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Effects of Ice Blasting on Some Mechanical Properties of Composite Boards

Hamid Reza Taghiyari[1]* **and Yousef Lotfinejad-Sani**[1]

[1]Wood Science and Technology Department, Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Lavizan, Shanbaloo St., Tehran, Iran

Ice-blast (frozen CO_2, -78.5°C) is one of modern methods of cleaning for industrial purposes. Effects of ice-blasting were studied here on mechanical properties of plain and laminated medium-density fiberboards (MDF) and particleboard. Modulus of rupture (MOR) and modulus of elasticity (MOE) were measured and compared in accordance with the EN 312-4 standard values. Results showed that MOR and MOE of MDF specimens were significantly higher in comparison to those of the particleboard; the higher values were related to the more compression ratio between wood fibers in the MDF-matrix. Ice-blasting did not significantly affect MOR values; however, it significantly decreased MOE values in all treatments. Furthermore, ice-blasting had a negative abrading effect on the surface of both plain and laminated wood-composite boards. It was concluded that ice-blasting cannot be recommended for wood-composite materials as to its abrading effects on the surface of composite boards as well as its decreasing effects on some mechanical properties.

Keywords: Cleaning; Composite boards; Fracture; Ice-Blasting; Mechanical Properties.

INTRODUCTION

Ice blasting, or dry ice-blasting, is a form of abrasive blasting, where dry ice, the solid form of carbon dioxide, is accelerated in a pressurized air stream and directed at a surface in order to clean it (Taghiyari et al. 2012ab). The method is similar to other forms of abrasive blasting such as sand blasting, plastic bead blasting, or soda blasting but substitutes dry ice as the blasting medium (Taghiyari et al. 2012ab; Dong et al. 2013ab). Dry ice blasting leaves no chemical residue as dry ice sublimates at room temperature. The frigid temperature of the dry ice (109.3°F or -78.5°C) "blasting" against the material to be removed causes it to shrink and loose adhesion from its sub surface. Additionally, when some of dry ice penetrates through the material to be removed, it comes in contact with the underlying surface. The warmer sub surface causes the dry ice to convert back into carbon dioxide gas. The gas has 800 times greater volume and expands behind the material speeding up its removal. Paint, oil, grease, asphalt, tar, decals, soot, dirt, ink, resins, and adhesives are some of the materials removed by this procedure. Only the removed material must be disposed of, as the dry ice sublimes into the atmosphere. No damage to the work-piece with a resultant effect on the function was detected (Spur et al., 1999). Some privileges for using ice blast on afore mentioned project was ice blast's low volume of waste generated (in regard to containment and collection), no blast media to purchase, worker safety features, and its ease of operation. Ice blasting and atmospheric plasma spraying have recently been used for aluminum coatings (Dong et al. 2013ab).

Different mechanical methods have so far been used for removing finishes and cleaning wood and wood composites such as: scraping, sanding, wet or dry sandblasting, spraying with pressurized water (power

*Corresponding author: htaghiyari@srttu.edu
htaghiyari@yahoo.com

washing), and using electrically heated pads, hot air guns, and bowtorches (Williams 2010). Sandblasting was even suggested for removing the weathered surface prior to finishing by latex and oil-based opaque stains (Williams & Feist, 1999). Dry ice blast cleaning is often being used for restoration of fire damaged buildings and rooms - successfully removing the char and smoke damage to wood and other materials. Dry ice blast cleaning has been proved highly successful with mold removal because the force of the spray of pellets can quickly wipe a surface clean. Many hours of time are saved. Not only is the mold removed but the top layer of wood that has the roots of the mold can be removed too. This will leave the wood clean and mold free. However, ice blast erodes soft materials such as wood and wood-composite panels (Taghiyari et al. 2012ab).

Very little scientific field tests have so far been carried out on the effects of ice blast on physical and mechanical properties of wood (Taghiyari et al. 2012ab); and authors came to no study on its effects on wood-composite materials. As to the fact that natural regeneration of trees (Ruprecht et al. 2012) is not enough for the increasing need of the wood industry, and wood-composite materials are increasingly used in home and office furniture, moreover due to the abrading effects of ice-blasting on the surface of wood-composite panels, the present study was carried out to find out if ice-blasting, as a modern cleaning method, has any significant effects on mechanical properties of wood-composite panels.

MATERIALS AND METHODS

Plain medium-density fiberboard (MDF) and particleboard (PB), as well as laminated MDF and PB, were prepared from the local market of Tehran, Iran. From each group, 40 specimens were prepared. 20 specimens of each group were ice-blasted (IB specimens) before the mechanical tests; the results were then compared with those of the control (un-treated) specimens.

Mechanical tests

Mechanical tests, as well as the number and location of the specimens, were carried out in accordance with the ISIRI 9044 PB Type P2 (compatible with ASTM D1037-99) specifications. Location of physical, mechanical, and permeability specimens was the same as carried out by Taghiyari & Farajpour (2013).

Three-point static flexural tests were performed to measure modulus of rupture (MOR) and modulus of elasticity (MOE). Nominal sizes of the specimens were 380 × 70 × 1.6 mm, with loading speed of 3 mm/min. 20 samples of the same location for each treatment were tested using an Instron testing machine, model 4486, with 5 kN capacity. MOR and MOE were calculated using Equations 1 and 2, respectively.

$$MOR = \frac{1.5\,FL}{bd^2} \quad (N/mm^2) \qquad \text{(Equation 1)}$$

$$MOE = \frac{FL^3}{4bd^3D} \quad (N/mm^2) \qquad \text{(Equation 2)}$$

Specimens were kept in conditioning chamber (25±3°C, and 45±4% relative humidity) for three months before ice-blasting treatment and mechanical tests. Moisture content (MC) of all specimens (ice-blasted and un-treated) was 8.5% when the tests were carried out because wood has a thermo-hygromechanical behavior and its deformation properties depends on the combined action of temperature, relative humidity, and mechanical local variations (Figueroa et al. 2012).

Ice-blasting

Ice-blasting was carried out by an apparatus designed and built by Ice-Palayesh Co. in Iran. The system used small pellets of dry ice forced under pressure out of a medium size flat nozzle (3.5 cm) using compressed air (3 bars). Cylindrical ice pellets were used in the present research project; the diameter of the ice pellets was 3±0.1 mm. Both sides of the middle part of the specimens were ice-blasted for 3.5 seconds (Figure 1).

Statistical Analysis

Statistical analysis was conducted using SAS software program, version 9.2 (2010). One-way ANOVA was performed to discern significant difference at the 95% level of confidence. Grouping was then made between treatments using the Duncan's test. Hierarchical cluster analysis, including dendrogram and using Ward methods with squared Euclidean distance intervals, was carried out by SPSS/18 (2010). Cluster analysis was performed to find similarities and dissimilarities between treatments based on more than one property simultaneously. The scaled indicator in each cluster analysis shows how much treatments are similar or different; lower scale numbers show more similarities while higher ones show dissimilarities. Fitted-line plot was made by Minitab software, version 16.2.2 (2010).

RESULTS

Results showed that all MOR and MOE values of the control plain and laminated MDF and particleboard specimens were significantly higher than the EN-standard values (Figures 2 and 3); only the MOR value of the

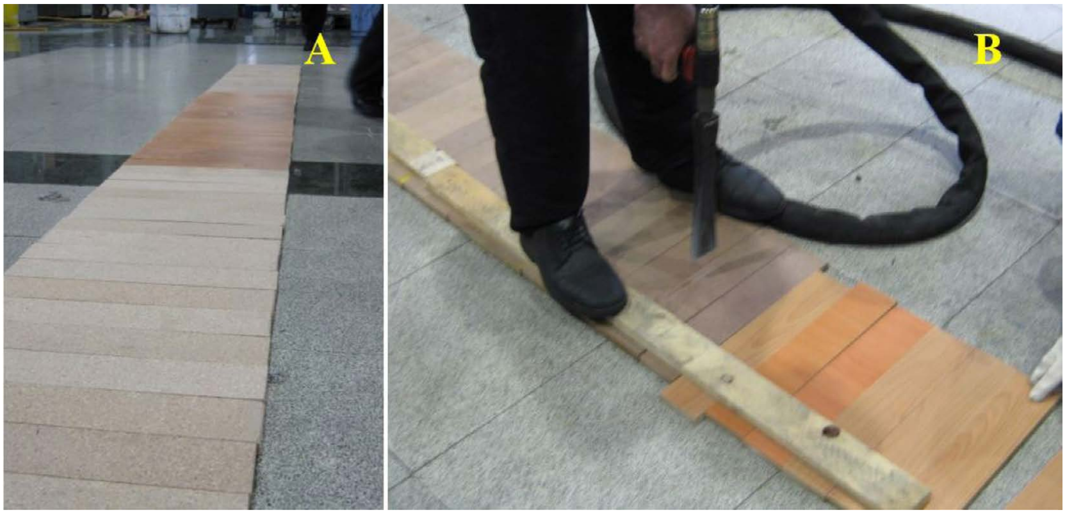

Figure 1. MDF and particleboard specimens arranged on the flour (A) ready to be ice-blasted with a medium-size flat nozzle (B).

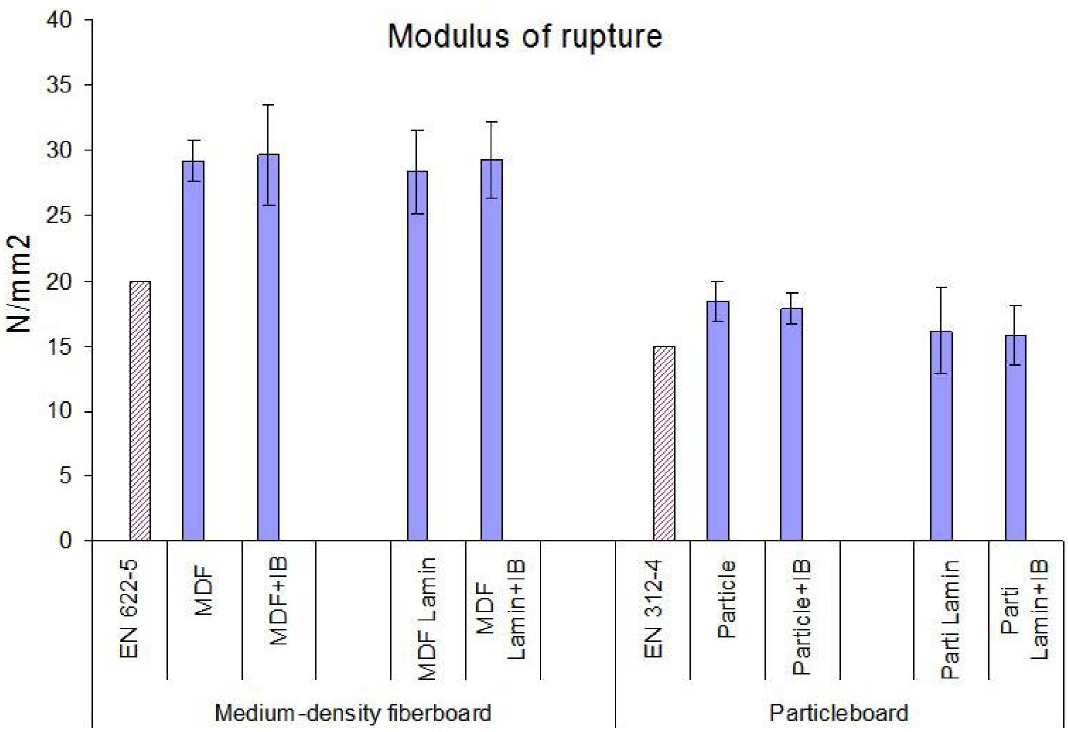

Figure 2. MOR values of the eight treatments of composite-boards (N/mm²) (MDF=medium-density fiberboard; IB=ice-blasted; Lamin=laminated composite-boards; Particle=particleboard) (mean values for 20 sound specimens for each combination, at MC of 8.5%)

laminated particleboard was not significantly higher. Ice-blasting did not significantly change the MOR values; however, MOE values decreased significantly. MOR and MOE values of MDF specimens were significantly higher than those of the particleboard. The highest and lowest MOR values were observed in the ice-blasted MDF specimens (29.7 N/mm²) and ice-blasted laminated particleboard (15.8 N/mm²), respectively. The highest and lowest MOE values were found in laminated MDF (3474 N/mm²) and ice-blasted particleboard (1725 N/mm²), respectively. The highest percentage of decrease in MOR values caused by ice-blasting was 2.8% in the

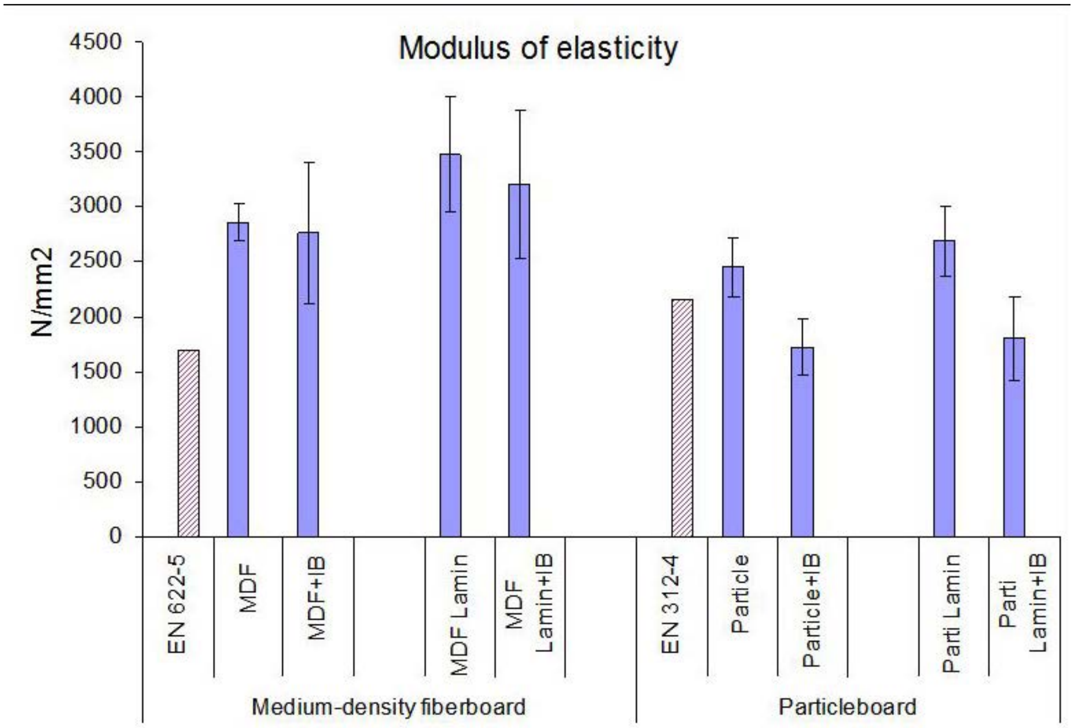

Figure 3. MOE values of the eight treatments of composite-boards (N/mm²) (MDF=medium-density fiberboard; IB=ice-blasted; Lamin=laminated composite-boards; Particle=particleboard) (mean values for 20 sound specimens for each combination, at MC of 8.5%).

ice-blasted particleboard specimens in comparison to the control (not ice-blasted) particleboard specimens. As to the MOE values, the highest percentage of decrease by ice-blasting occurred in the laminated particleboard specimens (33%) in comparison to the control laminated particleboard specimens.

DISCUSSION

MOR and MOE values were significantly higher in MDF specimens. This was due to more compression ratio in the MDF mat; that is, the wood fiber had to be more compacted and compressed to form the MDF-matrix in the final composite-board than the wood chips in the particleboard, resulting in more compression ratio. The more compression ratio in its turn caused more contact area in the composite-matrix, resulting in significant higher mechanical strength. Fitted-line plot between MOR versus MOE values also showed clear distinct grouping between the particleboard and MDF combinations (Figure 4); moreover, significant correlation, although not very high, were found between MOR and MOE values (R-square of 51%).

Visual observation of the ice-blasted surface of the specimens revealed abrasion in all specimens of any kind by the naked eye (Figures. 5-7). In the laminated specimens, parts of the laminated veneer were completely removed (Fig. 5). However, MOR values did not show significant decrease due to ice-blasting. It can therefore be concluded that MOR in composite-boards cannot be easily affected by ice-blasting. However, MOE values significantly decreased in nearly all treatment by ice-blasting. Thus, it was concluded that ice-blasting significantly affects modulus of elasticity in wood-composite materials, both plain and laminated.

MOR values of the medium-density fiberboard specimens showed a slight increase in their values, although not significant (Fig. 2). This was related to the irreversible hydrogen bonding in the course of water movements within the pore system of the cell walls (Borrega & Karenhampi, 2010; Taghiyari 2013). In fact, due to the extreme cold by the ice-blasting, water was frozen and driven out of the wood fiber structure; as to the irreversible hydrogen bonding formed during the course of water movement from the cell walls, wood fibers were more stiff and hard, resulting in the slight increase in the MOR values (Taghiyari 2013).

MOE significantly decreased in all treatments (Fig. 3). This decrease was due to the abrasion of the surface of the specimens (Figs. 5-7). The extreme cold along with the high pressure of the nozzle during the ice-blasting

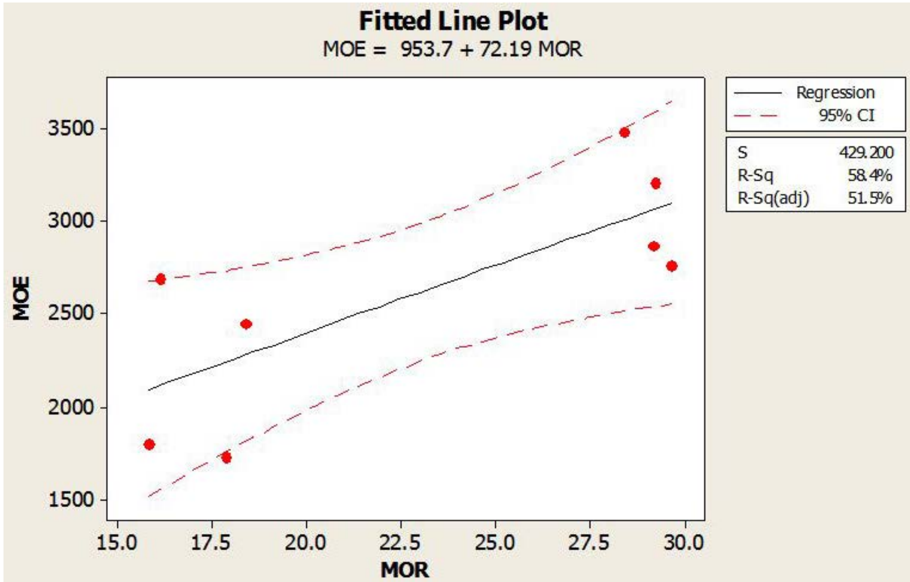

Figure 4. Fitted-line plot between MOR versus MOE values in the eight combinations of wood-composite materials.

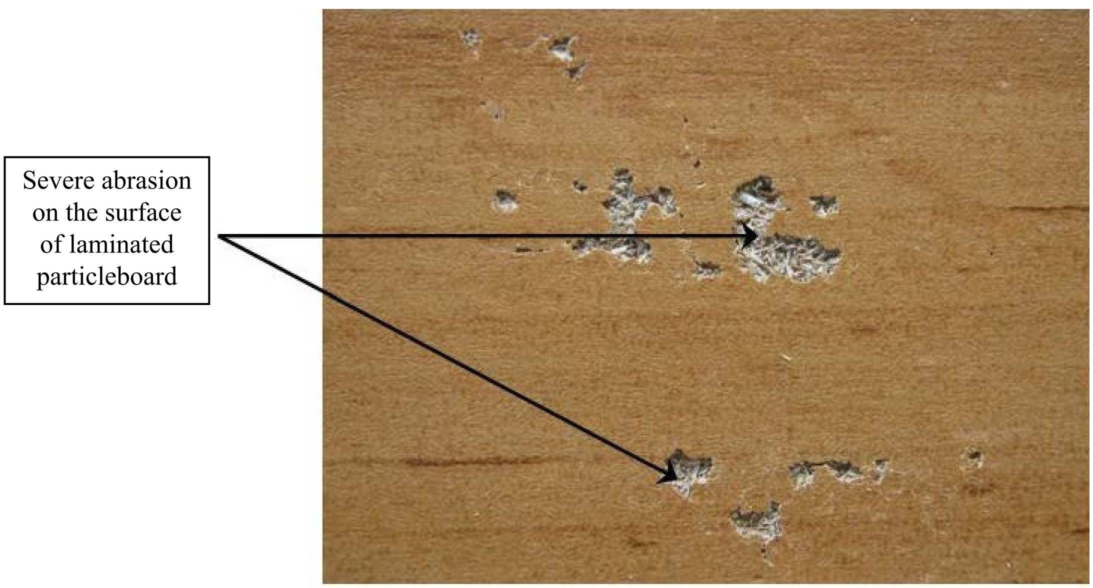

Figure 5. Severe abrasion caused by ice-blasting on the surface of a laminated particleboard specimen.

process resulted in the severe abrasion of the surface of specimens, causing MOE values to significantly decrease.

Cluster analysis of the eight different combinations of wood-composite materials based on MOR and MOE values showed clear significant difference between MDF and particleboard combinations (Figure 8), proving the high effect of compression ratio on the overall mechanical behavior of composite-boards. Plain MDF specimens were significantly clustered with the laminated MDF specimens, showing that lamination of MDF significantly affect its mechanical properties; however, laminating particleboards did not significantly affect its mechanical properties as plain and laminated particleboard specimens were closely clustered. Ice-blasted plain or laminated MDF specimens were closely clustered with their counterparts, indicating that ice-blasting had low insignificant effect on the mechanical properties in MDF. In the particleboard specimens though, ice-blasted specimens were clustered significantly different from the un-treated specimens. It was then concluded that ice-blasting had higher negative

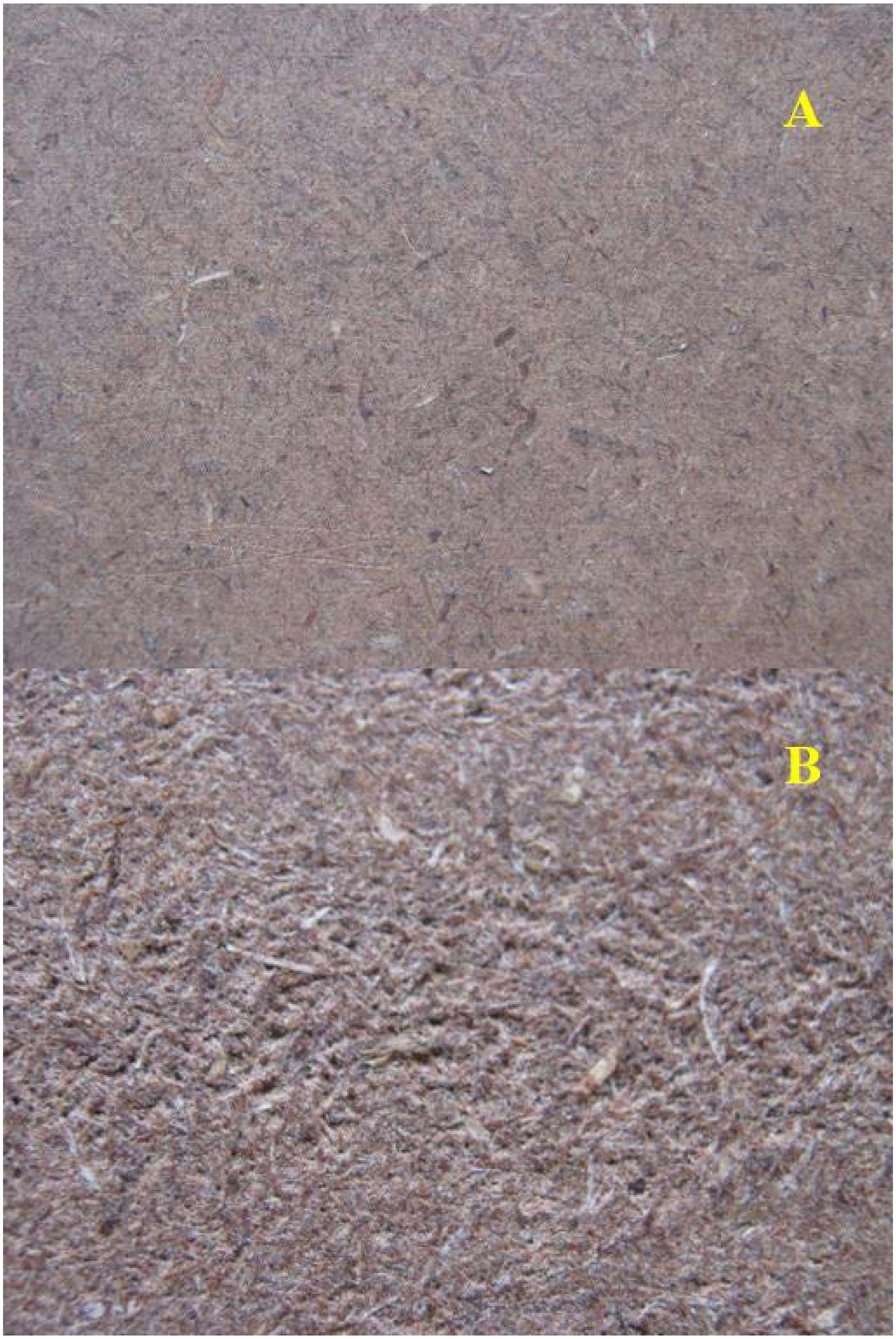

Fig. 6. Surface appearance of the MDF specimens (A) before the ice-blasting, and (B) after the ice-blasting, showing severe abrading effects.

Figure 7. Surface appearance of the particleboard specimens (A) before the ice-blasting, and (B) after the ice-blasting, showing severe abrading effects.

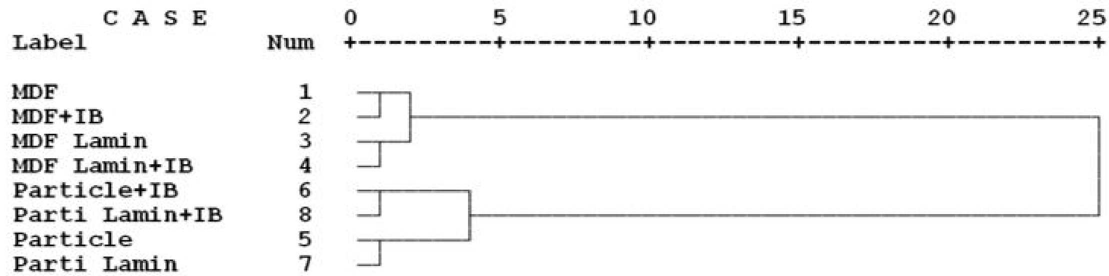

Figure 8. Cluster analysis based on MOR and MOE values in the eight combinations of wood-composite materials (IB=ice-blasted; Lamin=laminated; Parti=particleboard).

effects on the mechanical properties in particleboard in comparison to MDF specimens.

Although MOR values did not significantly decrease, and in MDF specimens they even slightly increased, it should be considered that ice-blasting resulted in significant decrease in the MOE values in all treatments; moreover, it resulted in severe abrasion of the surface layers in all kinds of composite-boards, both plain and laminated. Considering the fact that ice-blast cleaning is not usually carried out only once during the service life of a piece of furniture, it can be predicted that even MOR values would eventually decrease after the second or third run of ice-blast cleaning. Overall, it can be concluded that ice-blasting, as a modern method for cleaning, is not recommended for cleaning wood-composite materials due to its negative abrading effects on the surface of the boards, as well as its negative impact on some mechanical properties.

Heat-transferring property of metal nanoparticles (Pati 2012; Saber et al. 2013) was reported to mitigate the negative effects of ice-blasting on mechanical properties in solid woods (Taghiyari et al. 2012a) and improve permeability (Taghiyari et al. 2012b). The authors are therefore planning to ice-blast the nanometal-treated wood-composites to find out if the heat-transferring property of metal nano-particles can mitigate the negative effects of ice-blasting in wood-composite materials.

CONCLUSION

Effects of ice-blasting, as a modern cleaning technique, on wood-composite materials were studied in plain and laminated medium-density fiberboard (MDF) and particleboards. Results showed that severe abrasion occurred on the surface of the ice-blasted specimens, both in the plain as well as laminated specimens. MOR did not significantly affected by the first run of ice-blasting process; MOE values, though, significantly decreased by the process. Due to the negative visual and mechanical effects of ice-blasting, it was concluded that this modern cleaning technique is not recommended to be used for wood-composite materials.

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