

Tensile Strength, Thermal, and Acoustic Performance of Low-Cost Honeycomb Sandwich Structures

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المخلص— في هذا البحث تم تصنيع ألواح ألومنيوم مركبة على هيئة خلية نحل ذات تكلفة منخفضة ومصنعة من رقائق الألومنيوم 6061 وأوراق تم إعادة تدويرها، حيث اختبرت هذه الألواح بخصائص عزلها للحرارة وامتصاص الصوت، بالإضافة إلى مقاومة الشد. أظهرت النتائج أن هذه الألواح ذات التكلفة المنخفضة، تُعد عازلاً حرارياً فعالاً. بالإضافة إلى ذلك، فهي ممتصة فعالة للصوت، خاصةً عند الترددات المنخفضة، أيضاً أظهرت نتائج اختبارات الشد أداء ميكانيكياً متميزاً لهذه الألواح.

الكلمات المفتاحية— ألواح على هيئة خلية النحل؛ عزل الحرارة؛ امتصاص الصوت؛ قوة الشد

Abstract—In this study, low-cost honeycomb sandwich panels fabricated from 6061 aluminum alloy and shredded recycled papers were tested for their heat insulation and sound absorption as well as tensile properties. The results showed that this cost-effective honeycomb sandwich structure is an efficient heat insulator, as well as an effective sound absorber particularly at low frequencies. In addition, tensile test results also exhibited outstanding mechanical performance of the honeycomb sandwich structure.

Keywords— Honeycomb structure; Heat insulation; Sound absorption; Tensile strength

1. Introduction

Reliable and versatile engineering materials are essential components in a wide range of applications, including construction, transportation, marine structures, and recreational products. Among these, fiber-reinforced polymer composites and aluminum alloys are commonly utilized to form the open hexagonal cell cores of sandwich panel structures [1,2]. Honeycomb structures, in particular, are recognized for their excellent balance of lightweight characteristics and combined thermal, chemical, and mechanical advantages, making them highly attractive for diverse industrial applications [3–5]. A promising approach toward developing low-cost, high-strength and lightweight materials would be to increase the production of honeycomb sandwich panels which are durable and versatile making them the go-to product in the modern industrial applications [1,2]. However, such outstanding mechanical and chemical properties have been critically limited by the poor thermal and acoustic performance of the open cell honeycomb sandwich structure. Foams can provide attractive combinations of properties for such heat insulation and sound absorption applications. However, foam was not found to be inherently mechanically-robust [6]. Sandwich constructions may be utilized

for thermally-, physically-, and mechanically-robust structure to fulfil requirements for advanced industrial applicability such as strength, lightweight, heat insulation and sound absorption [7–9].

This paper is focused on evaluating the mechanical, thermal and acoustic behavior of honeycomb sandwich panels. Honeycomb sandwich panels are made up of strips forming a hexagonal shape. Aluminum which is one of the popular materials used as honeycomb cores exhibit high mechanical strength and shear modules. If honeycomb open cells are filled with an insulating material, it will combine all mechanical and physical properties [6]. The purpose of this paper is to evaluate the heat insulation, sound absorption and tensile strength of low-cost honeycomb sandwich panels fabricated from aluminum alloy and shredded recycled papers.

2. Experimental Procedure

2.1. Sample Preparation

Honeycomb sandwich panels were fabricated using 6061 aluminum alloy foil (0.45 mm thickness), 331 epoxy resin adhesive, 2964 hardener, and shredded waste paper. Aluminum alloy was selected for the honeycomb structure due to its high stiffness, low weight, and excellent corrosion resistance. To construct the core, aluminum sheets were first cut into uniform strips, then corrugated and bonded together using epoxy resin to form a regular hexagonal honeycomb cell configuration. This geometry provides the minimum density for a given amount of material. Recycled papers were filled inside the honeycomb cells to substantially enhance the thermal insulation and sound absorption capability. In order to dry the recycled papers, honeycomb core was heated in an oven for 24 hours at 80°C. Then, the honeycomb core was rigidly attached to the facings by using an adhesive in order for loads to be transmitted from one facing to the other, to the final form of honeycomb sandwich panels with a thickness of 16mm [10]. Fig. 1 shows the fabrication steps of the honeycomb sandwich panel, and Tables 1 and 2 show percentage and weight proportion of materials that were utilized as well as the properties of honeycomb sandwich panels.

Table 1. Percentage and weight proportion of materials utilized to fabricate the honeycomb sandwich panels

Materials	Weight (kg)	Percentage (%)
Recycled paper	0.07801	10.1
Facial skin	0.37728	59.3
Core	0.20016	30.6
Overall	0.65593	100

Table 2. Properties of honeycomb sandwich panels

Materials	Weight, m (kg)	Volume, V (m ³)	Density ρ (kg/m ³)
Honeycomb	0. 65593	8.64 X 10 ⁻⁴	759.18

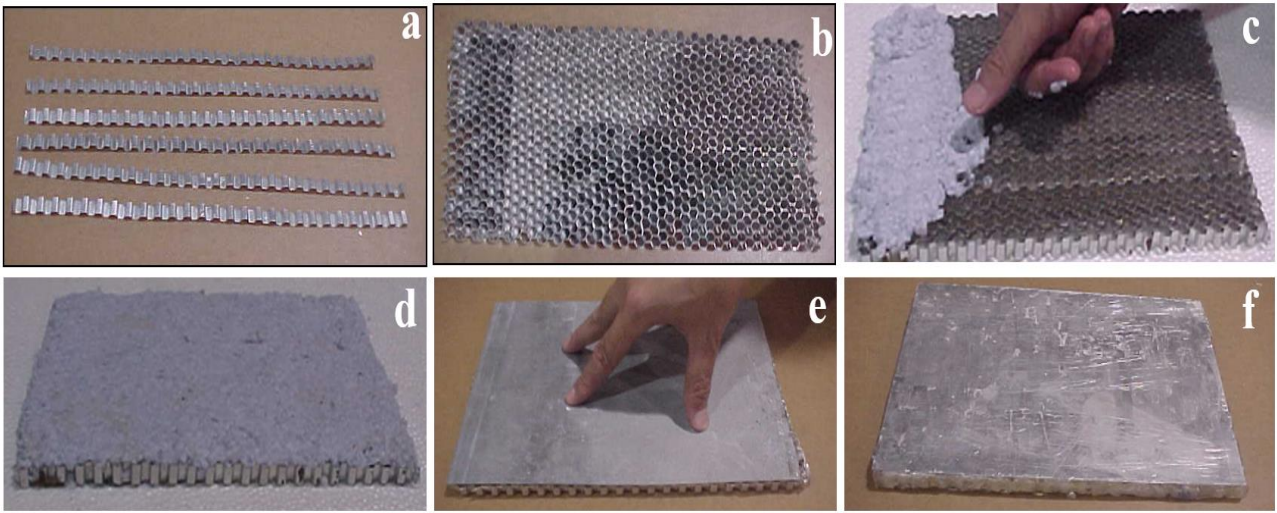


Figure 1. (a) Sheets of 6061 aluminum alloy are cut into strips and converted to hexagonal honeycomb cell pattern. (b) Strips are adhered together by using epoxy resin to form honeycomb core pattern. (c & d) Recycled papers are filled inside the honeycomb cells. (e) Honeycomb core is attached to the facings by using an adhesive. (f) Final shape of honeycomb sandwich panel.

2.2. Characterization of Honeycomb Structure

Three experimental tests were conducted on the produced honeycomb sandwich panels, namely; heat insulation, sound absorption and tensile tests. That was in order to estimate the thermal, physical, and mechanical properties of the fabricated honeycomb sandwich structure as well as its suitability for applications in the fields that require such features.

2.2.1. Heat Insulation Test

In the thermal insulation test, a testing model was built using polystyrene foam and cardboard as shown in Fig. 2 (a) [10]. A blower applying heat was placed in one side of the testing model and two thermocouples, each was placed in one side of the testing model to measure the temperature differences (T1 and T2) between both sides, while the sample (honeycomb sandwich panel) being tested for its heat insulating ability was positioned in the center as shown in Fig. 2 (b). In the first testing approach, each thermocouple was positioned in one side of the testing model, adjacent to the sample being tested, while the temperatures in both sides were recorded every 30 seconds for 3000 seconds [10]. In the second testing approach, however, each thermocouple was positioned in one side of the testing model at a distance of 10 cm away from the sample being tested, while the temperatures in both sides were recorded every 30 seconds for 3000 seconds. All the data was transferred into a graph for evaluation [10]. The heat resistance of honeycomb structure ($R_{H/C}$) was calculated according to the following Equation [1]:

$$R_{H/C} = \frac{t_c \rho_w}{k_w \rho_{H/C}} = \frac{0.16 \times 2700}{204 \times 759.18} = 2.789 \times 10^{-3} \text{ m}^2 \cdot \text{ }^\circ\text{C/W} \quad [1]$$

Where t_c is sandwich thickness, ρ_w is aluminium density, k_w is aluminium thermal conductivity and $\rho_{H/c}$ is honeycomb sandwich panel density.

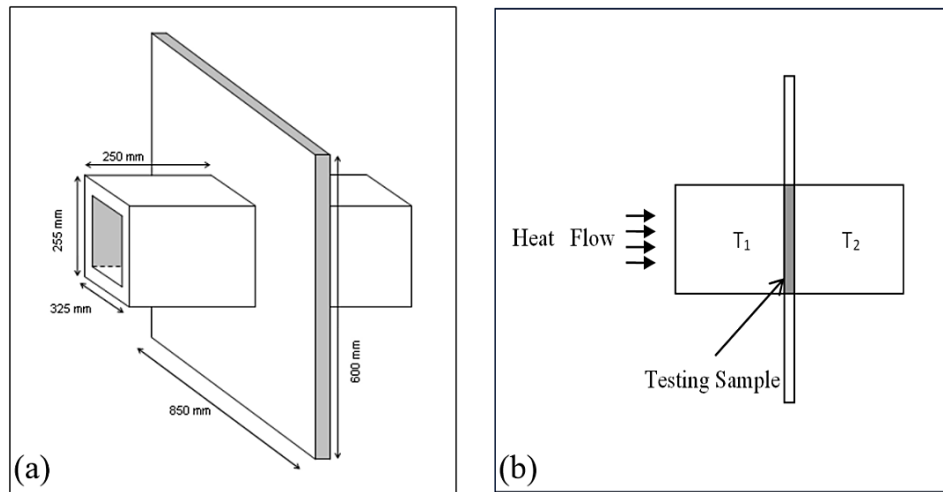


Figure 2. (a & b) Heat insulation test setup.

2.2.2. Sound Absorption Test

In the sound absorption test, the same testing model used to measure the heat insulation performance was also used to measure the sound absorption behavior of the honeycomb sandwich panels as shown in Fig 3 (a). A speaker was placed in one side of the testing model and a microphone was placed in the other side of the testing model, while the sample (honeycomb sandwich panel) being tested for its sound absorbing ability was placed in the center. A sound signal was generated by connecting the speaker to the audio generator that generated frequencies. This sound signal was, then, received by the microphone in the other side of testing model. The microphone connected to the amplifier transformed the signal output to the outputs on the digital oscilloscope screen [10].

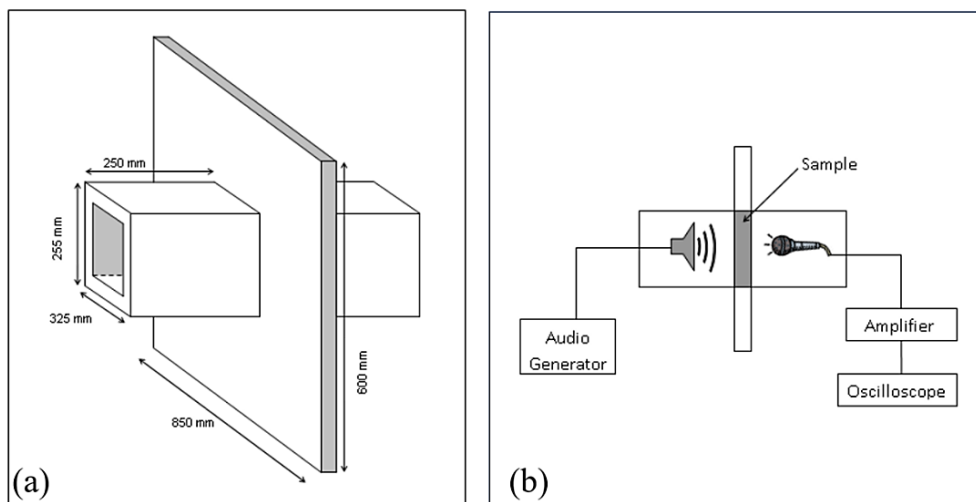


Figure 3. (a, b) Sound absorption test setup.

For signal wave calibration, the testing model was set up without placing any sound absorbing material (honeycomb sandwich panel) in the center. The calibration measurements were taken at frequencies of 150 Hz, 500 Hz, 800 Hz, 1000 Hz, 2000 Hz and 2500 Hz, all with a magnification of 0.2 Volts and a period of time of 0.5 milliseconds. This range was used because almost similar to the human voice [10]. The test measurements were also taken at the same frequencies, magnifications

and periods of time taken during the calibration procedure stated hereinbefore. The results were recorded by printing out the output waves displayed on digital oscilloscope [10]. The sound transmission loss was calculated according to Eq. 2.

$$\text{Sound transmission loss, } TL = 10\log_{10}(V_0/V_1) \quad [2]$$

Where, V_0 and V_1 are the magnification times the amplitude.

2.2.3. Tensile Test

Tensile testing of the 6061 aluminum alloy strips was performed using an Instron 8501 universal testing machine. The samples were subjected to uniaxial tensile loading by pulling from both ends until fracture occurred. During testing, load and elongation data were continuously recorded. The fracture mechanisms of the specimens were observed and documented following failure. Tensile strength was calculated using the recorded data, based on the maximum load and cross-sectional area of each sample.

3. Results and Discussion

3.1. Honeycomb Sandwich Panels

The density of honeycomb sandwich panel, 759.18 kg/m^3 (0.759 g/cm^3) is higher than the ones previously reported (0.26 g/cm^3) [10], (264.41 kg/m^3) [11] and (555.47 kg/m^3) [12]. The density obtained in this study is higher than the reported values because the size of the cell was 7.1 mm and aluminum foil thickness is 0.45 mm which required applying a considerable amount of aluminum strips for the honeycomb core fabrication.

3.2. Heat Insulation Test

In the thermal insulation test, the mechanism of heat transfer at a particular space area was forced convection because blowing process was used, and the heat in the air inside the space area was transferred through the honeycomb sandwich panel by several methods. First, heat transferred by conduction since the facing sheets utilized to fabricate the honeycomb sandwich panel was made of aluminum alloy, which is a good heat conducting material. The aluminum alloy heated up just as fast as the space area. Then, heat transferred through the layer of recycled papers before it reached the honeycomb core. This layer passed a small amount of heat to the honeycomb core and the other layer of face sheet of the honeycomb sandwich panel. The combination of heat conduction, convection and radiation flowed parallel to the honeycomb orientations were faster than that of the insulating air.

The heat flowed through unfilled cell walls was by conduction while through the air in the cell was by convection and radiation as illustrated in Fig. 4. But, for the aluminium honeycomb core, the conductivity of aluminium was greater than that of air. Both convection and radiation were neglected compared to the heat conduction through the cell walls.

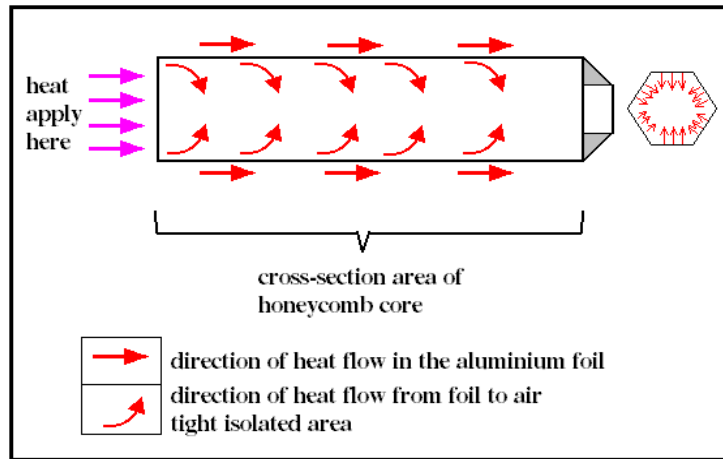


Figure 4. The mechanism of heat flow through the cross-sectional area of the honeycomb core structure.

Fig. 5 shows that the temperature increments in the space region on the side where the heating blower was applied (top lines), have a greater temperature increment rate compared to the space area region insulated by the honeycomb sandwich panel (bottom lines).

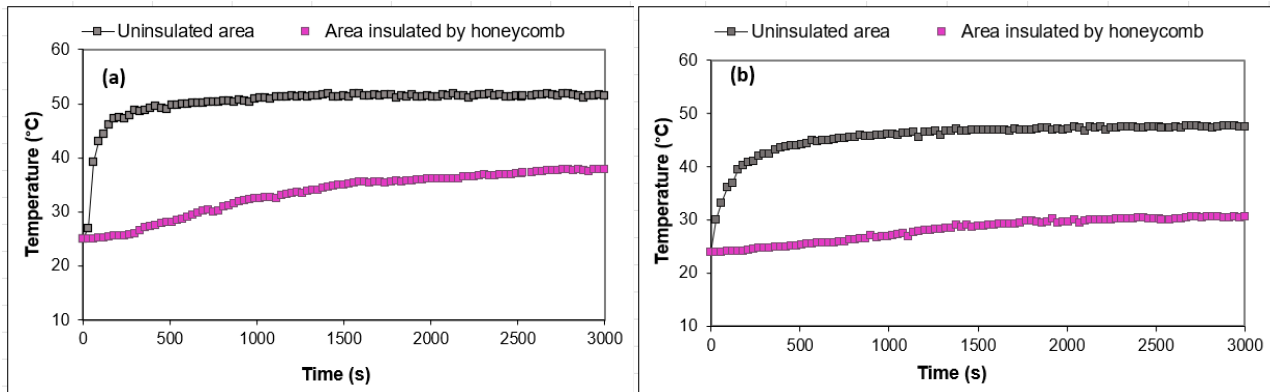


Figure 5. Temperature vs Time for the uninsulated area (top line) and the area insulated by honeycomb panel (bottom line): **(a)** where each thermocouple was adjacent to one side of the honeycomb panel; and **(b)** where each thermocouple was 10 cm away from one side of the honeycomb panel (right).

In the first testing approach described hereinbefore, there were a temperature of 52°C at the blower side and a temperature of 38°C at the insulated side for the final stabilized equilibrium temperature from the initial temperature of 24°C as shown in Fig. 5(a). As a result, the sandwich panel insulated 50% from the heat flowed after 3000 seconds. However, in the second testing approach illustrated hereinbefore, there were a temperature of 48°C at the blower side and a temperature of 30°C at the insulated side for the final stabilized equilibrium temperature from the initial temperature of 24°C as shown in Fig. 5(b). As a consequence, the honeycomb sandwich panel insulated 75% from the heat flowed after 3000 seconds. These values which exhibited heat insulated were not far from the heat insulation values reported for the honeycomb sandwich panels fabricated from 360.0 and 413.0 aluminum alloys as well as recycled papers [10]. That was attributed to applying the same thickness of recycling paper layer for both studies.

This indicates that the fabricated honeycomb sandwich panel insulated temperature effectively. The heat convection in the heating blower side was forced convection because of the blowing process and the insulated side was free convection due to the buoyancy effects between the solid honeycomb

panel and the air that surrounded it. This shows that the honeycomb sandwich panel reduces the heat transfer from one area to another. Although other panels may have the same ability of insulating heat, honeycomb sandwich panels are capable of insulating heat and offering better properties such as strength, light weight, corrosion resistance and low density. Table 3 shows that the total thermal resistance of the panel is 1.873 m²·°C/W.

Table 3. Thermal resistances for every layer of honeycomb sandwich panel

Materials layer	Thermal conductivity, k (W/m·°C)	Thickness, t (m)	Thermal resistance, R (m ² ·°C/W)
Skin R _S	205.0	0.00045	2.2 x10 ⁻⁶
Epoxy resin R _{ER}	2.61	0.0005	1.92x10 ⁻⁴
Honeycomb core R _{H/C}	-	-	2.789x10 ⁻³
Overall recycled paper R _{RP}	0.07	0.131	1.87
Epoxy resin R _{ER}	2.61	0.0005	1.92x10 ⁻⁴
Skin R _S	205.0	0.00045	2.2 x10 ⁻⁶
Total resistance			1.873

3.3. Sound Absorption Test

Honeycomb sandwich panel did not affect the frequency of sound wave, but it reduced the amplitude as Fig. 6&7 reveal. They also show a significant reduction in the amplitude of sound wave. The reduction was measured by calculating it as sound transmission loss.

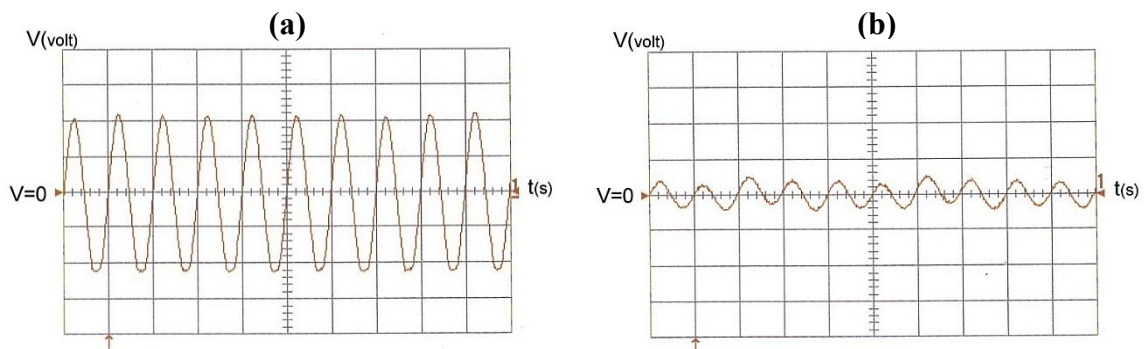


Figure 6. (a) Sound signals at 150 Hz (low frequency) without any absorbing materials, and (b) sound signals at 150 Hz with honeycomb sandwich panel as an absorbing material.

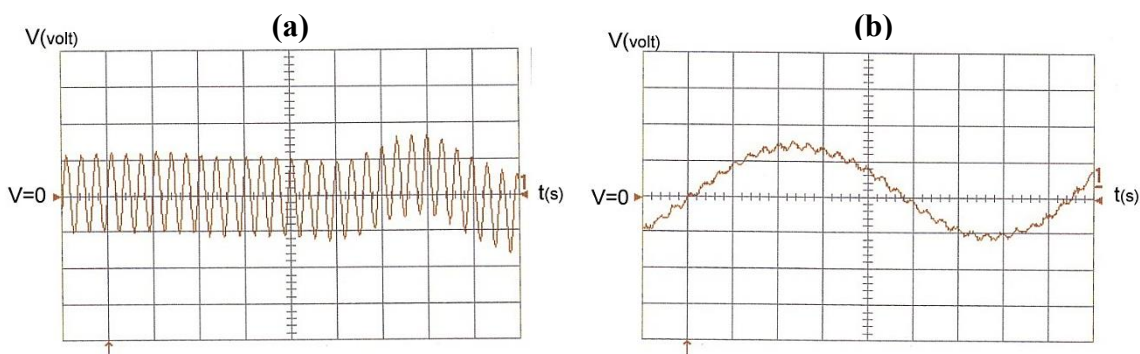


Figure 7. (a) Sound signals at 2500 Hz (high frequency) without any absorbing materials, and (b) sound signals at 2500 Hz with honeycomb sandwich panel as an absorbing material.

From the calculations, Table 4 shows that the honeycomb sandwich panel exhibited significant sound absorption, as reflected in the measured transmission loss (TL) values, which were also not far from the sound absorbing values reported for the honeycomb sandwich panels fabricated from the 360.0 and 413.0 aluminum alloys as well as recycled papers [10].

Table 4. Sound transmission loss (TL) for testing honeycomb sandwich panel

Material	Sound transmission loss, TL (db)					
	150 Hz	500 Hz	800 Hz	1000 Hz	2000 Hz	2500 Hz
Honeycomb sandwich panel	8.88	6.45	8.59	5.95	5.35	6.85

Sounds from the background and the degree of insulation of the microphone and the speaker were taken into consideration. However, sounds from the air-conditioner machine and the sound pressure level were neglected since they were small. As for the microphone insulation, the insulation wall made by polystyrene foam absorbed sounds effectively and only slight sound leakage from the edge of the bonding area interrupted the clean sound from the audio generator. From the theory of sound conduction, honeycomb sandwich panel has the ability to reflect a portion of the sound vibration that reached its surface because of the aluminum alloy sheets used as a facing skin. The sound absorbance by honeycomb sandwich panel was high at the recycled paper layer. The vibration of sound stopped or reduced considerably in this layer. Honeycomb sandwich panels have lower density, which makes it an effective sound damper.

3.4. Tensile Test

Tensile test results summarized in Table 5, indicate consistent mechanical performance across all samples. An average tensile strength of 83.75 MPa was recorded, accompanied by a peak load of 241.2 N and an average strain of 2.50% which falls within the range of values reported [11]. These values reflect the alloy’s capability to withstand considerable mechanical stress while maintaining structural integrity, which is critical for the load-bearing function of the honeycomb panel. The consistency in cross-sectional area and initial length across samples further supports the reliability of the measurements. These results validate the suitability of the chosen material and fabrication process for applications requiring strength, durability, and multifunctional performance in a low-cost configuration.

Table 5. Tensile test result of the 6061-aluminum alloy

Description	Sample 1	Sample 2	Sample 3	Average Value
Load at Peak, (N)	232.3	236.5	254.7	241.2
Cross-section area, (m ²)	2.88X10 ⁻⁶	2.88X10 ⁻⁶	2.88X10 ⁻⁶	2.88X10 ⁻⁶
Tensile Strength, (MPa)	80.6	82.11	88.4	83.75
Initial Length, (mm)	30.0	30.0	30.0	30.0
Elongation, (mm)	4.9	4.3	3.9	4.37
Strain, (%)	2.49	2.59	2.43	2.50

4. Conclusion

This study demonstrated the successful fabrication of a low-cost honeycomb sandwich structure composed of 6061 aluminum alloy and shredded recycled paper. The resulting panels were strong, lightweight, low in density, and exhibited superior thermal and acoustic performance. Thermal analysis showed that the panel reduced heat transmission by approximately 50% in the area adjacent to it, and by up to 75% at a distance of 10 cm, with a calculated total thermal resistance of $1.873 \text{ m}^2 \cdot ^\circ\text{C}/\text{W}$. The honeycomb sandwich panel demonstrated significant sound absorption. Sound transmission loss values were 8.88 db, 6.45 db, 8.59 db, 5.95 db, 5.35 db and 6.85 db conducted at frequencies of 150 Hz, 500 Hz, 800 Hz, 1000 Hz, 2000 Hz and 2500 Hz respectively. Tensile testing revealed an average tensile strength of 83.75 MPa, with a corresponding peak load of 241.2 N and average strain of 2.50%. These results highlight the alloy's ability to withstand substantial mechanical stress while maintaining structural integrity, which is an essential requirement for load-bearing components in sandwich structures. Overall, the fabricated honeycomb sandwich panels demonstrate strong potential as a multifunctional structural material suitable for modern industrial applications requiring thermal insulation, sound control, and mechanical integrity. However, further mechanical evaluations such as three-point bending, shear strength, edge compression, impact resistance, explosive testing, and peel strength are recommended to fully assess their failure modes and expand their applicability across various engineering domains.

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References

- [1] Understanding Honeycomb Panels, Chemique Adhesives Company, UK, 2025, <https://www.chemiqueadhesives.com/en/understanding-honeycomb-panels/1>.
- [2] Understanding Honeycomb Panels, Plascore Company, Michigan, USA, 2025, <https://www.plascore.com/honeycomb/honeycomb-panels>.
- [3] C. Qi, F. Jiang, S. Yang, "Advanced honeycomb designs for improving mechanical properties: A review," *Composites Part B: Engineering*, Vol. 227, 109393, 2021.
- [4] G. Yu, L. Feng, L. Wu, "Thermal and mechanical properties of a multifunctional composite square honeycomb sandwich structure," *Materials & Design*, Vol. 102, 238-246, 2016.
- [5] K. Rao, C. Reddy, R. Krishna, V. Subhakar, R. Vignesh, "Mechanical and corrosion characteristics of low-density polyethylene reinforced with aluminum alloy AA6065 honeycomb structure," *Polym. Bull.*, 1–26, 2025.
- [6] T. Bitzer, "Honeycomb Technology: materials, design, manufacturing, applications and testing," Chapman and Hall, UK, 1997.
- [7] D. Filippov, Y. Liu, P. Zhou, B. Ge, J. Liu, J. Zhang, T. Zhang, G. Srinivasan, "Theory of Magnetolectric Effect for Three-Layer Piezo-Magnetostrictive Asymmetric Composites," *Journal of Composite Science*, Vol. 6(11), 346, 2022.
- [8] G. Feng, S. Yoshida, G. Lacidogna, "Special Issue on New Advances in Acoustic Emission and Microseismic Monitoring Technologies in Civil Engineering," *Applied Sciences*, Vol. 13(2), 2076-3417, 2023.

- [9] A. Monti, A. El Mahi, Z. Jendli, L. Guillaumat, “Quasi-static and fatigue properties of a balsa cored sandwich structure with thermoplastic skins reinforced by flax fibres,” *Journal of Sandwich Structure & Materials*, Vol. 21(7), 2358–2381, 2019.
- [10] L. Hussain I. Hakim, “Quasi Recycling and Formulation of Aluminum Scrap via Mass Balance Die Casting and Forming,” *Materials and Manufacturing Processes*, 22, 916–921, 2007.
- [11] L. Choong, “Fabrications of high strength and stiffness honeycomb sandwich panel from recycling and waste materials,” M.Sc. thesis, Universiti Sains Malaysia, 2002.
- [12] M. Bin Shaari, “Fabrication of honeycomb sandwich panel for sound damping and thermal insulation,” M.Sc. thesis, Universiti Sains Malaysia, 2003.