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Investigated the Sound Absorption Performance of Wood-Based Sandwich Panels with Reinforced BFRP, GFRP, and Jute Fabric

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Abstract

The sound absorption efficiency of the wood based sandwich panels with reinforced basalt fiber reinforced (BFRP), glass fiber reinforced (GFRP), and jute fabric composite materials and evaluate their potential as acoustic panels were investigated. Four experimental groups were created. Wood based sandwich panels were reinforced with BFRP (Group A), jute fabric (Group B), GFRP (Group C), and unreinforced (Group D). The sound absorption coefficients of the unreinforced and experimental groups were tested *via* the impedance tube method, according to ASTM standard E1050 (2006). Attention was paid to the acoustic behavior at low frequencies (200 Hz to 800 Hz), mid frequencies (1000 Hz to 1600 Hz), and high frequencies (1800 Hz to 2400 Hz). The sound absorption coefficient was highest in sapwood at 200 Hz frequency level with 0.67, while the highest in heartwood was 0.05 at 2400 Hz frequency level. It can be suggested that the experimental groups be used as sound absorbing acoustic panels.

Keywords: sound absorption coefficient; acoustic properties; industrial design

1. Introduction

Wood-based sandwich panels (WBSPs) have experienced significant technological and scientific advancements over the past several decades. Initially developed in the mid-20th century as lightweight and thermally efficient structural materials, WBSPs were designed to provide sustainable alternatives to traditional construction components. Early investigations primarily focused on understanding their basic mechanical performance and potential as energy-efficient building elements. Fundamental studies in the late 20th century [1] clarified the structural behavior of sandwich panels under different stress states, including bending, compression, and shear, thereby establishing the theoretical foundation for modern applications. With the progress of material science, polymer chemistry, and adhesive technologies, the functionality of these composites has been remarkably enhanced. More recently, sustainability-driven innovations have introduced new adhesives and core materials derived from recycled or renewable resources, aligning WBSP development with circular economy principles.

The layered structure of WBSPs provides distinct mechanical and thermal advantages. Typically consisting of two stiff outer face sheets bonded to a lightweight core via an adhesive, the design enables the efficient transfer of loads while maintaining low mass. The outer faces primarily bear bending and tensile stresses and protect the core from external damage, while the core acts as a shear-resistant element that distributes stresses between the facings [2]. As a result, WBSPs demonstrate a unique combination of high mechanical strength, good thermal insulation, and low density, offering significant benefits such as reduced transportation costs and simplified installation. Moreover, the use of wood — a renewable and carbon-sequestering resource — directly supports global sustainability targets, contributing to reduced greenhouse gas emissions and resource-efficient construction [3,4].

One of the key performance parameters for WBSPs is the strength-to-density ratio, which reflects the structural efficiency of the panel by integrating its mechanical properties and mass. Studies have shown that in plywood-based sandwich panels, variations in veneer thickness or orientation ratios significantly influence stress distribution, stiffness, and flexural behavior. Increasing the proportion of parallel-oriented veneer sheets typically enhances panel rigidity and overall bending resistance [7]. Compared with conventional materials such as solid wood, concrete, and steel, WBSPs exhibit considerably higher specific strength values [5]. This feature makes them ideal for modern lightweight construction, prefabricated housing, and furniture applications where both strength and portability are essential [6].

From a manufacturing standpoint, WBSPs can be fabricated using either discontinuous or continuous processes. Discontinuous production methods generally involve the lamination of pre-expanded foam cores onto prefabricated facings such as thin veneers, particleboard, MDF, or plywood. Although this multi-stage process is relatively slow, it enables the use of wood fiber-based facings that cannot be processed continuously due to dimensional constraints [10]. Continuous production techniques, on the other hand, are more suitable for foam-core or thin-layer composites, facilitating uniform quality and scalability. Based on their core design, WBSPs are generally categorized as hollow-core or solid-core structures. Hollow-core configurations, often incorporating geometric cavities or lattice reinforcements, enable significant weight reduction and increased specific stiffness. In contrast, solid-core structures utilize homogeneous or particulate lightweight materials—such as cork, low-density wood, or polymer foams—offering simpler fabrication routes [6].

Recent research has expanded the range of core materials used in WBSPs, including low-density wood fiber [11,12], plywood [13–16], wood strips [17], cork [6], wooden dowel lattices [18], corrugated cardboard [19,20], and 3D-shaped wood strands [21]. Other works have incorporated polymeric or hybrid cores such as balsa wood, polypropylene honeycomb, and polystyrene foam [22], as well as advanced combinations like balsa/glass-epoxy [23], jute/epoxy–cork [24], aluminum honeycomb–balsa hybrids [25], paulownia or southern pine wood cores with glass fiber-reinforced polymer (GFRP) skins [26–28], and thermoplastic GF/PP composite layers bonded to plywood [27]. Such diversification reflects the increasing effort to tailor mechanical, thermal, and acoustic performance by optimizing the interface between organic (wood-based) and polymeric (synthetic or natural fiber) components.

Among the various reinforcing strategies, fiber-reinforced polymers (FRPs) have gained significant attention due to their high strength-to-weight ratio, corrosion resistance, and versatile bonding compatibility with wood substrates. FRPs are composite materials consisting of high-strength fibers embedded in a polymer matrix. Common fibers include glass (GFRP), basalt (BFRP), carbon (CFRP), and aramid (AFRP) [32]. The reinforcement of WBSPs with FRPs effectively enhances stiffness, load-bearing capacity, and flexural strength while maintaining lightweight characteristics. For instance, Keller et al. [33] successfully developed and validated a GFRP–balsa sandwich bridge deck that met serviceability criteria for load-bearing applications. Shi et al. [34] reported pseudo-ductile flexural behavior in wood-core sandwich beams reinforced with GFRP skins and lattice webs, while Nadir et al. [35] demonstrated that FRP sheets significantly improve the mechanical performance of laminated wood beams. Likewise, studies by Qi et al. [28], Almutairi et al. [36], and Szwajka et al. [37] confirmed that GFRP and CFRP reinforcements can substantially enhance flexural rigidity, bending strength, and energy absorption. Li et al. [38] also examined fiberglass-faced foam-core panels, highlighting the mechanical failure mechanisms and the role of polymer–wood interfacial bonding.

While most studies have focused on the mechanical and structural performance of FRP-reinforced WBSPs, there is growing recognition that the acoustic properties of such composites are equally important, particularly in modern architectural applications. Increasing urbanization has intensified the demand for sound-absorbing, noise-reducing, and vibration-damping materials [39]. Owing to its natural porosity and anisotropic structure, wood inherently exhibits favorable acoustic properties, including the ability to absorb and diffuse sound waves [40,41]. The directionality of fibers plays a crucial role in sound conductivity—longitudinally oriented fibers transmit sound more effectively, whereas transverse orientations enhance absorption [42]. Acoustic parameters such as sound absorption, sound insulation, and noise reduction coefficients are therefore critical for evaluating the suitability of wood composites in interior environments [43].

Studies have shown that porous and fibrous materials can improve sound clarity, reduce reverberation time, and increase speech intelligibility in enclosed spaces such as theatres, concert halls, and conference rooms [44–46]. The sound absorption coefficient of wood-based materials generally increases with higher internal porosity, rougher surface texture, and lower density [47,48]. Research on related composites has revealed that carbon fiber materials tend to reflect or transmit low-frequency (bass) sound waves rather than absorb them [49]. Conversely, bark-based insulation panels [50], plywood–carbon fiber composites [51], and rice stick–wood splinter boards [52] demonstrated enhanced sound absorption across mid and high frequencies. The acoustic efficiency of wooden materials also depends on species type, fiber structure, and surface geometry; for instance, perforated panels of Scots pine have shown superior absorption between 400 and 1000 Hz compared to flat panels or denser hardwood species [53,54].

The aim of this study is to investigate the sound absorption performance of wood-based sandwich panels with reinforced BFRP, GFRP, and jute fabric at low (bass), medium, and high (treble) frequencies (Hz). There is no comprehensive research in the literature on the acoustic properties of wood-based sandwich panels produced using BFRP, GFRP, and jute fabric. Consequently, this study makes a significant original scientific contribution to the field.

2. Materials and Methods

2.1. Materials

The materials used for face layer and bottom layer was 4 mm thickness poplar plywood (PPWD) produced from three types of veneer that is widely used in the furniture industry (Fig. 1a). As the core layer materials, 9 mm thickness oriented strand borads (OSB-2 class) were used (Fig. 1a). These materials were obtained by random selection from Usak 1 September industrial site market.

The adhesive used was one component polyurethane adhesive (Apel Kimya Industrial Industry and Trade Company, Istanbul, Turkey) (Fig. 1b). As the fiber reinforced polymers (FRP) materials, the BFRP, and GFRP for 200 gr/m^2 (Dost Kimya Industrial Raw Materials Industry and Trading Company, Istanbul, Turkey). and and jute fabric for for 265 gr/m^2 (Polatoglu Garden-Agriculture-Hardware Company in Turkey) used in the study (Fig. 1c). Density of the materials used in the production of wood-based sandwich panels are presented in Table 1.

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

No	Material Name	Density (gr/cm^3)	Where used in the panel
1	OSB-2 Class	0.630	core layer
2	PPWD	0.500	face layer and bottom layer
3	BFRP	2.800	face layer betwen core layer, and bottom layer between layer
4	GFRP	2.500	face layer betwen core layer, and bottom layer between layer
5	Jute Fabric	1.300	face layer betwen core layer, and bottom layer between layer

The BFRP values of young’s modulus, tensile strength, and elongation to fracture were 89 GPa, 2800 MPa, 3.15 % respectively [55]. 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 [56].

At a temperature of 20°C, the density of the material is measured to be 1.11 ± 0.02 g/cm3, while at 25°C, the viscosity is determined to be 14.000 ± 3.000 mPas, When exposed to an environment with a temperature of 20°C ± 2 and a relative humidity of 65 ± 3, the material undergoes hardening within a time frame of 30 minutes.

Figure 1. Materials used in experiments.

2.2. Preparation of Test Samples

The OSB-2 panels and 4 mm thickness PPWD were precisely cut into 31 pieces per panel, each measuring 162 × 1700 ± 1 mm using a CNC machine (Fig. 2a). For interlayer samples, two layer of reinforced materials (BFRP, GFRP, and Jute Fabric) were used for intermediate support between OSB and plywood layers. Approximately 200 g/m2 of adhesives were used for surface (Fig. 2b). 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 (Fig. 2c). The press exerted a pressure of approximately 1.5 N/mm2 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. Test specimens were named according to the species as the face, PPWD abbreviated as BP, and PP, respectively. For the cork board, OSB-2 class, abbreviated as O. For the FRP materials, BFRP, GFRP, and fabric jute were abbreviated as B, G, and J, respectively. The layers are arranged as shown Figure 3. Based on these combinations, a total of 12 types wood-based sandwich panels were manufactured in Table 2.

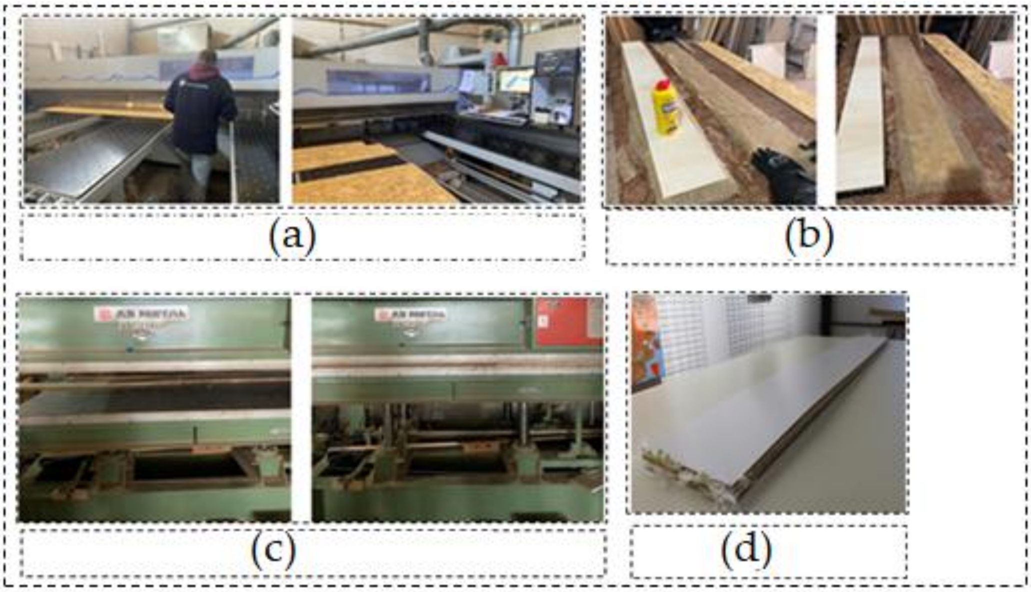

Figure 2. The production process of test samples: (a) using a CNC machine; (b) polyurethane adhesive was used for surface; (c) Hydraulic Veneer SSP-80; ASMETAL; (d) the pressing of samples.

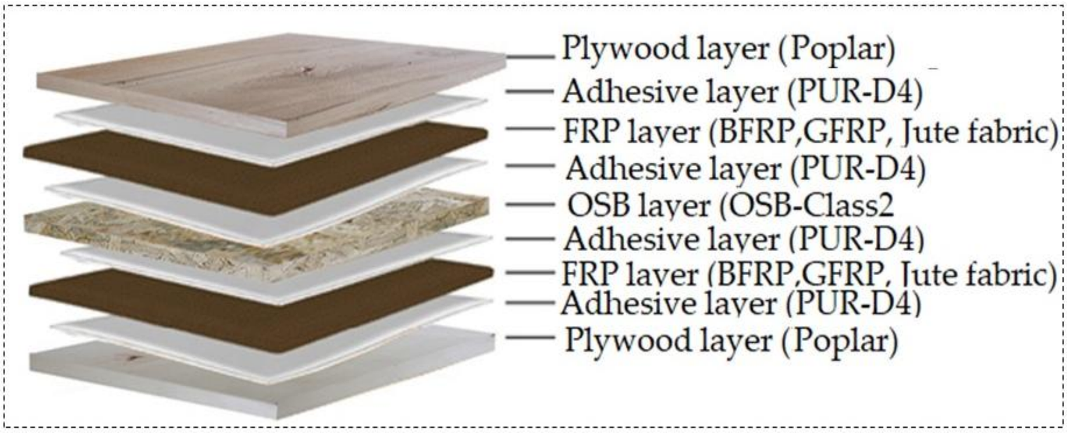

Figure 3. Exploded view of a multi-layered wood-based sandwich panels structure.

Table 2. Combinations of wood-based sandwich panels were manufactured.

Group	Code	Face Layer	FRP Types	Core Layer	Bottom Layer
A	PP-B-O-B-PP	PP (PPWD)	B (BFRP)	O (OSB-2 class)	PP (PPWD)
B	PP-J-O-J-PP	PP (PPWD)	J (Jute Fabric)	O (OSB-2 class)	PP (PPWD)
C	PP-G-O-G-PP	PP (PPWD)	G (GFRP)	O (OSB-2 class)	PP (PPWD)
D	PP-O-PP	PP (PPWD)	-	O (OSB-2 class)	PP (PPWD)

After the test samples (A, B, C, D groups) were conditioned at a temperature of 20 °C ± 3 °C and a relative humidity of 65%.

2.3. Test Method

The air-dried density δ_{12} test samples were prepared according to TS EN 323/1 [57], standards. All specimens (10 replications for each sample group) were prepared for each property. The air-dry densities (δ_{12}) of these specimens were calculated using the following Eq. 1,

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

where δ_{12} denotes the air-dry density in grams per cubic centimeter (g/cm^3), M_{12} is the air-dry mass in grams (g), and V_{12} is the air-dry volume in cubic centimeters (cm^3).

Determinations of sound absorption coefficients of (SAC) of the wood based sandwich panels produced in this study were performed based on the ASTM E 1050 - 19 [58] standard. The wood composite panels were precisely cut into the required dimensions for testing using a Computer Numerical Control (CNC) machine to ensure accurate and consistent sample preparation (Fig. 4a). The impedance tube (BSWA TECH SW422) method was used. According to this standard, the sound absorption coefficients of the test specimens prepared with a diameter of 30 mm in the frequency bands from 0 Hz to 2400 Hz were determined. The test specimens and impedance tube that were used to determine the sound absorption coefficient are shown in Figure 4b,c.

The impedance tube can measure low frequencies (0 to 2400 Hz) with high frequencies with a small diameter tube (29.95 mm). The acoustic performance of the wood based sandwich composites across different frequency ranges low (bass), mid, and high (treble) frequencies were evaluated by measuring the SAC over a frequency range of 0 Hz to 2000Hz. The measurements were carried out using an impedance tube setup, where the samples were exposed to incident sound waves, and the absorbed, transmitted, and reflected sound pressures were recorded to calculate the SAC values. Each composite sample was tested at least three times. This refers to the testing of ten different samples of the same formula, with the objective of ensuring reproducibility. By repeating the tests on distinct samples, the aim was to verify that the results were consistent across different specimens, thus ensuring the robustness and repeatability of the findings. The obtained SAC values were analyzed to assess the acoustic performance of the materials across the specified frequency range.

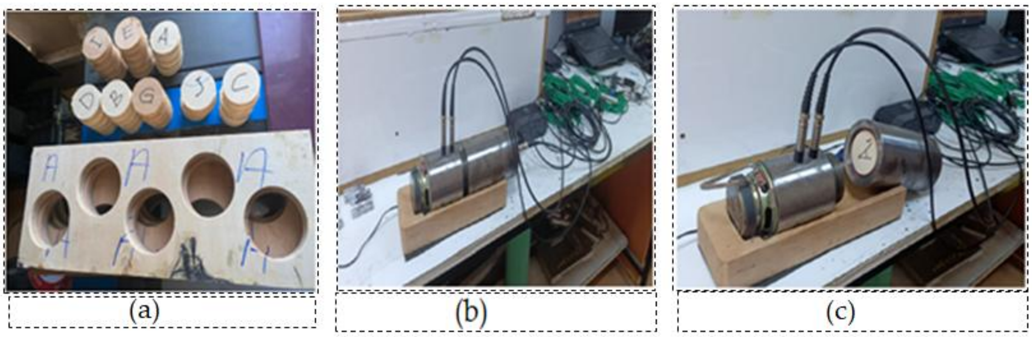
(a) (b) (c)

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

2.4. Data Analyses

The multiple variance analysis was performed to determine the differences among the factors (wood-based panel types, fiber reinforced polymers types) by using the SPSS program (Statistical Software, a computer-based statistical package) program, version 22. It was determined with the Tukey test if there is a meaningful difference among the groups.

3. Results and Discussion

When Tables 3 through 5 were examined in detail, the results of the ANOVA in the tables showed that the differences reinforcement designs had significant (a p-value less than 0.05) effects on the sound absorption coefficient values. The sound absorption coefficient (SAC) values of the experimental groups were higher than the SAC values of the B group. It was determined that the acoustic performances of the reinforced wood based sandwich panels had improved. In general, it was determined that the sound absorption coefficient values of the composite materials increased as the frequency increased. While the highest sound absorption performance was measured in the A group, the lowest sound absorption performance was measured in the B group.

Table 3. Sound Absorption Coefficient (SAC) Values (0 Hz to 800 Hz) and ANOVA Results (p-value equals 0.05).

Group	**Frequency (Hz)**			
	200 (Hz)	**400 (Hz)**	**600 (Hz)**	**800 (Hz)**
A	0.67	0.54	0.20	0.52
B	0.48	0.42	0.28	0.13
C	0.55	0.44	0.38	0.33
D	0.53	0.42	0.16	0.41
X	0.56	0.46	0.26	0.35
S	0.09	0.06	0.10	0.15
X min	0.48	0.42	0.16	0.13
X max	0.67	0.56	0.38	0.52
($P \leq 0.05$)	0.000*	0.000*	0.0000*	0.000*

Note: X: average value; S: the standard deviation; X min: minimum value; and X max: maximum value.

Table 4. Sound Absorption Coefficient (SAC) Values (1000 Hz to 1600 Hz) and ANOVA Results (p-value equals 0.05).

Group	Frequency (Hz)			
	1000	**1200**	**1400**	**1600**
A	0.44	0.09	0.12	0.16
B	0.16	0.85	0.62	0.37
C	0.16	0.18	0.51	0.07
D	0.34	0.07	0.10	0.13
X	0.26	0.30	0.34	0.18
S	0.01	0.34	0.24	0.12
X min	0.16	0.07	0.10	0.07
X max	0.44	0.85	0.62	0.37
($P \leq 0.05$)	0.000*	0.000*	0.000*	0.000*

Note: X: average value; S: the standard deviation; X min: minimum value; and X max: maximum value

Table 5. Sound Absorption Coefficient (SAC) Values (1800 Hz to 2400 Hz) and ANOVA Results (p-value equals 0.05).

Group	Frequency (Hz)			
	1800	**2000**	**2200**	**2400**
A	0.20	0.11	0.07	0.05
B	0.10	0.27	0.37	0.07
C	0.12	0.14	0.32	0.08
D	0.16	0.09	0.06	0.05
X	0.14	0.15	0.21	0.06

S	0.04	0.09	0.14	0.18
X min	0.10	0.09	0.06	0.05
X max	0.20	0.27	0.37	0.08
($P \leq 0.05$)	0.000*	0.000*	0.000*	0.000*

Note: X: average value; S: the standard deviation; X min: minimum value; and X max: maximum value

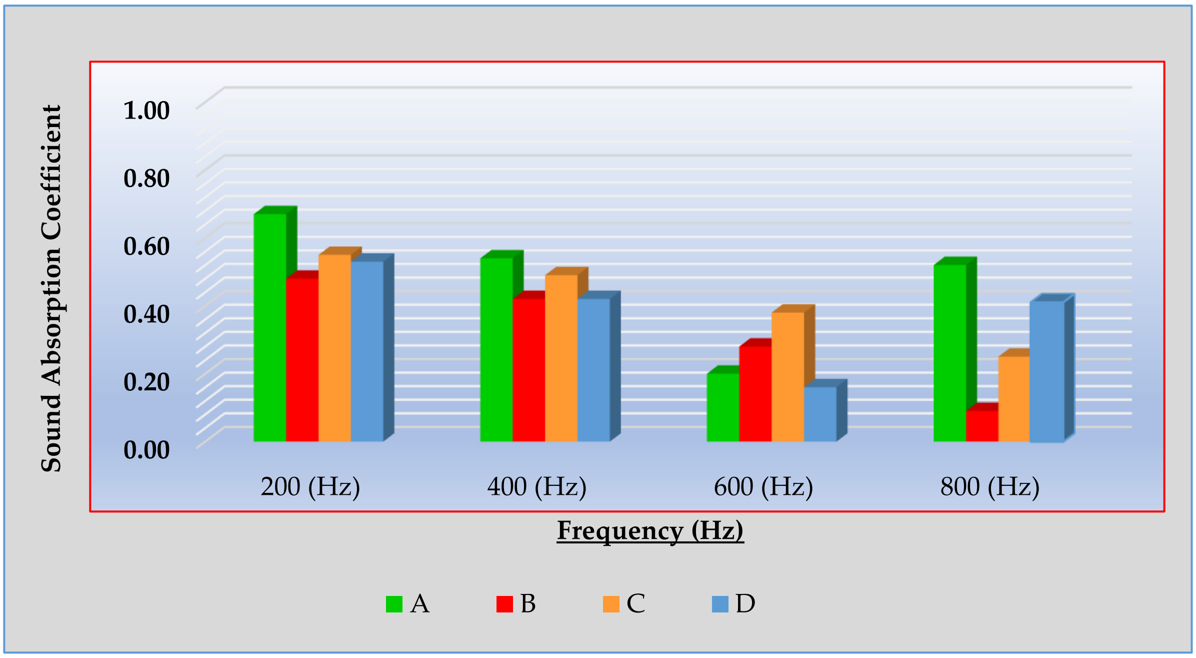

Figure 5. Low (bass) frequency SAC values of the A, B, C and D groups.

The values of the wood based sandwich panels reinforced FRP's were higher than the SAC values of the B group. A direct relationship was observed between the increase in frequency and the enhancement in sound absorption coefficient. It was determined that the acoustic performances of the FRP's had improved. The acoustic performance of the produced composite materials at low (bass), medium, and high (treble) frequencies is presented in Figure 5, 6, and 4, respectively.

Table 3 and Figure 5 indicates that the SAC values (the highest) for the A, B, C, and D groups within the 200 Hz to 800 Hz frequency range were measured as 0.67, 0.48, 0.53, and 0.55, respectively. These results indicate that the highest sound absorption performance was achieved by Group A. It is understood that the sound absorption performance of wood based sandwich panels with FRP's composite materials low (bass) frequencies is sufficient. It was determined that the composite materials absorbtion a significant portion of sound waves at low (bass) frequencies.

Low (bass) frequency sound waves have longer wavelengths and generally require thicker, more porous, or flexible materials to be effectively absorbed. Plywood, OSB, and FRP's, while providing strength and rigidity to the composite, are likely to exhibit relatively high stiffness and low porosity. These characteristics limit their ability to dissipate the energy of lower frequency sound waves through friction or internal damping. Additionally, the laminated structure may lack the necessary thickness or compliance to induce sufficient air movement or create resonant cavities that enhance low-frequency absorption. To enhance the low (bass) frequency absorption characteristics, several strategies could be considered in future work. For instance, increasing the composite thickness could create a deeper structure that absorbs more sound in the bass range. Additionally, integrating perforated or porous designs, or combining the composite with other damping materials such as rubber or polyurethane foam, could significantly improve low-frequency sound absorption.

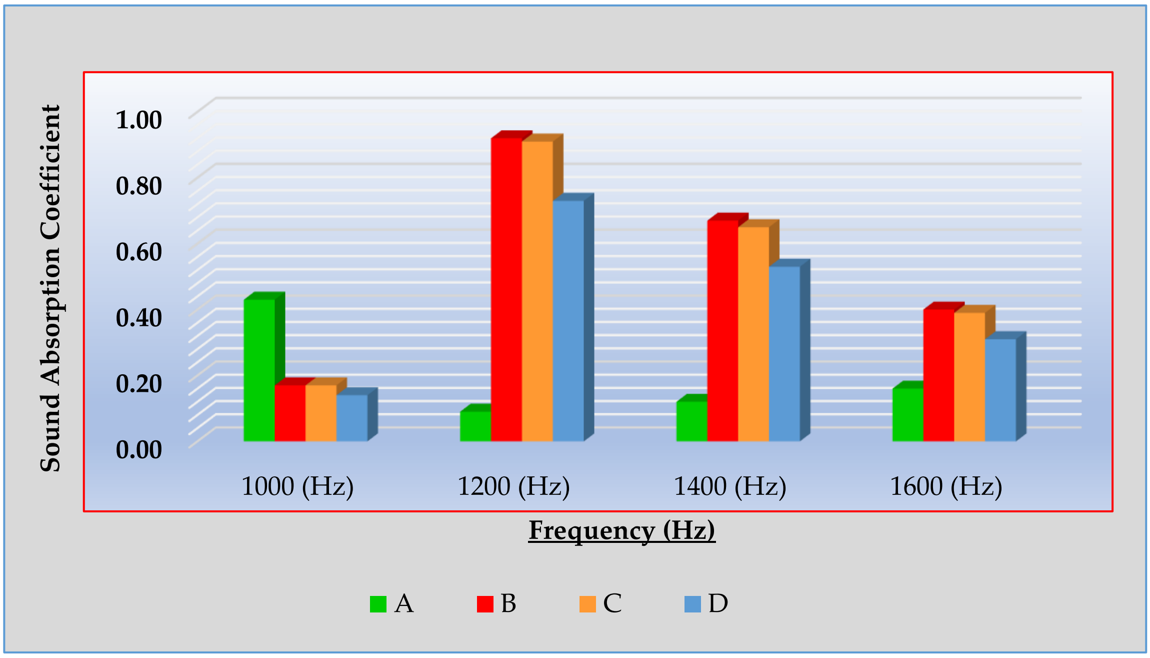

Figure 5. Middle frequency SAC values of the A, B, C and D groups.

A close examination of Figure 6 revealed that the maximum sound absorption coefficient (SAC) values in the mid-frequency range (1000–1600 Hz) for groups A, B, C, and D were 0.44, 0.85, 0.51, and 0.37 at 1000 Hz, 1200 Hz, 1400 Hz, and 1600 Hz, respectively. The composite materials in the B group primarily reflected or transmitted sound waves within this frequency range, indicating limited absorption capability. In contrast, the incorporation of fiber-reinforced polymers (FRPs) significantly enhanced the acoustic performance of the composites.

The hybrid structure of the plywood–FRP–OSB composite improves its ability to dissipate acoustic energy through increased internal friction. Both plywood and OSB, as natural wood-based materials, possess inherently porous microstructures that facilitate sound absorption, particularly in the mid-frequency range where sound waves interact with internal voids, fibers, and particles. This interaction leads to the conversion of acoustic energy into heat through frictional losses. Moreover, the acoustic impedance mismatch between the plywood, OSB, and FRP layers induces multiple internal reflections and scattering of sound waves, thereby promoting additional energy dissipation. The FRP reinforcement also introduces further internal interfaces that disrupt sound propagation, collectively contributing to an improved sound absorption capacity of the composite system.

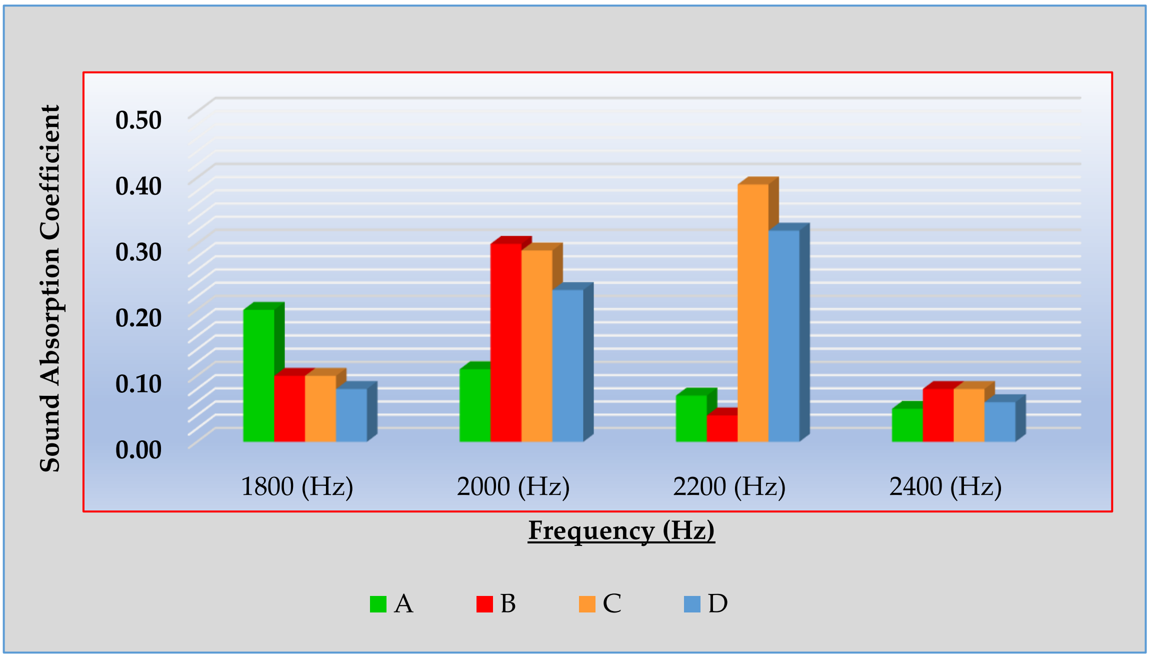

Figure 7. High (treble) frequency SAC values of the A, B, C and D groups.

A detailed analysis of Figure 7 indicates that groups A, B, C, and D exhibited relatively low sound absorption efficiency in the high-frequency (treble) range. The wood-based sandwich panels reinforced with FRP composites showed the lowest sound absorption performance at 2400 Hz within the 1800–2400 Hz frequency band. The measured sound absorption coefficients (SAC) for groups A, B, C, and D were 0.14, 0.15, 0.21, and 0.06, respectively.

Recent studies in the literature have investigated the sound absorption performance of carbon fiber–based materials, particularly at low (bass) frequencies, and have shown that these materials predominantly transmit or reflect incident sound waves [49,51,59] 2025). The results indicated that the sound absorption performance of carbon fiber composites is generally inadequate in the low-frequency range [51]. In contrast, a study examining the acoustic performance of carbon fiber materials in the mid-frequency range (315–1600 Hz) reported that approximately 40% of the sound waves were absorbed within this frequency band [49].In another investigation, laminated wood composite panels were fabricated using poplar veneer, PVAc adhesive, natural rubber, elastomeric sponge, felt, and linoleum, and their sound absorption behavior was evaluated. The reinforced laminated wood composites exhibited significantly higher sound absorption performance compared to the control samples [59]. Multiple studies have similarly demonstrated that reinforced laminated wood (RLW) composite materials possess markedly improved acoustic properties. These findings suggest that incorporating advanced materials and innovative lamination designs can effectively enhance the sound absorption capabilities of RLW composites [59-60].

The findings of the present research contribute to the existing body of knowledge in wood material science and acoustics by introducing a novel hybrid composite that integrates plywood with carbon fiber. This hybrid configuration demonstrates enhanced acoustic performance relative to traditional plywood, thereby representing a new direction in the development of sound-absorbing structural materials that bridge the gap between conventional wood-based systems and modern composite technologies.

4. Conclusions

In this study, the sound absorption performance of wood-based sandwich panels reinforced with basalt fiber-reinforced polymer (BFRP), glass fiber-reinforced polymer (GFRP), and jute fabric was investigated across low (bass), medium, and high (treble) frequency ranges. The results demonstrated that the jute-fabric-reinforced panels exhibited the highest overall sound absorption coefficients among the tested composites. Significant differences were observed between the sound absorption coefficients of the FRP-based panels, depending on the frequency level. Specifically, the maximum sound absorption of the B group occurred at 1200 Hz, whereas the lowest absorption coefficients for the A and D groups were recorded at 2400 Hz.

Furthermore, the plywood–carbon fiber composites showed a tendency to reflect or transmit sound waves predominantly at low frequencies, while exhibiting enhanced sound absorption capacity at higher frequencies. The highest sound absorption performance of the FRP-reinforced panels was observed at 200 Hz. Overall, the acoustic properties of the experimental composites improved considerably, confirming that BFRP, GFRP, and jute fabric are effective reinforcements for the development of sound-insulating materials.

These findings indicate that wood-based sandwich panels reinforced with FRP composites possess promising potential for applications in furniture manufacturing and wood-based structural systems due to their superior acoustic insulation performance. The present study provides a foundation for future research on the design and optimization of advanced wood-based composites with tailored acoustic characteristics for engineering and architectural applications.

Author Contributions: Conceptualization: K.A.; Data curation: K.A.; Formal analysis: K.A.; Funding acquisition: Y.H.; Investigation: Y.H; Methodology: K.A.; Writing—original draft: K.A.; Writing—review &editing: Y.H. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: Original contributions to this study are included in the article. For further inquiries, please contact the corresponding author directly.

Conflicts of Interest: The authors declare no conflict of interest.

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