Quest Journals
Journal of Architecture and Civil Engineering
Volume 10 ~ Issue 8 (August 2025) pp: 17-24
ISSN(Online): 2321-8193
www.questjournals.org

Research Paper

Determination of The Effects of Fiber-Reinforced Polymer Types on the Screw Withdrawal Strength of Wood Based Sandwich Panels

Abdurrahman Karaman
Forestry and Forest Products Department Uşak University Turkey)

ABSTRACT: *Sandwich panels are favorable materials for structural or non-structural components due to durability, lightness, and longevity in service life. The strength of a structural system often depends on the interconnections between the components of the structure. Screws are one of the most widely used fasteners in construction. In this study, the screw withdrawal strength of wood based sandwich panels reinforced with jute fabric, glass fiber reinforced polymers (GFRP), and plaster mesh (PSM) via polyurethane adhesive (PUR-D4) was investigated. In predicting the screw withdrawal resistance, withdrawal load capacity, density, and withdrawal stiffness of the wood based materials and fabric jute, GFRP, and PSM in each layer, were considered. Moreover, the screw withdrawal strength of the panels was examined. Screw withdrawal tests of panels were conducted according to TS EN 13446 standard. The highest screw withdrawal strength was obtained for the based sandwich panels reinforced with GFRP (9.31 N/mm2). Furthermore, the difference between experimental and predicted screw withdrawal resistance changed from 4% to 9%. Besides, the highest air-dry density was obtained for the based sandwich panels reinforced with GFRP (0.620 g/cm3). Furthermore, the difference between experimental and predicted screw withdrawal resistance changed from 1.2% to 2%. In addition, the wood based sandwich panels reinforced with GFRP had a considerable increase in the screw withdrawal strength compared with the unreinforced, fabric jute, and PSM reinforced samples.*

KEYWORDS: *Screw withdrawal strength, Sandwich panel, Jute fabric, Glass fiber reinforced polymers, Plaster mesh: Polyurethane adhesive.*

***R**eceived 26 July, 2025; **R**evised 03 Aug., 2025; **A**ccepted 05 Aug., 2025 © The author(s) 2025.*
P**ublished with open access at **www.questjournas.org

I. INTRODUCTION

Sandwich panels are innovative products that have a significant impact on modern construction. Their applications include many construction projects, including residential and commercial buildings. They offer flexible options that meet the high standards of modern building design [1]. The sandwich panels were a kind of structural material composed of two high-strength stiff layers (facings) and one low-density layer (core) [2]. Surface layer can bear the in-plane load and bending moment, which can be made from steel [3], wood [4], fibre reinforced concrete [5] or concrete [6], and other materials [7]; the core layer mainly serves to transmit the load, and its function is to maintain the distance between the two layers and increase the inertia moment and bending stiffness of the panel.

Wood-based sandwich panels are unique for their layered structure; thus, they have improved mechanical strength, good thermal insulation, and weight reduction [1]. It helps reduce transportation and construction costs. Also, using such renewable resources as wood corresponds with sustainable development goals, whose purpose is to prioritize and promote resource efficiency and lower greenhouse gas emissions [8]. Recent advancements in wood-based sandwich panel technology have explored a diverserange of core configurations, including low-density wood fibers [9], plywood [10], solid wood strips [11], cork agglomerates [12], dowel-type wooden lattices [13], corrugated paperboard [14], and three-dimensional wood strands [15]. Recent studies have highlighted the importance of materials used for the faces and cores of the sandwich panels and their geometric configurations in the determination of the thermal and mechanical behaviours of such panels. For instance, wood-based faces com bined with various core materials like balsa (Ochroma pyramidale) wood and polyurethane (PUR) foam significantly influenced the panels' performance [16].

Fiber reinforced polymers (FRP) have a kind of high performance material formed by mixing fiber material and matrix material (resin) in a certain proportion including for some of the most common composites used as reinforcements have been aramid (AFRP), glass (GFRP), basalt (BFRP), and carbon (CFRP) fibre-reinforced polymers [17]. The FRP reinforcement technique can also be used to extend the span length of existing timber beams [18]. The FRP have the advantages of light weight, non-conductive, high mechanical strength, less recycling and corrosion resistance [19]. The FRP is also widely used in retrofitting of ancient buildings by strengthening damaged mortise and other damaged parts. FRP strengthening could also improve the ultimate bearing capacity and flexural rigidity of timber beams [20] The incorporation of the FRP materials in timber structures has proven to significantly enhance both strength and stiffness. The FRP composites, which combine high-strength fibers with a polymer matrix, offer numerous advantages, including high strength-to-weight ratio, corrosion resistance, electromagnetic neutrality, and ease of handling [18,19]. These properties make the FRP an attractive solution for the conservation and structural rehabilitation of heritage timber structures, including the reinforcement of degraded mortise joints. Research has demonstrated that the application of the FRP can significantly improve both the load-bearing capacity and flexural stiffness of timber beams [20].

When the literature is examined, reveals numerous publications on wood-based sandwich panels in general. However, there are no studies on these panels reinforced with jute fabric, glass fiber reinforced polymers (GFRP), or plaster mesh (PSM). Therefore, it is necessary to investigate the screw withdrawal strength of reinforced wood-based sandwich panels needs to be examined in detail. In this study, the screw withdrawal strength (SWS) of wood based sandwich panels reinforced with jute fabric, GFRP, and PSM via polyurethane adhesive (PUR-D4) was determined.

II. MATERIALS AND METHODS

2.1 Materials

In the preparation of test specimens, melamine-coated medium density fiberboard (MDFLam) with 4 mm thickness and oriented strand board (OSB-2) class boards with 9 mm thickness were used (Figure 1a,b). These materials were obtained by random selection from Usak 1 September industrial site market. Some of the characteristics of the wood-based materials are given in Table 1.

Table 1. Physical and mechanical properties of the wood-based materials used in this study.

Properties	MDF-Lam	OSB-2
Air-Dry Density (g/cm^3)	0.670	780
Bending Strength (N/mm^2) (//)	22	26
Bending Strength (N/mm^2) ┴	11	13
Modulus of Elasticity (N/mm^2) (//)	3500	4300
Modulus of Elasticity (N/mm^2) (┴)	1400	2100
Tensile Strength (N/mm^2)	0.34	0.73

The PUR-D4 adhesive was obtained from Beta Kimya Industry and Trade Inc., in Turkey (Figure 1c). The technical properties of the PUR-D4 were as follows: density of 1.110 g/cm3, pH of 5.0 (25°C), viscosity of 5000-10000 mPas (20°C), and application amount of (200 gr/m2). The jute fabric for 265 gr/m2 plain materials were obtained from Polatoglu Garden-Agriculture-Hardware Company in Turkey (Figure 1d). The GFRP for 200 gr/m2 plain materials were obtained from Dost Chemical Industry Raw Material Industry and Trading Company in Turkey (Figure 2e). The density of GFRP and Jute Fabric are 2.5 gr/cm3 and 1.3 gr/cm3, respectively. The GFRP and Jute Fabric values of young's modulus, tensile strength, and elongation to fracture were 70 GPa, and 26.5 GPa, 2000-3500 MPa and 393-773 MPa, 0.9% and 1.8%, respectively [21]. The PSM for 160 g/m2 materials were obtained from Tumerler Construction Materials Ind. and Trade Co. Ltd. in Turkey. It was alkali resistant and orange in color, with a 4 mm × 4 mm mesh pattern (Figure 1f).

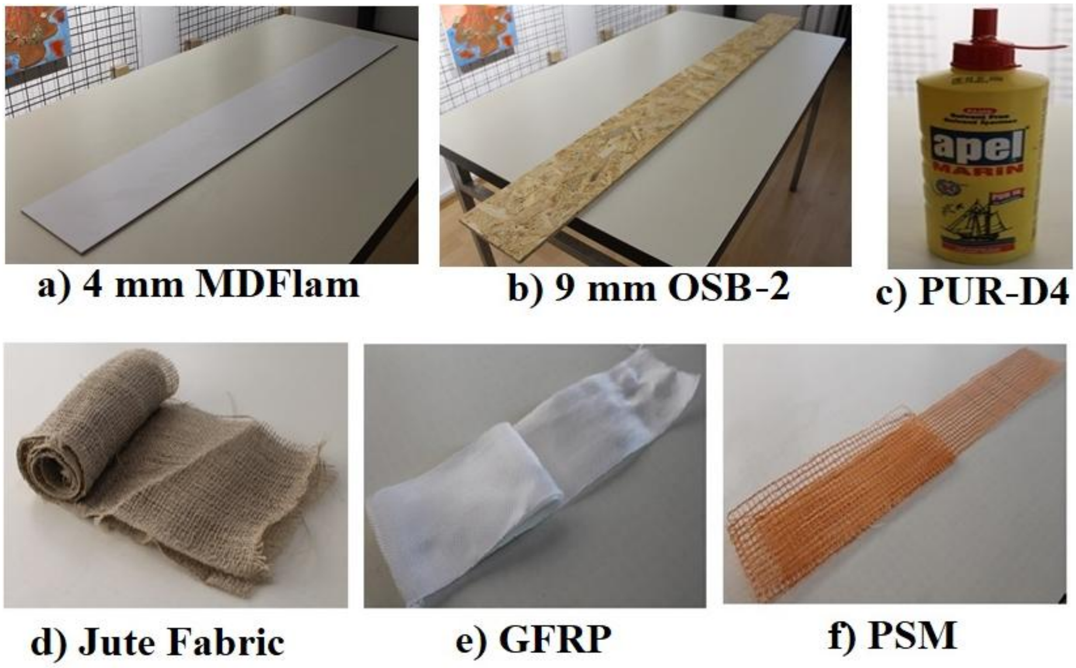

Figure 1: Materials used in experiments: a) 4 mm MDFLam, b) 9 mm OSB-2 Class, c) PUR-D4 adhesive, d)Jute fabric, e) GFRP, and e) PSM.

2.2. Preparation and Construction of Specimens

The OSB-2 panels and 4 mm thickness MDFL-lam were precisely cut into 31 pieces per panel, each measuring 162 × 1700 ± 1 mm using a CNC machine (Figure 2a). For interlayer samples, two layer of reinforced materials (Jute fabric, GFRP, and PSM) was used for intermediate support between OSB and MDF-Lam layers. Approximately 200 g/m^2 of adhesive was used for surface (Figure 2b). The configuration of the different elaborated composite panels is shown in Table 2. The samples, which consisted of three layers, were placed into a hydraulic press (Hydraulic Veneer SSP-80; ASMETAL Wood Working Machinery Industry Inc., Ikitelli, Istanbul, Turkey) at room temperature (Figure 2c). The press exerted a pressure of approximately 1.5 N/mm^2 at 25 °C for 3 h. As a result, the test samples were produced in cold pressure at 20 ± 2 °C and 65 ± 5% relative humidity. The pressing of samples in the are shown in Figure 2d.

Table 2. Composition of wood based sandwich panel sets in this study.

Panel Set	Description	Construction
MO	Sandwich panel by non-reinforcing	M-O-M
MGO	Sandwich panel by reinforcing PURD4 with GFRP	M-G-O-G-M
MJO	Sandwich panel by reinforcing PURD4 with Jute fabric	M-J-O-J-M
MPO	Sandwich panel by reinforcing PURD4 with PSM	M-P-O-P-M

After the process test samples were stored for a week for exact curing. The air-dried density (ρ_{12}), and the SWS test samples were prepared according to TS EN 323 [22], and TS EN 13446 [23] standards. All specimens (10 replications for each sample group) were prepared for each property; ρ_{12}, and the SWS. A total of 50 specimens were prepared for this study, incorporating OSB-2 panels and 4 mm MDF-Lam, three fiber-reinforced polymers (Unreinforced, Jute fabric, GFRP, and PSM), alongside control samples, each replicated ten times. Before testing, all samples were conditioned in a humidity chamber controlled at 20 ± 2 °C and 65% relative humidity (RH) for two weeks.

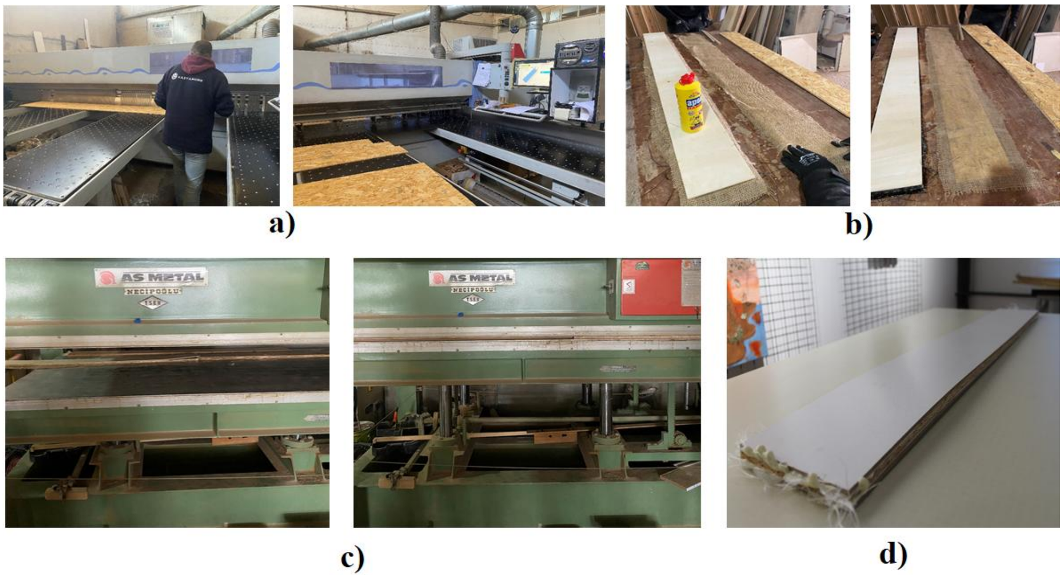

Figure 2: Production stages of test samples.

All of the specimens (10 replications for each sample group) were cut into 50 mm by 50 mm nominal dimensions from all panels respectively (Figure 3).

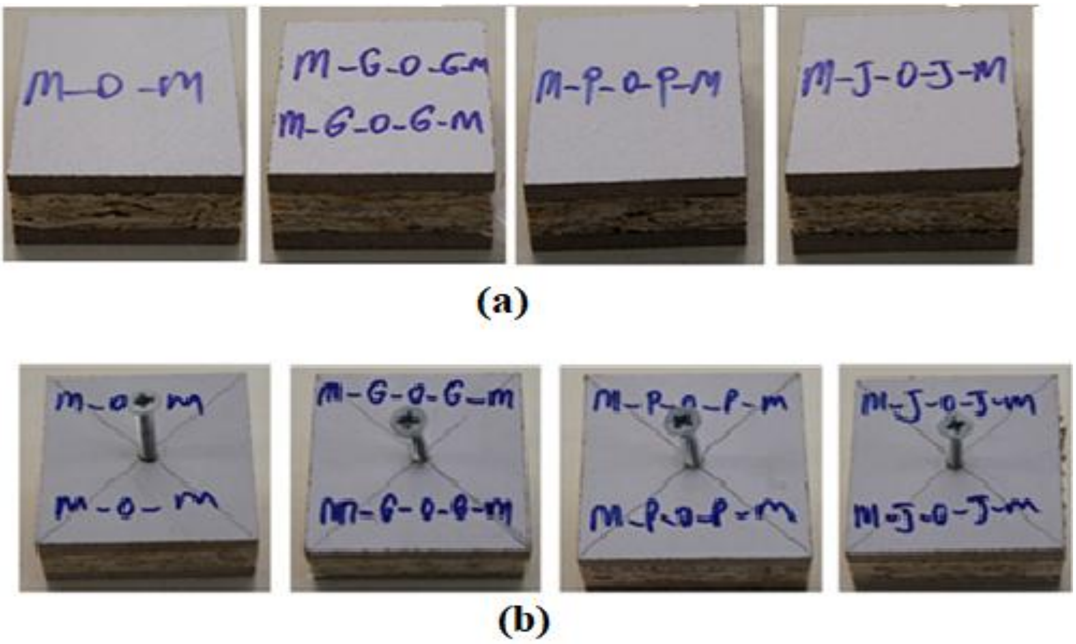

Figure 3: The configuration of test samples. a) Test samples of δ_{12}, b) Test samples of the SWS.

2.3. Density

According to TS EN 323 [23], a total of 10 test specimens for each sample group with dimensions of 50x50 were prepared. All specimens were acclimatized at 20±2 °C and 65 ± 5% relative humidity according to TS-EN 326-1 [24] and weighed with a 0.01 g precision scale. Their dimensions were measured with a 0.01 mm precision caliper. The density of the sandwich panels was calculated by using Equation 1.

$$\delta_{12} = \frac{M_{12}}{V_{12}} \qquad (1)$$

where δ_{12} is air-dry density (g/cm^3), and M_{12} is the weight of the material (g), and V_{12} is the volume of the material (cm^3).

2.3. Screw Withdrawal Strength (SWS)

All tests for the SWS were conducted on the SHIMADZU universal test machine according to TS EN 13446 [23]. Withdrawal load capacities were obtained by applying a withdrawal load parallel to the screw axis from the face of specimens with a rate of 2 mm/min and continued until the ultimate load reached (Figure 4). Equation 2 was used to calculate the SWS (N/mm^2) of panels.

$$\sigma_{SWS} = \frac{F_{max}}{2 \times \pi \times r \times d} \qquad (2)$$

where, *Fmax* is the ultimate withdrawal load (N), *r* is the radius of the screw (mm), and *d* is the penetration length (mm).

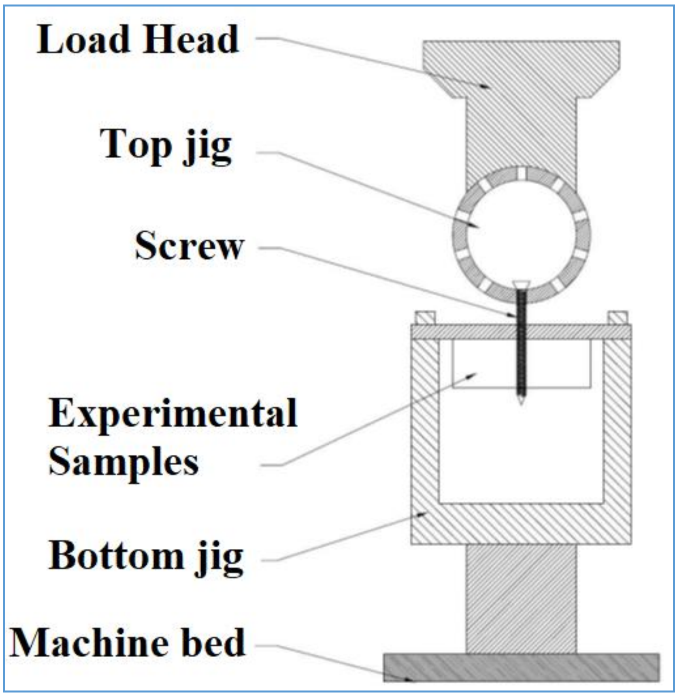

Figure 4: Test configuration for screw withdrawal strength from face.

2.5. Statistical Analysis

Data collected for the presence of statistical significance among all sample groups through one-way ANOVA and Tukey pair-wise comparisons were examined in SPSS. To determine the significance level of the interaction between the factors, Duncan's test was utilized, with a significance level set at 5% ($p < 0.05$). This allowed for determining the degree of significance if the mutual strength of the factors exhibited a significant effect.

III. RESULTS

Table 3 presents a summary of the test results for the δ_{12}(g/cm^3), and the SWS (N/mm^2) properties of the samples. Descriptive statistics, including the maximum, minimum, mean, and standard deviation, were used to summarize the data. These statistical values provide an overview of the observed variability and central tendencies in the tested properties of the samples.

Table 3. Descriptive Statistical Values of δ_{12} (g/cm^3), and σ_{SWS} (N/mm^2).

Density and SWS	Values	M-O-M	M-G-O-G-M	M-J-O-J-M	M-P-O-P-M
δ_{12}	X	0.608	0.620	0.618	0.616
	SD	2.94	3.71	3.23	2.60
	COV (%)	0.48	0.60	0.52	0.42
	Min,	0.612	0.618	0.614	0.612
	Max,	0.619	0.630	0.622	0.619
	N	10	10	10	10
	X	7.95	9.31	8.67	8.29

σ_{SWS}	SD	0.67	0.91	0.94	1.05
	COV (%)	8.42	9.77	10.84	12.66
	Min,	6.96	8.29	7.46	7.07
	Max,	8.92	11.58	10.57	10.02
	N	10	10	10	10

δ_{12}: Air-Dry-Density, σ_{SWS}: Screw withdrawal strength, X: Mean values, SD: Standart deviation, COV (%): Coefficient of variation, N: Number of samples, M-O-M : (Unreinforced wood sandwich panel), M-G-O-G-M (wood based sandwich panel with reinforced GFRP), M-J-O-J-M (wood based sandwich panel with reinforced jute fabric), and M-P-O-P-M (wood based sandwich panel with reinforced PSM).

According to Table 4, the comparison between the M-O-M, M-G-O-G-M, M-J-O-J-M, and M-P-O-P-M samples was dependent on the ANOVA analysis. According to analysis, the δ_{12}, and σ_{SWS} was were statistically significant at the level of 0.05.

Table 4. The result of ANOVA.

Physical and Mechanical Properties	Source	SO	DF	MS	F Value	Sig.
δ_{12}	Between Groups	144.875	3	48.292	4.882	0.006
	Within Groups	356.100	36	9.892		
	Total	500.975	39			
σ_{SWS}	Between Groups	10.209	3	3.403	4.158	0.013
	Within Groups	29.459	36	0.818		
	Total	39.668	39			

In cases where the observed differences between groups were deemed statistically significant, the Duncan test was employed to determine the specific differences between means. This analysis was conducted at a predetermined significance level of α=0.05. The results of the Duncan test, indicating the significant differences between means, can be found in Table 5.

Table 5. The result of Duncan Test.

Physical and Mechanical Properties	Process							
	M-O-M		M-G-O-G-M		M-J-O-J-M		M-P-O-P-M	
	X	HG	X	HG	X	HG	X	HG
δ_{12} (g/cm^3)	0.608	B	0.620	A	0.618	AB	0.616	B
σ_{SWS} (N/mm^2)	7.95	B	9.31	A	8.67	AB	8.29	AB

HG: Homogeneity groups

In cases where the observed differences between groups were deemed statistically significant, the Duncan test was employed to determine the specific differences between means. This analysis was conducted at a predetermined significance level of α=0.05. The results of the Duncan test, indicating the significant differences between means, can be found in Table 5.

This Table 5 shows that the some physical and mechanical of the M-O-M samples showed was the lowest, and the some physical and mechanical properties of the M-G-O-G-M was the highest, the δ_{12} of the M-G-O-G-M samples were determined 0.620 g/cm^3, and σ_{SWS} values is 8.67 N/mm^2. Upon through examination of the overall results, it was observed that the M-G-O-G-M samples exhibited the most favorable properties. However, it is worth noting that the M-O-M samples demonstrated the lowest value among all the tested. The some and mechanical properties of the M-G-O-G-M were higher than that of the M-O-M samples δ_{12} 2 %, and σ_{SWS} 17.00 %.

Similarly, some physical and mechanical of properties the M-P-O-P-M samples were higher than that of the M-O-M samples (δ_{12} 1.2 %, and σ_{SWS} 4 %). The M-J-O-J-M samples were higher than that of the M-O-M samples (δ_{12} 1.6 %, and σ_{SWS} 9 %). Based on results, wood based sandwich panels, higher values the the M-G-O-G-M, M-J-O-J-M, M-P-O-P-M samples and than the M-O-M samples which were representing their kinds.

Similar results regarding the increase in the density values of reinforced LVL samples were reported by [25-29]. The screw withdrawal strength of heat-treated scotch pine (*Pinus sylvestris* L.) samples reinforced with glass and carbon fibers *via* Desmodur-vinyl trie ketonol acetate adhesive was investigated. Test results showed that the reinforcement with glass and carbon fibers increased the screw withdrawal strength up to 38% and 49% in the tangential, 13% and 20% in the radial, and 17% and 25% in the axial direction, respectively, compared to solid wood [29]. The predict screw withdrawal resistance of the plywood laminated medium-density fiberboard and particleboard, and sandwich panels was estimated. According to the experimental results, it is stated that there is a proportional correlation between the density of the panels and the screw pull-out strength, and the highest screw pull-out strength is obtained in sandwich panels made of plywood and medium density fiberboard (12.51 N/mm^2) [30].

IV. CONCLUSION

In this study, the screw withdrawal strength of wood based sandwich panels reinforced with the jute fabric, GFRP, and PSM via PUR-D4 adhesive was investigated.

The reinforcement fiber types have a significantly effect on the SWS. Depending on the type of reinforcing material, the GFRP yielded more positive effects in terms of the SWS. The SWS values of the test samples that were reinforced with jute fabric, GFRP, and PSM materials are higher than unreinforced wood based sandwich panels. Given the substantial enhancements in the resistance properties of the intermediate filling material utilized in reinforced wood based sandwich panels, it is advisable to prioritize high-strength properties in wood furniture and structural wood based materials. In wooden structures where the screw withdrawal strength is important, the use of GFRP, and jute fabric as the FRP type can be recommended.

In future scientific studies on wood-based sandwich panels, the following may be recommended:

1- Plywood and particleboard as wood-based panels

2- Epoxy and polyvinyl acetate adhesives as adhesives

3- Basalt fiber fabric, carbon fiber fabric, and aramid fiber fabric may be recommended for reinforcement.

4- Additionally, the bending strength, modulus of elasticity, and dowel tensile strength of wood-based sandwich panels produced using the above materials may be investigated.

The Double pendulum is a very complex system. Due to the complexity of the system there are many assumptions, if there was friction, and the system was non-conservative, the system would be chaotic. Chaos is a state of apparent disorder and irregularity. Chaos over time is highly sensitive to starting conditions and can only occur in non-conservative systems. The time of this motion is called the period, the period does not depend on the mass of the double pendulum or on the size of the arcs through which they swing. Another factor involved in the period of motion is, the acceleration due to gravity.

REFERENCES

[1]. Wei, P.X., et al., Wood-based sandwich panels: A review. Wood Research, 2021. 66 (5): p.875-890. doi; https://doi.org/10.37763/wr.1336-4561/66.5.875890

[2]. Birman, V. and Kardomateas, G. A. Review of current trends in research and applications of sandwich structures. Composites Part B: Engineering, 2018. 142: p. 221-240. https://doi.org/10.1016/j.compositesb.2018.01.027

[3]. Nilsson, P., et al., Transverse shear stiffness of corrugated core steel sandwich panels with dual weld lines. Thin-Walled Structures, 2017. 117: p. 98-112.https://doi.org/10.1016/j.tws.2017.04.008

[4]. Kljak, J. and Brezovic, M. Influence of plywood structure on sandwich panel properties: Variability of veneer thickness ratio. Wood Research, 2007. 52(2): p. 77-88.

[5]. O'Hegarty, R., et al., Composite behaviour of fibre-reinforced concrete sandwich panels with FRP shear connectors. Engineering Structures, 2018. 198: pp. 1-15. https://doi.org/10.1016/j.engstruct.2019.109475

[6]. O'Hegarty, R. and Kinnane, O. Review of precast concrete sandwich panels and their innovations. Construction and Building Materials, 2020. 233: pp. 117145. https://doi.org/10.1016/j.conbuildmat.2019.117145

[7]. Boldis, M., et al., Compression set of PU foam mattresses with self-clamping joints and sandwich structure. Wood Research, 2016. 61(6): p. 1003-1016.

[8]. Barbu, M., et al., New technology for the continuous production of wood-based lightweight panels. In Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe-Timber Committee, Geneva, Switzerland, 11–14 October 2010; pp. 1–10.

[9]. Zhang, Y., et al., Characteristic and prediction model of vertical density profile of fiberboard with fiberboard with “pretreatment-hot pressing” united technology. Wood Research, 2010. 57(4): p.613-630.

[10]. Susainathan, J., et al., Experimental investigation of impact behavior of wood-based sandwich structures. Composites Part A: Applied Science and Manufacturing, 2018. 109: p. 10-19. https://doi.org/10.1016/j.compositesa.2018.02.029

[11]. Li, Y.S., et al.. Experimental study on mechanical behavior of profiled steel sheet-bamboo plywood composite slabs. Journal of Building Structures, 2008. 29(1): p. 96-102.

[12]. Lakreb, N., et al., Mechanical behavior of multilayered sandwich panels of wood veneer and a core of cork agglomerates. Materials & Design, 2015. 65: p. 627-636. https://doi.org/10.1016/j.matdes.2014.09.059

[13]. Jin, M., et al., Compressive and bending behaviours of wood-based two-dimensional lattice truss core sandwich structures. Composite Structures, 2015. 124: p. 337-344. https://doi.org/10.1016/j.compstruct.2015.01.033

[14]. McCracken, A. and Sadeghian, P. Corrugated cardboard core sandwich beams with bio-based flax fiber composite skins. Journal of Building Engineering, 2018. 20: p. 114-122. https://doi.org/10.1016/j.jobe.2018.07.009

[15]. Mohammadabadi, M., et al., Low-velocity impact response of wood-strand sandwich panels and their components. Holzforschung, 2018. 72(8): p. 681-689. https://doi.org/10.1515/hf-2017-0169

[16]. Mazzuca, P. Flexural behaviour of GFRP sandwich panels with eco-friendly PET foam core for the rehabilitation of building floors. Structures, 2024. 60: 105815. https://doi.org/10.1016/j.istruc.2023.105815

[17]. Wang, Z. Q., et al., Reinforcement of laminated veneer lumber with ramie fibre. Advanced Materials Research, 2011. 332: p. 41-44.

[18]. Schober, K. U., et al., FRP reinforcement of timber structures. Construction and building material, 2015. 97: p. 106-118. https://doi.org/10.1016/j.conbuildmat.2015.06.020

[19]. Jiang, J., et al., Local and global prediction on stress-strain behavior of FRP-confined square concrete sections. Composite Structures, 2019. 226: 111205. https://doi.org/10.1016/j.compstruct.2019.111205

[20]. Zhao, X. B., et al., Shaking table tests on seismic behavior of ancient timber structure reinforced with CFRP sheet. Engineering Structures,2019. 197: 109405. https://doi.org/10.1016/j.engstruct.2019.109405

[21]. Pai, A. R., and Jagtap, R. N. Surface morphology & mechanical properties of some unique natural fiber reinforced polymer composites-a review. Journal of Materials and Environmental Science, 2015. 6(4): p. 902-917.

[22]. TS EN 323 (1999). Wood-based panels – Determination of density. Institute of Turkish Standards, Ankara, Turkey.

[23]. TS EN 13446 (2002). Wood-based panels – Determination of withdrawal capacity of fasteners. Institute of Turkish Standards, Ankara, Turkey.

[24]. TS EN 326-1 [1999]. Wood-based panels – Sampling, cutting and inspection – Part 1: Sampling and cutting of test pieces and expression of test results. Institute of Turkish Standards, Ankara, Turkey.

[25]. Wei, P., et al., Mechanical properties of poplar laminated veneer lumber modified by carbon fiber reinforced polymer. BioResources, 2013. 8(4): p. 4883-4898.

[26]. Bal, B. C. Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber. Construction and Building Materials, 2014. 51: p. 9-14. https://doi.org/10.1016/j.conbuildmat.2013.10.041

[27]. Wang, J., Guo, X., Zhong, W., Wang, H., & Cao, O. (2015). Evaluation of mechanical properties of reinforced poplar laminated veneer lumber. BioResources, 2015. 10(4): p. 7455- 7465.

[28]. Auriga, R., et al., Performance properties of plywood composites reinforced with carbon fibers. Composites Structures 2020. 248: 112533 https://doi.org/10.1016/j.compstruct.2020.112533

[29]. Perçin, O. and Uzun, O. (2022). Screw withdrawal strength of heat-treated and laminated veneer lumber reinforced with carbon and glass fibers. BioResources, 2022. 17(2): p. 2486–2500. https://doi.org/10.15376/biores.17.2.2486-2500

[30]. Uysal, M. and Güntekin, E. (2024). Prediction of screw withdrawal resistance for plywood laminated panels and sandwich panels. Turkish Journal of Forestry, 2024. 25 (1): p. 81-88.