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# Thermal Stability and Sound Absorption Behaviour of Sisal–Luffa Hybrid Epoxy Composites for Automotive Interior Applications

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## Abstract

*Natural fiber–reinforced composites are gaining popularity as substitutes for synthetic fiber composites because of their environmental and sustainability advantages. Their adoption is steadily increasing across various industries. In automotive interior applications, these materials must exhibit strong thermal stability and efficient sound absorption to meet performance requirements. In this experiment, composites were made by mixing sisal and luffa fibers with epoxy resin. The hand lay-up method was used for fabrication. Two types of hybrid composites were prepared. In the first type, luffa fiber was kept constant at 30 wt.% and sisal fiber was varied at 10, 15, and 20 wt.%. In the second type, sisal fiber was fixed at 30 wt.% and luffa fiber was varied at 10, 15, and 20 wt.%. The thermal and acoustic behaviour of the composites was evaluated in this study. Thermal behaviour of the composites was studied using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Sound absorption performance was evaluated using the impedance tube method by calculating the sound absorption coefficient. The tests were conduct for frequency range of 400–2000 Hz with 25 mm, 35 mm and 45 mm of thickness. The findings show that sisal-based composites have high char residue and good thermal stability. In contrast, luffa -based hybrid composites exhibit higher sound absorption due to their porous structure. Due to hybridization, both thermal and acoustic properties are improved. The composites ES30L15 and EL30S15 show optimum performance in both thermal and sound absorption behaviour. The maximum sound absorption coefficient increases from 0.30 to 0.38 at higher frequencies. In addition, these composites exhibit stable thermal behaviour before the onset of thermal degradation.*

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**Keywords:** Hybrid composites, thermal stability, sound absorption, automotive interiors, sisal, luffa

## INTRODUCTION

Natural fiber reinforced polymer composites lightweight, eco-friendly, biodegradable, good strength-to-weight ratio, porosity and reducing noise. Because of these advantages, they are widely used in many applications such as automobile interior parts such as door trim panels, roof liners, dashboards, parcel shelves, and pillar covers. These composites offer better acoustic performance and thermal stability throughout service [1–3].

Conventional fibers such as glass and carbon fibers are good in mechanical strength, high density, poor recyclability, high in energy during production and not environmentally friendly. Because of its limitations of conventional fibers research interest is shifting toward natural fibers in many applications. When compared glass fiber with natural fiber composites show better vibration damping and sound absorption [4–6].

This is mainly due to their hollow cellular structure, lumen, rough surface, and natural porosity, which help in reducing sound energy through friction and heat loss as sound waves pass through the material. As a result, natural fiber composites are widely used in automotive interior parts, where passenger comfort, noise reduction, and thermal insulation are more important than carrying very high loads [7, 8]. Despite these benefits, the use of single-fiber natural composites is still limited because they absorb moisture easily, dimensional instable, high in fiber swelling and have moderate thermal resistance [9, 10]. Automotive interior parts are usually exposed to temperatures below 120°C Because a vehicle remains in direct contact with sunlight, has electrical systems, and is used for long periods, its temperature increases.

Therefore, the materials used in the vehicle must be thermally stable and mechanically strong to ensure safe and reliable performance [11, 12] To use natural fiber composites in automobile interior applications, they must have good thermal behaviour, low degradation, and proper acoustic performance so that they can work reliably for a long time.

To overcome the limitations of single natural fiber composites, hybridization is used.

By combining two different fibers, they complement each other, which helps to improve fiber–matrix bonding, delay thermal degradation, increase char formation, and enhance the sound absorption coefficient [13–16] Sisal fibers have higher lignin content, stiffness, and crystallinity, which help improve thermal resistance and structural stability.

In contrast, luffa fibers have a highly porous and open structure, which makes them very effective for sound absorption due to better airflow resistance and internal friction [17, 18]. The synergistic combination of sisal and luffa fibers gives a multifunctional hybrid composite that helps control noise in automobile interiors and also provides good thermal performance. Many studies have reported either thermal behaviour or acoustic performance of natural fiber composites. However, combined studies on both thermal and acoustic performance of sisal–luffa hybrid epoxy composites are still limited.

The effects of fiber dominance (sisal-rich or luffa-rich), laminate thickness, and automotive noise-related frequency range (400–2000 Hz) have not been studied in detail [19, 20]. In addition, comparative studies to identify the best hybrid compositions that balance thermal stability and sound absorption are rarely reported. In this study, sisal–luffa hybrid epoxy composites were fabricated and tested using different fiber ratios and laminate thicknesses.

The thermal behaviour of the composites was studied using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) in accordance with the ASTM standards. [21, 22]. The acoustic performance was measured using the impedance tube method following ASTM E1050 [23]. The main aim of this work is to identify optimized hybrid composites that are suitable for sustainable automotive interior applications, with good noise reduction and stable thermal performance.

## LITERATURE REVIEW

Natural fiber reinforced polymer composites are widely studied for automotive interior applications because they are lightweight, renewable, low-cost and have good vibration damping. Earlier studies have shown that natural fibers such as jute, sisal, flax, kenaf, banana, coir etc are successfully used in interior parts like door panels, roof liners, dashboards, parcel shelves, and pillar covers [1–3].

Compared to glass fiber composites, these materials reduce weight and improve vibration damping, which helps increase passenger comfort and fuel efficiency.

Besides being sustainable, natural fiber composites also show good sound damping due to their fibrous structure and natural porosity. However, their thermal stability and sound absorption performance depend strongly on the type of fiber, fiber content, matrix material and fabrication method [4–6]. Therefore, proper material selection and composite design are important to meet the performance needs of automotive interior applications. Hybrid composites can improve mechanical, dimensional stability, moisture resistance, durability and thermal stability when optimized fiber types and matrix compatibility are used and this play an important role in specific applications like construction and automobile [24, 25]. Hybrid fiber-reinforced polymer composites have been shown in recent studies to enhance vibration damping and noise reduction while optimizing stiffness, toughness, and thermal stability. These advantages are suitable for automobile interiors parts such as dashboards and door panels [26, 27].

## THERMAL BEHAVIOUR OF NATURAL FIBER AND HYBRID COMPOSITES

Thermal stability is very important for natural fiber composites used in automotive interiors, because these parts are exposed to moderate heat for long periods. Techniques such as thermogravimetric analysis (TGA), derivative thermogravimetric analysis (DTG) and differential scanning calorimetry (DSC) are commonly used to study thermal degradation, glass transition temperature, and char formation in natural fiber composites [14, 18, 28, 29].

Many studies have shown that hybridizing natural fibers is an effective way to improve thermal stability by delaying the start of degradation and increasing char residue. Hybrid composites such as banana/jute, kenaf/PALF, and glass/curaua show better resistance to heat than single-fiber composites. This improvement is mainly due to better fiber–matrix bonding and more uniform degradation. [1, 2, 29, 30].

However, most thermal studies focus only on single-fiber composites or hybrid systems without clearly linking thermal behaviour with functional properties, such as acoustic performance. Thermal stability of sisal and jute fiber composite was improved due to improve in degradation temperature and char residue. Hybrid of sisal and luffa shows delayed degradation while conducting thermal investigation [31]. Thermal behaviour of composites is summarized in Table 1.

Table 1 summarizes key studies on the thermal behaviour of natural fiber and hybrid polymer composites. It illustrates the effects of fiber type, composition, and fabrication technique on thermal resistance and deterioration.

## ACOUSTIC ABSORPTION BEHAVIOUR OF NATURAL FIBER COMPOSITES

Natural fibers are used for sound absorption because they have a porous structure, a rough surface, and high airflow resistance. These features help sound waves enter the material and lose energy inside it. Several studies report that natural fiber materials absorb sound better in the mid-frequency range compared to synthetic fibers. This mid-frequency range is very important for automotive interiors, as it covers most of the noise produced by engines, road contact, and passenger movement. [2, 7, 8, 12].

The sound absorption performance of natural fiber materials depends on factors such as fiber type, porosity, panel thickness, bonding method, and manufacturing process [13–16]. Luffa fibers show very good sound absorption because they have a highly open and interconnected porous structure, which helps reduce sound through friction and energy loss [2]. Similarly, sisal, coir, kenaf, ramie, cotton, and sugarcane fibers also absorb sound well when they are made into bonded panels or composite laminates [8, 13–16].

Many studies have also shown that increasing the thickness of the material improves sound absorption at lower frequencies, which is useful for automotive interiors where low- and mid-frequency noise is more common [7, 15]. Table 2 summarizes earlier studies on the sound absorption performance of natural fiber and hybrid composites. It highlights the effects of fiber structure, material thickness, fabrication method, and testing technique.

## Research Gap

Based on the studies summarized in Tables 1 and 2, earlier research has studied thermal and acoustic properties of natural fiber composites separately. Although some hybrid natural fiber composites show either better thermal stability or improved sound absorption, detailed studies on the combined thermal and acoustic performance of sisal–luffa hybrid epoxy composites are still limited. In particular, the effects of fiber dominance (sisal-rich or luffa-rich hybrids), laminate thickness, and automotive noise-related frequency range (400–2000 Hz) have not been studied in a comprehensive way. Also, comparative studies that identify the best hybrid compositions balancing thermal resistance and sound absorption are very limited. This study bridges this gap by analyzing sisal-luffa hybrid epoxy composites combined thermal and acoustic characteristics, focusing attention in particular to thickness variation and useful automobile interior applications.

**Table 1.** Summary of previous studies on thermal behaviour of natural fiber and hybrid polymer composites.

| **Author (Year)** | **Fiber / Matrix / Fabrication** | **Thermal Analysis** | **Key Parameters Reported** | **Major Thermal Findings** |
|---|---|---|---|---|
| Faruk et al. (2012) [3] | Various natural fibers / Thermoset polymers | Review (TGA, DSC) | Tg trends, degradation pattern | Natural fiber composites show competitive thermal stability for semi-structural uses |
| Pickering et al. (2016) [4] | Natural fiber hybrids / Polymer matrices | Review (TGA-based studies) | Degradation onset, char yield | Hybridization improves thermal resistance by combining complementary fibers |
| Angrizani et al. (2017) [14] | Glass–Curaua hybrid / Polyester / Hand lay-up | DSC, HDT | Tg, HDT | Hybrid system showed higher Tg and improved heat resistance |
| Asim et al. (2018) [15] | Kenaf–PALF hybrid / Phenolic / Hot press moulding | TGA | $T_5$%, Tmax | Hybridization delayed onset degradation and improved residual stability |
| Devireddy & Biswas (2018) [32] | Banana–Jute hybrid / Epoxy / Hand lay-up | TGA | Degradation behaviour | Jute-rich hybrids exhibited superior thermal resistance |
| Moudood et al. (2019) [33] | Flax fiber / Bio-epoxy / Compression moulding | TGA, DSC | Tg after ageing | Environmental exposure reduced Tg and long-term durability |
| Dharmalingam et al. (2021) [34] | Luffa fiber / Epoxy / Hand lay-up | TGA | Onset temperature, char residue | Fiber treatment enhanced interfacial bonding and thermal stability |
| Mokhena et al. (2023) [35] | Bast-fiber based hybrid composites / Polymeric matrices / Various processing | Thermal properties review | Degradation behaviour, thermal stability, melting | Bast fiber hybrids demonstrate enhanced thermal resistance with appropriate processing |
| Ajayi, N. E. (2025) [36] | Natural fiber reinforced polymer composites / Various / Review | TGA, DSC, thermal stability | Tg, $T_5$%, Tmax, char yield trends | Review highlights recent advancements in thermal behavior and influencing factors |
| Kirubakaran et al. (2025) [37] | Coir fiber / PVC / Composite fabrication | TGA | Degradation onset ($T_5$%), Tmax peaks, char residue | Coir reinforcement improves thermal degradation behavior and stability |

**Table 2.** Acoustic absorption performance of natural fiber and hybrid polymer composites.

| Author (Year) | Composite System (Fiber / Matrix) | Thickness (mm) | αmax | Peak Frequency (Hz) | Measurement Method | Main Reported Finding | Application Focus |
|---|---|---|---|---|---|---|---|
| Chen et al. (2010) [38] | Ramie / PLLA | 10 | 0.35–0.45 | ~2000–3000 | Impedance tube | Porosity enhanced damping | General acoustic |
| Fouladi MH et al. (2010) [39] | Coir fiber | 20–45 | ~0.8 | 578–1360 | Impedance tube + analytical models | Thicker samples shifted absorption to lower frequencies | Building acoustics |
| da Silva et al. (2014) [40] | Sisal / PVAc | 40 | 0.9–1.0 | ~1600 | Impedance tube | Fiber tortuosity increased acoustic absorption | General acoustic use |
| Samaei et al. (2016) [41] | Kenaf / PVA | 30 | 0.56–0.63 | ~3000 | Impedance tube | Surface treatment improved absorption | Acoustic panels |
| Küçük & Korkmaz (2017) [42] | Cotton / Polyester | 2.3–8.3 | ~0.20 | ~6300 | Impedance tube | Bonding technique influenced performance | Textile acoustics |
| Buratti & Belloni (2018) [24] | Rice husk / Polyurethane | 35 | ~0.87 | ~3500 | Impedance tube | Bonded panels performed better than loose fibers | Building acoustics |
| Taban et al. (2019) [43] | Coir / PVA | 25–45 | 0.27–0.54 | <1000 | Impedance tube + DB, Miki models | Thickness improved low-frequency absorption | Building acoustics |
| Hariprasad et al. (2020) [44] | Natural fibers / Polypropylene | 10–20 | 0.87–0.96 | ~2000 | Impedance tube | Increasing thickness enhanced absorption | Automotive interior panels |
| Saygili & Genç (2022) [18] | Jute–Luffa / Epoxy | 4 | 0.07–0.10 | ~1000 | Impedance tube | Luffa-dominant configuration showed higher damping | General acoustic panels |
| Rezaieyan et al. (2024) [45] | Cork fiber / PLA (3D-printed MPP) | Various | α measured | - | Impedance tube/ modelling | Thickness & design parameters influenced acoustic absorption | Sustainable acoustic panels |
| Shankar et al. (2025) [46] | Coir & sponge gourd natural fibres | Various | Sound Transmission Loss | - | Impedance tube | Thickness & surface treatment affects sound transmission | Natural fibre insulation |
| This Work | Sisal–Luffa / Epoxy | 25–45 | ~0.38 | ~2000 | Impedance tube (ASTM E1050-19) | Hybridization + thickness improved absorption in automotive frequency range (400–2000 Hz) | Automotive interior NVH |

# MATERIALS AND METHODS

## Materials

### *Fibers*

In this study, luffa and sisal fibers were employed as reinforcing materials. For greater strength, stiffness, and higher lignin content, sisal fibers were chosen to enhance the composites structural performance and thermal stability. The porous structure of luffa fibers, which is advantageous for sound absorption, led to their selection. Both fibers were used for the fabrication of the composite after being cut into small lengths of two to three centimeters.

### *Epoxy Matrix*

Epoxy resin (LY556) was used with HY951 hardener as the matrix material. The resin and hardener were mixed in a 10:1 ratio by weight, as suggested by the manufacturer.

This epoxy was chosen because it bonds well, remains dimensionally stable, and works well with natural fibers. It properly wets sisal and luffa fibers and provides good thermal and mechanical performance for automotive interior use.

## Composite Fabrication

Hybrid sisal–luffa fiber reinforced epoxy composites were made using the hand lay-up method. The fibers were placed in the mould as per the required compositions, and epoxy resin was applied evenly to fully wet the fibers.

During fabrication, care was taken to reduce voids and trapped air by manual rolling and controlled resin application. The laminates were then cured at room temperature to allow proper hardening of the epoxy. All composite compositions were defined using weight percentage (wt.%). The details of the composite compositions are given in Table 3

## Experimental Methods

### *Thermal Analysis*

Thermal testing of the composites was done using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). TGA was carried out according to ASTM E1131 under a nitrogen atmosphere to study how the weight of the sample changes with temperature. Samples weighing about 500 mg to 1 g were heated from 30°C to 700°C at a constant rate of 10°C per minute. This test helped identify degradation stages, starting temperature of degradation, maximum degradation temperature ($T_{max}$), and residual char content. The TGA data was used to create DTG curves in order to better understand the degradation process.

DSC analysis was carried out in accordance with ASTM D3418 to investigate thermal changes, including matrix relaxation behaviour and the glass transition temperature (Tg). The fiber and matrix interactions and the movement of the polymer chains under temperatures relevant to interior automobile use are clarified by the DSC results.

### *Acoustic Absorption Coefficient*

In accordance with ASTM E1050-19, the impedance tube method was used to determine the composites' sound absorption coefficient. The frequency range used for the tests was 400–2000 Hz. The effects of thickness on sound absorption were investigated using circular specimens with a diameter of 100 mm and three distinct thicknesses of 25 mm, 35 mm, and 45 mm.

**Table 3.** Composition of sisal–luffa hybrid epoxy composites.

| Designation | Compositions (wt.%) |
|---|---|
| ES40 | Epoxy 60% + Sisal 40% |
| EL40 | Epoxy 60% + Luffa 40% |
| ES30L10 | Epoxy 60% + Sisal 30% + Luffa 10% |
| ES30L15 | Epoxy 55% + Sisal 30% + Luffa 15% |
| ES30L20 | Epoxy 50% + Sisal 30% + Luffa 20% |
| EL30S10 | Epoxy 60% + Luffa 30% + Sisal 10% |
| EL30S15 | Epoxy 55% + Luffa 30% + Sisal 15% |
| EL30S20 | Epoxy 50% + Luffa 30% + Sisal 20% |

The impedance tube set up measured incident and reflected sound waves under typical incidence settings with a loudspeaker and microphones. The sound absorption coefficient (α) was measured using the transfer function method. This is a reliable and widely used technique for evaluating the acoustic performance of porous and fibrous materials.

## RESULTS AND DISCUSSION

### Thermal Behaviour of Sisal–Luffa Hybrid Epoxy Composites

The thermal behaviour of sisal fiber reinforced epoxy (ES series), luffa fiber reinforced epoxy (EL series), and sisal–luffa hybrid epoxy composites were studied to evaluate their performance under moderate thermal exposure conditions. Thermogravimetric analysis (TGA) and derivative thermogravimetric analysis (DTG) were used to examine thermal degradation and char formation, while differential scanning calorimetry (DSC) was applied to study matrix-related thermal transitions below the main decomposition temperature shown in Figure 1.

### *Thermogravimetric Analysis (TGA)*

The multi-stage heat degradation observed in all tested composites is common of epoxy composites reinforced with natural fibers. Below 120°C, natural fiber composites show a small weight loss due to evaporation of absorbed moisture. This weight loss is greater in luffa-fiber-based composites due to luffa's more porous structure and ability to absorb moisture. Until this point, no structural breakdown occurs in the composite. This stage is important because moisture has significant effects on the overall performance and dimensional stability on composites.

**Stage I.** Moisture Evaporation (≤120°C).

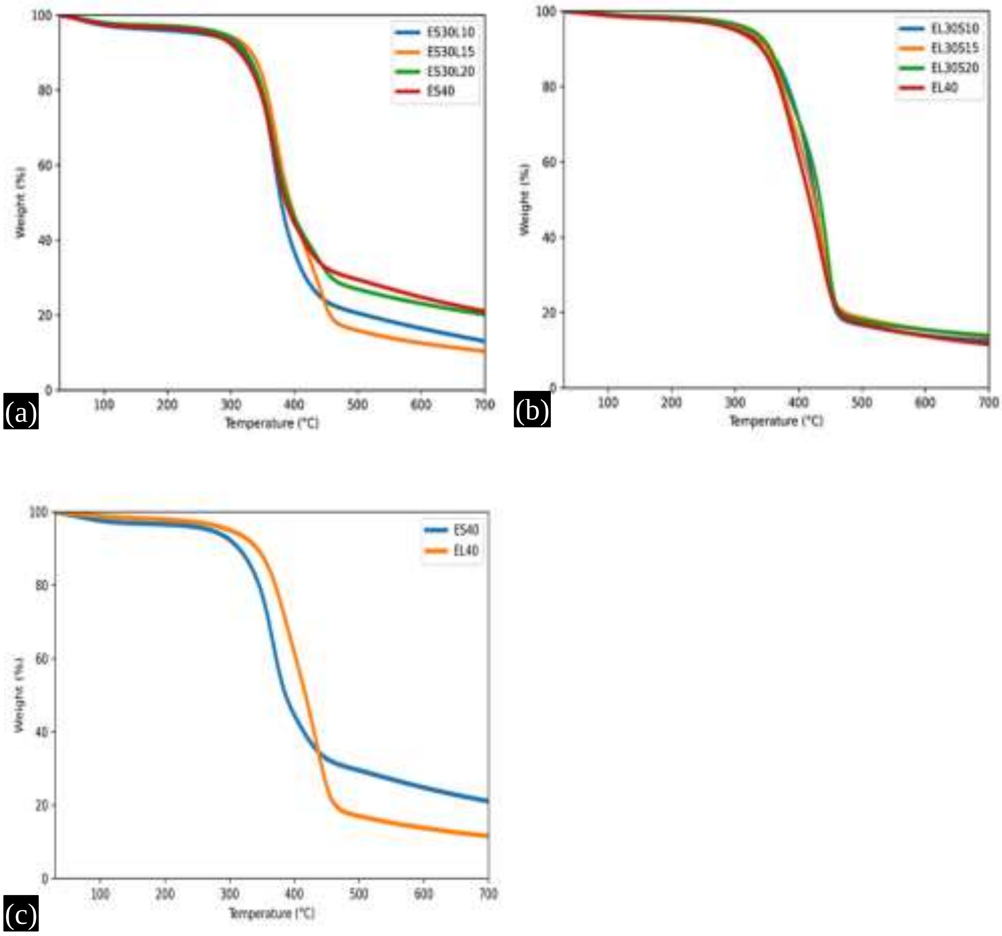

**Figure 1.** Thermogravimetric (TGA) curves of composites under nitrogen atmosphere: (a) ES series, (b) EL series, and (c) ES40 vs EL40.

### Stage II: Major Thermal Degradation (250–400°C)

In this stage the majority of weight loss takes place between $250^0$C and 400°C. Hemicellulose and cellulose in natural fibers begin to degrade in this temperature range, resulting in a gradual loss of mass. Simultaneously, the epoxy matrix starts to slowly degrade.

It found that sisal-based composites are more heat-resistant when compared to luffa -based composite, they lose weight more slowly and begin to deteriorate at higher temperatures. This is mostly due to the fact that sisal fibers are stronger, denser, more lignin and have a well-packed structure. Which helps them endure heat and minimize thermal damage.

In sisal-based composites, ES30L15 shows a greater degradation onset temperature ($T_5$% = 287.96°C) after that ES30L10 (258.44°C). ES30L20 also shows a similar improvement ($T_5$% = 288.56°C), which confirms that proper fiber hybridization improves thermal stability. In the luffa-based hybrid composites, EL30S15 shows a higher $T_5$% value (318.27°C) than EL30S10 (310.06°C). This shows that EL30S15 has an optimum balance between porosity and thermal stability.

### Stage III: High-Temperature Stability (>400°C) and char formation

Above 400°C, the weight loss becomes much slower and a stable residue (char) is left behind because lignin starts to break down and char is formed. compared to luffa-rich composites, sisal-rich and hybrid composites produce more char.

ES40 has the greatest char content (20.66%) of all the samples, followed by ES30L20 (19.78%). Higher char formation increases resistance to high temperatures and limits heat transmission by forming a protective layer. This behaviour is especially important for automotive interior applications, where thermal safety is required.

### *Derivative Thermogravimetric Analysis (Dtg)*

DTG curves give more information about the degradation process by showing the temperature at which the rate of weight loss is highest ($T_{\square ax}$). As shown in Figure 2, luffa-rich composites show higher $T_{\square ax}$ values, with EL30S20 reaching 449.19°C, compared to ES40 (366.21°C).

However, sisal-rich and hybrid composites show broader DTG peaks, which indicate overlapping degradation of the fibers and the epoxy matrix. This broader peak suggests a more gradual and distributed degradation process, often linked to better fiber–matrix interaction in hybrid composites.

Hybrid composites show only small changes in glass transition temperature compared to single-fiber composites. he Tg values are 40.07°C for ES30L15 and 40.00°C for EL30S15, indicating that hybridization does not significantly affect the matrix transition temperature. Table 4 presents the thermogravimetric degradation parameters of sisal–luffa hybrid epoxy composites under nitrogen atmosphere. The optimized hybrid composites have better heat-flow curves illustrate how heat distributes more uniformly throughout the materials. This helps the composite maintain its stability and shape under actual service circumstances by lowering internal stress.

**Table 4.** Thermogravimetric degradation parameters of sisal–luffa hybrid epoxy composites under nitrogen atmosphere.

| **Composite** | **$T_{5\%}$ (°C)** | **$T_{10\%}$ (°C)** | **$T_{max}$ (°C)** | **Residual char (%)** |
|---|---|---|---|---|
| ES30L10 | 258.44 | 320.41 | 375.10 | 12.83 |
| ES30L15 | 287.96 | 332.80 | 371.19 | 10.14 |
| ES30L20 | 288.56 | 324.60 | 369.20 | 19.78 |
| EL30S10 | 310.06 | 351.74 | 433.27 | 12.29 |
| EL30S15 | 318.27 | 350.50 | 443.46 | 13.35 |
| EL30S20 | 325.22 | 355.23 | 449.19 | 13.75 |
| ES40 | 271.49 | 314.41 | 366.21 | 20.66 |
| EL40 | 300.84 | 342.58 | 428.91 | 11.36 |

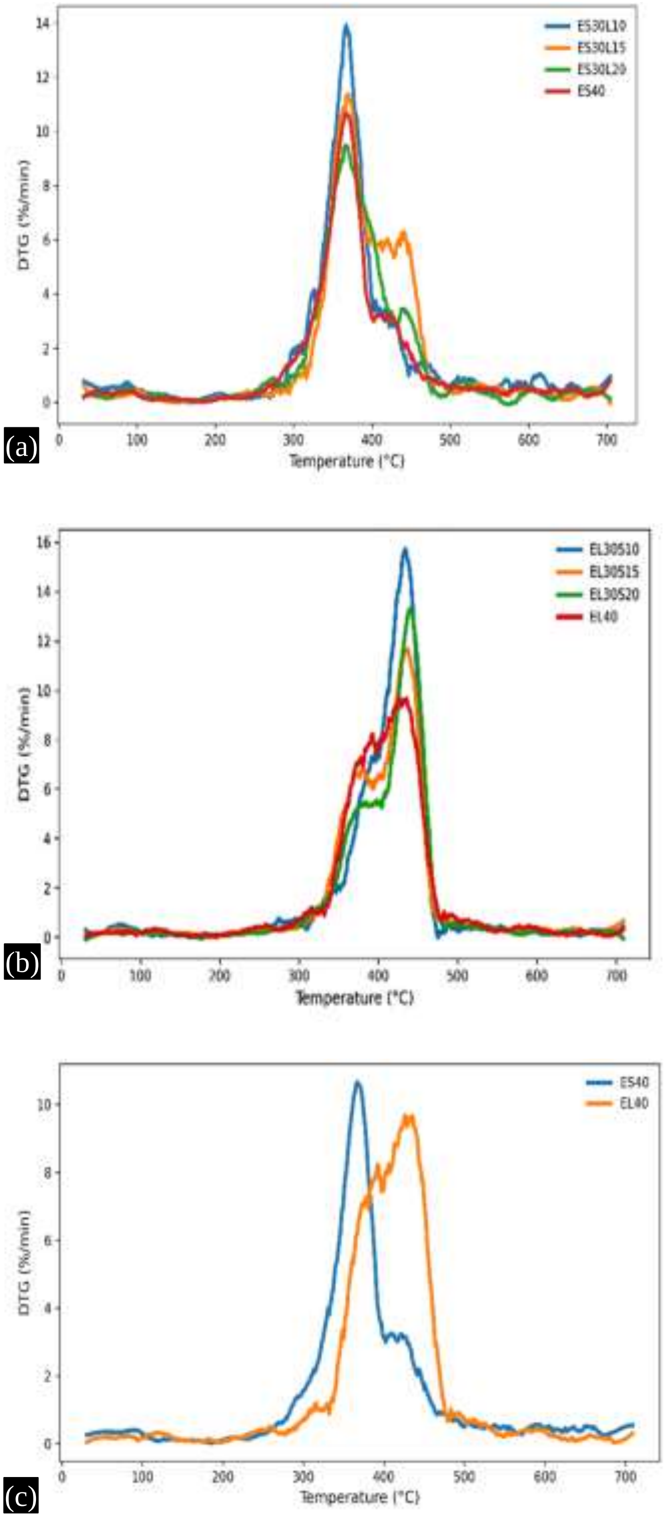

**Figure 2.** Derivative thermogravimetric (DTG) curves of composites under nitrogen atmosphere: (a) ES series, (b) EL series, and (c) ES40 vs EL40

## Acoustic Absorption Behaviour of Sisal–Luffa Hybrid Epoxy Composites

An impedance tube was used to investigate the sisal–luffa hybrid epoxy composites' sound absorption characteristics in the 400–2000 Hz frequency range. In porous and fibrous materials, sound absorption increases with frequency. Due to air flow and friction between the composite's pores, more sound energy is emitted at higher frequencies. Figure 3 show the variation of sound absorption coefficient vs frequency graph for sisal–luffa hybrid epoxy composites at three thickness (25mm, 35mm and 45mm).

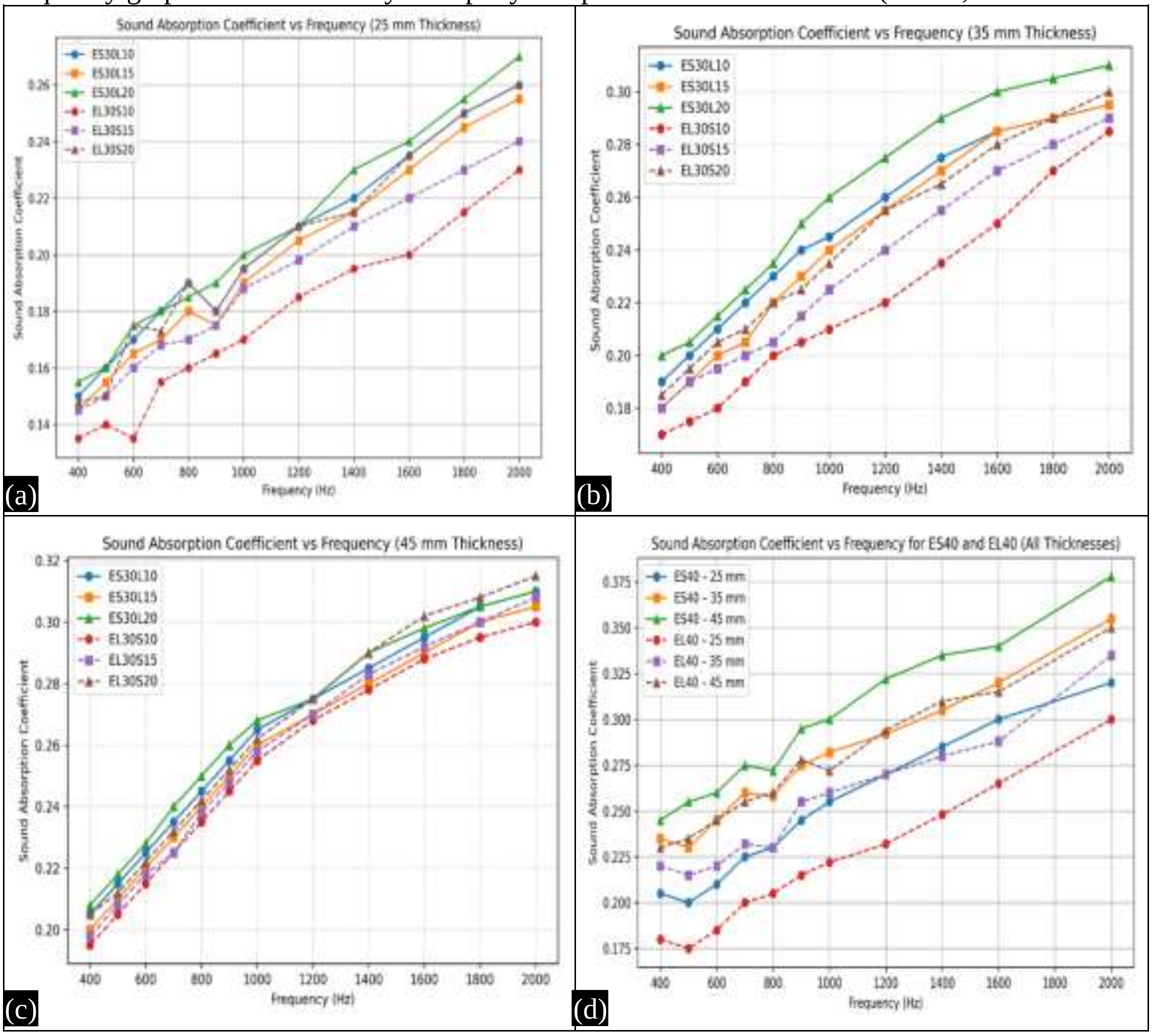

**Figure 3.** Sound absorption coefficient for sisal–luffa hybrid epoxy composites

For 25 mm thickness, the composites show only moderate sound absorption for tested frequency range. ES30L15 gives the best performance with a sound absorption value of 0.260 at 2000 Hz and EL30S15 reaches 0.245 at the same frequency. The lower absorption occurs for this thickness because sound waves cross short distance inside the material, so less energy is lost, particularly for low and medium frequencies.

At 35 mm thickness, composites show better sound absorption. Sound absorption coefficient for ES30L15 is 0.315 and for EL30S15 is 0.302 at 2000 Hz. For 45 mm thickness ES30L15 shows maximum sound absorption 0.378 at 2000 Hz and EL30S15 reaches 0.352 for same frequency. This improvement is due to sound wave travel longer distance inside the material so increase air resistance and friction.

Sound absorption of luffa-based composites are more because it has high porous and interconnected structure. It increases air resistance and improves in absorb sound through friction. Sisal fiber increase stiffness and improve bonding with epoxy resin, that supports the structure and avoids the pores from collapsing. Overall, the findings show that material thickness and fiber combination have a significant impact on sound absorption. ES30L15 at 45 mm thickness demonstrates the most optimal balance between adequate strength and effective noise absorption of all the tested samples. This makes it suitable for interior components such as dashboard insulation, roof liners, and door panels that reduce noise.

## CONCLUSIONS

In this study, it was observed that thermal stability and sound absorption behaviour of hybrid epoxy composites, and understand their suitability for interior applications. The composites were fabricated by fixed one fiber content at 30 wt.% and second fiber contents vary at 10, 15 and 20%. Thermal performance was evaluated using thermogravimetric analysis and differential scanning calorimetry, acoustic performance measured by impedance tube method.

TGA studies confirmed that hybrid composites have a significant effect on thermal behaviour. Compared to luffa-rich composites, sisal-rich and balanced hybrid composites degradation at higher temperatures and produced more residual char, indicating greater temperature resistance. Among all compositions, ES30L15 and ES30L20 demonstrated greater degradation onset temperatures ($T_5\% \geq$ 287.96°C) and enhanced char formation.

Although luffa-dominant composites reached higher maximum degradation temperatures, overall thermal stability based on degradation onset and char yield favoured the optimized hybrid systems.

DSC analysis indicated that all composites had similar glass transition temperatures, close to 40°C, showing that the epoxy matrix mainly controls the thermal transition behaviour. Hybridization did not significantly change Tg; however, smoother heat-flow curves in optimized hybrids suggest better thermal uniformity and reduced internal stress, which supports dimensional stability during service.

Acoustic testing exposed that sound absorption coefficient increased with both frequency and thickness for all composites. Composites having luffa fibers showed increased sound absorption due to their porous and interconnected structure, which increases air resistance and sound energy loss. At 45 mm thickness, ES30L15 attained a maximum sound absorption coefficient 0.378 at 2000 Hz, where EL30S15 achieved 0.352 showing the advantage of fiber hybridization for acoustic performance.

When both thermal and acoustic properties are considered together, ES30L15 and EL30S15 emerge as the most balanced hybrid composites. They combine delayed thermal degradation, stable glass transition behaviour, and high sound absorption efficiency. These results show that careful hybridization of sisal and luffa fibers can produce lightweight, eco-friendly composites with multifunctional performance.

Overall, sisal–luffa hybrid epoxy composites show strong potential as sustainable alternatives to synthetic fiber composites for interior components such as door panels, roof liners, dashboards, and noise insulation parts. This study offers the basis for future research on natural fiber hybrid composites with an objective of improving noise reduction, thermal stability and sustainability in automobile interiors.

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