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PHYSICAL AND MECHANICAL PROPERTIES OF WOOD-BASED SANDWICH PANELS REINFORCED WITH GFRP, JUTE FABRIC, AND PLASTER MESH

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Abstract:
This study investigates the density (ρ), modulus of rupture (MOR), and modulus of elasticity (MOE) of wood-based sandwich panels reinforced with glass fiber-reinforced polymer (GFRP), jute fabric, and plaster mesh (PSM). Melamine-coated medium-density fiberboard (MDF-Lam, 4mm thickness) was used as the face layers, while oriented strand board (OSB-2, 9 mm thickness) served as the core material. The reinforcement materials were incorporated as two interlayers within the sandwich structure using polyurethane adhesive. Mechanical tests were conducted to evaluate the effects of different reinforcement types on panel performance. According to the test results, GFRP reinforcement led to the highest performance values, with density, MOR, and MOE reaching 730kg/m³, 35.89N/mm², and 996N/mm², respectively. In contrast, the unreinforced panels exhibited the lowest corresponding values of 719kg/m³ for density, 23.98N/mm² for MOR, and 707N/mm² for MOE. Overall, the incorporation of reinforcement layers significantly enhanced the mechanical properties of the wood-based sandwich panels, with GFRP providing the most pronounced improvement.

Key words: *air-dry density; modulus of rupture; modulus of elasticity; jute fabric.*

INTRODUCTION

Sandwich panels are generally defined as composite structural systems consisting of two high-strength, load-bearing face sheets and a lightweight, low-density core (Birman and Kardomateas 2018). Face sheets in sandwich panels primarily resist in-plane loads and bending moments and can be manufactured from a wide range of materials, including steel (Nilsson et al. 2017), wood (Kljak and Brezovic 2007), fibre-reinforced concrete (O'Hegarty et al. 2019), conventional concrete (O'Hegarty and Kinnane 2020), and other engineered composites (Boldis et al. 2016). The core layer functions predominantly as a load-transfer medium, maintaining the separation between the face sheets while enhancing the overall moment of inertia and bending stiffness of the panel (Noor et al. 1996). Core configurations commonly include corrugated structures, plastically formed geometries, honeycomb cells, and other architectured forms (Noor et al. 1996). Due to the inherently low density of core materials, sandwich panels offer a substantial reduction in self-weight without compromising load-carrying capacity (Sandeep and Srinivasa 2020).

Owing to their layered configuration, wood-based sandwich panels (WSPs) offer a favorable balance between mechanical performance, thermal insulation capability, and reduced structural weight, which contributes to lower transportation and construction costs (Wei et al. 2021). Moreover, the use of wood-based and fiber-reinforced components aligns with sustainable construction strategies by promoting renewable resources, improving material efficiency, and reducing greenhouse gas emissions over the life cycle of building products (Myllyviita et al. 2021).

Wood-based sandwich panels have high strength-to-weight ratios that exceed those of common construction materials such as solid wood, concrete, and steel (Li et al. 2014) This makes these panels perfect for situations that require lightweight and strong materials. For example, their use in prefabricated construction demonstrates their ability to reduce overall wood consumption and construction weight while maintaining structural integrity (Hussain et al. 2019). It is essential to consider the ratio of strength to density when evaluating wood-based and other sandwich panels. This ratio reflects the panel's structural efficiency, combining its mechanical strength and weight. For instance, in the case of sandwich-structured composite plywood panels, the variations in the veneer thickness ratio in plywood significantly change the stress distribution in each layer of the sandwich panel. Also, it influences the stiffness of a sandwich panel. Stiffness can be increased by increasing the thickness ratio of the paralleloriented veneer sheets (Kljak and Brezovi 2007).

Qin et al. (2019) developed wood-based sandwich structures with OSB face sheets and birch dowel lattice cores and showed through out-of-plane compression tests that increasing face-sheet thickness significantly enhances compressive performance. Hao et al. (2020) examined sandwich panels with MDF and plywood face sheets and hexagonal and Taiji honeycomb cores, reporting superior compressive strength and elastic modulus for the Taiji configuration. These studies demonstrate that core geometry and face-sheet mechanical efficiency govern the global response of wood-based sandwich structures. Zheng et al. (2020)

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further highlighted the efficiency of hybrid wood-FRP systems using OSB and wood–plastic composite face sheets with GFRP lattice cores, achieving high specific strength and stiffness. Although fiber-reinforced face layers, such as GFRP and jute fabrics, are known to improve stiffness and load capacity (Alam et al. 2022), systematic studies on wood-based sandwich panels incorporating combined GFRP, jute fabric, and plaster mesh (PSM) reinforcements remain limited.

OBJECTIVE

This study aims to evaluate the density (δ_{12}), modulus of rupture (MOR), and modulus of elasticity (MOE) of MDF-faced wood-based sandwich panels with an OSB-2 core reinforced with jute fabric, glass fiber-reinforced polymer (GFRP), and plaster mesh (PSM), bonded using a polyurethane (PUR-D4) adhesive.

MATERIAL AND METHODS

Materials

In the preparation of test specimens, the face and bottom layers of the composite panels consisted of 4 mm thickness, melamine-coated medium density fiberboard (MDF-Lam) commonly utilized in the furniture sector (Fig. 1a). The core material was composed of 9mm thickness oriented strand board (OSB-2 class) (Fig. 1b). All materials were procured randomly from suppliers located within the Uşak 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

Physical and mechanical properties	OSB-2 Class	4 mm MDF-Lam
Density (kg/m^3)	670	780
Bending Strength (N/mm^2)	22	26
Modulus of Elasticity (N/mm^2)	3500	4300

The polyurethane adhesive (PUR-D4) was obtained from Apel Kimya Industry and Trade Inc., in Turkey (Fig. 1c). The technical properties of the PUR-D4 were as follows: density of 1.110g/cm^3, pH of 5.0 (25°C), viscosity of 5000 to 10000 mPas (20°C), and application amount of (200g/m^2).

As reinforcement were used jute, glass fiber polymer (GFRP) and plaster mash (PSM). The jute fabric for 265g/m^2 plain materials were obtained from Polatoglu Garden-Agriculture-Hardware Company in Turkey (Fig. 1d). Glass fiber reinforced polymers (GFRP) for 200g/m^2 plain materials were obtained from Dost Chemical Industry Raw Material Industry and Trading Company in Turkey (Fig. 2e). The density of GFRP and Jute Fabric are 2.5g/cm^3 and 1.3g/cm^3, 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 (Pai and Jagtap 2015). Plaster mesh (PSM) for 160g/m^2 materials were obatined from Tumerler Construction Materials Ind. and Trade Co. Ltd. in Turkey. It was alkali resistant and orange in color, with a 4mm × 4mm mesh pattern (Fig. 1f).

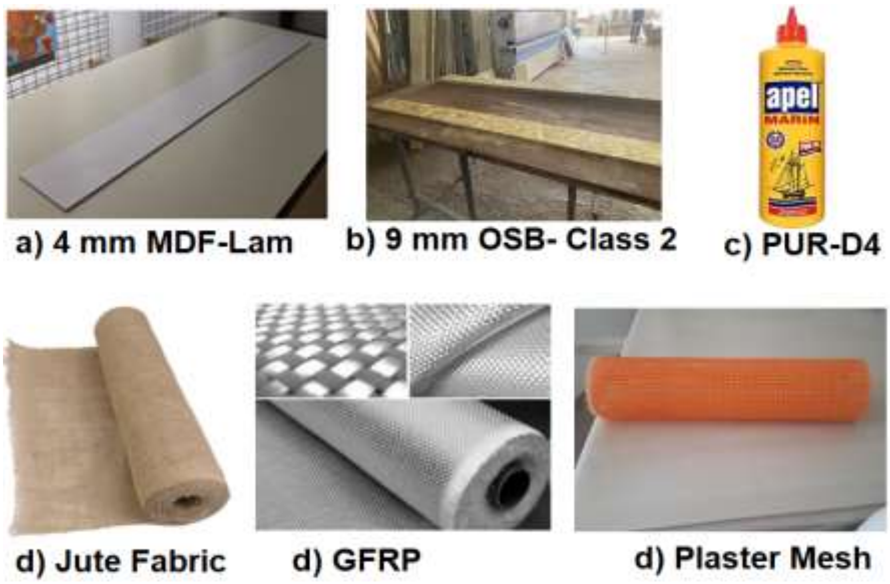

Fig. 1.
Materials used in experiments.

Preparation of experimental samples

The 9mm thick OSB-2 and 4mm thick MDF-Lam panels were CNC-machined into 31 specimens per panel, each measuring 162 × 1700 ± 1mm (Fig. 2a). Two layers of reinforcing materials (GFRP, jute fabric, or PSM) were introduced as interlayers between the OSB and MDF-Lam faces. An adhesive was applied to the bonding surfaces at a spread rate of approximately 200g/m² (Fig. 2b). The resulting three-layer assemblies were consolidated in a hydraulic press (Hydraulic Veneer SSP-80; ASMETAL Wood Working Machinery Industry Inc., Istanbul, Turkey) at room temperature under a pressure of 1.5N/mm² for 3 h at 25°C (Fig. 2c-d). Following pressing, all specimens were conditioned for one week to ensure complete curing. The panels were coded according to their constituent materials: MDF-Lam (M), OSB-2 (O), and basalt, glass, and jute reinforcements (B, G, and J), respectively. The sandwich panel configurations are presented in Table 2.

Table 2

Combinations of wood-based sandwich panels were manufactured

Groups	Code	Face Layer	FRP Types	Core Layer	Bottom Layer
A	M-O-M	M (MDF-Lam)	Unreinforced	O (OSB-2 class)	M (MDF-Lam)
B	M-G-O-G-M	M (MDF-Lam)	G (GFRP)	O (OSB-2 class)	M (MDF-Lam)
C	M-J-O-J-M	M (MDF-Lam)	J (Jute Fabric)	O (OSB-2 class)	M (MDF-Lam)
D	M-P-O-P-M	M (MDF-Lam)	P (PSM)	O (OSB-2 class)	M (MDF-Lam)

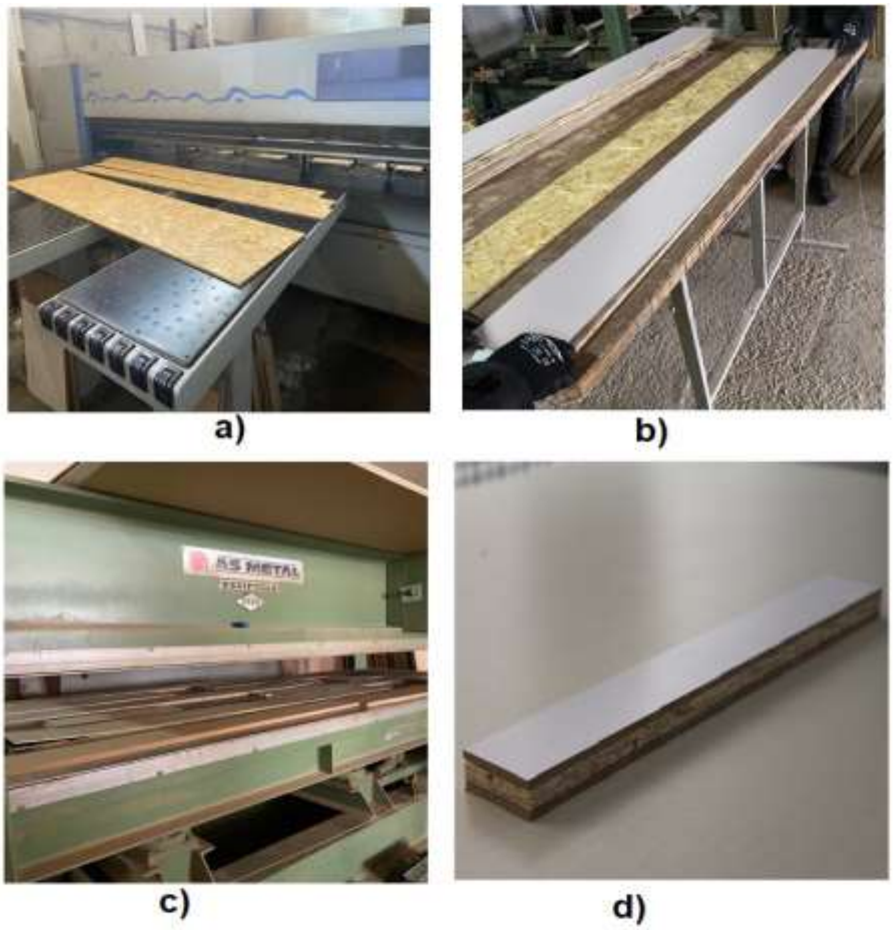

Fig. 2.
The production process of test samples.

The density (δ_{12}), the modulus of rupture (MOR), and the modulus of elasticity (MOE) test samples were prepared according to TS EN 323 (1999), and TS EN 310 (1999) standards. All specimens (10 replications for each sample group) were prepared for each property (Fig. 3).

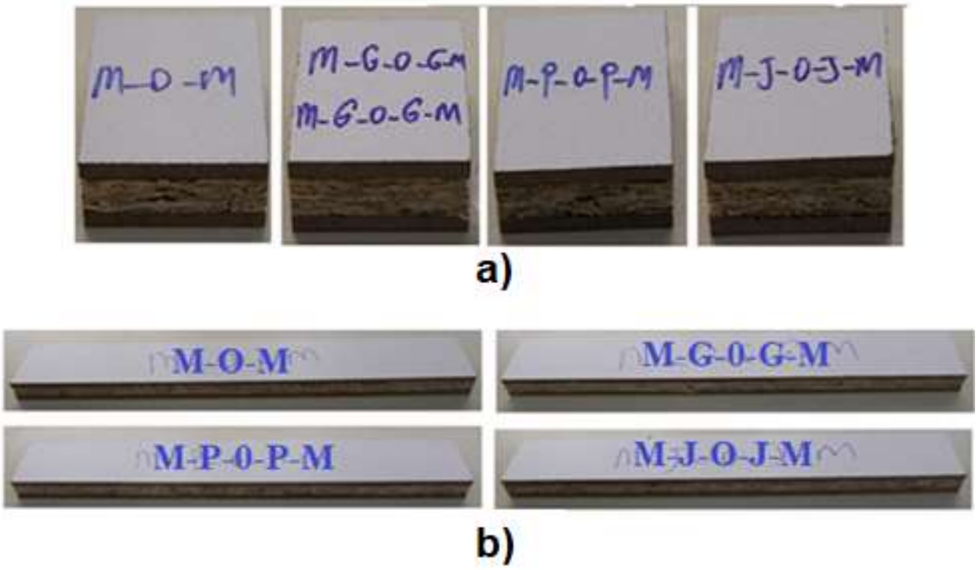

Fig. 3.
The configuration of test samples. (a) Test samples of density. (b) Test samples of modulus of elasticity in bending and of bending strength.

A total of 50 specimens were prepared for this study. All specimens were conditioned at 20±2°C and 65±2% relative humidity to achieve equilibrium moisture content before testing.

Test Method

The density was measured following the guidelines specified in TS EN 323 (1999). Test samples were prepared with dimensions of 18x50x50mm. The density was calculated using following formula:

$$\delta_{12} = \frac{M_{12}}{V12} \qquad (1)$$

where:

δ_{12} = density (kg/m^3),
M_{12} = mass of specimen (kg),
V = volume of specimen (m^3).

Test specime for MOR and MOE were prepared in dimensions of 410 × 50 × 18mm, with 10 specimens from each group, resulting in a total of 50 specimens. The support span (L1) was set to 20 times the specimen thickness, while the specimen length (L2) was defined as L1 + 50mm. Three-points bending test method were carried (Fig. 4). The bending tests were performed on an electromechanical universal testing machine (UTM) with a capacity of 10kN. When performing the bending strength tests, the force was applied to the edge wise position of the test sample in a direction parallel to the glue line and a direction perpendicular to glue line. The test speed was set to 2 mm/min, and the span between the supports was fixed at 300mm, corresponding to approximately 20 times the total thickness of the sandwich specimens. This span-to-thickness ratio was selected in accordance with standard bending test recommendations to ensure a bending-dominated failure mode and to minimize the influence of shear effects. The preload amount was 10N, and the test ended at 70% of the maximum force. The modulus of rupture (MOR) and modulus of elasticity (MOE) have been determined using following formulas:

$$MOE = \frac{3 \times F_{max} \times L_1}{2 \times b \times h^2} \qquad (2)$$

where:

Fmax = maximum load at failure (N),
L_1 = span length of specimen (mm),
B = width (mm); h= depth (mm).

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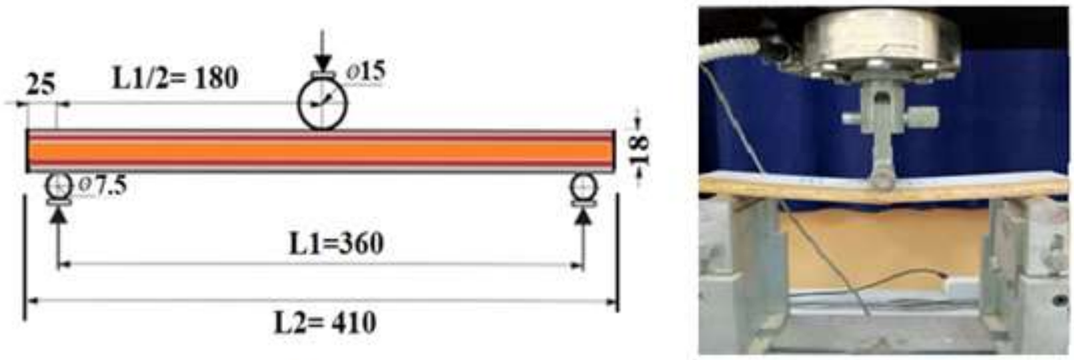
$$MOE = \frac{(F_2-F_1)\times L_1^3}{4\times b\times h^3\times(a_2-a_1)} \quad (3)$$

where:

F_2-F_1 = load at proportional limit (N),
L_1 = span length of specimen (mm),
b = width (mm),
h = depth (mm),
a_2-a_1= deflection at proportional limit (mm).



a) b)

Fig. 4.
Three-point bending test set-up for test samples. (a) the static system (in mm). (b) testing.

Statistical Analysis

The statistical analysis of the experimental data involved calculating the arithmetic mean and standard deviation. Analysis of variance (ANOVA) was employed to assess the impact of various factors on the values obtained for all sample groups. 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.

RESULTS AND DISCUSSION

Table 3 presents a summary of the test results for the physical and mechanical 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 some physical and mechanical properties

Groups	Values	δ_{12} (kg/m³)	MOR (N/mm²)	MOE (N/mm²)
A	X	719	23.98	707
	SD	3.89	2.80	74.79
	COV (%)	0.54	11.68	10.58
	Min,	711	21.23	607
	Max,	723	28.20	852
	N	10	10	10
B	X	730	35.89	996
	SD	3.31	1.47	32.37
	COV (%)	0.45	4.10	3.25
	Min,	725	33.62	920
	Max,	735	38.06	1033
	N	10	10	10
C	X	726	32.69	886
	SD	1.56	1.20	28.46
	COV (%)	0.22	3,67	3.21
	Min,	724	30.37	852
	Max,	728	34.17	937
	N	10	10	10

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D	X	721	26.31	761
	SD	2.96	0.94	46.96
	COV (%)	0.41	3.57	6.51
	Min,	717	25.17	689
	Max,	726	27.73	834
	N	10	10	10

X: Mean values, SD: Standart deviation, COV (%): Coefficient of variation, N: Number of samples.

The comparison between A, B, C, D groups were dependent on the ANOVA analysis (Table 4). According to analysis, $\boldsymbol{\delta_{12}}$, MOR, and MOE were statistically significant at the level of 0.05.

Table 4

The result of ANOVA

	Source	**SO**	**DF**	**MS**	**F Value**	**P <0.05**
$\boldsymbol{\delta_{12}}$ (kg/m^3)	Between Groups	1722.920	4	430.730	41.434	0.000
	Within Groups	467.800	45	10.396		
	Total	2190.720	49			
MOR (N/mm^2)	**Source**	**SO**	**DF**	**MS**	**F Value**	**P <0.05**
	Between Groups	1286.952	4	321.738	119.296	0.000
	Within Groups	121.363	45	2.697		
	Total	1408.315	49			
MOE (N/mm^2)	**Source**	**SO**	**DF**	**MS**	**F Value**	**P <0.05**
	Between Groups	767366.664	4	191841.666	84.718	0.000
	Within Groups	101901.766	45	2264.484		
	Total	869268.430	49			

SO: Sum of Squares, DF: Degrees of freedom, MS: Mean Squares.

According to the ANOVA test results given in Table 4, the difference between the groups was found to be statistically significant ($p < 0.05$). The results of the Duncan test, which was conducted to determine which groups the differences were significant between, are given in Table 5.

Table 5

The result of Duncan Test

Groups	**Physical and Mechanical Properties**					
	$\boldsymbol{\delta_{12}}$ (kg/m^3)		**MOR (N/mm^2)**		**MOE (N/mm^2)**	
	X	**HG**	**X**	**HG**	**X**	**HG**
A	719	C	23.98	D	C	707
B	730	A	35.89	A	A	996
C	726	B	32.69	B	B	886
D	721	C	26.31	C	C	761

X: Mean values, HG: Homogenity Groups.

According to the results presented in Table 5, the reference samples (Group A) exhibited the lowest density (δ_{12} = 719kg/m^3), while the highest density was obtained in Group B (730kg/m^3), corresponding to an increase of approximately 1.5% compared to Group A. The reinforced samples in Groups C and D showed intermediate density values of 726kg/m^3 and 721kg/m^3, respectively. Among the reinforced groups, Group D (PSM-reinforced) exhibited the lowest density, which was very close to that of the reference samples. This similarity can be attributed to the relatively low mass contribution and open mesh structure of PSM compared to GFRP and jute fabric, which introduces less additional material per unit area and therefore results in a more limited increase in panel density.

The higher density observed in Group B can be explained by the higher areal weight and compact structure of the GFRP reinforcement, as well as its more effective impregnation with the PUR adhesive, leading to increased mass and reduced internal voids. In contrast, the lowest density among the reinforced panels (Group D) is associated with the lightweight nature of PSM and its limited resin uptake, which results in a density level comparable to that of the unreinforced reference panels.

When the mechanical properties are compared to the reference samples (Group A), a clear improvement is observed for all reinforced groups. The MOR of Group A was measured as 23.98N/mm², whereas Groups B, C, and D exhibited MOR values of 35.89N/mm², 32.69N/mm², and 26.31N/mm², respectively. Compared to Group A, the MOR increased by approximately 50% in Group B, 36% in Group C, and 10% in Group D. Similarly, the MOE value of the reference samples (707N/mm²) was substantially lower than those of the reinforced samples, with Group B showing the highest MOE (996N/mm²), followed by Groups C (886N/mm²) and D (761N/mm²). Among the reinforced samples, Group D exhibited the lowest MOE; however, its stiffness was still approximately 8% higher than that of the reference group.

The observed improvements in MOR and MOE with increasing density indicate a strong correlation between density and mechanical performance. Higher density generally enhances load transfer efficiency between layers, improves interfacial bonding, and reduces stress concentrations, resulting in increased bending strength and stiffness. This trend is consistent with previous studies reporting that denser wood-based sandwich panels exhibit superior mechanical properties due to improved compaction and more effective stress distribution (Almutairi et al. 2023; Gozdecki and Kociszewski 2021).

The relatively similar mechanical behavior of the reference samples (Group A) and the PSM-reinforced samples (Group D) can be attributed to the limited structural contribution of the PSM layer. Although PSM improved interfacial bonding and slightly enhanced bending performance, its low stiffness and open structure prevented it from providing the same level of reinforcement as GFRP or jute fabric. This explains why Group D exhibited density and mechanical properties closer to those of the reference samples.

Similar enhancements in bending performance due to reinforcement incorporation have been reported in the literature. Osei-Antwi et al. (2014) reported flexural strengths ranging from 29.90 to 34.14 MPa for GFRP-reinforced sandwich panels with balsa cores, which is comparable to the MOR values obtained for Group B in this study at similar density levels. Furthermore, multilayer wood-based sandwich panels reinforced with different wood-based cores and bonded using PUR adhesives have been shown to achieve significant increases in MOR and MOE (Gozdecki and Kociszewski 2021). Studies on non-wood sandwich structures with GFRP skins and lightweight cores also reported stiffness and strength increases of up to 140% compared to unreinforced configurations, emphasizing the effectiveness of fiber-based reinforcements in sandwich systems (Fam and Sharaf 2010).

Overall, the results demonstrate that the incorporation of reinforcement materials significantly improves the mechanical performance of wood-based sandwich panels compared to the reference samples, with GFRP providing the most pronounced enhancement due to its high stiffness, strength, and contribution to increased density.

CONCLUSION

This study investigates the density (δ_{12}), modulus of rupture (MOR), and modulus of elasticity (MOE) of wood-based sandwich panels reinforced with glass fiber-reinforced polymer (GFRP), jute fabric, and plaster mesh (PSM) using a polyurethane-based adhesive (PUR-D4). The type of reinforcing fiber exerted a statistically significant influence on δ_{12}, MOR, and MOE. Specimens reinforced with GFRP, jute fabric, and PSM exhibited markedly higher δ_{12}, MOR, and MOE values compared with the unreinforced control samples. The findings confirm that incorporating high-strength reinforcement layers markedly improves the overall mechanical performance of wood-based sandwich panels by enhancing stress distribution and interfacial integrity throughout the entire structure. Reinforced panels exhibited delayed damage initiation and reduced core cracking compared to the reference samples, indicating superior structural stability. From a sustainability perspective, the improved mechanical efficiency allows the use of thinner or lighter wood-based components while maintaining structural performance, thereby contributing to reduced material consumption and extended service life in furniture applications.

For future research on wood-based sandwich panels, the following directions are recommended:

The use of plywood and particleboard as alternative wood-based panel configurations.

The evaluation of epoxy and polyvinyl acetate (PVAc) adhesives as potential bonding systems.

The investigation of basalt, carbon, and aramid fiber fabrics as advanced reinforcement materials.

The examination of the tensile strength and related mechanical properties of wood-based sandwich panels manufactured with the aforementioned materials.

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