Effects of Wollastonite on Selected Properties of Medium-Density Fiberboards Made from Wood and Palm Leaf Residues

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Effects of adding wollastonite (W, at 5% and 10%) and palm leaf residues(at 10%), based on the dry weight of wood fibers, were evaluated relative to selected properties of medium-density fiberboards (MDF), bonded with two adhesive systems, *i.e.*, urea-formaldehyde (UF, at 10%) and isocyanate (IC, at 5%) resins. The results indicated a general improvement in screw withdrawal resistance in the UF-bonded panels due to the addition of wollastonite. This enhancement is attributed to the reinforcing effect of wollastonite. In the IC-bonded panels, the addition of wollastonite had an improving effect when W-content was 5%. The addition of defibrated palm leaves generally decreased the screw withdrawal resistance of the MDF panels due to the soft nature of the palm fibers. The fire properties of the IC-bonded panels tended to be more favorable or at least comparable to those of the UF-bonded panels, which was attributed to the formation of bubbles in the cured resin. The addition of wollastonite generally improved fire properties in both resins. It was concluded that wollastonite and defibrated palm leaves can be recommended for MDF production when the contents of wollastonite and palm leaves do not exceed 5% and 10%, respectively.

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INTRODUCTION

Wood composite panels are considered a growing field of wood-based products in many countries that satisfy a wide range of needs and cover a myriad of applications. Adhesives and resins are an inseparable part of wood composites. As public awareness and the environmental concerns on fossil-based resins and polymers increase in the world, researchers are investigating newly-developed bio-adhesives (Pizzi *et al.* 2020).

Though substituting the unsustainable petroleum-based resins with bio-based wood adhesive is a hot topic that could alleviate numerous environmental concerns (Li *et al*. 2019; Li *et al.* 2022; Maulana *et al.* 2024; Yang *et al.* 2025), fully bio-based resins have not yet been successfully utilized on an industrial scale (Arias *et al.* 2022). Therefore, another potential option would be to reinforce existing chemical resins, enabling the production of composite panels with lower resin content and reduced formaldehyde emissions, while physical and mechanical properties are not deteriorated and are even improved(Selakjani *et al.* 2021; Kelleci *et al*. 2022; Zamani *et al.* 2022; Antov *et al.* 2023; Savov 2023; Almeida *et al.* 2024; Kawalerczyk *et al.* 2024).

In this context, composite panels have been studied from various perspectives. Different metal and mineral materials at nano- and micro-scales have been reported to successfully enhance various properties in wood-based composite panels (mainly MDF, particleboard, and oriented strand lumber) (Valenzuela *et al.* 2012; Candan and Akbulut 2014; Sheikholeslami *et al.* 2016; Tajvidi *et al.* 2016; Lu *et al.* 2017; Mantanis *et al.* 2017; Yadav 2021). Addition of mineral fillers to the polymers and binders to produce composites was reported to result in improved properties (Savov 2023). Silicon oxide (SiO_2) was added to modified PVA/palm oil starch to improve resistance to rot in particleboard (Abd Norani *et al.* 2017). Sepiolite and clay are considered other mineral materials that have been used to improve different properties in bio-composites and particleboards (Ismita and Lokesh 2017; Olivato *et al.* 2017; Savov 2023).

Wollastonite is another mineral material that can be found abundantly in many countries, including the US, China, and Iran. It has little or no health side effects on humans or wildlife (Huuskonen *et al.* 1983a,b). It was reported to be effective in improving biological resistance to wood decay fungi, and to act as a resin extender (Maxim and McConnell 2005). This mineral has also successfully improved some of the mechanical and hygric properties in wood-based composite panels (Taghiyari *et al.* 2018). Therefore, in the present study, wollastonite has been added to UF resin, as the predominant formaldehyde-based resin used for bonding wood-based composites to find out its effects on some of the less-studied properties of MDF panels, including fire properties and screw withdrawal resistance in the surface and lateral directions.

Adhesive and wood (mainly in form of forest pruning and wood waste) are the two main material costs in a wood-based composite manufacturing factory (Odozi *et al.* 1986). Therefore, it is quite reasonable to look for new sources of lignocellulosic materials to substitute for wood in the production process. In fact, using alternative raw materials, such as agricultural biomass and lignocellulosic waste and by-products, in the manufacture of wood-based composites represents a sustainable response to the rising global demand for wood-based materials and aligns with key circular economy principles. In this connection, different lignocellulosic materials have been reported to be successful in production of composite panels, including straw, stalk, bagasse, fruit seeds, different tree leaves, grass, and palm trees (Pirayesh *et al.* 2013; Nurdin *et al.* 2020).

In this work, to investigate the feasibility of using new fiber sources in MDF panel production, defibrated pruned date palm leaves were partially added to industrial wood fibers. The properties of the resulting composites were then compared with those of panels produced from 100% wood fibers. Given the importance of surface hardness on fire properties and fire spread, hardness was also measured at penetration depths of 1 and 2 mm.

EXPERIMENTAL

Production of MDF Panels

Medium-density fiberboard (MDF) panels were produced using a dry process. To ensure that the produced panels closely resemble industrial ones, wood fibers were sourced from a major MDF panel producer (Sanaye Choobe Khazar Co., Aamol, Mazandaran Province, Iran). The fibers were composed of a mixture of different wood species, including maple (*Acer hyrcanum*), hornbeam (*Carpinus betulus*), beech (*Fagus orientalis*), alder (*Alnus glutinosa*), and three poplar species (*Populus nigra*, *Populus deltoides*, and *Populus euroamericana*). The fibers were dried to the average moisture content of 3% in a vertical cylinder hot-air blow dryer, produced by Mehrabadi Machinery Mfg. Co. (Tehran, Iran).Then they were kept in plastic bags for24 h before the production of panels. Wollastonite was mixed with the adhesives in a laboratory magnetic stirrer for 5 min. The mixed suspension was then uniformly sprayed onto the wood fibers in a rotating drum. The fibers were then weighed, poured into a frame (45 cm × 45 cm) and pressed to form the mat. The average moisture content (MC) of the mat was 7.5%. The mat was pressed for 4 min at 170 °C and a pressure of 160 bar. The hot press was produced by Latibari Mfg. Co. (Tehran, Iran). The target density of the MDF composite panels produced was 700 kg/m^3. Four replicate laboratory-made MDF panels were produced for each treatment. Once produced, all panels were kept in a room at a temperature of 25±2 °C and 42±3% relative humidity for three weeks before being cut to size for the tests. A 40-mm edge was trimmed from each side of all panels to eliminate any source of bias.

Fig. 1. Date palm in Bushehr province (Iran)

Preparation of Palm Pruned Leaves

Date palm (*Phoenix dactylifera* L.) leaves were obtained from an orchard located in Borazjan city (Dashtestan), Bushehr province, Iran (Fig. 1). The geographical location of the garden is latitude: 29° 16' 11" N, longitude: 51° 13' 7" E, with an elevation of 70 m above sea level. Once delivered to Shahid Rajaee Teacher Training University in Tehran, Iran, the leaves were washed with water and then cooked in boiling water for 2 h. Then they were defibrated in a refiner produced by Afshar Mfg. Co. (Tehran, Iran). As to the environmental concerns in many countries, and shortage of water resources as well, no chemical solution (like NaOH) was used in this study. The defibration of the leaves was carried out twice with a 4-h interval in between the two processes. The defibrated palm leaf fibers were mixed with wood fibers at 10%; this percentage was calculated based on the dried weight of the mixed wood fibers. The properties of the MDF panels fabricated with mixed fibers were then compared to those of the control panels made entirely of wood fibers.

Resin Application and Wollastonite Mixing

Two different resins were used for bonding the laboratory-made MDF panels: urea formaldehyde (UF) and isocyanate (IC, pMDI type) resins. The UF and IC resin contents used were 10% and 5%, respectively (based on the dry weight of the composite furnish). The resins were purchased from Tehran Chemical Center (Tehran, Iran). Based on the information from the supplier, the UF resin was produced by Sari Resin Mfg. Co. (Sari, Iran), and the IC resin was produced by Pars Chemical Industries Co. (Tehran, Iran). The specifications of the resins are listed in Table 1.

Table 1. Specifications of the UF and Isocyanate Resins Used in this Work

Resin Type	Density ($g.cm^{-3}$)	Solid Content (%)	pH	Viscosity (cP)	Gel Time (s)
Urea formaldehyde (UF)	1.28	60 to 65	6.8 to 7.1	200-250	50 – 65
Isocyanate (IC)	1.27	100	7	300	-

Table 2. Chemical Composition of the Wollastonite (Taghiyari *et al*. 2018) Mixed with UF and IC Resins

Component	Proportion (% w/w)
CaO	39.77
SiO_2	46.96
Al_2O_3	3.95
Fe_2O_3	2.79
TiO_2	0.22
K_2O	0.04
MgO	1.39
Na_2O	0.16
SO_3	0.05
Water	4.67

Wollastonite suspension with 40% solid content (Fig. 2) was purchased from Mehrabadi Machinery Mfg. Co. (Tehran, Iran). The chemical composition of which is detailed in Table 2. Wollastonite suspension was mixed with UF and IC resins at three addition levels of 0, 5, and 10%, based on the wet weight of the suspension (the stock solution) and the dry weight of the resins. No additional washing or purification was performed on the purchased wollastonite to ensure the production process would be similar to future industrial-scale practices. The resins and wollastonite contents were selected to align with previous projects.

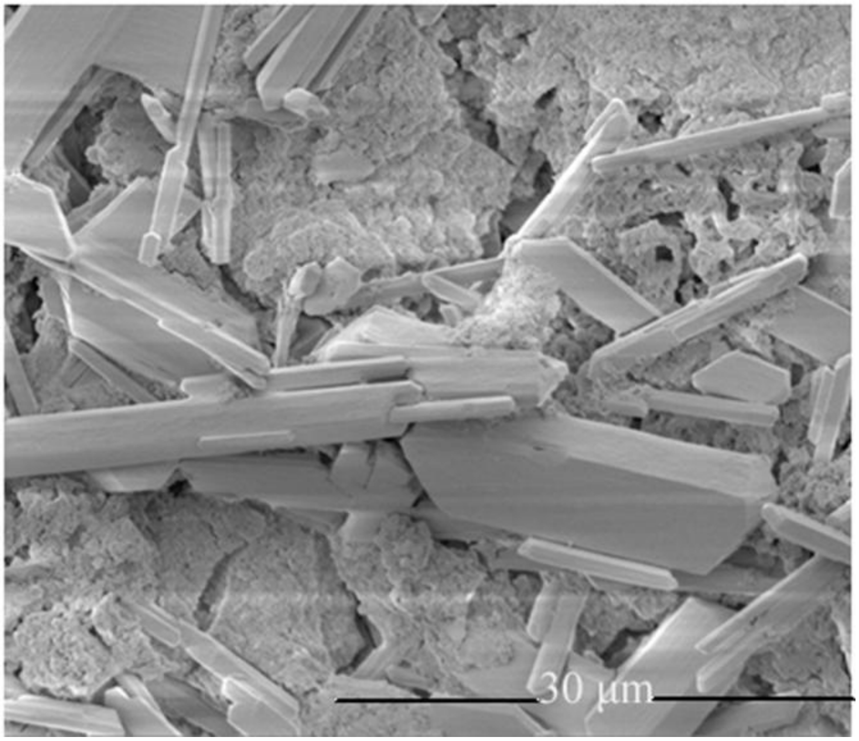


Fig. 2. SEM image of the wollastonite needle-like particles used in this work

Screw Withdrawal, Hardness, and Fire Tests

Screws were installed according to ASTM D1761-20 (2020) standard specifications. Two 75 mm × 75 mm specimens were cut at scattered locations from each panel, totaling 96 screw withdrawal specimens (Fig. 3A and B). Once cut, all specimens were kept at a temperature of 28 °C and relative humidity of 40 ± 3%.

The diameter of MDF screws was 4.23 mm (Fig. 3A). A 2-mm pilot hole was drilled on the surface and lateral side of the specimens. The depth of screw penetration in both directions was 17 mm. It was ensured that the tip of the screws was exposed on the bottom surface of the specimens.

Hardness specimens were prepared according to ASTM D1037-12 (2020) standard specifications. The force against the penetration of the hardness ball (in Newton) was measured at 1- and 2-mm depths to find out the difference in the surface layers between different panel treatments.

Screw withdrawal and hardness tests were performed on an Instron 4486 Universal Testing machine with 10 kN capacity, at the Wood Mechanical Properties Laboratory (Shahid Rajaee Teacher Training University, Tehran, Iran). The loading speed was set to a fixed rate of 2 mm per minute for all tests.

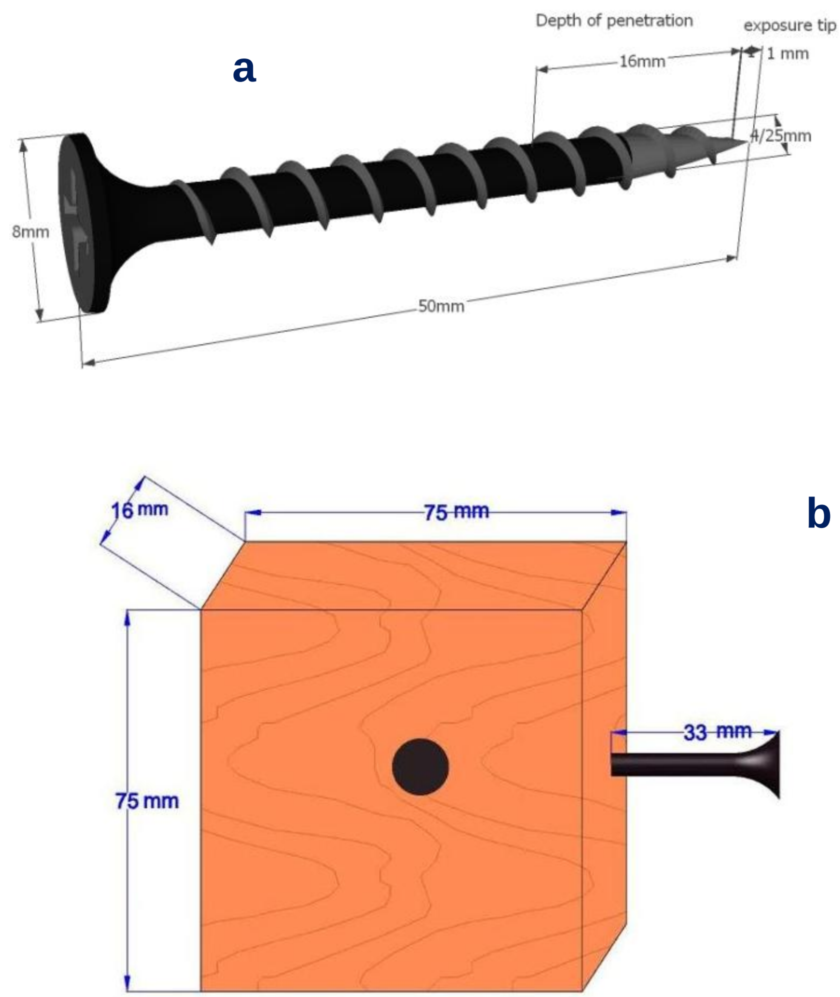


Fig. 3. Schematic drawings of: a) the MDF screw, and b) the screw withdrawal test specimen with two screws on the surface and lateral directions

Fire properties were measured using an apparatus (slide fire test apparatus, SFTA), built based on the requirements of standard ISO 11925-3 (1997). Upright specimens were exposed to a Bunsen-type burner for 120 s and held at a 45° angle. The whole apparatus and the specimen were kept in a three-wall compartment to limit movement of the surrounding air. Fire properties included times to the onset of ignition, to the onset of glowing, duration of glowing after 120 s, the burnet area, and weight loss after 120 s exposure to piloted fire.

Statistical Analysis

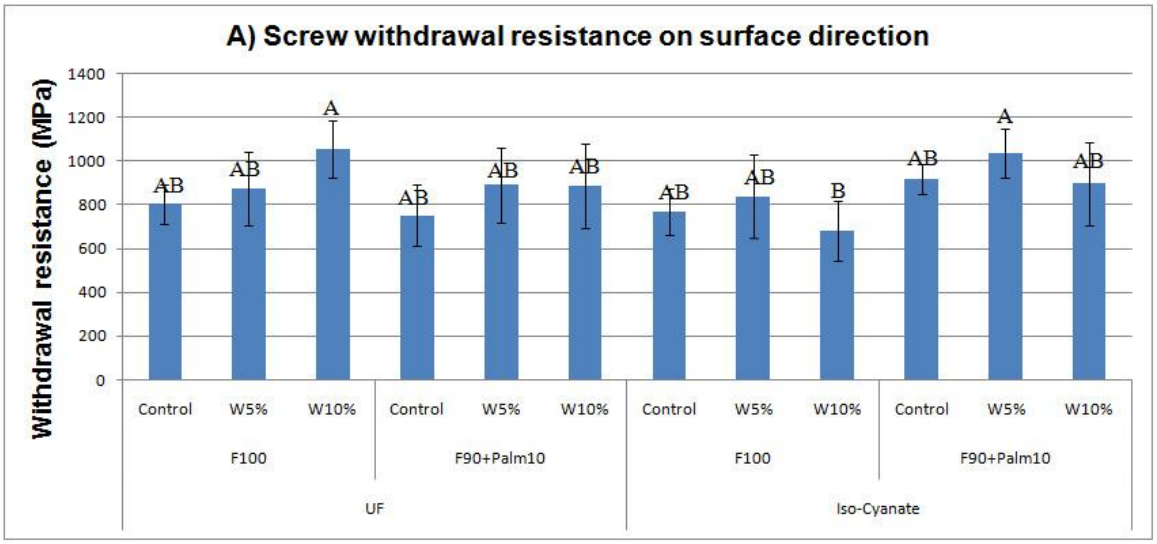
Analysis of variance (ANOVA) was carried out to find out statistical significance at a 95% of confidence among the MDF panels produced, using SAS software, version 9.2 (2010). For grouping of similar treatments based on each property, Duncan's multiple range test was performed. Hierarchical cluster analysis (including dendrograms and using Ward methods with squared Euclidean distance intervals) was carried out using SPSS/18 software (2010). To investigate the correlation among different properties, fitted line and contour plots were designed by Minitab software (version 16.2.2, 2010).

RESULTS

Screw Withdrawal Resistance

Screw withdrawal resistance values were generally higher in the face direction compared to the lateral direction (Fig. 4 A and B). The highest and lowest values in the face direction were found in UF-bonded panels manufactured from 100% wood fibers and 10% wollastonite (1057.8 MPa) and IC-bonded MDF panels fabricated from 100% wood fibers and 10% wollastonite (682.5 MPa), respectively (Fig. 4 A).

The addition of defibrated palm leaves resulted in decreased screw withdrawal values in the face direction of all UF-bonded panels. Conversely, in the panels produced with isocyanate resin, it resulted in an increase in these values.



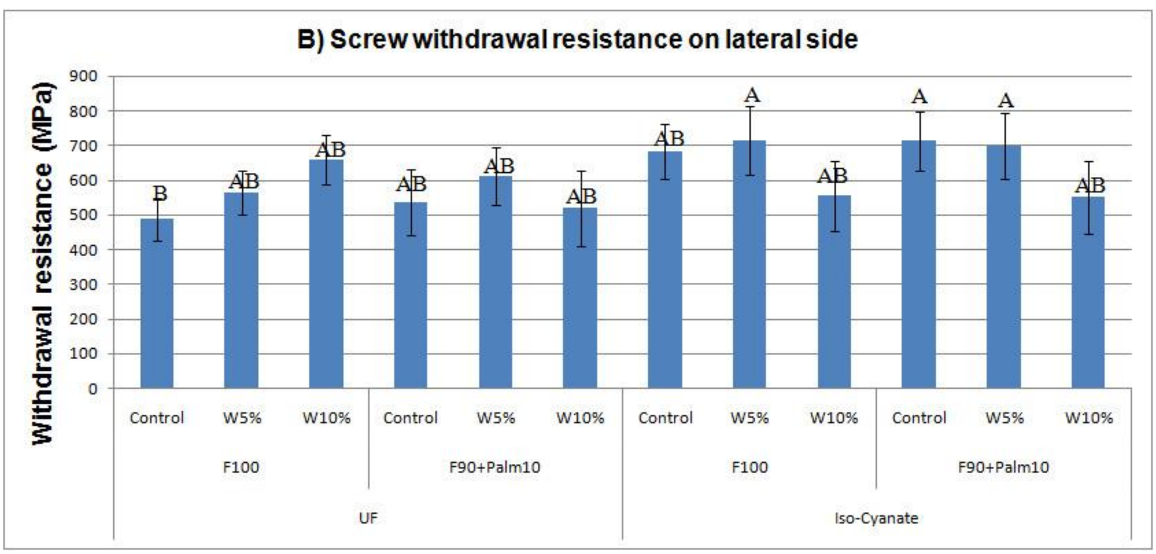


Fig. 4 (A & B). Screw withdrawal resistance values (MPa) in face (A) and lateral (B) directions and disturbed area (mm^2) in face direction (C) in MDF panels manufactured from wood fibers and defibrated pruned palm leaves and two resins (W=wollastonite content; F=wood fiber content; Palm=defibrated palm leave content; UF=urea-formaldehyde resin) (Letters on each column represent Duncan's Multiple Range Groupings at 95% level of confidence)

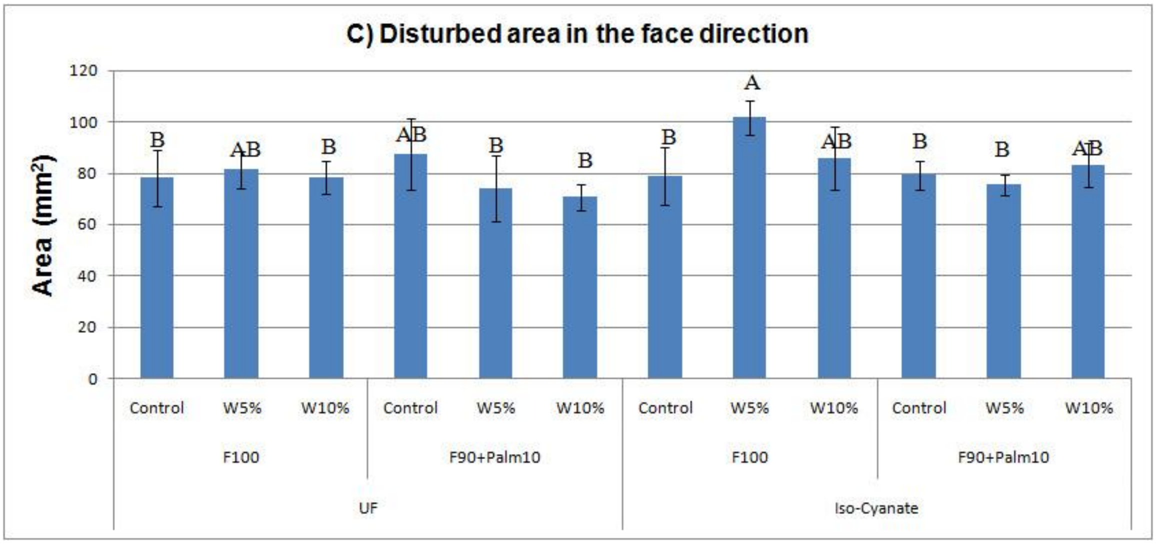


Fig. 4 (C). Screw withdrawal resistance values (MPa) in face (A) and lateral (B) directions and disturbed area (mm^2) in face direction (C) in MDF panels manufactured from wood fibers and defibrated pruned palm leaves and two resins (W=wollastonite content; F=wood fiber content; Palm=defibrated palm leave content; UF=urea-formaldehyde resin) (Letters on each column represent Duncan's Multiple Range Groupings at 95% level of confidence)

In lateral direction, the highest and lowest screw withdrawal values were determined in the IC-bonded panels with 5% wollastonite and 100% wood fibers (714 MPa) and UF-bonded panels with 10% wollastonite and mixed furnish (519 MPa), respectively (Fig. 4B). The lateral screw withdrawal resistance values were generally higher in the laboratory-made MDF panels bonded with isocyanate resin compared to their counterparts manufactured with UF resin (Fig. 4B), except for the panels with 100% wood fibers and 10% wollastonite.

The addition of 5% wollastonite resulted in an increase in all UF-bonded panels. Wollastonite content of 5% showed no statistical significance in the panels, bonded with isocyanate resin. Increasing the wollastonite content to 10% showed an improvement only in the panels produced with 100% wood fibers and UF resin. In all other treatments, screw withdrawal resistance in lateral direction decreased significantly as a result of addition of 10% wollastonite.

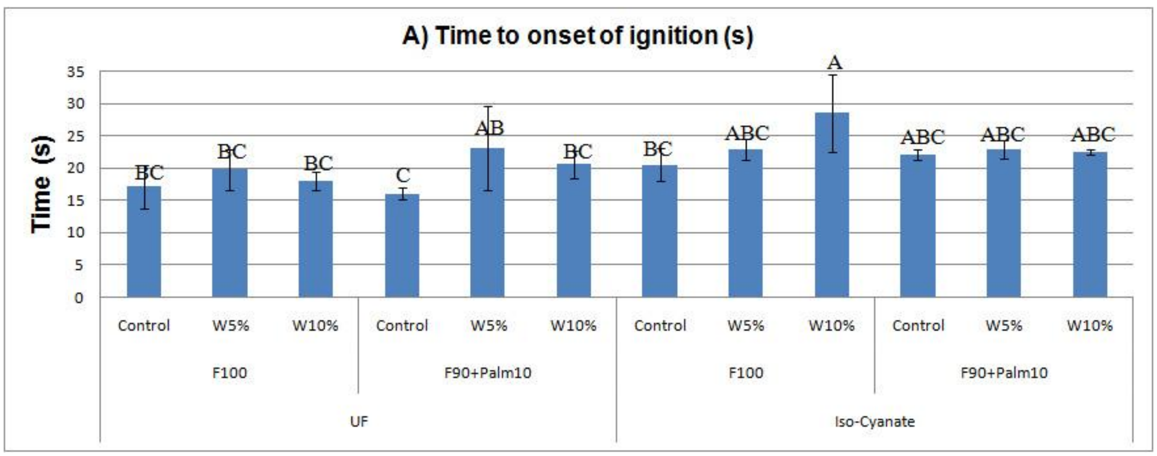
The addition of defibrated palm leaves resulted in insignificant changes in the disturbed area of the UF-bonded MDF panels (Fig. 4C). In the case of IC-bonded panels, the addition of palm leaves tended to decrease the values, although not always significantly. The addition of wollastonite demonstrated an increasing effect in both UF- and IC-bonded panels fabricated from 100% wood fibers. Wollastonite tended to have a decreasing effect in the panels containing defibrated palm leaves.

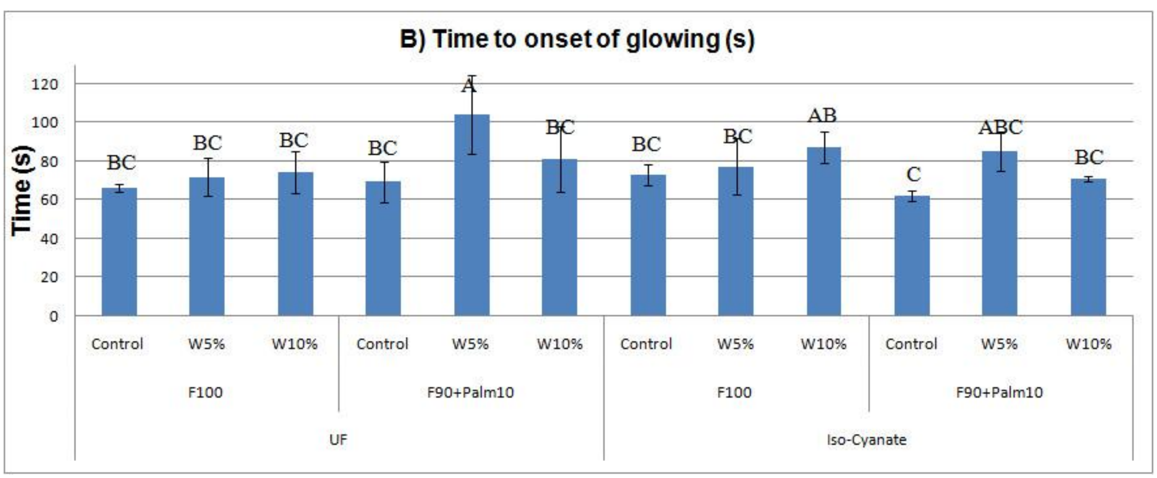
Fire Properties

The longest and shortest times to onset of ignition were found in the IC-bonded panels with 100% wood fibers and 10% wollastonite (28.5 s), and UF-bonded panels and mixed furnish (90% wood fibers and 10% defibrated palm leaves) (16.5 s), respectively (Fig. 5A). The MDF panels produced with IC resin generally exhibited longer times to onset of ignition compared to those produced with UF resin. The addition of wollastonite increased the time to onset of ignition in all treatments, although the improvement was not statistically significant in all cases (Fig. 5A).

In terms of the time to onset of glowing (Fig. 5B), the longest and shortest times were found in UF-bonded panels with 5% wollastonite and mixed furnish (104.5s) and IC-bonded panels with a mixed furnish (62s), respectively. The addition of both wollastonite and defibrated palm leaves increased this property, although in some cases, the improvements were not statistically significant. With the exception of the IC-bonded panels with 100% wood fibers, the addition of 5% wollastonite seemed to be more effective in increasing the time to onset of ignition. Though significant in some cases, the addition of defibrated palm leaves did not have any obvious trend in the time to onset of glowing.

The longest and shortest duration of glowing were found in the UF-bonded panels with 100% wood fibers (236 s) and UF-bonded panels with 10% wollastonite and the mixed furnish (185 s) (Fig. 5C). The highest and lowest burnt areas were calculated in the laboratory-made MDF panels, fabricated from 100% wood fibers and 10% wollastonite, bonded with isocyanate resin (1777 mm^2), and in the UF-bonded panels with 5% wollastonite and mixed furnish (1292 mm^2) (Fig. 5D). The highest and lowest weight losses were calculated in the IC-bonded panels with 10% wollastonite and mixed furnish (0.83%) and UF-bonded panels with 5% wollastonite and mixed furnish (0.54%), respectively (Fig. 5E). No general trends were observed in the duration of glowing, burnt area, or weight loss among the treatments, although significant differences were found in some cases.





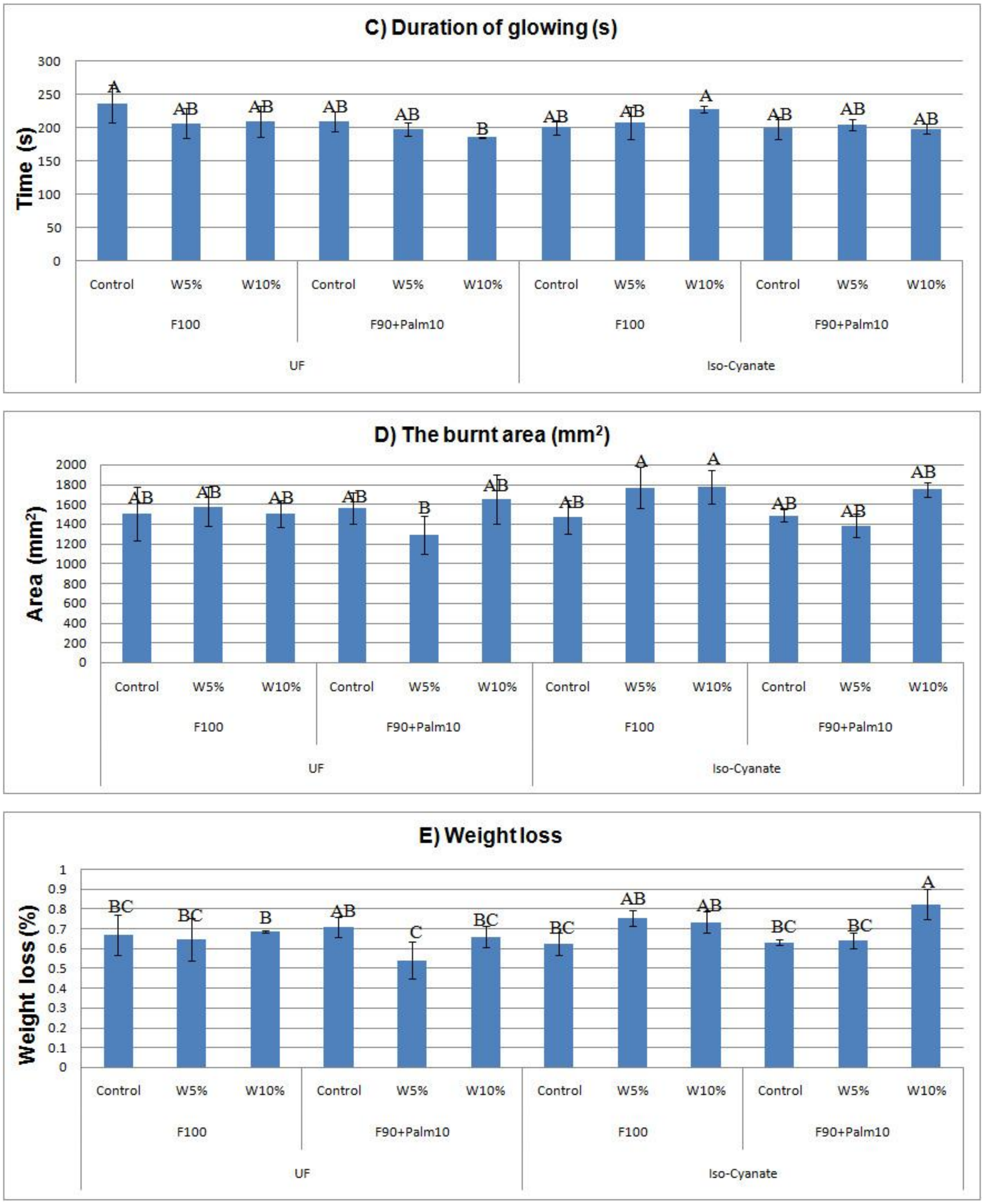


Fig. 5. Fire properties of time to onset of ignition (A), time to onset of glowing (B), duration of glowing (C), burnt area (D), and weight loss (E) in MDF panels with wood fibers and defibrated palm leaves and two resins (W=wollastonite content; F=wood fiber content; Palm=defibrated pruned palm leave content; UF=urea-formaldehyde resin)(Letters on each column represent Duncan's Multiple Range Groupings at 95% level of confidence)

Hardness

The highest and lowest hardness values at 2 mm depth of penetration were found in the UF-bonded panels made with 10% wollastonite and mixed furnish (1,013 N) and IC-bonded panels with 10% wollastonite and 100% wood fibers (650 N), respectively (Fig.

6). The addition of wollastonite had an increasing effect on the hardness values in all panels, bonded with UF resin, both at 5% and 10% wollastonite contents, though W10% panels exhibited hardness values that were lower than those of W5% panels. In terms of the panels, bonded with isocyanate resin, the addition of wollastonite resulted in decreased hardness values at both wollastonite addition levels. Although slight fluctuations were observed in the treatments (most of them statistically insignificant), the addition of defibrated palm leaves showed no consistent trend in hardness values.

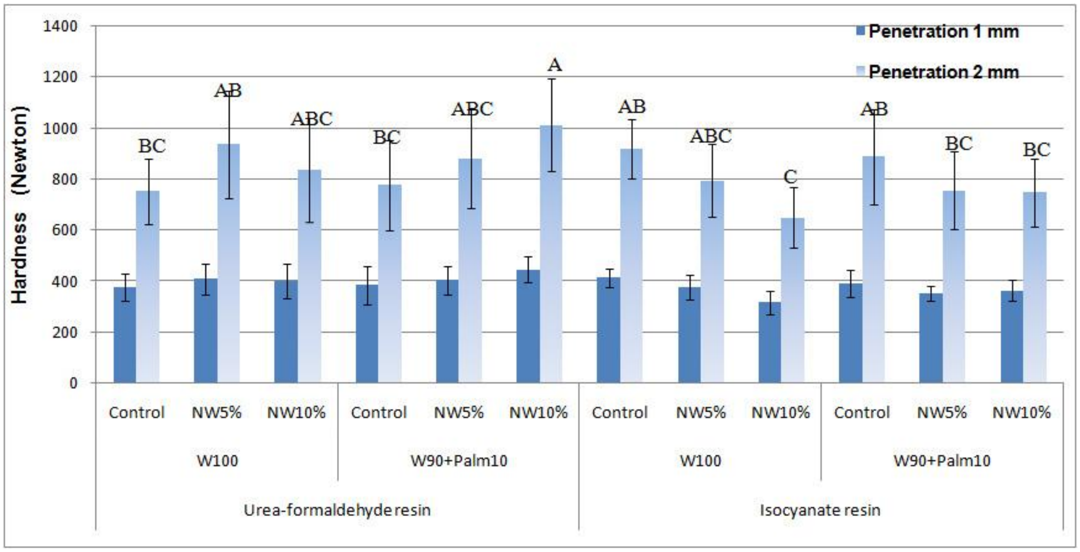


Fig. 6. Hardness values (Newton) at two depths of penetration (1 and 2 mm) in MDF panels with wood fibers and defibrated palm leaves and two resins (W=wollastonite content; F=wood fiber content; Palm=defibrated pruned palm leave content; UF=urea-formaldehyde resin) (Letters on each column represent Duncan's Multiple Range Groupings at 95% level of confidence for 2 mm depth of penetration)

DISCUSSION

Higher screw withdrawal resistance in the face direction was attributed to the higher density and integrity of wood fibers on the surface layers of composite panels. Studies have repeatedly shown that the surface layers of wood-based composite panels (mainly MDF and particleboard) have higher density and strength compared to the core layer (Suchsland 1959; Dai and Steiner 1997; Winistorfer *et al.* 1999; Wong *et al.* 1999; Wang and Winistorfer 2000).

Although the isocyanate resin content was half that of UF resin, screw withdrawal resistance values in the face direction of the IC-bonded panels were comparable to those of the UF-bonded panels. Markedly, screw withdrawal resistance values in the lateral direction were generally higher in the IC-bonded MDF panels, which demonstrated the efficiency of IC resin in comparison to UF resin. In this connection, high correlation was found between internal bond with screw withdrawal resistance in the lateral direction in IC-panels (Fig. 7A and B). However, correlation was low and insignificant in UF-panels, though the target density of all panels was the same. This implied an effective influence of IC-resin in various mechanical properties of panels produced with IC-resin. In this regard, IC resin makes bubbles while curing during hot pressing(Frihart 2005; Pizzi and Mittal

2010). These bubbles are formed within the micro-sized spaces among fibers and chips in a composite panel. It is hypothesized that their formation makes the entire core layer structure more integrated in the IC-bonded panels compared to their UF counterparts, where the UF resin only covers the surface of the fibers.

It has previously been reported that the formation of these bubbles significantly decreases water absorption and thickness swelling of wood-based composite panels (Taghiyari *et al.* 2018). The higher efficiency of IC resin can be attributed to the formation of these bubbles during resin polymerization (Frihart 2005; Pizzi and Mittal 2010), adding to the integrity and strength of the whole composite structure. However, further studies should be carried out, with special attention to the density profile of the produced panels in relation to their physical and mechanical properties, before making a final firm conclusion in this regard.

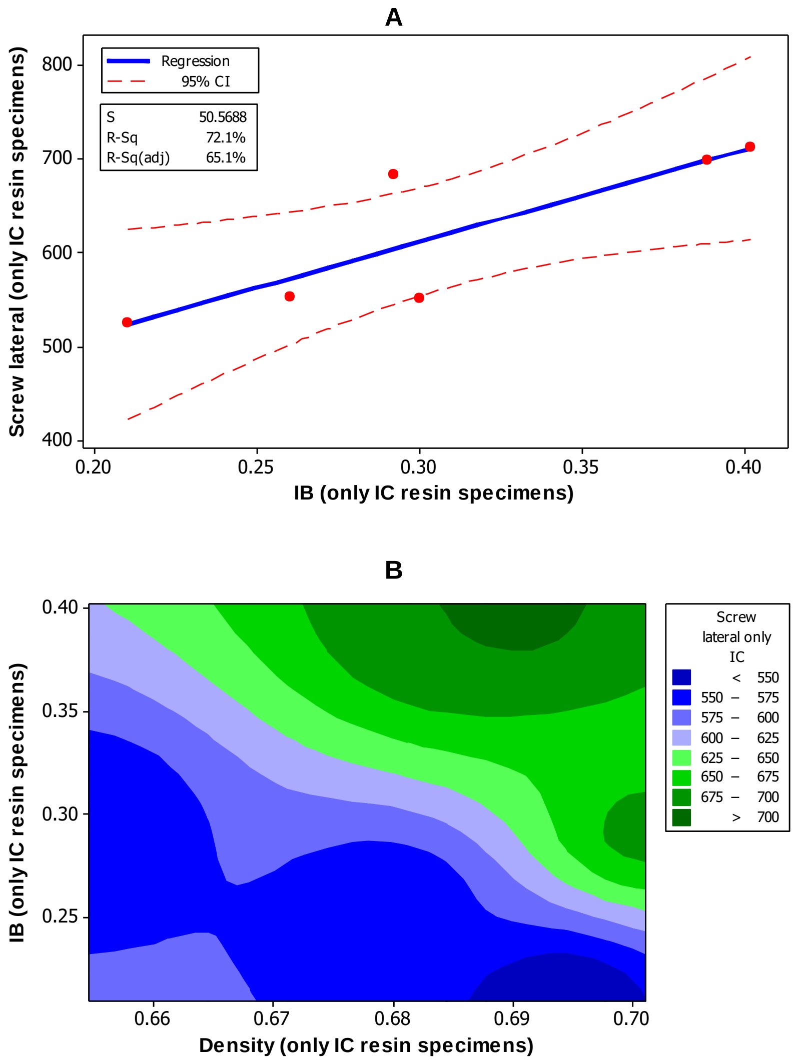


Fig. 7. Relation between the internal bond (IB) and screw withdrawal resistance values (A) in panels produced with isocyanate (IC) resin, and their connection with the density of panels (B)

The increase in screw withdrawal resistance in the UF-bonded panels, caused by the addition of wollastonite, was attributed to its reinforcing effect. However, further studies are to be carried out to find more about the mechanism that wollastonite interacts with different resins (especially UF, IC, and PVA) and causes of its reinforcing effect. This reinforcing effect also caused the disturbed area in UF- and IC-bonded panels with 5% wollastonite to increase significantly (Fig. 4C). However, it is to be noted that the reinforcing effect seemed to be less effective in panels containing palm leaves; this might be attributed to the softer texture of the palm leaves so that wollastonite could not compensate for the strength loss. Wollastonite demonstrated an increasing effect at both content levels of 5% and 10% in UF-bonded panels; while in the IC-bonded MDF panels, the increases were significant only at 5% wollastonite content. The laboratory-fabricated MDF panels, bonded with isocyanate resin and 10% addition level of wollastonite showed a decrease which was attributed to the absorption of part of the resin by wollastonite needles. The lower properties in panels with 10% wollastonite content were also attributed to the widespread observation demonstrating that higher levels of fiber reinforcement in a matrix (in this case, the UF resin) lead to decreased strength of panels. It is explained that clusters of fibers, which often are not completely wetted by the resin, can create weak points in the composite, causing breakage at these locations (Hubbe 2023). In the same article, it was also reported that fibers may collide with each other during mixing process and by the shearing action during agitation.

In terms of fire properties, IC-bonded panels demonstrated longer times to onset of ignition and glowing in comparison to UF-bonded panels. It is hypothesized that the micro-bubble structure acted like intumescent paint, significantly increasing the time to onset of ignition and glowing. However, further studies focusing on the micro-structure of IC resin and its reaction to piloted ignition (White and Dietenberger 1999) are necessary. The advantageous effect of the isocyanate introduction to formaldehyde-based resin (PF) on fire properties has also been reported in the study on the production of particleboards with enhanced fire resistance. It was hypothesized that the extension of ignition time and the increase in flash point temperature could have been caused by a stronger adhesion or improved morphology of cured bond lines; however, the authors also concluded that more analysis is needed to fully explain this phenomenon (Kawalerczyk *et al.* 2024).

The addition of wollastonite tended to increase the times to onset of ignition and glowing, though the increased values were not statistically significant in all cases. Wollastonite contributed to the formation of an incombustible layer, leading to a favorable increase in these two fire properties. Moreover, wollastonite also demonstrates high thermal conductivity, which prevents the heat accumulation within a spot exposed to a heat source. Consequently, it can lead to the extension of both ignition and glowing time (Kawalerczyk*et al.* 2023). The addition of defibrated palm leaves did not demonstrate a clear trend in fire properties, showing both decreasing and increasing effects. The lack of a clear trend and the observed mixed alterations indicated that the interaction between different variables plays a decisive role in the overall outcome. Therefore, further studies with varying contents of defibrated palm leaves are necessary to better clarify the extent of their effects on fire properties.

The increase in hardness values in UF-bonded panels was attributed to the reinforcing effect of wollastonite in UF resin, as previously reported (Taghiyari *et al.* 2018). However, due to the low resin content in the IC-bonded panels, some resin was absorbed by wollastonite particles (needles), resulting in a decreased hardness values in the IC-bonded MDF panels containing wollastonite.

The absorption of UF resin by wollastonite needles in the laboratory-made MDF panels with 10% wollastonite and 100% wood fibers had the same effect on hardness; that is, hardness value of UF-bonded panels (100% wood fibers) with 10% wollastonite was lower than that of 5% wollastonite, though the hardness value was still higher than the control specimens.

In the present research study and with due consideration to the limitation of raw materials in Iran, it should be noticed that rather high variability was found within groups in each and every panel treatments, demonstrated by the error bars in Figs.4, 5, and 6. This high variability might seem to be rather high in wood-based composite panels, which are considered to have a more uniform structure in comparison to solid wood. However, and as it was mentioned in the Experimental section, a mixture of different wood species were sourced from a major MDF panel producer so that the final products at a laboratory scale can closely resemble those at an industrial scale. Therefore, production of more uniform composite panels with less variation in the raw materials can be considered the topic of further research studies.

In terms of the cluster analysis, the different impacts of the addition of the above-mentioned materials on different fire and screw withdrawal properties were translated into a mixed grouping of different treatments. Taghiyari *et al.*(2018) found a distinct grouping between treatments (panels) with UF resin *versus* the panels bonded with IC resin when the physical and mechanical properties of panels were studied (including modulus of rupture, modulus of elasticity, internal bond strength, water absorption, and thickness swelling). However, in terms of the fire and screw withdrawal properties in the present study, no clear trend was observed due to the varying impact of the addition of wollastonite and defibrated pruned palm leaves to the composite furnish (Fig. 8). Therefore, it was concluded that generalization and prediction on the effects of addition of wollastonite and defibrated palm leaves cannot be done for fire and screw withdrawal properties.

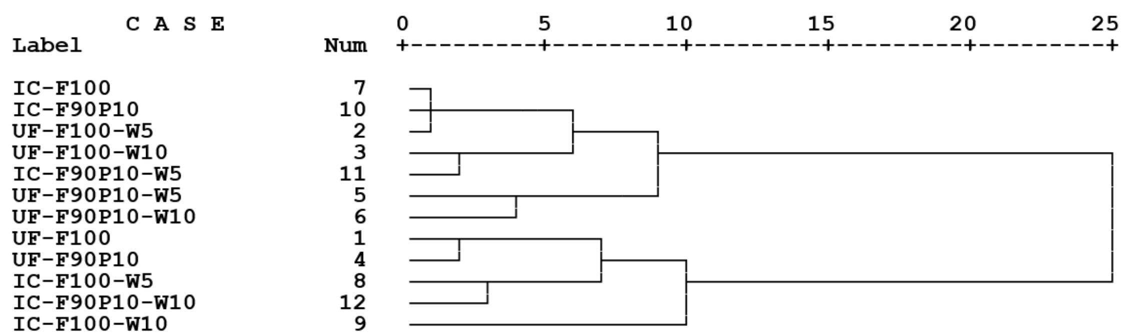


Fig. 8. Cluster analysis of the twelve MDF composite treatments based on fire properties, screw withdrawal resistance, and hardness values (IC=isocyanate resin; UF=urea-formaldehyde resin; F=wood fiber; P=palm defibrated leave; W=wollastonite)

CONCLUSIONS

1. Wollastonite at a content level of 5% (dry weight of the resin used) can be recommended in the production of medium density fiberboard (MDF) panels.
2. The reinforcing effect of wollastonite resulted in a general improvement in screw withdrawal resistance and hardness of the laboratory-made MDF panels.

3. In terms of fire properties, wollastonite acted as an incombustible physical barrier towards the penetration of flame into the texture of MDF specimens, and the spread of fire on the adjacent surface of panels.
4. The addition of defibrated palm leaves had a deteriorating effect on some properties. However, this effect was negligible considering its positive impact on other properties. Therefore, this renewable source of lignocellulosic fibers can be considered a promising alternative source of fibers to be mixed with wood fibers.

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