EFFECTS OF NANO-SILVER IMPREGNATION ON SOME MECHANICAL PROPERTIES OF ICE-BLASTED WOOD SPECIMENS

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TAGHIYARI HR, RASSAM G, LOTFINEJAD SANI Y & KARIMI A. 2012. Effects of nano-silver impregnation on some mechanical properties of ice-blasted wood specimens. Ice blasting (frozen CO_2, -78.5 °C) is one of the modern methods of cleaning for industrial purposes. Effects of ice blasting were studied on untreated solid wood as well as 200 ppm nano-silver impregnated wood of *Populus nigra* (poplar) and *Fagus orientalis* (beech). Modulus of rupture (MOR), modulus of elasticity (MOE) and compression strength parallel to the grain were measured. Ice blasting decreased MOR by 31.5 and 6% in poplar and beech respectively. However, when specimens were impregnated with nano-silver, MOR would only decrease by 4.8% in beech and increase by 1.7% in poplar. Ice blasting decreased MOE and compression strength parallel to the grain by 62.5 and 2.5% respectively in poplar, and 8.6 and 4.4% in beech. The lower the density of a wood the more mechanical properties would decrease in untreated wood as a result of ice blasting. On the other hand, nano-silver impregnation decreased the amount of losses in MOR, MOE and compression strength parallel to the grain. Heat conductivity of nano-silver particles transferred the cold accumulated on the surface layers of specimens. Consequently, mechanical properties would be improved by preventing the formation of microscopic fissures and surface checks.

Keywords: Cleaning, ice blasting, metal nanoparticles, solid wood

TAGHIYARI HR, RASSAM G, LOTFINEJAD SANI Y & KARIMI A. 2012. Kesan pengawetan nanoperak terhadap beberapa ciri mekanik spesimen kayu yang dibagas ais. Bagas ais (CO_2 sejuk beku, -78.5 °C) merupakan salah satu kaedah pembersihan untuk tujuan industri. Kesan bagas ais terhadap kayu padu *Populus nigra* (poplar) dan *Fagus orientalis* (bic) yang tidak dirawat serta yang dirawat dengan 200 ppm nanoperak dikaji. Modulus kepecahan (MOR), modulus kekenyalan (MOE) dan kekuatan mampatan selari ira disukat. Bagas ais mengurangkan MOR sebanyak 31.5% dalam kayu poplar dan 6% dalam kayu bic. Namun, MOR cuma berkurangan sebanyak 4.8% dalam kayu bic dan bertambah sebanyak 1.7% dalam kayu poplar apabila diawet dengan nanoperak. Bagas ais mengurangkan MOE dan kekuatan mampatan selari ira masing-masing sebanyak 62.5% dan 2.5% dalam kayu poplar serta 8.6% dan 4.4% dalam kayu bic. Semakin rendah ketumpatan kayu, semakin banyak ciri mekanik akan berkurangan nilainya akibat bagas ais. Sebaliknya, rawatan nanoperak mengurangkan penurunan nilai MOR, MOE dan kekuatan mampatan selari ira. Kekonduksian haba oleh zarah nanoperak mengalihkan kesejukan yang terkumpul pada permukaan spesimen. Akibatnya ciri mekanik akan bertambah baik dengan menghalang pembentukan rekah mikroskopik dan retak permukaan.

INTRODUCTION

Ice blasting or dry ice blasting is a form of abrasive blasting, where dry ice, the solid form of carbon dioxide (CO_2), is accelerated in a pressurised air stream and directed at a surface in order to clean it. This method is similar to other forms of abrasive blasting such as sand-blasting, plastic bead blasting or soda blasting but uses dry ice as the blasting medium. Dry ice blasting leaves no chemical residue as dry ice sublimates at room temperature. The frigid temperature of dry ice (-78.5 °C) blasting against the material to be removed causes it to shrink and loose adhesion from its subsurface. When some dry ice penetrates the material to be removed, it comes in contact with the underlying surface. The warmer subsurface causes the dry ice to convert back to

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CO_2 gas. The gas has 800 times greater volume and expands behind the material, speeding up its removal. Paint, oil, grease, asphalt, tar, decal, soot, dirt, ink, resin and adhesive are some of the materials removed by this procedure. Only the removed material must be disposed of as the dry ice sublimates into the atmosphere. Damage to the work piece with resultant effect on the function is not detected (Spur et al. 1999).

Different mechanical methods have so far been used for removing finishes and cleaning wood and wood composites such as scraping, sanding, wet or dry sand-blasting, spraying with pressurised water (power washing), and using electrically-heated pads, hot air guns and blowtorches (Williams 2010). Sand-blasting was even suggested for removing the weathered surface prior to finishing by latex and oil-based opaque stains (Williams & Feist 1999). Recently, ice blast has been used successfully on wood where lead-based coatings have to be removed prior to the demolition of the structure. However, wood is one of the few substrates that ice blast will erode. The benefits of using ice blast are that ice blast generates low volume of waste (with regard to containment and collection), need not purchase blast media, safe to worker and ease of operation. Dry ice blast cleaning is often used for restoration of fire damaged buildings—removing char and smoke. Dry ice blast cleaning has also been proven successful to remove mould. Not only is the mould removed but also the top layer of wood that has the hyphae of the mould (Anonymous 2010).

There is little or no scientific studies on the effects of ice blast on the mechanical properties of wood (Aminzadeh et al. 2010, Lotfinejad 2010). Therefore, we studied modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength parallel to the grain (P_{cll}). In the preliminary study, 40 specimens for each mechanical property were prepared and divided into two groups of 20 specimens each of the control and ice-blasting experiments. The mechanical properties were measured and we came to a conclusion that the mechanical loss was partly due to the accumulation of extreme cold in the surface layers of specimens. Therefore, if the extreme cold could be transferred to deeper parts, the amount of fissures and checks caused by cold shrinkage and frozen water crystals would decrease. The heat (or cold) transfer property of nano-silver particles makes it apt to be studied further (Taghiyari 2011). Based on the above preliminary results and due to the wide use of solid wood as structural elements in the northern provinces of Iran, the effects of nano-silver impregnation on mechanical properties of ice-blasted specimens of two native species were studied.

MATERIALS AND METHODS

Poplar (*Populus nigra*) specimens were procured from 11-year-old planted trees in the local gardens of Rasht city and beech (*Fagus orientalis*) specimens, from 60-year-old trees of the natural forest near Roodbar city. These two species were chosen due to their wide applications for structural and industrial purposes. Specimen dimensions and testing were in accordance to ASTM D0143-94 (ASTM 2007). For MOR and MOE, specimen size was 25 × 25 × 410 mm, centre-point loading. For P_{cll} specimen size was 25 × 25 × 100 mm.

To study the effect of nano-silver absorption, sampling was done from the sapwood. Specimens were divided into three groups: 1—control specimens (without nano-silver impregnation and ice-blast cleaning), 2—ice-blasted specimens, 3—nano-silver impregnated and ice-blasted specimens. For each group, 20 sound specimens were prepared, free from checks, fissures or knots. Modulus of rupture, MOE and P_{cll} were calculated using equations 1, 2 and 3 respectively.

$$MOR = \frac{1.5\ FL}{bd^2}\ (N\ mm^{-2}) \tag{1}$$

$$MOE = \frac{FL^3}{4bd^3D}\ (N\ mm^{-2}) \tag{2}$$

$$P_{cll} = \frac{F_{max}}{A}\ (N\ mm^{-2}) \tag{3}$$

where

F = maximum force at first failure
L = length of the specimen
b = width of the specimen
d = thickness of the specimen
D = deflection at failure
F_{max} = maximum force
A = cross-section area of the specimen

Nano-silver was produced and applied to the specimens using electrochemical technique in collaboration with Jafr Sorkhe Fajr Company.

Nano-silver impregnation was done in a pressure vessel with pressure of 3 bars and 200 ppm nano-silver solution using empty-cell process (Rueping method). The size range of silver nanoparticles was 20–80 nm. All specimens were weighed just before and after impregnation process to measure the amount of absorption. Impregnated specimens were kept in a conditioning chamber (30 °C and 45% relative humidity) for three months together with control specimens before ice-blasting treatment and the mechanical tests. Moisture content (MC) of all specimens (treated and untreated) was 8.5% when the tests were carried out. All nano-silver-impregnated specimens were again weighed (at 8.5% MC). There were 0.8% decrease in beech and 1.7% decrease in poplar. The amount of decrease was due to the empty-cell process, washing out part of the extractives.

The ice-blasting system used small pellets of dry ice forced under pressure out of a medium-sized flat nozzle (3.5 cm) using compressed air (3 bars). The middle parts of all four sides of MOR and MOE specimens were ice blasted for 3.5 s. For $P_{c||}$ specimens, whole specimens were ice blasted.

The static bending test was performed using centre-point loading over 360 mm span with the load applied through the bearing block to the tangential surface nearest the pith. The loading speed was 2 mm min^{-1}. All tests were conducted using Instron testing machine. Scanning electron microscope (SEM) imaging was done. A field-emission cathode in the electron gun of SEM provides narrower probing beams at low and high electron energies, resulting in both improved spatial resolution and minimised sample charging and damage.

Two-way analysis of variance (ANOVA) was conducted using SAS software program, version 9.1 at 99% confidence level. Hierarchical cluster analysis, including dendrogram and using Ward methods with squared Euclidean distance intervals, was done by SPSS/16.

RESULTS

The amount of nano-silver solution absorption was significantly more in beech compared with poplar specimens (Table 1). Densities of the two untreated species in the present study were 0.43 and 0.62 g cm^{-3} for poplar and beech respectively. The values were compatible to those reported, i.e. 0.41 and 0.63 g cm^{-3} respectively (Parsapajouh 1984).

Figure 1 illustrates that the ice-blasted poplar specimens show significant difference from control specimens (31.5% decrease). Comparison between control specimens with nano-silver-impregnated ice-blasted specimens showed little increase in nano-silver-impregnated specimens (1.7%).

Little difference was observed between the three treatments in beech (Figure 1). Control specimens were higher in value while nano-ice-blasted specimens showed slight increase in comparison with ice-blasted specimens. Ice-blasted specimens showed 6% decrease compared with the controls. MOR values of nano-silver-impregnated ice-blasted specimens showed 4.8% decrease compared with control specimens.

Ice blasting caused MOE values to decrease as much as 62.5% in poplar but only 8.6% in beech (Figure 2). When specimens were nano-silver impregnated, the decrease was as low as 11.8 and 4% in poplar and beech respectively.

Table 1 Density and nano-silver solution absorption in two different wood

Parameter	Poplar	Beech
Nano-silver absorption (g cm^{-3})	0.296 ± 0.028	0.359 ± 0.021
Density (g cm^{-3}) (present study) (MC 8.5%)	0.43 ± 0.031	0.62 ± 0.045
Density (g cm^{-3}) (Parsapajouh 1984)	0.41	0.63

Figures are means ± standard deviations; mean values were obtained from 10 specimens

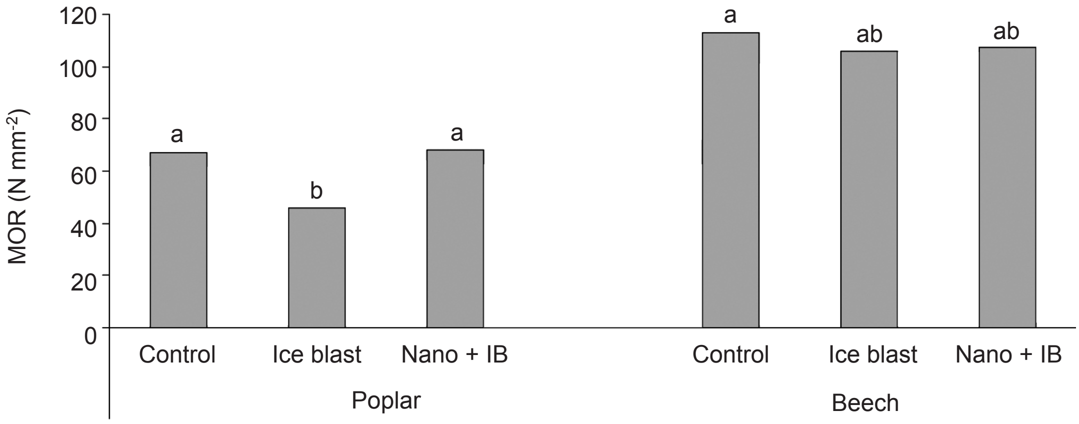

Figure 1 MOR values of control, ice-blasted and nano-silver-impregnated ice-blasted (IB) poplar and beech specimens

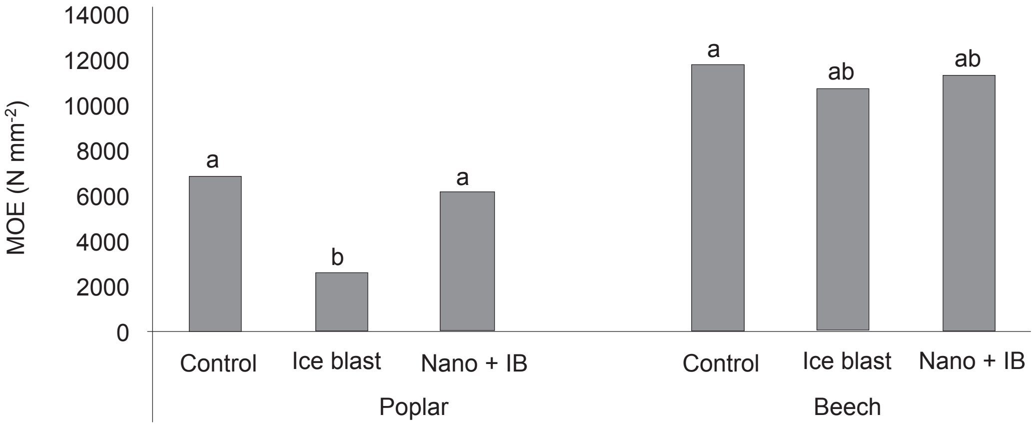

Figure 2 MOE values of control, ice-blasted and nano-silver-impregnated ice-blasted (IB) poplar and beech specimens

Compression strength parallel to the grain values of ice-blasted specimens showed 2.5 and 4.4% decrease in poplar and beech respectively (Figure 3). Specimens which were nano-silver impregnated before ice-blasting showed a little increase (0.02%) in poplar but 2.5% decrease in beech in comparison with control specimens.

DISCUSSION

As the amount of woody mass in beech was greater, the amount of nano-silver absorption was higher compared with poplar (Table 1). This is because the impregnation used is the empty-cell process. Only cell walls are supposed to absorb the nano-silver solution and no solution fills up the lumen cavity and remains in it after the impregnation process. Therefore, the more the mass of a wood the more is the absorption by the cell wall. Nano-silver was only used to cover the surfaces of cell cavities and vessel elements where extreme heat could be transferred through. Therefore, we utilised empty-cell process in which extra nano-silver solution would be forced out of wood specimen once the pressure in the impregnation vessel was removed.

Ice blasting significantly decreased the mechanical properties in most cases. This decrease may be overcome using nano-silver impregnation. A little increase in MOR and $P_{c||}$ of poplar specimens impregnated with nano-silver was observed although not significant. It is hypothesised that the extreme cold of ice blasting has made the ultrastructure of the outer layer of wood alter in a way that makes it stiffer. The silver ions that are free in nano-silver solution may have formed some bonds with hydroxyl groups of cellulose, hemicellulose and even lignin. These extra bonds may have made the surface layer of wood stiffer and stronger than non-ice-blasted wood. Thus, higher values for mechanical properties.

For all three mechanical properties measured, increase in nano-silver-impregnated specimens could be observed in comparison with ice-blasted specimens, although not all increases were statistically significant. It may be concluded that heat is transferred through nano-silver particles from the surface to the deeper parts of the specimens (Taghiyari 2011). Consequently, ultrastructure fissures and checks caused by extreme cold and frozen water crystals in wood structure could be prevented (Figure 4).

Cluster analysis based on properties measured for all three treatments of both species showed that nano-silver-impregnated ice-blasted specimens were closely clustered to control specimens (Figure 5). This proves the potentiality of nano-silver-impregnation in mitigating the negative effects of dry-ice treatment on solid wood. However, cluster analysis of beech specimens alone showed that nano-silver-impregnated ice-blasted specimens were clustered to ice-blasted specimens (Figure 6). Therefore, it may be concluded that the effect of nano-silver impregnation varied according to the density and/or structure of wood species.

CONCLUSIONS

Ice blasting decreased the mechanical properties of solid wood. When solid wood was impregnated with nano-silver solution, the amount of loss in mechanical properties would decrease in higher density wood and would even increase a little in lower density wood. Statistically the amount of decrease in nano-silver-impregnated specimens was not significant. Therefore, this method may

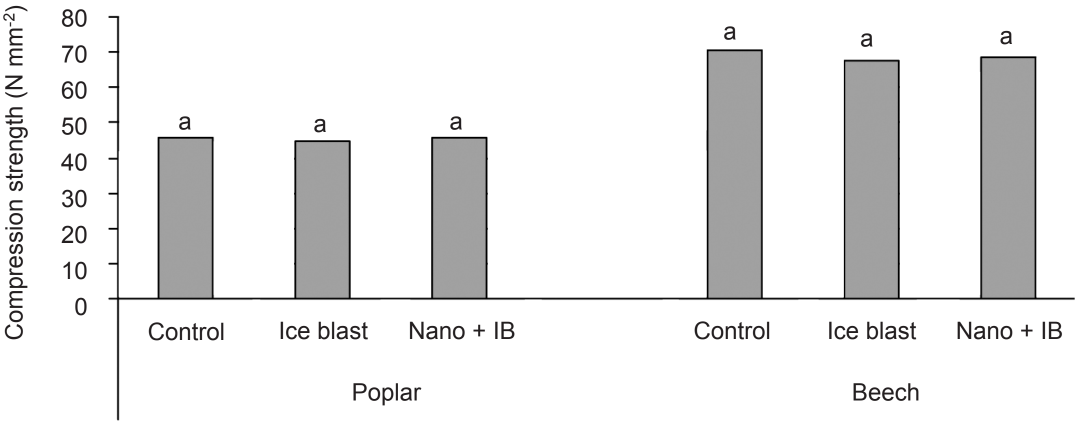

Figure 3 Compression strength parallel to the grain values of control, ice-blasted and nano-silver-impregnated ice-blasted poplar and beech specimens

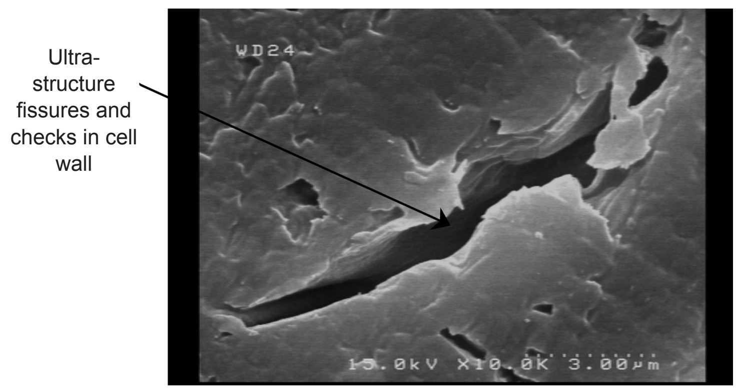

Figure 4 Fissures and checks occurred in cell wall due to extreme cold shock caused by ice-blast treatment on beech specimen

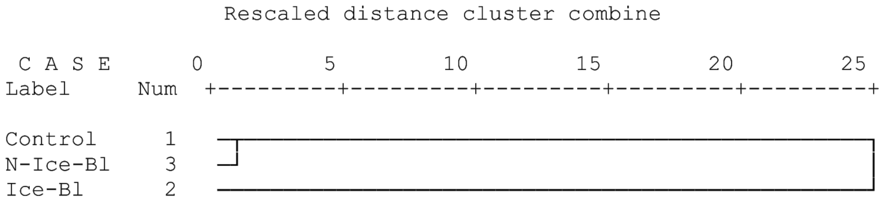

Figure 5 Cluster analysis based on MOR, MOE and P_{cll} values of both species and all treatments: control, ice-blasted (Ice-Bl) and nano-silver-impregnated ice-blasted (N-Ice-Bl)

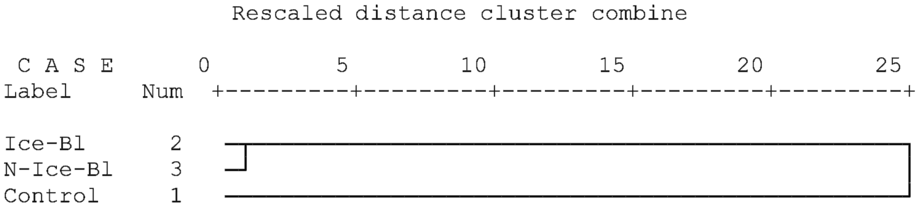

Figure 6 Cluster analysis based on MOR, MOE and P_{cll} values of beech specimens

be used for structural purpose as well as industrial application.

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