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EFFECTS OF FACTORS ON DIRECT SCREW WITHDRAWAL RESISTANCE IN MEDIUM DENSITY FIBERBOARD AND PARTICLEBOARD

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ABSTRACT

An increase in demand on solid wood that is insufficient supply to meet in the world necessarily directed to other engineering materials that could be an alternative to the solid wood. In this context, instead of using solid wood in furniture and construction industry, wood-based panels such as medium density fiberboard (MDF) and particleboard (PB) have become widely used as construction material. Limited research has been done in the field of fastener performance as mechanical properties with different parameters in the joints constructed with these panels. Therefore, in this study, the parameters of screw type, pilot hole, screw orientation, water treatment and adhesives were investigated in MDF and PB. The results indicated that the highest direct screw withdrawal (DSW) resistance was observed in the test blocks applied with PU and the lowest DSW resistance was in the test blocks without a pilot hole drilled in both materials. In addition, MDF in general had better DSW resistance than PB in almost all combinations of the parameters. The treatment of water into MDF and PB test blocks negatively affects the DSW resistance. The DSW resistance in the face orientation was found to be higher than the corresponding ones in the side orientation in both materials.

Keywords: Adhesives, density, medium density fiberboard, particleboard, screw, water treatment.

INTRODUCTION

Nowadays, wood-based composites become most widely used in interior and exterior purposes in furniture and support structures in buildings because of their availability in different thicknesses, sizes, grades, and exposure durability classifications. There is a great variety of wood-based composites depending on various elements including the type of adhesives in order to bond wood elements such as fibers, particles, strands, flakes, veneer, and lumber and density of final products to make them durable, strong, and economically viable applications. Medium density fiberboard (MDF) and particleboard (PB) are the most common wood-based composite panels used for various of structural and nonstructural applications in the furniture and construction industries. The physical and mechanical properties of these panel products need to be known to acquire knowledge about the products. One of the strength properties of joints constructed with these products was fastener performance which was critical in terms of providing structural integrity. The durability and stability of these joints are highly affected by the withdrawal capacity of fastener from the joints (Cai *et al.* 2004, Zhang *et al.* 2005, Celebi and Kilic 2007, Smardzewski and Klos 2011, Smardzewski *et al.* 2015, Percin *et al.* 2017, Azambuja *et al.* 2018, Dehghan *et al.* 2019). Screws are the most commonly used mechanical woodworking fasteners which provide strong connection to hold pieces of joints together.

There are some studies about the factors affecting DSW resistance in literature. The particles used in the outer layers of PB were smaller than the ones in the middle layers which resulted in low DSW resistance in the side orientation of the material. (Cai *et al*. 2004, Abu and Ahmad 2015). The internal bond strength was an another factor which directly affected the DSW resistance in MDF and PB (Semple and Smith 2006). In another study, a variety of adhesives were applied to the pilot holes drilled to reinforce the screw which improved the DSW resistance in different screwing directions (Sydor and Wołpiuk 2016). Broker and Krause (1991) carried out a study about DSW resistance on a three-layered PB and reported that the screw length was an important

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factor on the DSW resistance (Aytekin 2008). Akyildiz and Malkocoglu (2001) have found that the DSW resistance was inversely proportional to the amount of moisture of the material. The screw type, pilot hole, screw penetration depth, and material type were the other factors on the direct screw withdrawal resistance (Chen *et al*. 2016, Eshaghi *et al.* 2013, Semple and Smith 2006, Tankut 2006, Yorur *et al.* 2017). Therefore, the correct screw selection, adhesive type, and pilot-hole carry vital importance for the screw performance in the joints constructed with MDF and PB.

In this study, the objectives were to 1) obtain DSW values based on the load-time curves in MDF and PB 2) investigates the effects of pilot hole, adhesives, water soak, screw orientation along with screw major diameter on the DSW resistance, 3) obtain density profiles of MDF and PB and relate to DSW.

MATERIAL AND METHODS

Material

In this study, 18 mm thick MDF and PB panels with uncoated surface manufactured by Starwood, Bursa, Turkey were used. Two different adhesives of polyurethane (PU) obtained from Soudal, Belgium and polyvinyl acetate (PVAc) obtained from Filli Boya, Istanbul, Turkey were selected to be applied into the pilot holes. All screws were Philips flathead sheet metal screws made from stainless steel and plated by zinc. The screw major diameters were 3,5 and 4,0 mm with their lengths of 45 mm.

Experimental design

A complete five-factor factorial experiment with 7 replications per combination was conducted to evaluate factors on direct withdrawal loads of screw driven into MDF and PB. The five-factors were material (MDF and PB), pilot-hole type (no pilot-hole and pilot-hole drilled), adhesives (PU and PVAc), screw orientation (face and side) and screw major diameter (3,5 mm and 4,0 mm), soaking type (non-water and water soaked).

Therefore, a total of 448 DSW tests were performed on 224 test blocks. As shown in Figure 1, each test block had nominal dimensions of 50 mm × 50 mm × 18 mm (length x width x thickness) (TS EN 13446 2005).

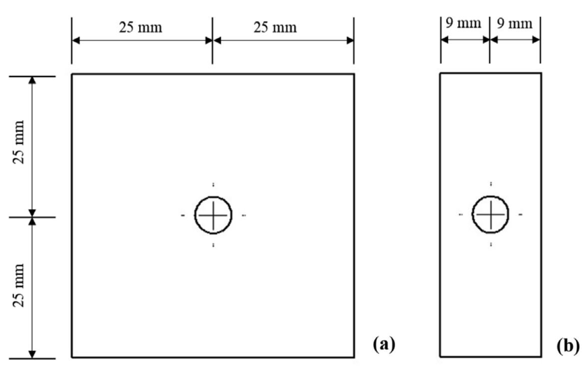

Figure 1: (a) Configuration of face and (b) side test blocks for evaluating DSW tests.

All test blocks were cut along the length direction of full-sized MDF and PB panels and were controlled at 20 °C ± 2 °C and 65 % relative humidity for two weeks in accordance with TS EN 320 (2011). The test blocks were divided into 4 groups based on the pilot-hole types. One of these groups did not have any pilot hole drilled into the test blocks. The test blocks in the other three groups had pilot-holes drilled in 80 % of screw major diameter. The pilot-hole diameters were 2,8 mm and 3,2 mm for the screw major diameter of 3,5 mm and 4,0 mm, respectively and drilled into the center of the side and face of MDF and PB test blocks. In two of these three groups, the pilot-holes of the test blocks were applied by two different adhesives which were PVAc and

PU with the amount of 1 drop by a 5 ml injector. The screws were driven into all test blocks after the test blocks had been applied by adhesives. Half of the test blocks in all groups were tested right away for DSW and then the other half were immersed in pure water and kept in it for two hours before testing. The DSW tests were carried out using a Shimadzu AGIC/20/50KN test machine according to TS EN 320 (2011) and TS EN 13446 (2005) standards. The determination of density profile of MDF and PB was performed on IMAL DPX200 test machine (Imal Pal Group, Italy) using 10 different test blocks.

RESULTS AND DISCUSSION

Table 1 summarizes mean value of overall, core and surface densities for MDF and PB. Typical density profiles of MDF and PB are illustrated in Figure 2.

Table 1: Density values of tested MDF and PB.

Materials	Density (kg/m^3)		
	Overall	Core	Surface
MDF	770	677	1044
PB	578	468	777

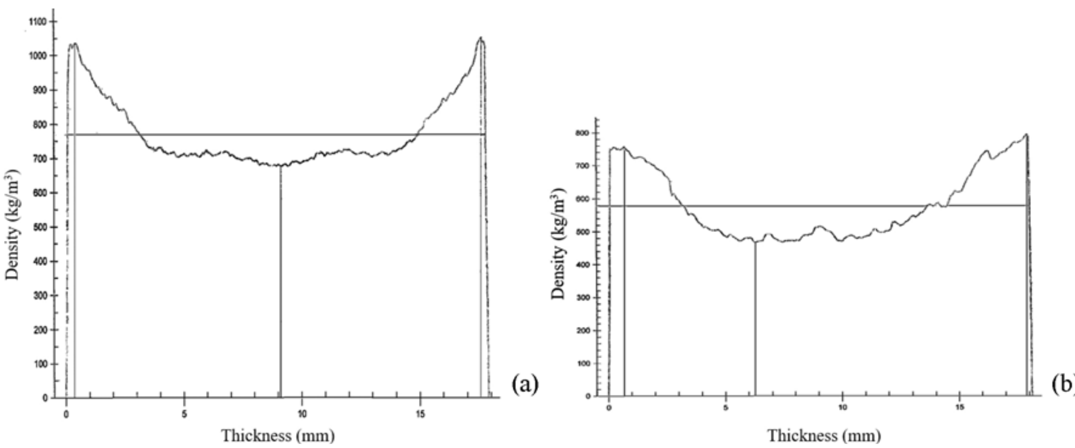

Figure 2: (a) Typical density profiles of MDF and (b) PB evaluated in this study.

Typical DSW curves

Load-time curve of DSW test for MDF and PB samples has shown in Figure 3. The curves illustrate a linear region that gradually becomes non-linear as it approaches the maximum load. After the maximum load was reached, the applied load decreased steadily until the test was concluded when screw was withdrawn from the face of MDF and PB. In the case of side orientation, the curves showed a linear relationship between load and time until a load drop, after which the load reached a plateau for both materials.

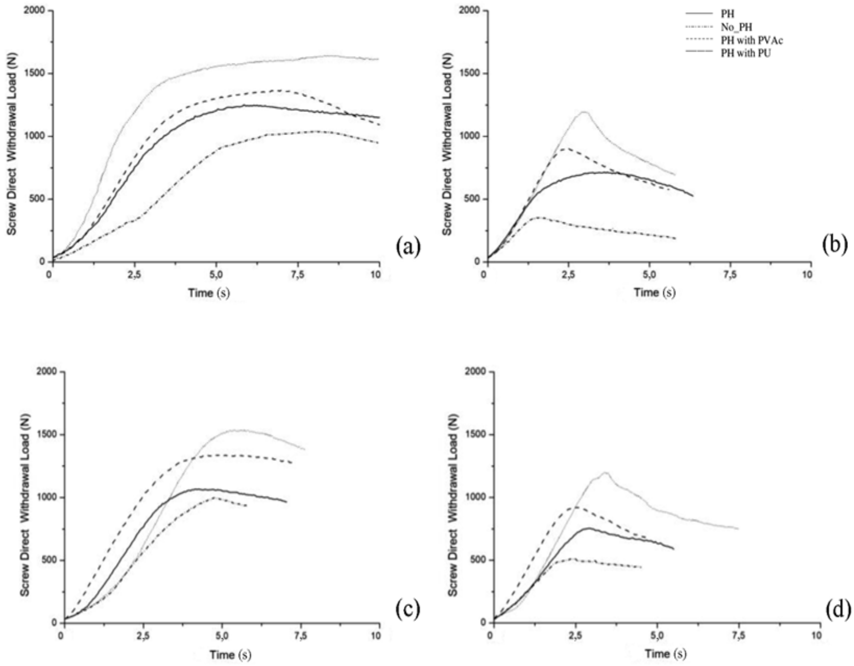

Figure 3: Load-time curves of DSW test for (a) MDF face, (b) MDF side, (c) PB face and (d) PB side.

Mean DSW comparisons

Table 2 summarizes mean DSW values of MDF and PB materials. In general, the mean DSW values ranged from 1048 N to 2076 N for face orientation of non-water soaked MDF whereas the values ranged from 695 N to 1018 N for water soaked MDF. For the side orientation, non-water soaked MDF had the values ranged from 335 N to 1634 N while water soaked MDF had the values ranged from 79 N to 767 N. In the case of face orientation of PB material, non-water-soaked ones ranged from 948 N to 1646 N whereas the values ranged from 474 N to 1053 N for water-soaked ones. The values for side orientation of non-water soaked PB ranged from 476 N to 1313 N while the values ranged from 190 N to 704 N for the water soaked PB material.

Table 3 summarizes ANOVA results obtained from the GLM procedure performed for data set. The five-factor interaction was significant which suggested that the significant interaction for the data set should be analyzed further. In general, four main effects of the data set were all significant with their p values less than 0,0001. Comparing the F values of the main effects, soaking type had a much greater F value of 1768,63 than the orientation with and F value of 1116,73, pilot-hole diameter with an F value of 311,88, screw major diameter with an F value of 75,59 and material with an F value of 57,17. Consequently, it was shown that the soaking type, which has the highest F value was the main factor affecting DSW when all parameters were compared (Freund *et al.* 2010, Kuang *et al.* 2017).

Effects of other four factors on DSW values were analyzed by considering their significant five-factor interactions. A one-way classification of 64 treatment combinations was created for DSW data set to evaluate mean differences among those combinations using the protected Least Significant Difference (LSD) multiple comparison procedure. Table 2, Table 4 and Table 5 summarize mean comparisons of DSW values for material, screw major diameter, pilot-hole, screw orientation, and soaking type, respectively, using the single LSD value of 135,03 N.

Table 2: Mean comparisons of DSW (N) for pilot-hole type within each combination of screw orientation, soaking type, screw major diameter and material.

Material	Screw major diameter (mm)	Soaking type	Screw orientation	Pilot-hole (PH)			
				PH	No - PH	PH with PVAc	PH with PU
MDF	3,5	Non-water soaked	Face	1135 (9) BC	1048 (17) C	1235 (6) B	1373 (9) A
			Side	641 (7) B	335 (7) C	758 (9) B	1155 (8) A
		Water soaked	Face	717 (23) B	677 (19) B	695 (13) B	1018 (25) A
			Side	294 (4) A	79 (11) C	323 (3) AB	427 (11) A
	4,0	Non-water soaked	Face	1239 (11) C	1167 (13) C	1396 (3) B	2076 (13) A
			Side	770 (4) B	401 (8) C	861 (1) B	1634 (15) A
		Water soaked	Face	817 (23) B	704 (22) C	866 (13) B	1057 (9) A
			Side	217 (20) BC	102 (20) C	267 (11) B	767 (11) A
PB	3,5	Non-water soaked	Face	948 (3) C	1007 (9) BC	1112 (3) B	1282 (11) A
			Side	674 (14) C	476 (20) D	922 (18) B	1152 (3) A
		Water soaked	Face	474 (10) B	484 (10) B	720 (3) A	831 (14) A
			Side	190 (10) B	257 (9) B	285 (5) B	612 (10) A
	4,0	Non-water soaked	Face	1042 (11) C	1053 (16) C	1385 (1) B	1646 (14) A
			Side	649 (14) C	620 (16) C	981 (6) B	1313 (3) A
		Water soaked	Face	563 (8) B	522 (11) B	555 (1) B	1053 (6) A
			Side	282 (8) B	226 (2) B	299 (14) B	704 (13) A

Table 3: Summary of ANOVA results on five-factors of DSW data set.

Source	F values	*p* value
Material	57,17	0,0001
Soaking type	1768,63	0,0001
Screw major diameter	75,59	0,0001
Pilot hole	311,88	0,0001
Screw orientation	1116,73	0,0001
2-way interaction	0,02-67,25	0,0001
3-way interaction	0,43-16,29	0,0001
4-way interaction	2,5-25,42	0,0001
5-way interaction	6,65	0,0002

Pilot-hole diameter effects

Table 2 indicated that in general, the pilot-hole diameter with PU had the highest mean DSW load than the other types of pilot-holes followed in all combinations. There were only two cases in which no statistical difference was found in mean DSW between the pilot-holes with PVAc and PU. These cases were in the face of water soaked PB test blocks and the side of water soaked MDF test blocks driven by screw with 3,5 mm major diameter. The mean lowest DSW values were found in all non-drilled MDF test blocks. The type of the adhesive have significant effects on DSW resistance of both MDF and PB (Ors *et al.* 1998, Conrad *et al.* 2004, Sackey *et al.* 2008).

Material effects

Table 4 indicated that the general trend was that the mean DSW was higher in MDF than PB in most cases. In a study by McNatt (1986), the MDF had higher DSW load than PB since MDF has a more uniform vertical density profile than PB. This is thought to be one of the reasons why the DSW resistance in MDF is higher than the corresponding ones in PB (Wang *et al.* 2007). The internal bond strength and density profile of the boards which directly affect DSW resistance depends on parameters such as fiber/chip properties and adhesive ratio (Mcnatt 1986).

Screw major diameter effects

Table 5 indicated that mostly the mean DSW was higher when the material was driven by the screw with 4,0 mm major diameter than the one with 3,5 mm. The screw major diameter statistically affected the mean DSW when the PU applied in pilot-hole for both materials. The screw major diameter of 4,0 mm had statistically higher mean DSW than the corresponding one with 3,5 mm in all combinations except one case. There was no significant difference between the screw major diameters in the PB side test blocks soaked in water. There was a clear trend that no significant difference was found in mean DSW among the screw major diameters when no adhesive applied in the pilot-holes of PB test blocks. The same trend was followed when no pilot-holes were drilled in MDF test blocks in all combinations.

Table 4: Mean comparisons of DSW (N) for MDF and PB within each combination of screw orientation, screw major diameter, material and soaking type.

Soaking type	Screw major diameter (mm)	Screw orientation	Pilot-hole	Material	
				MDF	PB
Non-water soaked	3,5	Face	PH	1135 A	948 B
			No - PH	1048 A	1007 A
			PH with PVAc	1235 A	1112 A
			PH with PU	1373 A	1282 A
		Side	PH	641 A	674 A
			No - PH	335 B	476 A
			PH with PVAc	758 A	922 B
			PH with PU	1155 A	1152 A
	4,0	Face	PH	1239 A	1042 B
			No - PH	1167 A	1053 A
			PH with PVAc	1396 A	1385 A
			PH with PU	2076 A	1646 B
		Side	PH	770 A	649 A
			No - PH	401 B	620 A
			PH with PVAc	861 A	981 A
			PH with PU	1634 A	1313 B
Water soaked	3,5	Face	PH	717 A	474 B
			No - PH	677 A	484 B
			PH with PVAc	695 A	720 A
			PH with PU	1018 A	831 B
		Side	PH	294 A	190 A
			No - PH	79 B	257 A
			PH with PVAc	323 A	285 A
			PH with PU	427 B	612 A
	4,0	Face	PH	817 A	563 B
			No - PH	704 A	522 B
			PH with PVAc	866 A	555 B
			PH with PU	1057 A	1053 A
		Side	PH	217 A	282 A
			No - PH	102 A	226 A
			PH with PVAc	267 A	299 A
			PH with PU	767 A	704 A

Table 5: Mean comparisons of DSW (N) for screw major diameter within each combination of pilot-hole diameter, screw orientation, material and soaking type.

Material	Soaking type	Screw orientation	Pilot-holes	Screw major diameter (mm)	
				3,5	4,0
MDF	Non-water soaked	Face	PH	1135 A	1239 A
			No - PH	1048 A	1167 A
			PH with PVAc	1235 A	1396 A
			PH with PU	1373 B	2076 A
		Side	PH	641 B	770 A
			No - PH	335 A	401 A
			PH with PVAc	758 A	861 A
			PH with PU	1155 B	1634 A
	Water soaked	Face	PH	717 A	817 A
			No - PH	677 A	704 A
			PH with PVAc	695 B	866 A
			PH with PU	1018 A	1057 A
		Side	PH	294 A	217 A
			No - PH	79 A	102 A
			PH with PVAc	323 A	267 A
			PH with PU	427 B	767 A
PB	Non-water soaked	Face	PH	948 A	1042 A
			No - PH	1007 A	1053 A
			PH with PVAc	1112 B	1385 A
			PH with PU	1282 B	1646 A
		Side	PH	674 A	649 A
			No - PH	476 B	620 A
			PH with PVAc	922 A	981 A
			PH with PU	1152 B	1313 A
	Water soaked	Face	PH	474 A	563 A
			No - PH	484 A	522 A
			PH with PVAc	720 A	555 B
			PH with PU	831 B	1053 A
		Side	PH	190 A	282 A
			No - PH	257 A	226 A
			PH with PVAc	285 A	299 A
			PH with PU	612 A	704 A

Soaking type effects

The mean DSW was statistically higher when the material was not soaked in water than the ones soaked in water because of swelling of the particles in the materials in all combinations (Figure 4). This can be explained by the gaps between the particles because of water absorption in which reduces the mechanical properties of particles as shown in Figure 4 MDF-b, MDF-d, PB-b and PB-d. The ratios of DSW in the material not soaked in water to the one in water soaked were 1,5 for face orientation and 3 for side orientation when using both screws in MDF. In the case of PB, the ratios were 2 and 2,5 for face and side orientations using both screws, respectively. This indicates that the PB which has larger particles than MDF have been affected more in the case of water soaking.

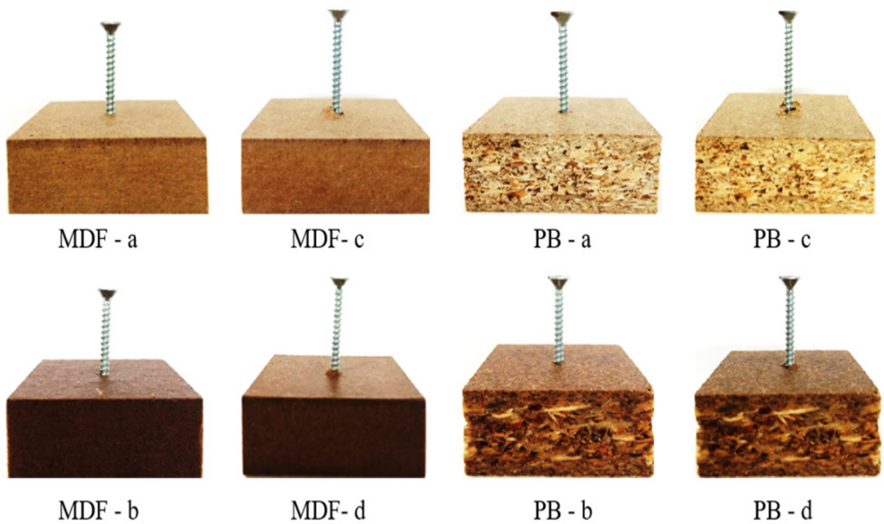

Figure 4: (a) MDF test blocks with non-water soaked before and (c) after testing, (b) water soaked before and (d) after testing; (a) PB test blocks with non-water soaked before and (c) after testing, (b) water soaked before and (d) after testing.

Screw orientation effects

The mean DSW was statistically higher when the screws driven into the face of both materials than the corresponding ones driven into the side orientation in all combinations since the screw was penetrated into three layers of the materials. This situation is related to the overall density of the materials in where the surface density of the panels was higher than the core density (Mcnatt 1986). In the case of the DSW resistance in side orientation in MDF and PB depended only on the core density of the panels where the particles were larger and wider than the ones in surfaces. Hung and Wu (2010) found a correlation between the DSW resistance and core density and reported that the reason of it was the interfacial adhesion between binding agent and particles of bamboo plastic composites. Rajak and Eckelman (1993) also reported that one of the parameters affecting the DSW was the core density of the material when driving screws in the side of the wood-based materials. A proper pilot-hole size needs to be drilled into the side of the material in order to prevent the splitting in the sides of material.

The DSW ratios from face to side orientation in MDF were 2 and 4 for the test blocks non-soaked in water whereas the ones soaked in water driven by both screw major diameters, respectively whereas the corresponding ratios were 1,5 and 2 in PB. The reason of the high ratio of face to side orientation in MDF and PB materials soaked in water could be the fractural particle deformation around the screw driven in the core of the materials during screw driving process. In addition, MDF has twice higher ratio than PB with the reason of having more fractural deformation in MDF which has higher density in the core.

CONCLUSIONS

Nowadays, the usage of MDF and PB materials especially in furniture and construction industries has been increased. In the case of mechanical properties of these materials, especially screw holding performance were investigated depending on the pilot-hole diameter, screw orientation, screw major diameter, soaking type, and adhesives in the pilot holes in this study. DSW curves for different screw orientations and materials indicated that the DSW process had linear and non-linear regions in both materials. Mean DSW ranged from 695 N to 2076 N for the face test blocks whereas it ranged from 79 N to 1634 N for the side ones in MDF. In the case of PB face test blocks, the mean DSW ranged from 474 N to 1646 N while it ranged from 190 N to 1313 N for side ones.

Statistical analyses indicated that the interaction among the factors of material, screw orientation, pilot-hole type, screw major diameter, and soaking type was significant. The results pointed out that there was significant difference among the screw orientation where the face of each material had higher DSW holding capacity than the ones in the side. A similar trend was followed by soaking type, the water-soaked materials had lower DSW than the non-water-soaked ones. Applying adhesives in the pilot holes increases the screw holding capacity and reduces fractural particle deformations in the material when driving screws into MDF and PB. Additionally, it improves the resistance of steel screws and the bonding strength of the joints while preventing the corrosion occurred by oxidation and issues caused by moisture in wood and steel materials due to the coating property of the glue.

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