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INVESTIGATION OF THE EFFECT OF EXTREME TEMPERATURE ON SCREW DIRECT WITHDRAWAL RESISTANCE OF WOOD PLASTIC COMPOSITE DECKING PROFILES

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ABSTRACT

In this study, the effects of extreme temperatures on screw direct withdrawal resistance (SDWR) of wood plastic composite (WPC) decking profiles were systematically investigated. Commercially produced WPC decking profiles were tested at different temperature levels (-40°C, -20°C, 0°C, room temperature, +40°C and +60°C); their effects on SDWR were evaluated by controlling parameters such as screw diameter (3.0 mm and 3.5 mm) and pilot hole diameter (60%, 70% and 85%). Additionally, the relationships between Shore D hardness and SDWR measured at each temperature level were revealed through statistical analyses. The results show that as the temperature increases, Shore D hardness decreases and accordingly, significant decreases occur in SDWR. The highest SDWR was obtained at -40°C temperature, 60% pilot hole ratio and 3.5 mm screw diameter combination. This highlights the influence of material hardness and screw-material interaction on joint performance. According to Pearson correlation analysis, a strong and statistically significant ($r=0.939$, $p=0.0055$) positive relationship was determined between Shore D hardness and SDWR.

KEYWORDS: Wood plastic composite, extreme temperature, screw withdrawal resistance, shore D hardness, decking profiles.

INTRODUCTION

WPC have become an important component of sustainable production thanks to both the utilization of waste materials and the low energy requirements of the production processes (Adhikary et al. 2009; Madhoushi et al. 2009; Bledzk et al. 2010; Guo et al. 2010; Zhao et al. 2020). WPC, which are heavily preferred in outdoor areas (terrace flooring, balcony coverings, garden furniture, etc.), are directly affected by environmental conditions. Particularly factors such as temperature differences, humidity, freeze-thaw cycles and UV rays can threaten both the physical-mechanical properties and the connection security of WPC (Srivabut et al. 2022; Zhang & Kamdem 2023; Friedrich 2023). Therefore, the durability of screw connections applied to these materials is of vital importance for application safety and long-term use (Li et al. 2022; Pour et al. 2022; Birinci & Kaymakci 2023; Friedrich & Luible 2023).

The performance of screw connections in wood and composite materials is often evaluated by screw direct withdrawal resistance (SDWR). SDWR is a key indicator of the strength with which a fastener separates from the assembly surface and reflects the structural integrity of the joint. In heterogeneous materials such as WPC, SDWR value varies depending on the interaction of many factors such as material density, polymer/wood ratio, installation direction, screw type, pilot hole diameter, screw diameter and ambient conditions (Durmaz 2021; Haftkhani et al. 2011; Machado et al. 2016). Pilot hole diameter is an important parameter for the success of screw connections. Pilot holes that are too small can cause cracking and damage to the material during screwdriving, while holes that are too large can reduce the friction between the screw and the material, lowering the SDWR (Pilarski & Matuana 2005; Eshaghi et al. 2013; Ghanbari et al. 2014). It was stated that the ratio of the pilot hole diameter to the screw root diameter should be between 60% and 85%. It has also been shown that as the screw diameter increases, the SDWR also increases due to the increase in the contact surface (Srubar III 2015; Perçin & Altunok 2019; Durmaz et al. 2020).

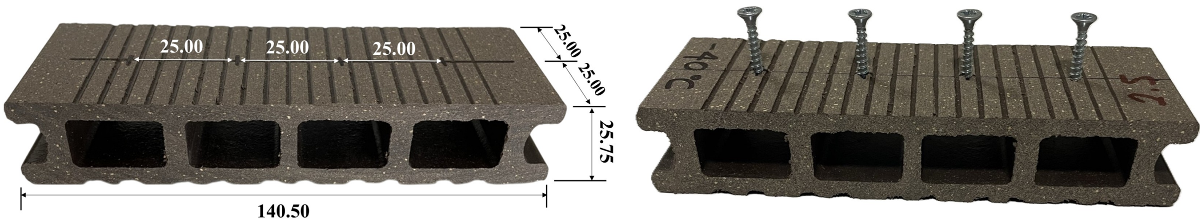
The temperature factor is a parameter that has a direct effect on the mechanical behaviour of polymer-based materials. Although WPCs are resistant to temperature changes to a certain extent, effects such as hardness loss, embrittlement, internal structure deformations and thermal expansion are observed in the material matrix, especially at extreme temperatures (-40°C to +60°C) (Yang et al. 2013,2018; Turku & Kärki 2016; Friedrich & Luible 2023). These effects can directly affect the security of the screw connection, causing a decrease in SDWR. Birinci & Kaymakci (2023) reported that WPC materials experienced losses of up to 20% in SDWR values under freeze-thaw cycles. These findings are critical to assessing the reliability of the material under actual field conditions.

Material hardness is an important factor affecting the success of screw connections, especially in composite structures containing polymers. The Shore D measurement method used to determine hardness expresses the resistance of the material to external forces. It is predicted that materials with higher Shore D hardness will have higher SDWR. Additionally, since there is an inverse relationship between Shore D value and temperature, it is expected that both hardness and screw adhesion will decrease with temperature (Madhoushi & Nadalizadeh 2009; Haftkhani et al. 2011; Yang et al. 2018; Pour et al. 2022).

The main purpose of this study is to experimentally evaluate the screw direct withdrawal resistance of commercially produced wood plastic composite profiles under different temperatures, pilot hole diameters and screw diameters. Additionally, the relationships between Shore D hardness and SDWR measured in different temperature environments were analysed.

MATERIAL AND METHODS

In this study, commercial WPC were specially produced by a decking company in Ankara/Turkey. WPC are composed of 30% wood flour (a mixture of *Pinus sylvestris* L., *Abies normanniana* spp *bornmulleriana* Mattf. and *Populus nigra*), 20% rice husk, 28% high density polyethylene (HDPE; Petkim Company, Izmir/Turkiye), 10% zinc powder (63 µm; DMR Suren Chemistry Company, Istanbul/Turkiye), 3% calcite (5 µm; Erciyes Micron Company, Istanbul/Turkiye), 3% compatibilizing agent (MAPE; Deckline Company, Ankara/Turkiye) and 6% dye. The company uses a co-extruder to keep production parameters constant. The wall thickness of profiles was measured as 5.43±12 mm (Fig. 1). Samples were conditioned at 22±2°C and 50% relative humidity for at least 14 days before the tests.



(a) (b)

Fig. 1: a) Commercial WPC profile dimensions (mm); b) screwed specimen.

Water absorption (WA) and thickness swelling (TS) tests were carried out in accordance with ISO 62:2008 After the samples were conditioned in the climate chamber at 23±2°C and 50±5% relative humidity, they were kept in water for 1, 7 and 28 days and then measured.

In this study, the experimental variables were determined as screw diameter (3.0 mm and 3.5 mm), temperature (-40°C, -20°C, 0°C, room temperature, 40°C and 60°C) and pilot hole diameter (60%, 70% and 85% of the screw diameter). In the study, Philips flat head sheet metal screws made of zinc-plated steel produced by Akdeniz were used. The screws used were selected in two different sizes as 3.0 mm and 3.5 mm (diameter) × 30 mm (length). After the samples were prepared in the dimensions specified in Fig. 1, the pilot holes were precisely drilled using a Dremel 3000 model drill and workstation. The pilot hole diameters are given in Tab. 1.

Tab. 1: Diameters of pilot hole of tested commercial WPC profile.

Pilot hole diameter	**Screw 3.0 x 30 mm**	**Screw 3.5 x 30 mm**
60%	1.80	2.10
70%	2.10	2.50
85%	2.50	3.00

During screwing, the screw direction was made at a 90° angle to the sample surface, with 18 mm of the screw remaining outside the sample. 30 samples for each group were kept in a laboratory-type freezer at temperatures of -40°C, -20°C, 0°C, room temperature, 40°C and 60°C before SDWR tests and subjected to instant tests. SDWR tests were carried out on the Shimadzu AGIC/20/50KN universal testing machine according to EN 320:2011.

Statistical evaluation of the data obtained within the scope of the study was carried out using the IBM SPSS 26.0 package program. In order to determine the significant differences between the results, variance analysis (ANOVA) was applied; post-hoc Duncan test was preferred at 95% confidence level in comparing the means.

RESULTS AND DISCUSSION

Density, water absorption and thickness swelling performance

The average density of commercial WPC samples was measured as 1.256±0.142 g/cm³. This value is compatible with the compact structure obtained by homogeneous mixture of high-density polyethylene (HDPE) and lignocellulosic components (Guo et al. 2010). In composite materials, density is considered a leading indicator of overall mechanical performance and screw-fastening ability (Haftkhani et al. 2011).

WA and TS tests performed according to ISO 62:2008 are critical in evaluating the water resistance of commercial WPC material. As a result of keeping the samples in water for 1, 7 and 28 days, WA values were determined as 41.50%, 46.35% and 51.18%, respectively. TS values were determined as 8.90%, 10.24% and 10.48% (Fig. 2). This increase indicates that the fibers may have difficulty absorbing water and the polymer matrix may have difficulty resisting long-term swelling. This means a risk of long-term deformation and loosening of connections, especially in outdoor areas exposed to rain and humidity (Pour et al. 2022).

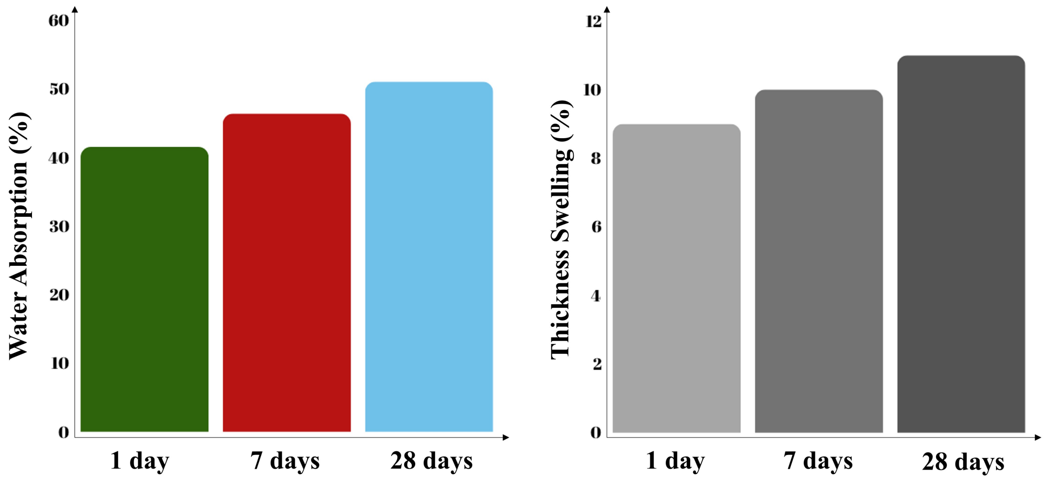


Fig. 2: WA and TS values (%) of commercial WPCs.

Shore D hardness and temperature change effect

Shore D hardness is an important parameter used to measure the resistance of commercial WPCs to external forces. According to the data obtained, there was a significant decrease in Shore D value as the temperature increased: the average value was 78.08 at -40°C, and decreased to 65.93 at +60°C (Tab. 2). This occurs due to the increased mobility of polymer chains at high temperatures, i.e., thermal softening (Yang et al. 2018).

Tab. 2: Shore D hardness values of commercial WPCs at different temperatures.

Shore D hardness (Min-Max)					
-40	**-20**	**0**	**Room temperature**	**+40**	**+60**
78.08±0.71 (77.0–79.5)	77.80±0.94 (76.0–80.0)	76.50±0.73 (75.0–77.5)	72.20±1.04 (70.5–74.0)	69.88±0.92 (68.5–71.5)	65.93±1.23 (64.0–68.5)

Loss of hardness at high temperatures increases the possibility of deformation on the connection surfaces, reducing screw adhesion performance. In addition, the existence of a linear relationship between Shore D value and SDWR shows that decreases in connection quality are inevitable depending on temperature. Similarly, studies in the literature have also stated that decreases in Shore D hardness negatively affect connection strength (Haftkhani et al. 2011; Pour et al. 2022).

Effect of pilot hole diameter on screw direct withdrawal resistance

It is seen that 60% pilot holes provide the highest connection strength. For example, with 3.0 x 30 mm screw, 901.33 MPa SDWR was obtained at 60% pilot hole and only 652.39 MPa SDWR was obtained at 85% pilot hole at -40°C (Tab. 3). A similar trend is valid for 3.5 mm screw (974.76 MPa vs. 712.47 MPa). Some studies state that the ratio of the pilot hole diameter to the screw root diameter should be between 60% and 85% (Pilarski & Matuana 2005; Eshaghi et al. 2013). This study shows that the highest performance is achieved at 60% and that the screw-material friction surface decreases as the diameter increases. However, it should be noted that pilot holes with very small diameters may cause cracking, especially at low temperatures.

Tab. 3: The effect of pilot hole diameter on SDWR (MPa) of commercial WPCs.

Screw diameter (mm)	Temperature (°C)	Direct withdrawal resistance (MPa) (Min-Max)		
		60%	**70%**	**85%**
3.0 x 30	**-40**	^{B}901.33±33.63 (850.48 – 940.36)	^{B}811.57±86.96 (724.93 – 975.14)	^{BC}652.39±71.04 (485.14 – 761.35)
	-20	^{D}791.57±43.96 (712.36 – 865.47)	^{C}718.47±70.47 (612.36 – 821.47)	^{C}632.39±57.16 (528.36 – 688.94)
	0	^{CD}810.48±52.21 (742.45 – 875.85)	^{C}720.05±83.36 (612.32 – 877.47)	^{C}640.43±73.34 (524.36 – 731.69)
	Room temperature	^{EF}523.22±51.93 (450.14 – 591.44)	^{DE}473.30±38.16 (423.22 – 551.19)	^{DE}434.80±26.54 (401.23 – 473.22)
	+40	^{FG}490.81±59.32 (411.74 – 596.36)	^{E}461.13±41.93 (401.23 – 551.19)	^{E}407.37±50.92 (350.25 – 497.85)
	+60	^{G}456.65±49.78 (360.25 – 513.58)	^{F}305.94±45.61 (204.60 – 391.25)	^{F}283.42±59.88 (184.30 – 350.86)
3.5 x 30	**-40**	^{A}974.76±85.35 (800.45 – 1095.36)	^{A}880.80±70.66 (750.11 – 974.36)	^{A}712.47±76.51 (605.41 – 865.13)
	-20	^{BC}861.00±83.29 (745.14 – 1077.93)	^{B}784.13±56.71 (685.14 – 864.17)	^{AB}686.50±35.67 (608.97 – 754.13)
	0	^{B}894.44±82.35 (745.14 – 985.36)	^{B}791.70±48.34 (729.09 – 861.63)	^{A}702.33±44.41 (640.14 – 766.78)
	Room temperature	^{E}564.97±91.76 (454.91 – 763.32)	^{D}513.50±43.81 (433.72 – 566.53)	^{D}470.43±20.08 (431.23 – 496.61)
	+40	^{EF}534.50±81.47 (423.22 – 685.14)	^{DE}501.80±24.70 (453.03 – 535.91)	^{DE}447.66±37.09 (374.25 – 500.88)

	+60	^{FG}492.58±45.20 (423.22 – 567.45)	^{F}331.19±24.78 (293.47 – 361.06)	^{F}306.50±13.91 (274.69 – 332.44)
Note: mean, arithmetic mean; SD, standard deviation. Superscript letters of A, B, C, D, E, F, and G are homogeneous subset of post-hoc test results (p<0.05).				

Effect of screw diameter on screw direct withdrawal resistance

Screw diameter has a significant effect on SDWR. 3.5 mm screws showed higher strength than 3.0 mm screws at all temperatures and pilot hole combinations. This difference became more pronounced especially at low temperatures. For example, 974.76 MPa was obtained with 3.5 mm screw at 60% pilot hole at -40°C, while 901.33 MPa was obtained with 3.0 mm screw under the same conditions (Tab. 4). Increasing the screw diameter allows the screw to contact more surface area and resist greater torque forces. Perçin & Altunok (2019) have clearly demonstrated this relationship. Additionally, thicker screws compress the micro-voids within the material more, creating a stronger hold around the screw (Perçin & Uzun 2022).

Tab. 4: The effect of screw diameter on SDWR (MPa) of commercial WPC.

Pilot hole diameter	Temperature (°C)	Direct withdrawal resistance (MPa) (Min-Max)	
		3.0 x 30 mm	**3.5 x 30 mm**
60%	**-40**	^{A}901.33±33.63 (850.48 – 940.36)	^{A}974.76±85.35 (800.45 – 1095.36)
	-20	^{B}791.57±43.96 (712.36 – 865.47)	^{B}861.00±83.29 (745.14 – 1077.93)
	0	^{B}810.48±52.21 (742.45 – 875.85)	^{B}894.44±82.35 (745.14 – 985.36)
	Room temperature	^{E}523.22±51.93 (450.14 – 591.44)	^{E}564.97±91.76 (454.91 – 763.32)
	+40	^{EF}490.81±59.32 (411.74 – 596.36)	^{EF}534.50±81.47 (423.22 – 685.14)
	+60	^{FG}456.65±49.78 (360.25 – 513.58)	^{FGH}492.58±45.20 (423.22 – 567.45)
70%	**-40**	^{B}811.57±86.96 (724.93 – 975.14)	^{B}880.80±70.66 (750.11 – 974.36)
	-20	^{C}718.47±70.47 (612.36 – 821.47)	^{C}784.13±56.71 (685.14 – 864.17)
	0	^{C}720.05±83.36 (612.32 – 877.47)	^{C}791.70±48.34 (729.09 – 861.63)
	Room temperature	^{FG}473.30±38.16 (423.22 – 551.19)	^{FG}513.50±43.81 (433.72 – 566.53)
	+40	^{FG}461.13±41.93 (401.23 – 551.19)	^{FG}501.80±24.70 (453.03 – 535.91)
	+60	^{I}305.94±45.61 (204.60 – 391.25)	^{I}331.19±24.78 (293.47 – 361.06)
85%	**-40**	^{D}652.39±71.04 (485.14 – 761.35)	^{D}712.47±76.51 (605.41 – 865.13)
	-20	^{D}632.39±57.16 (528.36 – 688.94)	^{D}686.50±35.67 (608.97 – 754.13)
	0	^{D}640.43±73.34 (524.36 – 731.69)	^{D}702.33±44.41 (640.14 – 766.78)
	Room temperature	^{GH}434.80±26.54 (401.23 – 473.22)	^{GH}470.43±20.08 (431.23 – 496.61)
	+40	^{H}407.37±50.92 (350.25 – 497.85)	^{H}447.66±37.09 (374.25 – 500.88)
	+60	^{I}283.42±59.88 (184.30 – 350.86)	^{I}306.50±13.91 (274.69 – 332.44)
Note: mean, arithmetic mean; SD, standard deviation. Superscript letters of A, B, C, D, E, F, G, H, and I are homogeneous subset of post-hoc test results (p<0.05).			

Effect of temperature on screw direct withdrawal resistance

SDWR values are temperature sensitive (Ayrilmis et al. 2011; Zhou et al. 2021). SDWR values decreased as temperature increased for all screw and pilot hole combinations. At -40°C, screw-material interaction is more rigid and tighter, while at +60°C, bond strength is significantly weakened due to polymer embrittlement and deformation tendencies (Tab. 5). SDWR value obtained with a 3.5 x 30 mm screw and 60% pilot hole was 974.75 MPa at -40°C, while it was only 492.58 MPa at +60°C. These findings are in line with Birinci & Kaymakci (2023) reporting SDWR losses under freeze-thaw cycles. In addition, the decrease in Shore D hardness with temperature further increases the possibility of mechanical deformation (Yang et al. 2018).

Tab. 5: The effect of temperature on SDWR (MPa) of commercial WPCs.

Screw type (mm)	Pilot hole diameter	Direct withdrawal resistance (MPa)					
		-40	-20	0	Room temperature	+40	+60
3.0 x 30	60%	^{B}901.33	^{B}791.57	^{B}810.48	^{B}523.22	^{ABC}490.81	^{B}456.65
	70%	^{C}811.57	^{C}718.47	^{C}720.05	^{CD}473.30	^{BC}461.13	^{CD}305.94
	85%	^{E}652.39	^{D}632.39	^{D}640.43	^{D}434.80	^{D}407.37	^{D}283.42
3.5 x 30	60%	^{A}974.75	^{A}861.00	^{A}894.44	^{A}564.97	^{A}534.50	^{A}492.58
	70%	^{B}880.80	^{B}784.13	^{B}791.70	^{BC}513.50	^{AB}501.80	^{C}331.19
	85%	^{D}712.47	^{C}686.50	^{C}702.33	^{CD}470.43	^{CD}447.66	^{CD}306.50

Note: mean, arithmetic mean; SD, standard deviation. Superscript letters of A, B, C, D, and E are homogeneous subset of post-hoc test results ($p<0.05$).

Correlation between shore D hardness and screw direct withdrawal resistance

For this purpose, the average SDWR values of the 3.5 x 30 mm screw and 60% pilot hole combination at temperatures ranging from -40°C to +60°C were compared with the Shore D hardness values measured at the same temperatures. Pearson correlation analysis was applied to evaluate the statistical relationship between these two variables. As a result of the analysis, the correlation coefficient and the significance level were calculated and are given in Tab. 6.

Tab. 6: Shore D hardness values of commercial WPCs at different temperatures.

Correlation coefficient (r)	0.939
Significance level (p)	0.0055

This result shows that there is a very strong and positive relationship between Shore D hardness and SDWR ($r>0.9$). That is, the harder the material, the higher the screw pull-out resistance. The correlation was confirmed to be statistically significant at $p<0.01$, indicating that the observed relationship is unlikely to be due to chance. Some researchers have reported that Shore D hardness plays a decisive role on joint strength and that these parameters decrease with temperature (Haftkhani et al. 2011; Pour et al. 2022). This strong correlation also suggests that Shore D can be used as an indicator parameter to indirectly estimate joint reliability in future material designs. This suggests a practical application that Shore D measurements can be used instead of costly tensile tests for long-term joint performance evaluations in the field. Fig. 3 visually demonstrates the linear regression relationship between Shore D hardness and SDWR. The linear regression equation obtained as a result of the analysis is shown in Eq. 1:

$$\text{SDWR (MPa)}=40.59 \times \text{Shore D} -2258.85 \qquad (1)$$

In particular, it was determined that each unit increase in Shore D hardness provides an SDWR increase of approximately 40.59 MPa. Based on these findings, Shore D hardness can be considered as a strong and reliable predictive variable for the estimation of SDWR. On the other hand, hardness changes caused by environmental factors such as temperature can indirectly affect the Shore D value and lead to deviations in long-term connection performance.

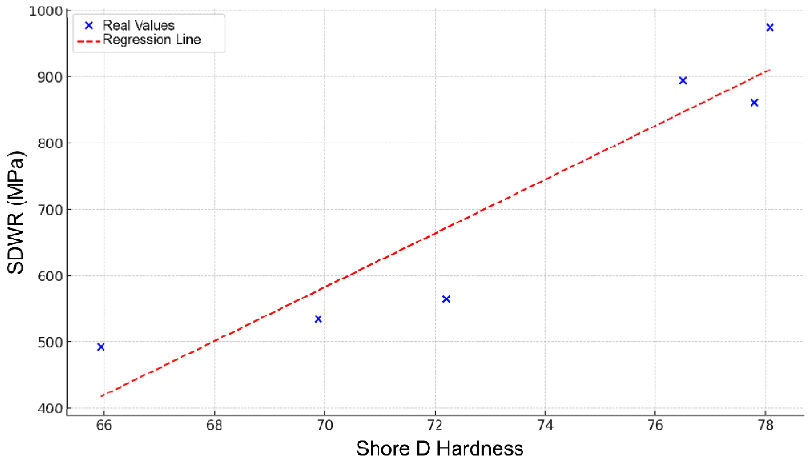


Fig. 3: Linear relationship between Shore D Hardness and SDWR.

CONCLUSIONS

Experiments conducted within the scope of this study revealed that the screw connection performance of commercial WPC materials is affected by multivariable factors: *(1)* Temperature is one of the most effective parameters on screw connection performance. Especially at high temperatures such as +60°C, losses of up to 50% in SDWR values have been observed. *(2)* As the screw diameter increases, SDWR values also increase significantly. Therefore, the use of larger diameter screws is recommended, especially in harsh environmental conditions. *(3)* Pilot hole diameter optimization plays a critical role in connection quality. The 60% ratio provided the best performance; screw adhesion weakened at 85%. *(4)* Shore D hardness is directly related to SDWR, and parallel decreases in both values were observed, especially with temperature. This finding suggests that Shore D hardness may be an effective indicator in predicting screw connection security.

REFERENCES

1. ADHIKARY K.B., PANG S. & STAIGER M.P. (2009): Effects of the accelerated freeze-thaw cycling on physical and mechanical properties of wood flour-recycled thermoplastic composites. In: Polymer Composites, 31(2), 185–194 pp.

2. AYRILMIS N., JARUSOMBUTI S., FUEANGVIVAT V. & BAUCHONGKOL P. (2011): Effect of thermal-treatment of wood fibres on properties of flat-pressed wood plastic composites. In: Polymer Degradation and Stability, 96(5), 818-822 pp.
3. BIRINCI E. & KAYMAKCI A. (2023): Effect of freeze–thaw cycling on the screw direct withdrawal resistance of beech, ozigo, and okoume plywoods. In: Forests, 14, 1243 pp.
4. BLEDZK A.K., LETMAN-SAKIEWICZ M. & MURR M. (2010): Influence of static and cyclic climate condition on bending properties of wood plastic composites (WPC). In: Express Polymer Letters, 4(6), 364–372 pp.
5. DURMAZ S., ERDIL Y.Z. & AVCI E. (2020): Screw withdrawal resistance and surface roughness of woven carbon and glass fiber-reinforced wood-plastic composites. In: BioResources 15(1), 1894–1903 pp.
6. DURMAZ S. (2021): Effect of wood flour content on the properties of flat pressed wood plastic composites. In: Wood Research, 67(2), 302–310 pp.
7. ESHAGHI S., TAGHIYARI H.R. & FAEZIPOUR M. (2013): Comparison between some factors affecting screw withdrawal resistance from different wood-composite panels. In: Lignocellulose, 2(2), 338–350 pp.
8. FRIEDRICH D. (2023): Change in key mechanical properties from postprocess hot pressing of commercial wood-plastic composites with different fibre contents. In: Polymer Bulletin, 80(4), 4263–4288.
9. FRIEDRICH D. & LUIBLE A. (2023): Investigations on ageing of wood-plastic composites for outdoor applications: A meta-analysis using empiric data derived from diverse weathering trials. In: Construction and Building Materials, 124, 1142–1152 pp.
10. GHANBARI A., MADHOUSHI M. & ASHORI A. (2014): Wood plastic composite panels: influence of the species, formulation variables and blending process on the density and withdrawal strength of fasteners. In: Journal of Polymers and the Environment, 22(2), 260–266 pp.
11. GUO J., TANG Y. & XU, Z. (2010): Wood plastic composite produced by nonmetals from pulverized waste printed circuit boards. In: Environmental Science & Technology, 44(1), 463–468 pp.
12. HAFTKHANI A.R., EBRAHIMI G., TAJVIDI M. & LAYEGHI, M. (2011): Investigation on withdrawal resistance of various screws in face and edge of wood–plastic composite panel. In: Materials & Design, 32(7), 4100–4106 pp.
13. LI J., HUO R., LIU W., FANG H., JIANG L. & ZHOU, D. (2022): Mechanical properties of PVC-based wood–plastic composites effected by temperature. In: Frontiers in Materials, 9, 1–12 pp.
14. MACHADO J.S., SANTOS S., PINHO F.F., LUÍS F., ALVES A., SIMÕES R. & RODRIGUES J.C. (2016): Impact of high moisture conditions on the serviceability performance of wood plastic composite decks. In: Materials & Design, 103, 122–131 pp.
15. MADHOUSHI M., NADALIZADEH H. & ANSELL M.P. (2009): Withdrawal strength of fasteners in rice straw fibre-thermoplastic composites under dry and wet conditions. In: Polymer Testing, 28 (3), 301–306 pp.

16. PERÇIN O. & ALTUNOK M. (2019): The effects of heat treatment, wood species and adhesive types on screw withdrawal strength of laminated veneer lumbers. In: Kastamonu University Journal of Forestry Faculty, 19(2), 152–163 pp.
17. PERÇIN O. & UZUN O. (2022): Screw Withdrawal strength of heat-treated and laminated veneer lumber reinforced with carbon and glass fibers. In: Bioresources, 17(2), 2486-2500 pp.
18. PILARSKI J.M. & MATUANA L.M. (2005): Durability of wood flour–plastic composites exposed to accelerated freeze–thaw cycling. Part I. Rigid PVC matrix. In: Journal of Vinyl & Additive Technology, 11(1), 1–8 pp.
19. POUR M. F., HATEFNIA H., DORIEH A., KIAMAHALLEH M.V. & AFROUZI Y.M. (2022): Research on medium density fiberboard (MDF) behavior against screw axial withdrawal: Impact of density and operational variables. In: Structures, 39, 194–206 pp.
20. SRIVABUT C., HOMKHIEW C., RAWANGWONG S. & BOONCHOUYTAN W. (2022): Possibility of using municipal solid waste for manufacturing wood-plastic composites: effects of natural weathering, wood waste types, and contents. In: Journal of Material Cycles and Waste Management, 24, 1407–1422 pp.
21. SRUBAR III W.V. (2015): An analytical model for predicting the freeze–thaw durability of wood–fiber composites. In: Composites Part B: Engineering, 69, 435-442 pp.
22. TAJVIDI M. & HAGHDAN S. (2009): Effects of accelerated freeze—thaw cycling on physical and mechanical properties of wood flour/PVC composites. In: Journal of Reinforced Plastics and Composites, 28(15), 1841–1846 pp.
23. TURKU I. & KÄRKI T. (2016): Durability of fire-retarded wood-polypropylene composites exposed to freeze-thaw cycling. In: Baltic Forestry, 22(2), 341–347 pp.
24. WANG X., KONG L., ZHAO W. & LIU Y. (2023): Chloride transport resistance of alkali-activated concrete exposed to combined chloride, sulfate and carbonation environment. In: Construction and Building Materials, 367, 130353 pp.
25. YANG W., XIE Y., WANG H., LIU B.Y. & WANG Q.W. (2013): Impacts of freezing and thermal treatments on dimensional and mechanical properties of wood flour–HDPE composite. In: Journal of Forestry Research, 24, 143–147 pp.
26. YANG X., MA L., ZHAO Q. & YU Y. (2018): Enduring performance of self-tapping screw connection in wood members and WPC members. In: Wood Research, 63(5), 833–842 pp.
27. ZHAO L., LV B., PENG X., & FU Y. (2021): Effect of natural and accelerated aging on the properties of wood-plastic composites. In: Wood Research, 66(5), 700–710 pp.
28. ZHOU Z., YANG Z., SUN H. & ZHANG J. (2021): Design of sandwich structure conductive polypropylene/styrene□butadiene□styrene triblock copolymer/carbon black composites with inherent morphological tunability. In: Journal of Applied Polymer Science, 138(24).

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