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Effects of silver and copper nanoparticles in particleboard to control *Trametes versicolor* fungus

Hamid R. Taghiyari [a,*], Bahman Moradi-Malek [b], Maryam Ghorbani Kookandeh [b], Omid Farajpour Bibalan [a]

[a] *Wood Science and Technology Department, Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Lavizan, Shabanloo St., Tehran, Iran*
[b] *Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, Iran*

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ABSTRACT

This study looked at commercial particleboard treatment with 200 ppm nanosilver (NS) and nanocopper (NC) suspensions (10–80 nm) to assess the effects on hardness and resistance to the white-rot fungus *Trametes versicolor*. Suspensions were added to mats at two levels (100 and 150 ml kg^{-1} dry weight wood particles) and comparison was made with control boards. Both metal nanoparticles had significantly improved resistance to *T. versicolor*, resulting in decreasing mass loss (ML). Nanocopper was more effective at lower levels. Fungal exposure was associated with reduced hardness in NS-control and NS100 treatments, whereas NS150 produced significant reduction in fungal growth. Copper more effectively protected panels from fungal attack. High significant correlation (85%) was found between ML and hardness values.

1. Introduction

Wood-composite panels are homogeneous materials that are useful in many applications because they are more uniform than solid wood and allow the use of smaller-diameter trees (Fernandez-Puratich and Oliver-Villanueva, 2014). Many wood species used for panel production tend to be susceptible to fungal insect attack. Nanomaterials can be used to improve some of the shortcomings in wood-composite materials (Taghiyari, 2014). The high thermal conductivity coefficient of some metal and mineral materials (Yu et al., 2012; Saber et al., 2013) shorten hot-press time, while improving thermal conductivity and fire-retarding properties in solid woods (Taghiyari, 2012). Mineral nano-fibers also significantly decreas mass losses in solid woods and wood-composites (Karimi et al., 2013; Taghiyari et al., 2014). Nanomaterials were also used to improve bonds in wood-plastic composites (Morrell et al., 2006; Lee et al., 2010).

Silver and copper nanoparticles significantly improve the physical and mechanical properties of particleboards (Taghiyari et al., 2011; Taghiyari and Farajpour Bibalan, 2013). The higher thermal conductivity coefficient of silver in comparison to copper is associated with de-polymerization of the resin bond in the surface layers of the panels, resulting in significant decreases in the hardness of nanosilver-treated particleboard panels. In the nanocopper-treated panels, though, the lower thermal conductivity coefficient of copper causes enough heat to be transferred to the composite mat, resulting in a significant improvement in hardness values. However, the effects of nanosilver and nanocopper on the biological resistance as well as the hardness of specimens exposed to fungi have not been not studied. Wood-deteriorating fungi attack both living trees and lumber (Maresi et al., 2013). The present study was carried out to investigate if a small amount of metal nanoparticles can increase the resistance of lumber to attack by wood-deteriorating fungi.

2. Materials and methods

2.1. Specimen preparation

Particleboards were produced at the Iran-Choob factory, Ghazvin, Iran. Panels were 16 mm in thickness and 0.7 g cm^{-3} in density. Chips were comprised of poplar species plus a small portion of pruned branches of various fruit trees (Table 1). An even layer was formed by a spreading head upon a moving caul

* Corresponding author. Tel.: +98 930 2005235 (mobile); fax: +98 21 22970021.
E-mail addresses: htaghiyari@srttu.edu, htaghiyari@yahoo.com (H.R. Taghiyari).

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Table 1
Specifications of the chips used in this study.

Specifications of the chips	Mean value of NS-treated panels	Mean value of NC-treated panels
Length of the chips (mm)	9.71	9.35
Thickness of the chips (mm)	1.26	1.28
Slenderness Ratio	7.72	7.30

that provided a continuous particle size gradient between the surface and core layers so that fine particles were on the surface and coarser particles in the core. Particle classification was performed using an air stream. Particle length was randomly formed along the machine direction; this generally made the bending strength across the boards approximately 20% lower than in the machine direction. Particle size distribution across the width of the boards resulted in particles of about 3 mm in thickness in the core of the mat, with a decrease to the surface where particles were less than 0.2–01 mm. Hot-press plate temperature was 200 °C; pressure was 25 kg cm^{-2}, and the total nominal pressure of the plates was 200 kgf. The press was equipped with electronic sensors that measured evaporation of gases and pressure. Board dimensions were 530 × 130 × 1.6 cm thick. Urea-formaldehyde (13%) plus 1% ammonium chloride (NH_4Cl) as hardener were used as the resin.

Aqueous nanosilver (NS) and nanocopper (NC) suspensions (200 ppm) were produced using an electrochemical technique (Taghiyari, 2011). The size range of the copper nanoparticles was 10–80 nm. The pH value of the suspensions was 6–7. Two kinds of surfactants (anionic and cationic) were used in the suspension as stabilizers at concentrations that were twice that of the copper nanoparticles. Nanoparticle size was monitored with a scanning electron microscope. Suspensions were added to the resin before mixing the resin with wood particles. Resin pH value and the viscosity of the resin were kept constant for all treatments. Nanosilver and nanocopper were used at 100 and 150 ml kg^{-1} of wood particles for each batch of production (dry-wood basis). There were four treatments of nano-treated panels plus two control panels: one–NS– and one–NC–control, two 100 ml of NS or NC kg^{-1}, and three 150 ml of NS or NC kg^{-1}. Four boards were manufactured for each treatment. Boards were stored for 2 wk before mechanical and physical tests were performed. The panels for the three treatments of each group of NS and NC panels were produced in one day. However, there was a gap of 3 wk between the production of NS and NC panels due to the industrial schedule and programming. Therefore, the hardness and mass loss values for each NS- or NC-treated panel should be compared to the control specimens of the same group.

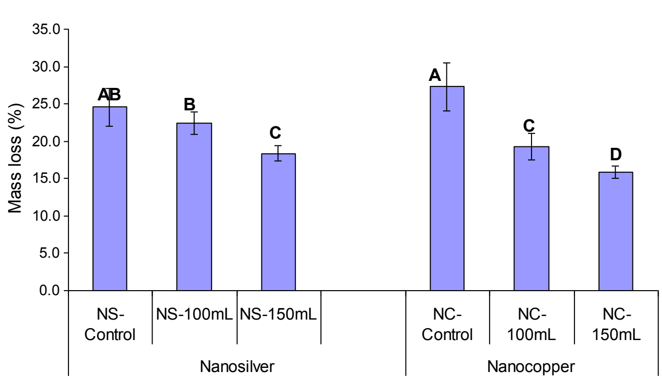

Fig. 1. Mass losses (%) of poplar particleboards with or without nanoparticles and exposed to *T. versicolor* in an EN 113 decay test.

2.2. Hardness measurement

Hardness was measured in accordance with Iranian Standard ISIRI 9044 PB Type P2 (compatible with ASTM D1037-99 specifications) using an 11.28-mm-diameter modified Janka ball with a projected area of 100 mm^2. Dimensions of the hardness specimens were 75 × 150 mm. As stipulated in the standard, two test specimens were bound together using the same resin to meet the required thickness of 25 mm; two penetrations were made on each of the flat faces of the specimens and averaged for analysis. Loading was applied at a uniform rate of 4 mm min^{-1}. The moisture content of the specimens at the time of testing was 7.5% (Figueroa et al., 2012).

2.3. Fungal degradation

Specimens, prepared according to the European standard EN 113, were dried at 103 °C for 24 h. They were then weighed and autoclaved at 120 °C for 20 min (Schmidt, 2006). Specimens were exposed in Kolle flasks on 4.8% malt extract agar (SIFIN GmbH) to the standard white-rot fungus *Trametes versicolor* (L.: Fr.) Pilát (strain 325) University of Sari. The isolate was re-identified by rDNA-ITS sequencing according to Schmidt and Moreth (2003). Specimens were incubated at 25 °C and 65% RH for 16 wk. Mass loss (ML) was then calculated according to the standard. Four specimens were prepared from each of the four replicate panels produced for each treatment, totaling 16 replicate specimens for each treatment. Following incubation, mycelia were removed from the sample surfaces and the specimens were dried at 103 °C for 24 h and weighed to determine the fungal mass loss.

2.4. Statistical analysis

A one-way ANOVA was performed to discern differences at the 95% confidence level, using SAS software version 9.2 (2010). The treatments were compared using a Duncan multiple range test. Hierarchical cluster analysis, including a dendrogram and the use of Ward methods with squared Euclidean distance intervals, was carried out by SPSS/18 (2010). Regression analysis was performed using a Minitab software program, version 16.2.2 (2010).

3. Results and discussion

The highest and lowest mass losses (ML) occurred in the NC-control (27.3%) and NC-150 (15.9%) panels, respectively (Fig. 1). Both silver and copper nanoparticles showed a significant decreasing effect on ML values. Nanocopper-treated panels showed greater decreases in ML values compared to the control panels, demonstrating the greater fungicidal property of copper in hindering the growth of fungus hyphae in comparison to silver (Palanti et al., 2012). Copper has been used for a long time as a fungicide (Schmidt, 2006; Kües, 2007). It was then concluded that the decreasing effect of copper nanoparticles on ML was contributed to the increased hardness as well as its fungicidal property. It was previously reported that this treatment also had the highest water absorption and thickness swelling values (Taghiyari and Farajpour Bibalan, 2013). It can therefore be concluded that the way water penetrates into the composite matrix is comparable to the penetration of fungi hyphae in to the