Comparison between Some Factors Affecting Screw Withdrawal Resistance from Different Wood-composite Panels

Saeed Eshaghi,[a] Hamid Reza Taghiyari,[b,]* and Mahdi Faezipour,[a]

Effects of screw type, screw diameter, and drive direction (perpendicular to the face and edge of specimens), as well as wood-composite panel type, on the withdrawal resistance in bagasse-fiber particleboard (BPB), medium density fiber board (MDF), and plywood were investigated in the present study. Two sizes of fine-thread drywall screw (sizes 8 and 10), and two sizes of sheet-metal screw (sizes 8 and 10), were chosen. All screws were 50 mm in length. The results showed that an increase in the screw size would result in higher withdrawal resistance in both screw types. Furthermore, plywood showed higher withdrawal resistance in comparison to the other two wood-composites. Due to higher integrity in the wood-composite, withdrawal resistance perpendicular to the face of the composites was higher in comparison to the edge direction. Longer thread in sheet-metal screws caused better involvement with the composites and therefore more connecting surface; consequently, stronger involvement with it, resulting in higher withdrawal resistance of sheet-metal screws.

Keywords: Agricultural residue; Bagasse fiber; Medium-Density Fiberboard (MDF); Natural fibers; Plywood; Screw drive direction; Withdrawal resistance.

*Contact information: a: Department of Wood & Paper Science, The Faculty of Natural Resources, The University of Tehran, Karadj, Iran; b: Wood Science & Technology Department, Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran; *Corresponding author: 0930-2005235; htaghiyari@srttu.edu & htaghiyari@yahoo.co*

INTRODUCTION

Composite panels such as particleboard, fiberboard, and plywood have numerous commercial applications and are widely used in furniture manufacturing in Iran and worldwide. Many research projects have been carried out to overcome the shortcomings of composite panels (Dashti et al. 2012; Stockel et al., 2012). In this connection, and due to the unsustainable harvesting, the amount of wooden resources has noticeably been decreasing (Barna, 2011). Thus, other lignocellulose fibers like agricultural residues have also aroused a lot of interest as a cheap raw material in composite manufacturing particleboard as well as paper manufacturing (Tofanica et al. 2011). Bagasse and other agricultural residues were reported to have promising results (Nikvash et al. 2010). In this connection, enhanced enzymatic delignification of bagasse fibers was reported to be an efficient approach (Rezende et al. 2011). Bagasse fibers have improving results in cement (Mahendran et al. 2013).

Numerous joints are being used in the furniture industry. Joints by different types of screws (Taghiyari et al. 2012) and treated by various nano-materials (Taghiyari 2013) are now becoming common in this industry. Eckelman (2003) stated that joints in every structure are the weakest part of it. Based on a theory termed "weakest link" by Weibull, the failure of a specimen will occur when the stress in the specimen is the same as the stress that would cause the failure of the weakest element of volume if tested independently (Eckelman 2003); it would therefore be quite necessary to evaluate the strength of joints in furniture. Some studies (Eckelman 2003; Taghiyari et al. 2012) were conducted on screwed joints in MDF, particleboard, plywood and OSB panels, and heat-treated solid woods, with most of them focusing on screw withdrawal resistance. These studies have revealed that screw withdrawal resistance depended on diameter of screw, corresponding lead hole and the penetration depth of the screw. Haftkhani et al. (2011) investigated the effect of geometrical size and various screw types on the withdrawal resistance of industrial WPC used in furniture industry. Their results indicated that screw withdrawal resistance increased with increase in screw's diameter, penetration depth, and loading rate. Nail withdrawal resistance in particleboard and MDF was almost similar to the manufactured WPC boards (particularly the WPC boards with 70% filler). Eckelman (2003) showed that screw withdrawal resistance in perpendicular direction to the face in comparison to its edge was 75% higher; they concluded that screw withdrawal resistance was influenced by the board density, internal bonding, screw diameter and penetration depth. Results revealed that screw withdrawal resistance was not influenced by percentage of wood flour.

Different types of screws are currently used frequently in furniture-manufacturing industry in Iran, and the lateral resistance to various composite panels was studied and compared (Eshaghi et al. 2013). Upon reviewing the above mentioned literature, one can see that many studies have so far been carried out on the effects of different factors affecting screw withdrawal resistance; however, little or no particular study reported comparison between different factors in one single study, reporting to what extent different variables affect the withdrawal resistance, so that the industry would be in a position to choose the best suited joint for a particular composite board. It was therefore decided to carry out a practical research project on the potential application of bagasse natural fibers and comparing common types and diameters of screws in commercial bagasse particleboard (BPB), medium-density fiberboard (MDF), and plywood.

EXPERIMENTAL

Screw Type and Size

Two type of screws were used in this research including sheet metal screws with 4 and 5 mm in nominal diameter (sizes 8 and 10, with normal thread) and fine thread drywall screws with nominal diameters of 4 and 5 mm (sizes 8 and 10). Table 1 presents features of the screws in this research. All screws in this study were 50 mm in length.

Table 1. Major specifications of screws

Screw type	Screw gauge	Nominal diameter	Actual diameter	Root diameter	Thread type

		(mm)	(mm)	(mm)	
Drywall	8	4	4.2	2.6	fine
Drywall	10	5	4.6	2.9	fine
Sheet metal	8	4	4.2	3	normal
Sheet metal	10	5	4.8	3.3	normal

Preparation of the Specimens

In this research, commercial bagasse particleboard (BPB) was prepared from bagasse particleboards (BPB) from Debel Composite Manufacturing Co.; medium density fiberboard (MDF) was prepared from Sanaye Choobe Khazar Company in Iran (MDF Caspian Khazar); and commercial plywood was prepared from Neka-Wood Co. Nominal thickness of bagasse particleboard and MDF was 16 mm; and that of plywood was 19 mm. An11-layer plywood was produced from three hardwood species of beech (*Fagus Orientalis*), Hornbeam (*Carpinus Betulus*), and Alder (*Alnus Glutinosa*). The moisture content and density of panels were measured according to EN 322 (2007), EN 323 (2007); internal bond strength, modulus of rupture (MOR) and modulus of elasticity (MOE) of the panel were performed according to EN 319 (2007), EN 310 (2007) and thickness swelling and water absorption of the panels were measured according to EN 317 (2007). Major properties of the panels are listed in Table 2.

Table 2. Major properties of the panels in this study

Panel type	Moisture content (%)	Density (g/cm^3)	Water absorption (%)	Thickness swelling (%)	IB (MPa)	MOE (MPa)	MOR (MPa)
BPB[1]	6.24	0.6	76.88	11.7	0.66	3308	25.25
MDF[2]	7.11	0.7	14.3	6.42	0.8	4432	36.13
Plywood	7	0.7	22.4	6	-	6800	66

The test specimens were prepared according to EN320 (2007) standard with the dimension of 75 × 75 mm. The specimens were maintained in conditioning chamber under relative humidity of 65 ± 1 % and the temperature of 20 ± 2^{o}C. Subsequently, the screws were driven on the face and the edge of the specimens. A schematic of the set-up specimens is depicted in Fig. 1.

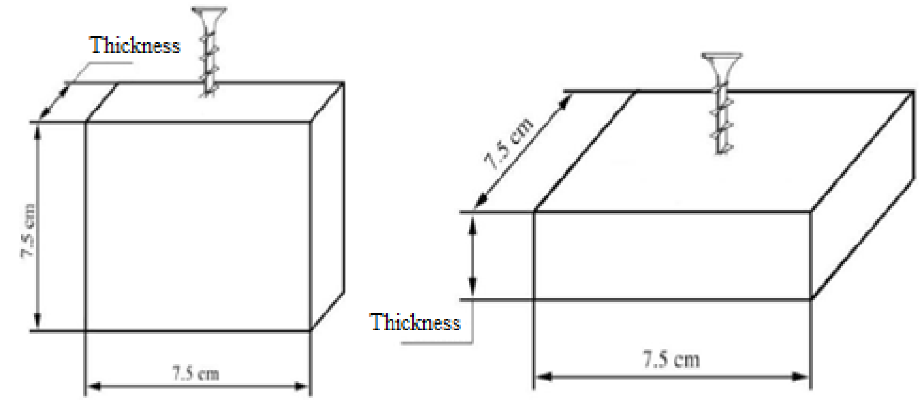

Fig. 1. Schematic drawing of the screw penetration directions of perpendicular to the edge and face of the composite specimens (Right: perpendicular to the face of specimen; and Left: perpendicular to the edge of specimen)

Loading rate was 2.5 mm/min. Constant factors in were board density, screw penetration depth, and board internal bonding; variable factors included panel type, screw type, and screw drive directions. Since penetration depth has a significant effect on withdrawal resistance (Eckelman 2003), the same penetration depth was used for edge and face for comparison between the withdrawal resistance values. Penetration depth for comparison between face and edge withdrawal resistance for various screws in plywood was 19 mm, and also 16 mm for BPB and MDF. Diameter of the pilot hole was 80-90% of the root diameter of each screw. Withdrawal resistance in perpendicular direction to the face (PF) and edge (PE) of the test specimens was measured by INSTRON testing machine (Model 4486). For each treatment, five replications were prepared and withdrawal resistance was calculated with Equation 1.

$$W = \frac{P_{max}}{L} \qquad \text{(Equation 1)}$$

Where W is screw withdrawal resistance (N/mm), P_{max} maximum load (N), and L penetration depth (mm).

Statistical Analysis

Statistical analysis was conducted using the SAS software program, version 9.2 (2010). One-way ANOVA was performed to discern significant differences at the 95% level of confidence. Groupings were carried out using Duncan's multiple range 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 determine 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.

RESULTS AND DISCUSSION

Results of withdrawal resistance measurement showed that the highest value was found in size 10 of sheet metal screw perpendicular to the face of plywood composite-boards (202.56 N/mm) while the lowest value was found in size 8 of sheet metal screw perpendicular to the edge of BPB composite-boards (57.89 N/mm) (Figures 2–4). Generally, withdrawal resistance values of plywood specimens were reported to be significantly higher than MDF and BPB; the reason was reported to be the orientation of wood grains in the composite structure (Eshaghi et al. 2013); that is, different layers were oriented at 90 degrees to each other, forming a hard network, and they were stuck together with resin, presenting a strong complex. In the other two composite boards (MDF and BPB), however, the small wood or bagasse particles did not have as much integrity as in plywood, resulting in weaker strengths. Sheet-metal screw with the smaller size (8) had higher withdrawal resistance perpendicular to the edge (193.2 N/mm) than that perpendicular to the face (179.5 N/mm) in plywood specimens (Fig. 4). The reason was to the lower integrity of layers in plywood in this direction; that is, the threads of the screw had a tendency to break the adhesive line when they were screwed in the perpendicular direction to the edge rather than being penetrated deep into the structure of the woody material, resulting in lower involvement and less contact surface between the screw-thread and woody layers. When the size of sheet-metal screw was made bigger (size 10), the withdrawal resistance perpendicular to the face of the plywood specimens were significantly higher (202.6 N/mm) in comparison to that perpendicular to the edge (178.2 N/mm) because more fibers where involved in the process of pulling back the screw.

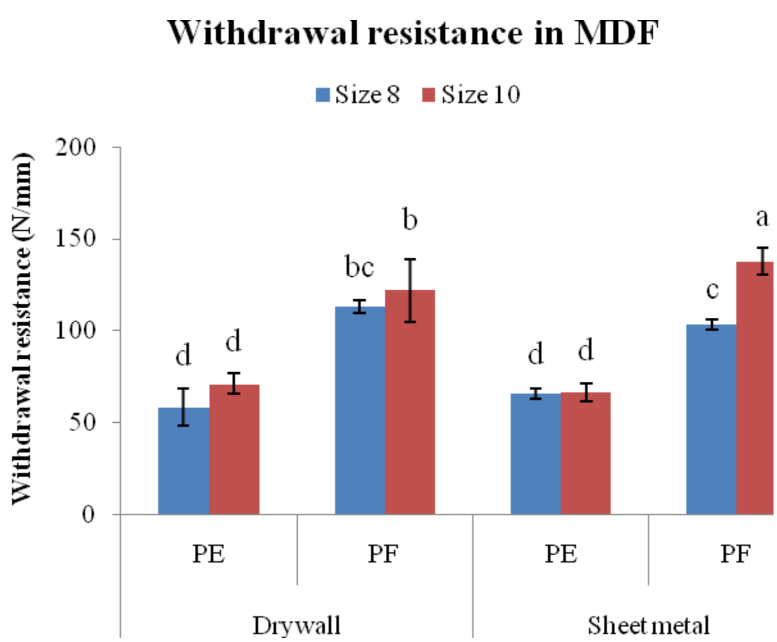

Fig. 2. Corresponding effect of screw type, screw size, and screw direction on the withdrawal resistance in medium-density fiberboard (MDF) (N/mm)

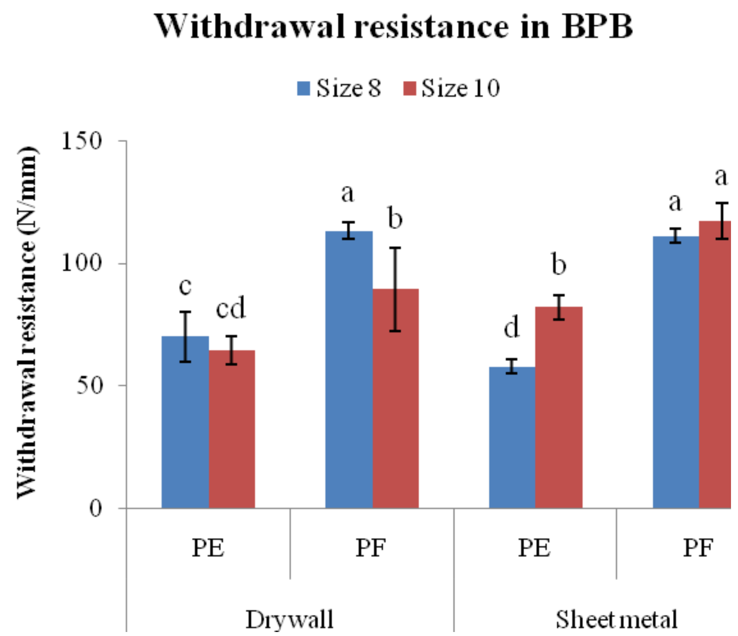

Fig. 3. Corresponding effect of screw type, screw size, and screw direction on the withdrawal resistance in bagasse particleboards (BPB) (N/mm)

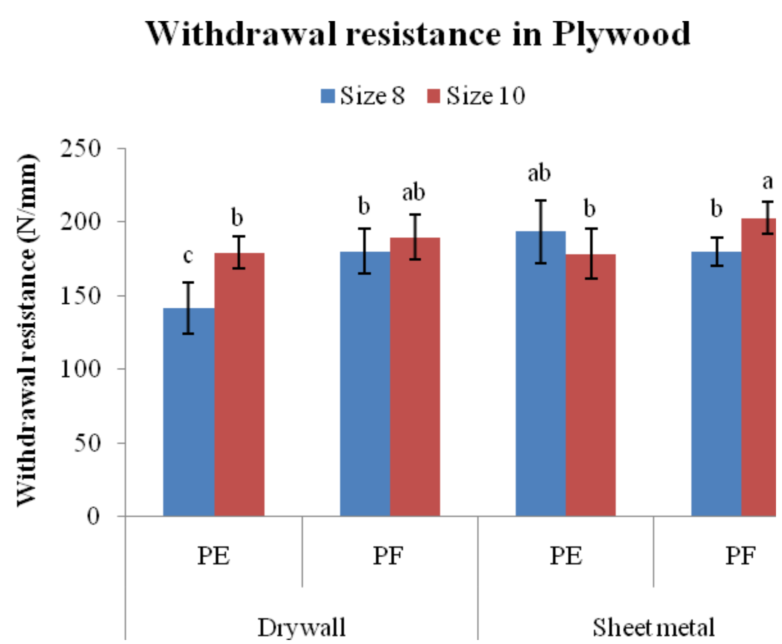

Fig. 4. Corresponding effect of screw type, screw size, and screw direction on the withdrawal resistance in plywood (N/mm)

Effect of Screw Type on Withdrawal Resistance

Figure 5 shows the effect of screw type and the corresponding effect of the panel and screw type on withdrawal resistance, respectively. The highest withdrawal was observed in plywood with sheet metal screw (188.38 N/mm) and the lowest in BPB joint with drywall screw (84.36 N/mm) (Fig. 5). Sheet metal screw resulted in a slight increase (7.3%) in withdrawal resistance in comparison to drywall screw; this increase can be attributed to the greater root diameter of drywall screw, resulting in better involvement of screw thread with the composite board.

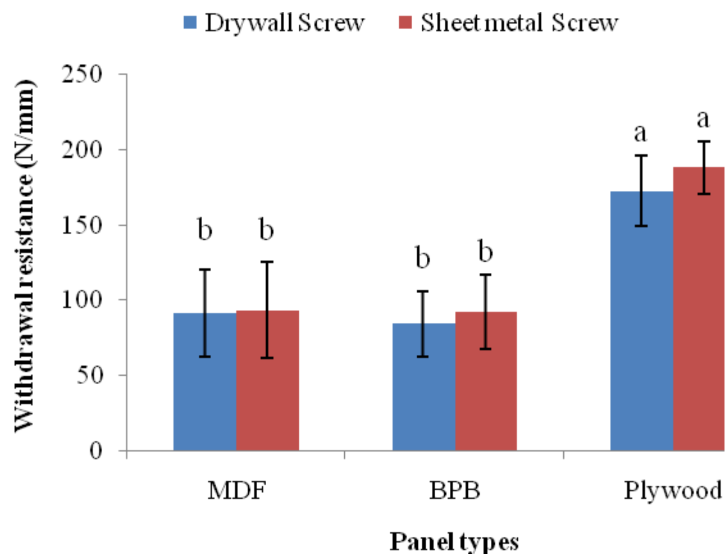

Fig. 5. Corresponding effect of the panel type and screw type on withdrawal resistance (N/mm)

Effect of Screw Diameter on Withdrawal Resistance

Figure 6 illustrates the effect of screw diameter and the corresponding effect of screw diameter and panel type on screw diameter on withdrawal resistance. The greatest withdrawal resistance (187.38 N/mm) was found in plywood panels with screw size 5 while the lowest value was found in MDF panels with screw diameter of 4 mm (size 8) (85.27 N/mm). Increase in screw diameter resulted in an increase (8.1%) in the withdrawal resistance. This was attributed to the more connecting surface between the screw and panel, resulting in higher withdrawal resistance.

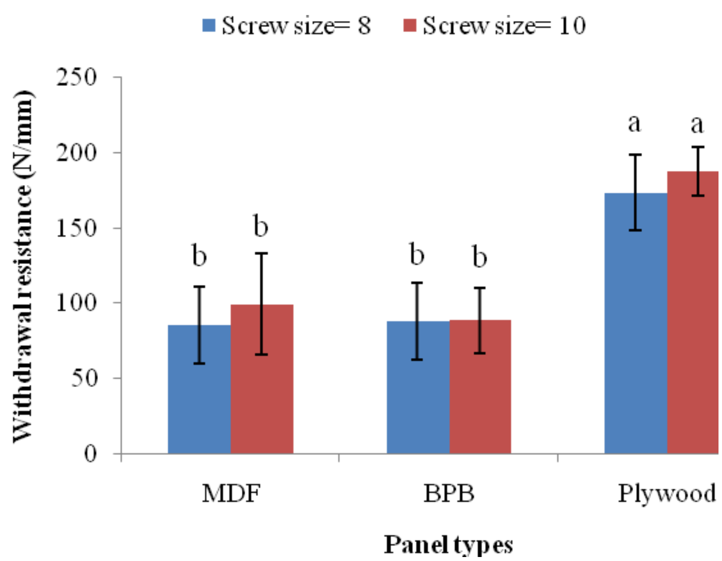

Fig. 6. Corresponding effect of panel type and screw diameter on withdrawal resistance (N/mm)

Effect of Screw drive direction on withdrawal resistance

Figure 7 represents the effect of screw drive direction and the corresponding effect of panel type and screw drive direction on withdrawal resistance. The greatest withdrawal resistance values perpendicular to the both edge and face were found in plywood panels (172.97 and 187.95 N/mm for PE and PF, respectively). The lowest withdrawal resistance perpendicular to the edge was found in MDF (65.53 N/mm), and that perpendicular to the face was found in BPB (107.79 N/mm).

Withdrawal resistance in perpendicular direction to the face of specimens (PF) was 35% greater than that perpendicular to the edge of specimens (PE). However, different panel types showed quite different trends (Fig. 7). Eckelman (2003) reported that higher withdrawal resistance in the face direction in comparison to the edge direction, but at different levels of difference according to the panel type. It may therefore be concluded that panel type affects the difference between the two withdrawal directions of perpendicular to the edge and face significantly. In plywood, for instance, screw passed through various layers, each layer contributing to the overall higher withdrawal resistance, resulting in the highest value. However, screws penetrated in edge direction tended to partially break the resin between the layers, making the screw joint weaker; furthermore, in plywood manufacturing factories, usually low quality layers are placed in the middle layers where screws in the edge direction are penetrated; thus, lower withdrawal resistance values could have been expected.

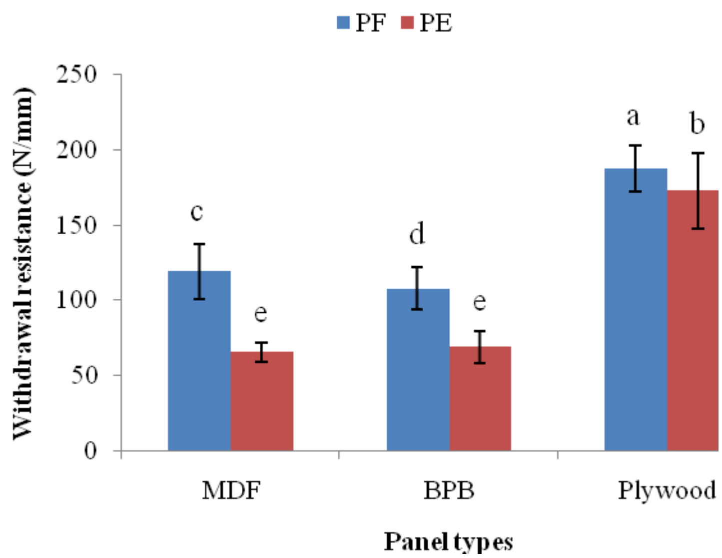

Fig. 7. Corresponding effect of the screw drive direction and panel type on the withdrawal resistance (N/mm)

Effect of Panel Type on Withdrawal Resistance

Fig. 8 shows the independent effect of panel type on withdrawal resistance. The greatest withdrawal resistance was found in the plywood and the lowest one was found in the BPB. The withdrawal resistance in plywood was 100 and 95 percent more than BPB and MDF, respectively; withdrawal resistance in MDF was 5 percent greater than that of BPB. The reason can firstly be attributed to the higher thickness; however, higher consistency and integrity of the woody layers used in the structure of plywood was more effective in increasing the withdrawal resistance. Comparing MDF and BPB, a slight higher withdrawal resistance was observed in MDF, although in most cases not significant (Figures 7 & 8). This showed that high integrity between MDF fibers overcame the self-bonding mechanism between bagasse composite-boards (Mobarak et al. 1982).

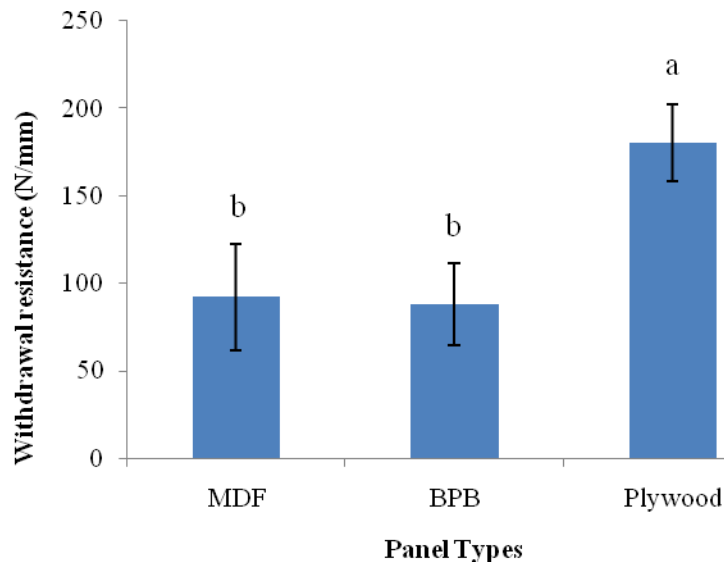

Fig. 8. Effect of panel type on withdrawal resistance (N/mm)

Cluster analysis of the three types of boards based on all physical and mechanical properties, with the exception of IB because IB was not carried out for plywood, showed that BPB was clustered quite differently from the other two board types. However, cluster analysis of the board types based on the withdrawal resistance of different screw types and diameters showed a significant difference between plywood and the other two types (MDF and BPB) (Fig. 9). This can imply that from the physical-mechanical point of view, MDF and plywood are more similar to each other; but from screw withdrawal resistance point of view, MDF tended to be more similar to BPB rather than plywood. It can therefore be concluded that if the physical-mechanical properties would be of vital importance of the furniture to be produced, MDF can offer almost the same strengths as in plywood. However, if different parts of the furniture are to be connected together by screw joints, plywood would offer significantly higher strength.

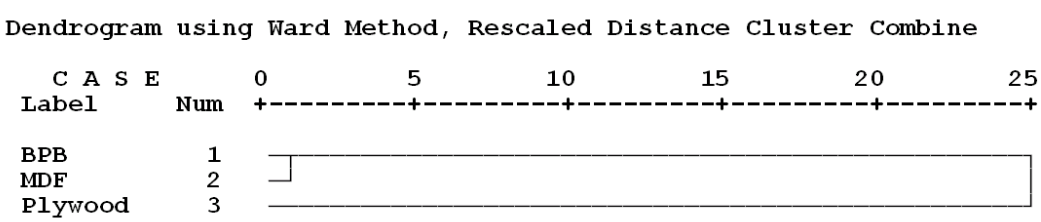

Fig. 9. Cluster analysis based on withdrawal resistance values of different screw types and diameters

Cluster analysis of different screw types and diameters, as well as drive direction, clearly showed that clustering was significantly influenced by drive direction; that is, all treatments with drive direction perpendicular to the face were significantly clustered differently from those perpendicular to the face (Fig. 10). The next source of differentiation was screw diameter; screws of the same diameter were closely clustered, regardless of the screw type. It may be concluded that at the first stage, drive direction should be taken into consideration for designing a strong joint; and at the next stage, the size of the screw would have a significant impact on the final withdrawal resistance.

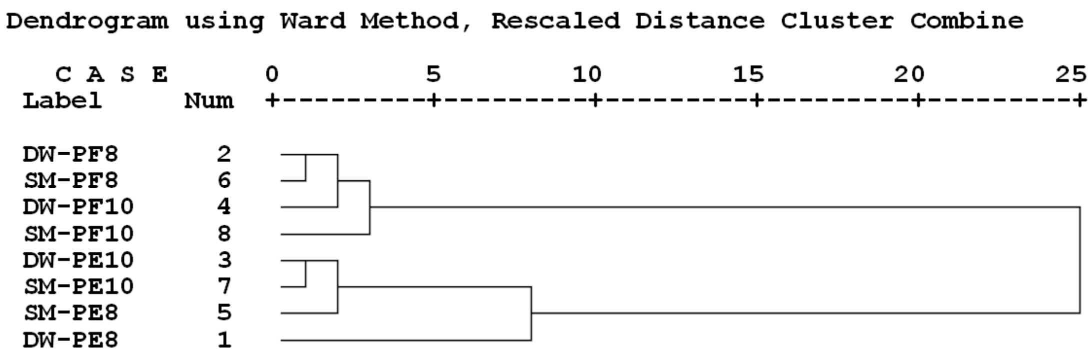

Fig. 10. Cluster analysis based on withdrawal resistance values of different screw types and diameters

As to the self-bonding property (Mobarak et al. 1982) of bagasse fibers as well as the ultra-structural mapping by oxalic acid fiber expansion (OAFEX) (Chandel et al. 2013), further study on binderless bagasse composite-boards using ultra-structural mapping and new techniques of enzymatic delignification would possibly have promising results.

CONCLUSIONS

1- Independent effects of panel type, screw type, screw diameter, and screw drive direction on screw withdrawal resistance were significantly different with each other at the 95% level of confidence.

2- Screw withdrawal resistance in plywood was the highest; this was primarily attributed to the better integrity of the woody layers and also partially to the higher thickness of the plywood panels.

3- Increase in the screw diameter significantly increased the withdrawal resistance due to the better involvement of screw with composite-board and more connecting surface between the screw threads and the composite material.

4- The greatest withdrawal resistance was found in sheet metal screw.

5- By the right selection of panel type and screw diameter, the withdrawal resistance can be increased significantly. The plywood with 5-mm sheet-metal screw had the highest withdrawal resistance in perpendicular direction to the face and edge of specimens. Joints made of plywood with sheet metal screw and 5 mm diameter (size 10) can be recommended in the furniture industry to achieve the highest strength.

ACKNOWLEDGMENT

The authors are grateful to Mr. Majid Ghazizadeh, the internal sales manager of Pars Chemical Industries Company, for the procurement of the resin for the present study.

REFERENCES CITED

Barna M (2011) Natural regeneration of *Fagus sylvatica* L.: A Review. *Austrian Journal of Forest Science*, Vol. 128, No. 2, pp 71 – 91, ISSN 03795292.

Chandel AK, Antunes FFA, Anjos V, Bell MJV, Rodrigues LN, Singh OV, Rosa CA, Pagnocca FC, and da Silva SS (2013) Ultra-structural mapping of sugarcane bagasse after oxalic acid fiber expansion (OAFEX) and ethanol production by *Candida shehatae* and *Saccharomyces cerevisiae*. Biotechnology for Biofuels 6(1): 4.

Dashti H, Salehpur Sh, Taghiyari HR, Akbarifar F, and Heshmati S (2012) The effect of nanoclay on the mass transfer properties of plywood. *Digest Journal of Nanomaterials and Biostructures*, 7(3): 853 – 860.

Eckelman CA, (2003) Textbook of product engineering and strength design of furniture. West Lafayette (IN): Purdue University Press.

EN 310, (2007) Standard Test Methods for Determination of modulus of elasticity in bending and bending strength, German version EN 310.

EN 317, (2007) Standard Test Methods for determination of swelling in thickness after immersion, German version EN 317.

EN 319, (2007) Standard Test Methods for Determination of tensile strength perpendicular to the plane of the board, German version EN 319.

EN 320 2007-08, (2007) Fiberboards, determination of resistance to axial withdrawal of screws, German version EN 320.

EN 322, (2007) wood–based panels; determination of moisture content, German version EN 322.

EN 323, (2007) wood–based panels, determination of density, German version EN 323.

Eshaghi S, Faezipour M, & Taghiyari HR (2013) Investigation on lateral resistance of joints made with drywall and sheet metal screws in bagasse particleboard and comparison with that of commercial MDF. *Maderas-Cienc Tecnol*, 15(2): 127 – 140; DOI 10.4067/S0718-221X2013000200001.

Haftkhani RA, Ebrahimi GH, Tajvidi M, Layeghi M, (2011) Investigation on withdrawal resistance of various screws in face and edge of wood–plastic composite panel. *Mater design* 32:4100-4106.

Mobarak F, Fahmy Y, Augustin H (1982) Binderless lignocellulose composite from bagasse and mechanism of self-bonding. Holzforschung 36(3): 131 – 135.

Nikvash. N, Kraft. R, Kharazipour. A, Euring. M, (2010) Comparative properties of bagasse, canola and hemp particleboards, Eur. J. Wood Prod. 68: 323–327.

Mahendran K, Gandhigram RTC, Chandran SK, Apsara D (2013) Effects of sugar-cane bagasse fiber reinforced concrete with the replacement of cement by silica fume. International Journal of Scienfitic & Engineering Research 4(5): 1242.

Rezende CA, Aparecida de Lima M, Maziero P, Ribeiro de Azevedo E, Garcia W, and Polikarpov I (2011) Chemical and morphological characterization of sugarcane bagasse submitted to a delignification process for enhanced enzymatic digestibility. Biotechnology for Biofuels 4(1): 54.

Stockel F, Konnerth J, Moser J, Kantner W & Gindl-Altmutter W. (2012) Micromechanical properties of the interphase in pMDI and UF lines. *Wood Science and Technology*, 46: 611 – 620 (2012); DOI 10.1007/s00226-011-0432-0.

Taghiyari HR, Gholamiyan H, and Karimi A (2012) Effects of Heat-Treatment on Screw and Nail Withdrawal Resistance of Nanosilver-Impregnated and Untreated Solid Woods. *Current Nanoscience*, 8: 637–642.

Taghiyari HR (2013) Effects of nano-silver and nano-zycosil on mechanical strength of heat, vapor, and dry-ice-treated biscuit and dovetail medium-density fiberboard miter joints. Materials and Design 51: 695 – 700.

Tofanica BM, Cappelletto E, Gavrilescu D, and Mueller K (2011) Properties of Rapeseed (*Brassica napus*) Stalks Fibers. *Journal of Natural Fibers*; 8: 241 – 262; DOI: 10.1080/15440478.2011.626189.

Article Submitted: October 25, 2013; Peer review completed: December 1, 2013; Revised version received and accepted: December 7, 2013; Published: December 15, 2013.