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Comparative sound absorption performance of wood-based sandwich panels reinforced with basalt, glass and jute fabric

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Abstract

The sound absorption performance of wood-based sandwich panels reinforced with basalt fiber fabric, glass fiber fabric, and jute fabric was investigated to assess their potential application as sustainable acoustic panel materials. Four experimental groups were prepared panels reinforced with basalt fabric (Group A), jute fabric (Group B). glass fabric (Group C), and unreinforced reference panels (Group D). The sound absorption coefficients (SAC) were determined using the impedance tube method in accordance with ISO 10534-2 over a frequency range of 800-2400 Hz. The highest sound absorption coefficient was recorded for Group B samples, reaching a maximum value of 0.85 at 1200 Hz. In comparison, Group A exhibited a lower peak absorption of 0.52 at 800 Hz, while Group C reached its maximum value of 0.51 at 1400 Hz. Similarly, Group D demonstrated its highest sound absorption coefficient of 0.41 at 800 Hz, indicating comparatively reduced acoustic performance among the tested groups. Both Group A and Group D samples exhibited their lowest sound absorption performance at 2400 Hz (α = 0.05).

1. Introduction

A layered structure of wood-based sandwich panels (WBSPs) offers significant mechanical and thermal advantages. Typically, these panels consist of two stiff outer face sheets bonded to a lightweight core with an adhesive. enabling efficient load transfer while maintaining a low overall weight [1]. As a result., WBSPs provide high mechanical strength. excellent thermal insulation. and low density, which helps reduce transportation costs and simplifies installation. Additionally, using wood as a renewable. carbon-sequestering material supports sustainability goals by reducing greenhouse gas emissions and encouraging resource-efficient construction practices [2–4].

The core is essential for reducing panel weight and decreasing the relative displacement between face sheets [5]. Face materials are typically made from engineered wood products like plywood. oriented strand board (OSB), or laminated veneer lumber (LVL), which provide the necessary structural stiffness for construction [6]. Additionally, the low density of these systems often indicates a partially hollow structure, which helps reduce weight and improve thermal and acoustic insulation. Recent studies have shown that innovative core designs can further enhance the mechanical performance of WBSPs [7].

Recent studies have expanded the range of core materials used in WBSPs to include low-density wood fibers [8,9], plywood [10–12], wood strips [13], cork [14], wooden dowel lattices [15], corrugated cardboard [16,17], and three-dimensionally shaped wood strands [18]. Further research has focused on polymeric and hybrid cores, such as balsa wood, polypropylene

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honeycomb, and polystyrene foam [19], along with advanced hybrid systems like balsa/glass–epoxy composites [20], jute/epoxy–cork structures [21], aluminum honeycomb–balsa hybrids [22], and paulownia or southern pine wood cores combined with glass fiber-reinforced polymer (GFRP) skins [23–25].

Fiber-reinforced polymers (FRPs) have gained considerable attention due to their high strength-to-weight ratio, corrosion resistance, and strong adhesion to wood substrates, Common fiber types include glass (GFRP), basalt (BFRP), carbon (CFRP), and aramid (AFRP) fibers [26].

While most existing studies focus on the mechanical and structural performance of FRP-reinforced WBSPs, recent attention has shifted toward their acoustic properties. especially in modern architectural applications. Rapid urbanization has increased the demand for materials that offer sound absorption. noise reduction. and vibration-damping properties [27]. Because of its inherent porosity and anisotropic cellular structure, wood exhibits beneficial acoustic behavior, including sound absorption and diffusion [28]. Fiber orientation significantly influences sound transmission: fibers aligned longitudinally tend to promote sound propagation. while transverse orientations improve sound absorption [29]. Therefore, acoustic parameters such as the sound absorption coefficient, sound insulation, and noise reduction coefficient are essential for evaluating the suitability of wood-based composites in interior environments [30].

Previous research indicates that porous and fibrous materials can improve sound clarity, reduce reverberation time, and enhance speech intelligibility in enclosed spaces such as theaters, concert halls, and conference rooms [31–33]. The sound absorption coefficient of wood-based materials generally increases with higher internal porosity, rougher surface textures, and lower density [34,35]. Studies on related composite systems suggest that carbon fiber-based materials are more likely to reflect or transmit low-frequency sound waves rather than absorb them [36]. Conversely, bark-based insulation panels [37], plywood–carbon fiber composites [38], and rice stick–wood splinter boards [39], have demonstrated better sound absorption in the low- and high-frequency ranges.

Natural fibers such as kenaf. coconut fiber, and jute have been widely researched for their sound-absorbing properties when incorporated into wood-based composite systems. Their acoustic performance largely depends on material density, internal porosity, and panel thickness [440]. Since they are renewable, biodegradable, and environmentally friendly, natural fibers offer a sustainable alternative to synthetic reinforcements, making wood composites more appealing for acoustic applications [41].

Despite the increasing interest in wood-based sandwich panels for acoustic applications, there is a lack of sufficient research in the literature on the comparative effect of basalt fiber fabric, glass fiber fabric, and natural jute fabric reinforcements on sound absorption behavior. Therefore, this study aims to provide a comprehensive and comparative evaluation of the frequency-dependent sound absorption performance of wood-based sandwich panels reinforced with these fiber types, and thus to elucidate the role of fiber reinforcement in determining acoustic damping mechanisms.

2. Materials and Methods

2.1 Materials

In the preparation of wood-based sandwich panels, 4 mm thickness poplar plywood (PPWD)(Fig, 1a) which was produced from consisting of three veneer used on the top and bottom surfaces, and 9 mm thickness oriented strand board (OSB-2 Class) (Fig,1b) is used as the core layer. All wood-based materials were randomly sourced from local suppliers operating in the Uşak 1 September Industrial Area Zone. Selected physical and mechanical characteristics of these materials are presented in Table 1.

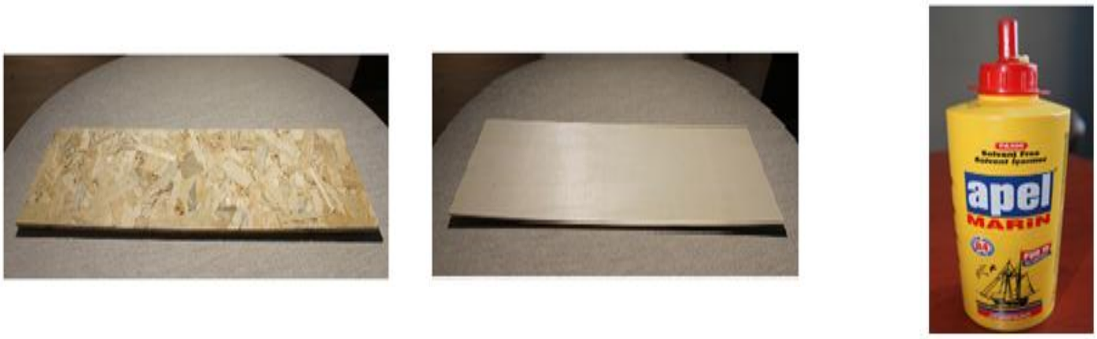
A single-component polyurethane adhesive (PUR-D4) was obtained from Apel Kimya Industry and Trade Inc. in Turkey (Fig. 1b). The technical properties of the PUR-D4 were as follows: density of 1,110 g/cm^3, pH of 5,0 (25 °C), viscosity of 5000 to 10000 mPas (20 °C), and application amount of (200 gr/m^2).

Basalt fiber fabric and glass fiber fabric with a nominal areal weight of 200 g/m^2 (Dost Kimya Industrial Raw Materials Industry and Trading Co., Istanbul, Turkey), along with a jute fabric with an area weight of 265 g/m^2 (Polatoğlu Garden Agriculture Hardware Co., Turkey), were employed as reinforcement layers (Fig. 1c). The densities of all constituent materials used in the fabrication of the wood-based sandwich panels are summarized in Table 1.

Table 1. Density of wood-based sandwich panels and FRP materials used in the study

No	Material Name	Between Face and Core
1	OSB-2 Class	core layer
2	PPWD	face layer and bottom layer
3	BFRP	between face and core layers
4	GFRP	between face and core layers
5	Jute Fabric	between face and core layers

The mechanical properties of the reinforcement materials were obtained from the literature. For basalt fiber fabric, the Young's modulus was reported as 89 GPa. [42]. Corresponding values for glass fiber fabric and jute fabric are 70 GPa and 26.5 GPa. respectively [43].



(a) (b)

(c)

Fig. 1. Materials used in experiments (a) wood-based materials, (b) PUR-D4 and (c) reinforcement materials

2.2. Preparation of Test Samples

The OSB and PPWD panels were cut with a CNC router into 31 identical specimens per panel, each with nominal dimensions of 162 × 170 ± 1 mm (Fig, 2a), In multilayer configurations, two layers of reinforcing fabrics such as basalt fiber fabric, glass fiber-fabric, or jute fabric were placed between the OSB core and the plywood face layers to provide additional structural reinforcement.

A single-component polyurethane adhesive (PUR-D4) was obtained from Apel Kimya Industry and Trade Inc. in Türkiye (Fig. 1b). The technical properties of the PUR-D4 were as follows: density of 1,110 g/cm^3, pH of 5,0 (25 °C), viscosity of 5000 to 10000 mPas (20°C), and application amount of (200 gr/m^2) (Fig. 2b). The assembled sandwich panels were then cold-pressed using a hydraulic press (Hydraulic Veneer SSP-80; ASMETAL Wood Working Machinery Industry Inc. Ikitelli. Istanbul. Turkey) under a pressure of 1.5 N/mm^2 at room temperature (25 °C) for 3 hours (Fig. 2c). After the pressing process, the experimental samples are shown in Fig. 2d.

The specimens were labeled based on their constituent materials, poplar plywood (PPWD) as "PP," oriented strand board (OSB-2) as "O," and the reinforcing basalt fiber fabric, glass fiber fabric, and jute fabric as "B," "G," and "J," respectively. The detailed structural configurations of the wood-based sandwich panels are shown in Fig. 3. A total of four different wood-based sandwich panel configurations were fabricated. as summarized in Table 2. Configurations of the manufactured wood-based sandwich panels

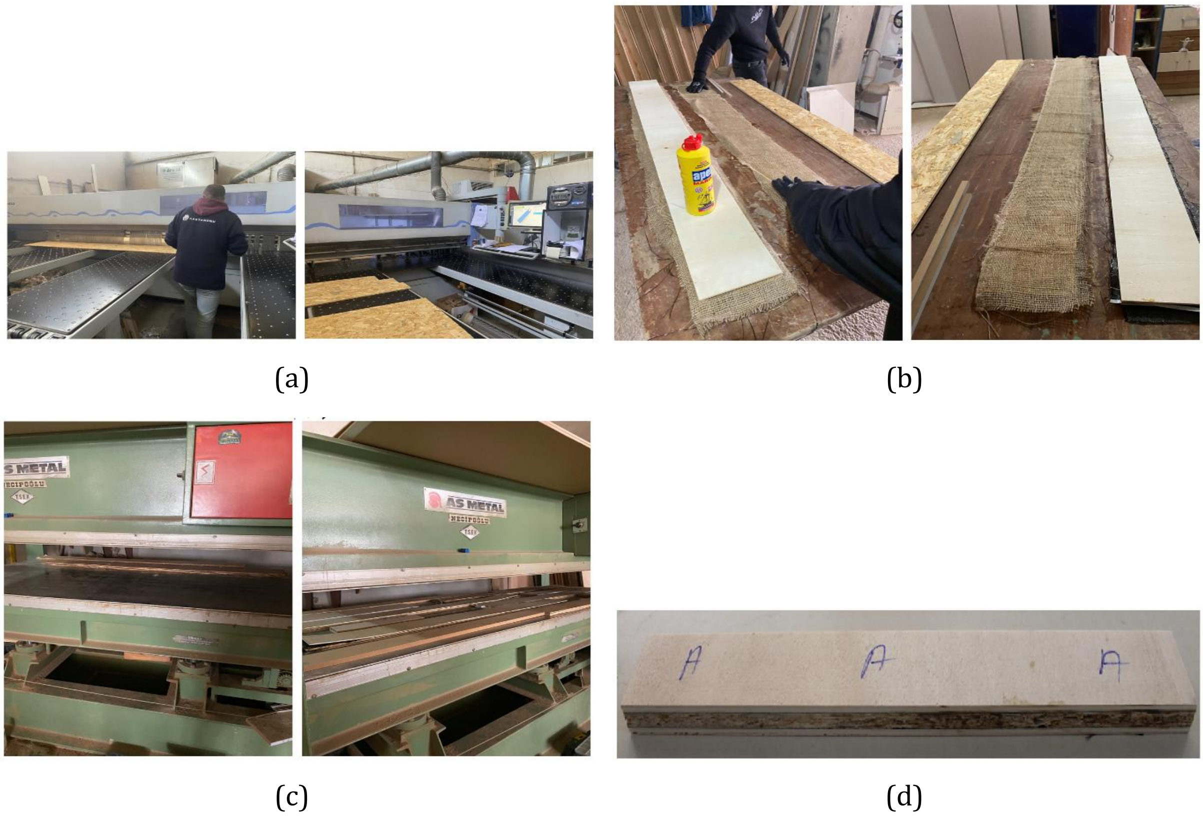


Fig. 2. The production process of test samples: (a) using a CNC machine; (b) polyurethane adhesive was used for surface; (c) Hydraulic Veneer SSP-80; ASMETAL; (d) the pressing of samples

Fig. 3. Exploded view of a multi-layered wood-based sandwich panels structure

Table 2. Configurations of the manufactured wood-based sandwich panels

Group	Code	Face Layer	Reinforcement Types	Core Layer	Bottom Layer
A	PP-B-O-B-PP	PP	Basalt fiber fabric	O	PP
B	PP-J-O-J-PP	PP	Jute fabric	O	PP
C	PP-G-O-G-PP	PP	Glass fiber fabric	O	PP
D	PP-O-PP	PP	Unreinforced	O	PP

2.3. Test Method

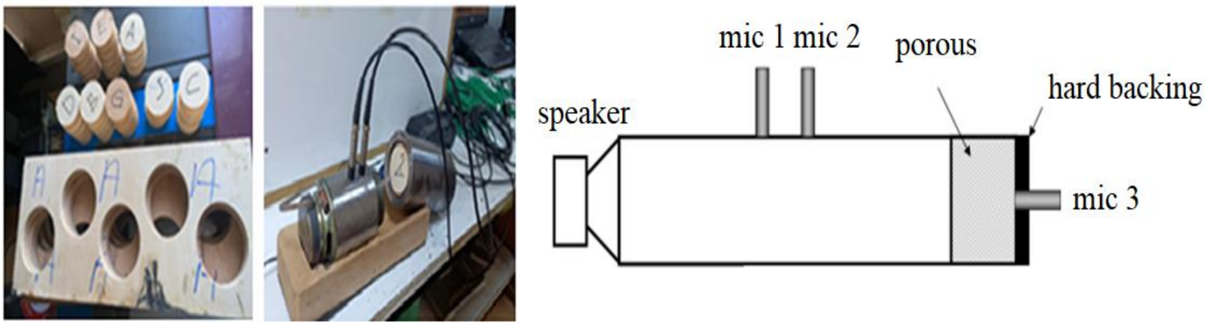
The air-dry density (δ_{12}) of the test specimens was determined following the TS EN 323/1 [44] standard. For each panel type. 10 replicate samples were prepared. The air-dry density was calculated using Eq. (1):

$$\delta_{12} = \frac{M_{12}}{V12} \tag{1}$$

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

The samples have dimensions of 18 mm thickness and 64 mm diameter and were prepared using computer-controlled (CNC) machining as shown in Figure 4a. For the suitable phase calibration, impedance tube with three microphones (see Figure 4b) is used. Distance between the first two microphones from the speaker is 30 mm means the useable frequency range is 120 Hz to 5700 Hz. In this study, range from 800 Hz to 2400 Hz is assumed to be acceptable for the analysis. Three identical samples of each panel type were prepared and tested. Image of the impedance tube setup are shown in Figures 4b. Measurements were taken over a frequency range of 800–2400 Hz under controlled laboratory conditions at 23 °C with 50% humidity. Three replicate specimens were prepared for each panel group. including small specimens.

The acoustic properties of the samples were evaluated based on the ISO 10534-2 [45] standard. The sound absorption properties of the samples were measured using the transfer function method of the reinforced and unreinforced samples. in which the three-microphone measurement scheme is shown in Figure 4c. This method allows to obtain acoustic characteristics of the groups as sound absorption coefficient (SAC).



(a) (b) (c)

Fig. 4. The sound absorption process of test samples: (a) Test samples; (b) Impedance tube equipment with test samples attached; (c) Impedance tube equipment

2.4. Data Analyses

Statistical analyses were conducted using SPSS software (version 22. IBM Corp. Armonk. NY. USA). Two-way ANOVA was used to evaluate the effects of the independent factors. frequency (Hz) and reinforcement types. on the SAC results. The interaction effect was also examined.

3. Results and Discussion

First, the densities of wood-based sandwich panels reinforced with basalt fiber fabric, glass fiber fabric, and jute fabric were measured. The average. maximum. minimum. and standard deviations of the air-dry densities of the test specimens are shown in Table 3. Table 3 presents the descriptive statistical parameters. The table displays the air-dry density values for the experimental groups (A–D). Significant differences were observed among the groups based on the reinforcement setup. Group A had the highest air-dry density coefficient at 0.566 g/cm^3, followed by Group C at 0.552 g/cm^3, and Group B at 0.529 g/cm^3. The lowest density was recorded in Group D. the unreinforced group. at 0.512 g/cm^3.

Table 3. Air-dry densities of experimental samples (gr/cm^3)

Values	Groups			
	A	B	C	D
Xmean	0.566	0.529	0.552	0.512
S	0.006	0.003	0.004	0.003
X min	0.558	0.522	0.558	0.508
X max	0.578	0.534	0.545	0.517
N	10	10	10	10

Note: S, the standard deviation

The higher density observed in Groups A and C is due to the inclusion of basalt fiber fabric glass fiber fabric layers. which have higher inherent densities compared to jute fabric and unreinforced setups. Conversely. the lower density in Group B results from the use of jute fabric, which is less dense and more porous. As expected, Group D, without reinforcement layers. shows the lowest density values.

The low standard deviations (S = 0.003–0.006) across all groups indicate high homogeneity and consistency in specimen preparation. The narrow range between the minimum and maximum density values further confirms the reliability of the manufacturing process and the reproducibility of the experimental samples.

The statistical data on the sound absorption coefficients of wood-based sandwich panels with reinforcement types are shown in Table 4. These results serve as the basis for analyzing the relationship between panel density, reinforcement types, and acoustic performance.

According to the data presented in Table 4, the sound absorption coefficient (SAC) of the wood-based sandwich panels varied significantly with both the reinforcement types and the frequency. This variation indicates that the acoustic behavior of the panels is strongly influenced by the characteristics of the reinforcement types and by frequency-dependent sound material interactions.

Basalt fiber fabric–reinforced panels (Group A) exhibited their highest sound absorption coefficient at 800 Hz (α = 0.52), followed by a gradual decline with increasing frequency, reaching a minimum value of approximately 0.05 at 2400 Hz. The consistently low standard deviation observed across the entire frequency range indicates a highly stable and repeatable acoustic response. This trend suggests that sound absorption in Group A is predominantly governed by resonance-related structural damping mechanisms that are effective at mid–low frequencies, whereas viscous and porous dissipation mechanisms remain limited at higher frequencies due to the relatively high stiffness and low porosity of basalt fibers.

Jute fiber fabric–reinforced panels (Group B) demonstrated the highest overall acoustic performance among all investigated groups, exhibiting a pronounced absorption peak at 1200 Hz (α= 0.85). In contrast to the other reinforcement types, Group B maintained comparatively elevated sound absorption coefficients over a broader frequency range, despite a gradual reduction at higher frequencies. The relatively larger standard deviation observed in the vicinity of the peak frequency reflects the heterogeneous morphology and irregular structure of natural jute fibers. These findings indicate that enhanced fiber mobility, increased porosity, and pronounced viscoelastic damping associated with jute fibers substantially improve acoustic energy dissipation, thereby confirming their effectiveness as sustainable acoustic reinforcement materials.

Table 4. Statistical results regarding sound absorption coefficient values (α)

Groups	Frequency	*X*min	*X*max	*X*mean	Std. Dev.
A	800	0.52	0.53	0.52	0.0018
	1000	0.43	0.44	0.43	0.0015
	1200	0.09	0.09	0.09	0.0003
	1400	0.12	0.13	0.12	0.0004
	1600	0.16	0.17	0.16	0.0006
	1800	0.20	0.20	0.20	0.0007
	2000	0.11	0.11	0.11	0.0004
	2200	0.07	0.08	0.07	0.0002
	2400	0.05	0.05	0.05	0.0002
B	800	0.08	0.10	0.09	0.0119
	1000	0.14	0.17	0.16	0.0201
	1200	0.73	0.92	0.85	0.1082
	1400	0.53	0.67	0.62	0.0781
	1600	0.31	0.40	0.37	0.0464
	1800	0.08	0.10	0.10	0.0122
	2000	0.23	0.30	0.27	0.0348
	2200	0.06	0.08	0.07	0.0094
	2400	0.06	0.08	0.07	0.0094
C	800	0.08	0.33	0.25	0.1432
	1000	0.14	0.18	0.16	0.0210
	1200	0.19	0.36	0.26	0.0868
	1400	0.48	0.55	0.51	0.0327
	1600	0.07	0.33	0.15	0.1488
	1800	0.09	0.14	0.12	0.0284
	2000	0.08	0.24	0.13	0.0967
	2200	0.31	0.33	0.32	0.0068
	2400	0.07	0.09	0.08	0.0158
D	800	0.40	0.42	0.41	0.0120
	1000	0.33	0.35	0.34	0.0099
	1200	0.07	0.08	0.08	0.0022
	1400	0.10	0.10	0.10	0.0029
	1600	0.13	0.14	0.13	0.0038
	1800	0.15	0.16	0.16	0.0045
	2000	0.09	0.09	0.09	0.0027
	2200	0.06	0.06	0.06	0.0017
	2400	0.04	0.05	0.05	0.0013

Glass fiber fabric–reinforced panels (Group C) exhibited a moderate and more frequency-dependent absorption behavior. The maximum mean sound absorption coefficient was observed at 1400 Hz (α= 0.51), accompanied by comparatively higher standard deviation values at several frequencies, particularly around 800 Hz and 1600 Hz. This variability can be attributed to irregularities in resin absorption of the glass fiber fabric, which restrict fiber vibration and lead to partial pore blockage. As a result, energy dissipation mechanisms such as interfacial friction and viscous losses become less effective, especially in the higher frequency

The unreinforced panels (Group D) displayed an intermediate acoustic performance, with a maximum mean sound absorption coefficient of approximately α= 0.41 at 800 Hz, followed by a steady decrease toward higher frequencies, reaching values close to α= 0.05 at 2400 Hz. Similar to Group A, the low standard deviation values indicate a stable acoustic response; however, the overall absorption capacity remained lower. This behavior suggests limited damping efficiency, primarily due to the absence of fiber-induced energy dissipation mechanisms and a reduced contribution from internal friction processes. To assess whether these observed differences were significant. an analysis of variance (ANOVA) was conducted. and the results are shown in Table 5.

Table 5. Summary of the Two-way ANOVA results for the sound absorption coefficients values

Source	Sum of Squares	DF	Mean Square	F Value	P < 0.05)
Corrected Model	3.605[a]	35	0.103	43.895	0.000
Intercept	5.051	1	5.051	2152.383	0.000
Reinforcement Types (A)	0.250	3	0.083	35.550	0.000
Frequency (B)	0.962	8	0.120	51.226	0.000
AXB	2.393	24	0.100	42.495	0.000
Error	0.169	72	0.002		
Corrected Total	8.825	108			
Total	3.774	107			

a. R Squared = 0.955 (Adjusted R Squared = 0.933)

The ANOVA results (Table 5) showed that reinforcement types. and sound absorption vary with frequency. The improved model showed a high coefficient of determination (R^2 = 0.955; adjusted R^2 = 933). indicating that the selected factors and their interaction account for most of the variability in the SAC values. The high F-values related to reinforcement types, frequency. and their interaction confirm the robustness of the experimental setup and the reliability of the measured acoustic data.

These statistical results support the experimental observations and confirm that the reinforcement types and frequency level are key factors in determining the acoustic performance of wood-based sandwich panels. The SAC shows that the independent effects of the test variables are presented in Tables 6 and 7. Table 6 presents the sound absorption coefficient values for reinforcement types and homogeneous groups. along with the derived results.

Table 6. The results from Tukey's test for reinforcement types

Source of variance	The mean SAC values (α)	HG
Jute fabric (Group B)	0.29	A
Glass fiber fabric (Group C)	0.22	B
Basalt fiber fabric (Group A)	0.20	BC
Unreinforced (Group D)	0.16	C

HG: Homogeneity Groups

Based on the experimental evaluation, the highest mean SAC value was observed for the jute fabric–reinforced panel (Group B) at 0.29. In contrast, the lowest mean value was observed in the unreinforced Group D with 0.16. The mean SAC values for the experimental groups were α = 0.29 for Group B, α = 0.22 for Group C, α = 0.20 for Group A, and α = 0.16 for Group D. These results clearly show that adding fiber reinforcements, especially natural jute fabric, dramatically improves the acoustic absorption performance of wood-based sandwich panels.

When comparing the performance of different reinforcement types, the jute fabric–reinforced panels (Group B) exhibited the highest overall sound absorption coefficients. Conversely, the lowest SAC values among all panel types were consistently observed in Group D.

A detailed analysis confirmed that Group D had lower sound absorption performance than all other reinforced groups (A, B, and C). Among the experimental setups. the wood-based sandwich composites reinforced with Group B demonstrated the highest sound absorption efficiency as summarized in Table 6.

The sound absorption coefficient values by frequency (Hz). the homogeneous groups, and the results based on these values are presented in Table 7.

Table 7: The results from Tukey's test for frequency (Hz)

Source of variance	The mean SAC value	HG
1400	0.34	A
1200	0.32	A
800	0.32	A
1000	0.28	AB
1600	0.20	BC
2000	0.15	CD
1800	0.14	CD
2200	0.13	CD
2400	0.06	D

HG: Homogeneity Groups

Graphs of sound absorption coefficients (α) for wood-based sandwich panels reinforced with reinforcement types, measured using the impedance tube method are displayed in Figure 5. Based on the data frequency-dependent absorption results shown in Figure 5. The highest sound absorption coefficient was observed in Group B samples at 1200 Hz (α = 0.85), while the lowest value occurred at 2400 Hz (α = 0.06). These results indicate that the acoustic response of wood-based sandwich panels is strongly frequency dependent and can be influenced through material selection and reinforcement configuration.

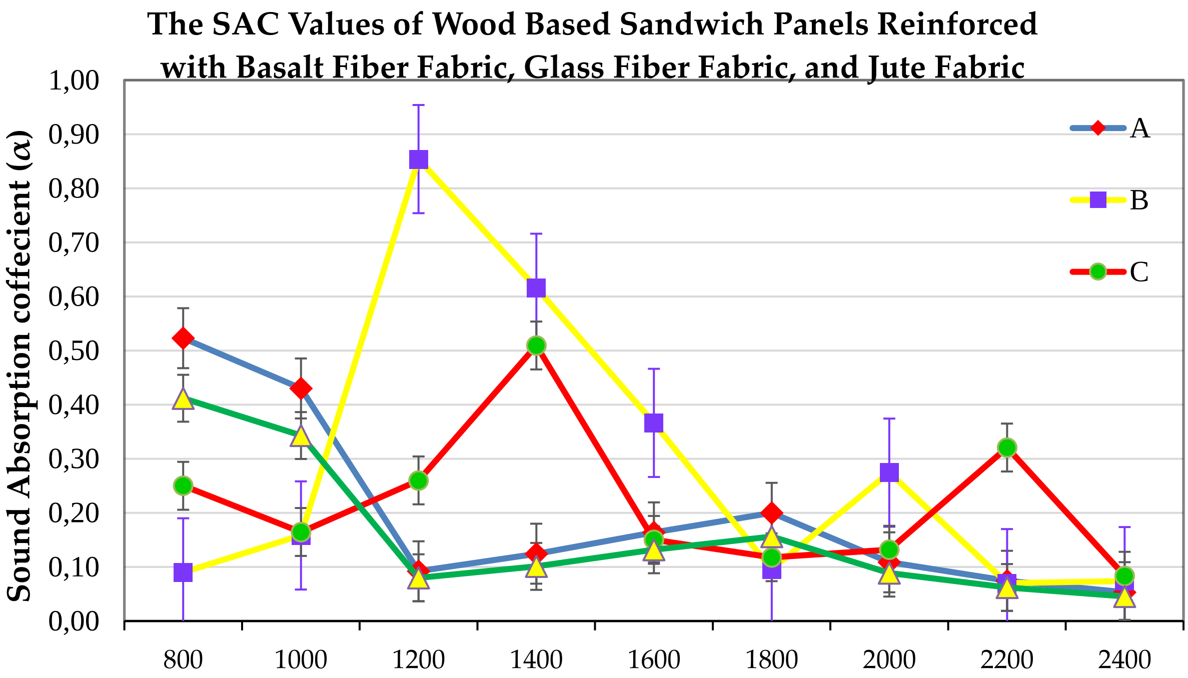


Fig. 5. The SAC values of wood-based sandwich panels with reinforced FRP

As shown in Table 7, the mean sound absorption coefficient exhibits a statistically significant dependence on frequency. The highest mean SAC values were observed at 1400 Hz (α= 0.34), 1200 Hz (α = 0.32), and 800 Hz (α = 0.32), which belong to the same homogeneous group (HG = A), indicating comparable and significantly higher absorption in the mid-frequency range. A slight decrease was recorded at 1000 Hz (α= 0.28, HG = AB), followed by a progressive reduction at 1600 Hz (α = 0.20, HG = BC). At higher frequencies (1800–2200 Hz), the mean SAC values further declined to 0.13–0.15 (HG = CD), with the lowest value observed at 2400 Hz (α= 0.06, HG = D). Overall, sound absorption is maximized at mid frequencies and decreases systematically with increasing frequency.

Overall, the statistical grouping supports the conclusion that sound absorption is maximized at mid frequencies and progressively decreases at higher frequencies. This trend is consistent with the resonance-dominated behavior of wood-based sandwich panels and does not indicate any inconsistency in the experimental results.

Altunok and Ayan [35] reported that laminated panels manufactured from lower-density Scots pine exhibited higher absorption than those produced from denser iroko wood. particularly under perforated conditions. Furthermore, Çavuş and Kara [47], who examined sound transmission characteristics of 16 wood species within the 100–1000 Hz frequency range, reported no strong correlation between wood density and mean sound transmission loss. Previous studies have shown that carbon fiber–reinforced composites typically have limited sound absorption at low frequencies but display significant absorption within the range of 800–1600 Hz, where absorption rates can reach about 70% of the incident sound energy [48]. Comparable trends have been reported by Ivanova et al. [49]. who observed peak absorption within the 600–2000 Hz range.

4. Conclusions

This study systematically analyzed the sound absorption performance of wood-based sandwich panels reinforced with basalt fiber fabric, glass fiber fabric, and jute fabric across the frequency range of 800–2400 Hz. Among all tested configurations. the jute fabric–reinforced panels demonstrated the highest overall sound absorption. Apparent frequency-dependent variations appeared in the acoustic behavior of all reinforced and unreinforced systems. Specifically, group B achieved its maximum absorption around 1200 Hz, while groups A and D showed their lowest absorption levels 2400 Hz. The best reinforced setup reached its peak absorption near 1200 Hz, indicating the presence of frequency-dependent damping mechanisms within the multilayered sandwich structure.

This study confirms that fiber-reinforced wood-based sandwich panels have significant potential for use in furniture. interior design. and architectural systems where sound insulation and noise control are essential. From an application perspective, variations in sound absorption behavior among wood-based panel systems may lead to meaningful differences in acoustic performance when such materials are used as interior panels or furniture components. These findings suggest that acoustic functionality should be considered during the design stage of engineered wood products, alongside structural and aesthetic requirements. Optimizing internal structure and reinforcement configuration may enable the development of multifunctional panels that balance mechanical performance with targeted acoustic behavior.

Consequently, analyzing absorption coefficients should adopt a system-level approach, where material properties and application contexts are assessed collectively. This perspective emphasizes the potential of engineered wood-based panels and furniture elements as versatile components that contribute to noise reduction and acoustic management in complex indoor settings.

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