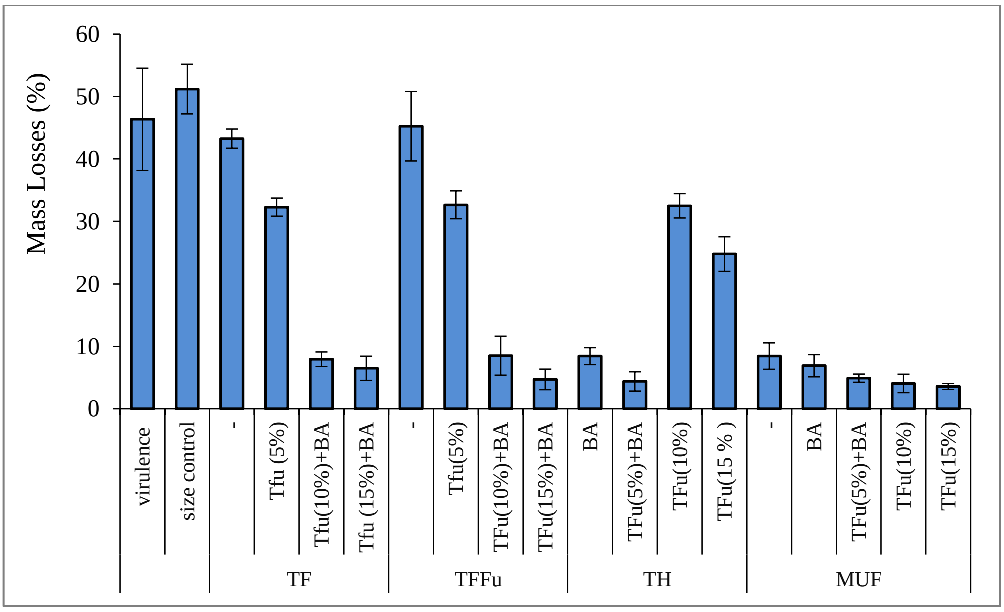

Fig. 1. Mean values of mass loss of the particleboard exposed to the fungus

Termite resistance

Tab. 1 illustrates the mass losses, mortality of termites and Visual rating caused by termite attacks on the specimens. The survival rate of the termites (above 50%) and strong attack of the controls allow to validate this test.

When compared to control samples, pretreatment of bagasse particles with resin TFu at low concentrations (i.e. 5%) results in higher termite mortality, but the panels were still severely degraded (visual rating 4). However, treatment at higher resin concentrations (without BA addition) has no significant effect. This could be because these boards have more thickness swelling (Ahmadi et al 2022) than the control samples, allowing the termite to enter the particleboard when under moist conditions (such as in the termite culture flasks, 75% RH). MUF-bonded boards have a higher termite mortality rate than tannin base adhesive-bonded boards, when without BA. Boards treated with resin and BA had higher termite mortality than control samples. Boric acid is not a repellent product, but its presence allows to bring efficient protection to the particleboards (Thevenon et al 2009). BA considerably increased the durability towards panels in our study.

Tab. 1. Termite Resistance of TFuR-impregnated particleboard bonded by TF, TFfu, TH, and MUF adhesives

Description of treatments			**Termite resistance**		**Sample distribution for the visual rating classes (%)**		
Adhesive Type	**Impregnation Resin (%)**	**BA (0.5 %)**	**Survival rate (%)**	**Visual Rating (*)**	**0**	**1**	**4**
TF	-	-	51	4			100
	Tfu (5%)	-	25	4			100
	Tfu(10%)	+	0	0-1	70	30	
	Tfu (15%)	+	0	0-1	80	20	
TFFu	-	-	23	4			100
	Tfu(5%)	-	21	4			100
	TFu(10%)	+	0	0-1	75	25	
	TFu(15%)	+	0	0-1	70	30	
TH	-	+	0	0	100		
	TFu(5%)	+	7	4			100
	TFu(10%)	-	29	4			100
	TFu(15%)	-	26	4			100
MUF	-	-	15	4			100
	-	+	0	0-1	60	40	
	TFu(5%)	+	0	4			100
	TFu(10%)	-	5	4			100
	TFu(15%)	-	5	4			100
Virulence control			56	4			100

(*) Rating of wood according to EN 117 (2013)
0 = No attack, No destruction
1= Attempt to attack/ Surface erosion in part of the surface/ The destruction depth of 0.5 mm of fog should not exceed 30% of the surface.
4 = Strong attack/ 1- and 3-mm erosion covering 1/10 of the surface/ The depth of destruction is about 3 mm in the form of holes in the wood mass

Conclusion and perspectives

Our study indicates that the impregnation of bagasse particles with resins improves the biological resistance of the particleboards. The mix with boric acid allows to increase significantly the particle board resistance. This work shows that treating bagasse with tannin-furfural resin to produce particleboard improves their biological characteristics as well as their physico-mechanical properties (Ahmadi et al. 2022). Therefore, particleboards made with bagasse treated with furfural tannin resin and furfural tannin resin with boric acid are suggested potential candidate to overcome the shortage of wooden raw materials for composite production in Iran.

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