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Development of Hemp/PLA based sustainable headliner for automotive interiors

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This study developed a sustainable automotive headliner using a hemp/PLA composite as the headliner board and an r-PET (recycled polyester) fibrous nonwoven mat as a foam replacement. The layers were joined with specialized headliner adhesives and evaluated for thermal and sound insulation properties. Hemp fibers were cut to 50 mm lengths to form a fiber mat. The composite was fabricated by stacking PLA films and hemp fiber web, then consolidating to 4 mm thickness via compression molding at elevated temperature. Composites with hemp fiber weight fractions of 40%, 50%, and 60% were prepared and tested for mechanical properties. Thermal bonded r-PET/low-melt polyester nonwoven fabrics with three areal densities were produced from blended webs. The complete headliner, assembled by laminating the hemp/PLA composite, nonwoven fabric, and knitted inner layer using adhesives, exhibited promising thermal and sound insulation. It offers potential as a foam-free alternative for automotive headliners.

Keywords: Hemp/PLA composites, r-PET nonwovens, Sustainable headliners, Thermal and sound insulation

1. Introduction

The headliner in automotive vehicles serves as a ceiling material, providing insulation against heat and noise whilst concealing electrical components. Key requirements include stiffness, strength, lightweight design, aesthetic appeal, energy absorption, heat resistance, and thermal stability. Conventional headliners consist of a fibreglass roof adhered to polyurethane foam for thermal and sound insulation[1]. Efforts have focused on recyclable headliners using sustainable materials. Various natural fibres have been explored to develop composite boards as alternatives to traditional glass fibre roofs. Chen *et al.*[2] investigated kenaf/ramie nonwoven composites for automotive headliners, bonded with PVA or acrylic copolymer binders, and evaluated their mechanical and thermal properties. Padding time significantly enhanced the tensile properties of acrylic copolymer-bonded composites. PVA-bonded composites showed higher tensile modulus and strength, whereas acrylic copolymer-bonded ones exhibited superior bending rigidity. Thermal conductivity was similar for both binders, increasing with nonwoven fabric density. Like kenaf,a biodegradable natural fibre from renewable sources is hemp which poses low health risks during composite manufacturing due to minimal toxic fume emissions under heat or incineration life[3]. Hemp fibres offer high tensile strength, excellent heat and abrasion resistance, durability, antimicrobial properties, and UV stability, making them suitable for headliner applications[4]. Limited research exists on hemp-based composites for such uses[5].

Yamamoto *et al.*[6] fabricated kenaf-hemp nonwoven composites impregnated with an acrylic matrix and analyzed their mechanical properties. With a 50:50 (wt%) kenaf:hemp ratio produced via compression molding, tensile strengths reached 28–75 MPa at molding pressures of 1.5–6 MPa, with elongation at fracture of 0.8–1.4%. Fractographic studies confirmed strong fibre-matrix adhesion. To develop biodegradable composites, poly(lactic acid) (PLA) which provides good mechanical strength and biodegradability was selected as an ideal alternative to petroleum-based polymers. Oksman *et al.*[7] studied flax fibre-reinforced PLA composites for industrial applications, using triacetin as a plasticizer. During the extrusion and compression moulding, there was no processing difficulty observed. The developed PLA/flax composites matched the tensile strength of PP/flax composites, achieved stiffness of 3.4–8.4 GPa with 30 wt% flax fibres, and showed improved thermal properties. Christian and Billington[8] found that hemp fibre-reinforced poly(hydroxybutyrate) (PHB) composites exhibited flexural strength and modulus of 65 MPa and 6500 MPa, respectively, with densities of kg/m^3 comparable to plywood.

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Hu and Lim[9] prepared biodegradable PLA composites reinforced with alkali-treated hemp fibres, which removed 26% of non-cellulosic components and enhanced fibre-matrix bonding. The composites had densities of 1.19–1.25 g/cm^3. At 40 vol% treated fibres, the composite showed tensile strength of 54.6 MPa, flexural strength of 112.7 MPa, and tensile modulus of 8.5 GPa compared to neat PLA having 3.5 GPa. Masirek *et al.*[10] investigated PLA/hemp composites, using 10 wt% polyethylene glycol (PEG) as a plasticizer. The modulus of elasticity of the composite was decided by hemp content and it reached 5.2 GPa for crystallized PLA with 20 wt% hemp. For automotive applications, polyester and polyamide dominate due to low cost, high temperature resistance (210–240°C short-term), tensile strength, chemical/abrasion resistance, electrical insulation, and low moisture absorption[11]. Recycled polyester (r-PET) nonwovens have gained traction for thermal/acoustic applications due to environmental and recyclability concerns[12]. Thirumurugan and Rameshkumar[13] found that 50% jute/25% flax/25% r-PET nonwovens exhibited superior sound absorption coefficients compared to other blends. Muthukumar *et al.*[14] reported higher thermal insulation in alkali treated r-PET nonwovens than untreated ones, though addition of comber noil reduced the insulation values. Sadeghi *et al.*[15] reviewed r-PET fibre production methods and applications in detail.

Headliner design requires attention to key parameters, including thickness, modulus of facing layer, core layer stiffness, thermal properties, and insulation against airborne and structure-borne noise. Polyurethane foam in conventional headliners can be replaced by nonwoven fibre mats that maintain porous structures for sound absorption and vibration damping. Headliners typically comprise two main layers: (i) a substrate providing structural integrity and impact protection, and (ii) a fabric-foam layer ensuring interior fit and aesthetics. These layers vary in thickness and composition across manufacturers. Savic and Hector[16] examined the mechanical behavior of three headliner materials at two thicknesses under out-of-plane compression. The material with higher density and low thickness exhibited greater stresses at equivalent deformation levels than lower density, higher thickness ones. Headliners need aesthetic appeal, sound absorption, thermal insulation, light weight, and cushioning [17]. The application of PET foam sheets and fibre-reinforced porous polymer sheets enhance sound absorption and heat insulation[18]. Basically, headliners attached to the car's roof interior, typically has a 2-mm-thick non-woven fabric or knitted backing. The knitted fabrics from polyester, nylon, or similar synthetic fibres are generally used in modern vehicles for their durability, flexibility, and ease of maintenance. Conventional headliners, made from polyurethane and glass fibres, can be replaced by composites reinforced with hemp fibres. This study uses biodegradable PLA film as the matrix to develop a sustainable, biodegradable hemp/PLA headliner composite. The special surface texturing has been introduced in the headliner panel for improving the thermal and sound insulation. The addition of polylactic acid (PLA) in the headliner assembly contributes to the reduction of greenhouse gas emissions due to its biodegradable and bio-based nature[19], while simultaneously functioning as the matrix material for the hemp/PLA composite. Hemp fibres, being renewable and biodegradable, provide effective reinforcement, ensuring structural integrity and dimensional stability of the composite[20-21]. The recycled PET (r-PET) nonwoven fabric added in the headliner assembly enhances the tensile strength[22], abrasion resistance[23], and fatigue resistance. The developed headliner was evaluated for thickness, air permeability, thermal resistance, sound insulation, and mechanical properties.

2. Materials and Methods

2.1 Materials Used

In this study, hemp fibre and polylactic acid (PLA) used as reinforcement and matrix, respectively, to develop the composite headliner board. The hemp fibre sourced from Go Green Products, Chennai, was chopped to 50 mm lengths to form a nonwoven web. Moldable-grade PLA film (density: 1.24 g/cm^3; thickness: 50 μm) was obtained from Arth Bioplast Products Private Limited, Gujarat. The PLA film exhibited a tensile strength of 36 MPa, elongation of 6%, melt flow index of 4.6 g/10 min (at 190°C), and notched Izod impact strength of 1.1 J. Recycled PET (r-PET) fibres (51 mm length), extracted from PET bottles, were sourced to produce nonwoven fabric. The low-melt polyester fibres (64 mm length) were obtained from Apex Polytex Pvt Ltd, Delhi. Table 1 lists the properties of the sourced hemp, r-PET, and low-melt polyester fibres.

2.2 Preparation of Fibre Web

The hemp fibre was given surface treatment to improve its adhesion properties. The chopped hemp fibres were treated with NaOH solution having 4%, 8% and 12% concentration at 80°C for 30 min. Then the treated fibres were neutralized with acetic acid to get the pH level of 7. Due to alkaline treatment, the lignin and other impurities present in the fibre were removed and weight reduction of treated fibre was calculated using the following expression.

Weight reduction $R = \frac{(w_1 - w_2)}{w_2} \times 100\%$

Where w_1 is the weight of untreated fibre, w_2 is the weight of treated fibre. The observed weight reduction of 24.3% aligns closely with the non-cellulosic content of hemp fibre reported by Hu and Lim[9]. Treated fibres were then carded using a miniature carding machine to produce fibre webs of varying thicknesses

2.3 Preparation of Composite Board

Hemp fibre composites were fabricated using hemp fibre as reinforcement and polylactic acid (PLA) as matrix via compression moulding. The hemp fibre webs were layered with PLA sheets in the following sequence: a single layer of hemp fibre web was sandwiched between PLA sheets placed at the top and bottom. Two such layered assemblies were stacked together and subjected to compression moulding at 170 °C for 30 min. Using this method, three composite panels were fabricated with fibre weight fractions of 30%, 40%, and 50%. These panels provide structural support and stiffness for automotive headliners. Serrations were incorporated during manufacturing to enhance sound and thermal insulation. Fig. 1 illustrates the process for developing the composite specimens. Table 2 details the composition of the developed hemp fibre composites.

The hemp fibre webs were layered with PLA sheets in the following sequence: a single layer of hemp fibre web was sandwiched between PLA sheets placed at the top and bottom. Two such layered assemblies were stacked together and subjected to compression moulding at 170 °C for 30 min. Using this method, three composite panels were fabricated with fibre weight fractions of 30%, 40%, and 50%.

Table 1 — Properties of sourced hemp, r-PET and low melt polyester fibres

Properties	Hemp	r-PET	Low melt PET
Fibre length (mm)	50	51	51
Fibre fineness (Denier)	360 (sourced)	1.4	4
Moisture content (%)	8	0.4	0.4
Melting Point (°C)	-	240	110
Fibre Density (measured) g/cm^3	1.2	1.22	1.2
Fibre Strength (cN/tex) and Elongation (%)	56, 1.6	4.8, 42	2, 55

2.4 Preparation of Thermal Bonded Non-woven Fabric

Thermal-bonded nonwoven fabric was developed to replace the foam backing of conventional headliners.

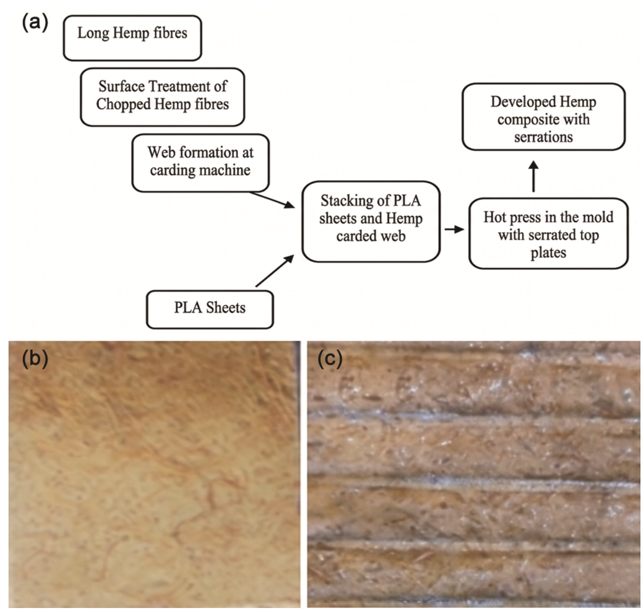

Fig. 1 — Diagrams of (a) methodology followed, (b) developed hemp/PLA composites (c) composite with corrugated surface

Table 2 — Composition of developed hemp fibre composites

Sample	Fibre Weight Fraction (serrations/2cm)	Thickness (mm)	Areal Density /(g/sq.m)	Density (g/cc)
CS1	50% (1/2cm)	4.25±3.7%	2725	0.660
CS2	50% (2/2cm)	4.12±2.0%	2561	0.603
CS3	50% (3/2cm)	4.11±1.4%	2495	0.612
CS4	40% (1/2cm)	4.25±1.7%	2450	0.560
CS5	40% (2/2cm)	4.37±2.71%	2480	0.583
CS6	40% (3/2cm)	4.18±1.9%	2368	0.596
CS7	30% (1/2 cm)	4.01±3.7%	2236	0.575
CS8	30% (2/2 cm)	3.89±1.3%	2143	0.563
CS9	30% (3/2 cm)	3.95±2.7%	2236	0.580

Table 3 — Sample description of nonwoven fabric

Code	Areal density (g/m^2)	Fibre Weight Fractions (Recycled PET: Low-melt polyester)	Thickness (mm)	Density (g/cc)	Air Permeability ($ft^3/ft^2/min$)	Porosity%
NS1	300	70:30	2.8±10.4%	0.1086	291±2.7%	92.04
NS2	400	70:30	3.3±8.2%	0.1148	208±4.5%	91.69
NS3	500	70:30	2.8±8.2%	0.1639	142±5.5%	82.27

Nonwoven fabric was produced by blending recycled PET (r-PET) with low-melt polyester (LmPET) fibres in a miniature carding machine operated at a feed rate of 0.20 m/min, licker-in speed of 70 rpm, cylinder speed of 120 rpm, doffer speed of 1.5 rpm, and delivery rate of 0.95 m/min. Carding was performed twice to promote random fibre distribution. A 70:30 (r-PET:LmPET) blend ratio was used, followed by thermal bonding at 120°C. Nonwoven samples with areal densities of 300, 400, and 500 g/m² were produced. This fabric enhances headliner strength, stability, and sound insulation by absorbing and damping noise. Table 3 lists the properties of the thermal-bonded nonwoven fabric.

2.5 Aesthetic Layer

Single jersey polyester knitted fabric sourced from Bhawana International, Uttar Pradesh, used as the headliner facing fabric (FF) with a tightness factor of 1.46. Fabric thickness was measured per ASTM D5736. The plain knit fabric was made from 34^s Ne yarn with a loop length of 2.5 mm, providing an areal density of 150 g/m² and stitch density of 1850 stitches/inch².

2.6 Designing of Sustainable Headliner

A new headliner design was developed in this study. Initially, a fibre composite panel with corrugations was fabricated and used as the base layer adjacent to the metal roof of the automotive vehicle. An SR97 headliner-grade adhesive was employed to bond the developed r-PET nonwoven fabric to the headliner board. Subsequently, the headliner facing fabric (FF) was bonded onto the surface of the nonwoven fabric. The schematic representation of the proposed headliner design is shown in Fig. 2.

The experimental plan for developing the various composite specimens and nonwoven fabrics is shown in Table 4.

For the headliner assembly, composites with a 50% fibre weight fraction (CS1, CS2, and CS3) were selected because they provide greater mechanical strength and stability than other weight fractions. The NS1 nonwoven was chosen due to its lower thermal conductivity, higher air permeability, lower weight, and greater porosity compared with NS2 and NS3. A facing fabric (FF) was bonded to the headliner assembly using headliner adhesive. Three headliner assemblies (HL1, HL2, and HL3) were produced, each incorporating different serration patterns on the hemp composite board.

Table 4 — Experimental design for developing headliner board and insulating nonwoven fabrics

Sample code	Fibre Weight Fraction (FWF) %	Serrations / 2cm	Thickness (mm)
CN	50	-	4
CS1	50	1	4
CS2	50	2	4
CS3	50	3	4
CS4	40	1	4
CS5	40	2	4
CS6	40	3	4
CS7	30	1	4
CS8	30	2	4
CS9	30	3	4
NS1	70	-	3
NS2	70	-	3
NS3	70	-	3
HL1 (CS1-NS1-FF)	-	1	4+3+2
HL2 (CS2-NS1-FF)	-	2	4+3+2
HL3 (CS3-NS1-FF)	-	3	4+3+2

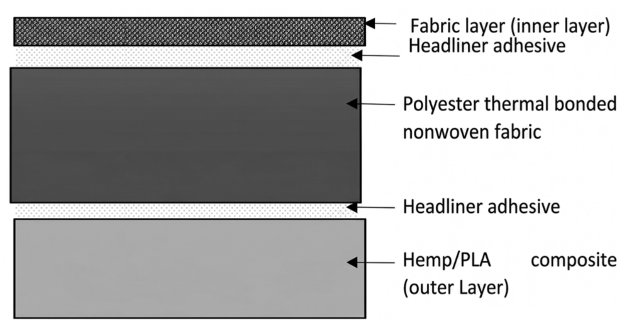

Fig. 2 — Schematic representation of the developed headliner assembly

2.7 Characterization of developed headliner materials

2.7.1 Fourier Transform Infrared Spectroscopy analysis of hemp fibres

The FTIR spectra of the hemp fibres were recorded using a Fourier Transform Infrared (FTIR) spectrometer

(Shimadzu, Japan). The samples were analysed in transmission mode by recording 45 scans in %T mode over the spectral range of 4000–500 cm^{-1}.

2.7.2 Thermal analysis of recycled polyester fibres

The thermal behaviour of the recycled polyester fibre was analysed using a DSC 300 Caliris instrument. The melting temperature and glass transition temperature of the samples were determined.

2.7.3 Air permeability of fabrics

The air permeability of the developed thermally bonded nonwoven fabrics and the headliner knitted fabric was measured using a Shirley Air Permeability Tester in accordance with ASTM D737. The test specimens had an area of 38 cm^2, and the testing pressure was maintained at 125 Pa. Variations in air permeability influence the thermal resistance and acoustic performance of the nonwoven fabrics.

2.7.4 Tensile and flexural strength testing

The tensile strength of the hemp fibre–reinforced composites and thermally bonded nonwoven fabrics was determined in accordance with ASTM D3039 using a Zwick/Roell Universal Testing Machine (Z100). The gauge length of 150 mm and a crosshead speed of 2 mm/min were used. The three-point flexural strength of the developed composite specimens was evaluated according to ASTM D790 using the same testing machine. The specimen dimensions were 125 × 12.7 × 3.2 mm, and the crosshead speed was maintained at 2 mm/min.

2.7.5 Impact strength of fabric composite

The Izod impact strength of the developed composite was determined using a pendulum impact testing machine supplied by Ratnakar Enterprises, Ichalkaranji, in accordance with ISO 1598:1960. The specimen dimensions were 75 × 10 × 10 mm. A V-notch with an angle of 45° was introduced at the top of each specimen prior to testing.

2.7.6 Thermal conductivity of developed headliner materials

The thermal conductivity of the developed headliner boards, nonwoven fabrics, and headliner assemblies was determined using Lee's disc apparatus in accordance with ASTM D7340–07. The test specimens had a diameter of 50 mm. Thermal conductivity (K) was calculated in W/(m·K) using the following equation.

$$K = \frac{M \times S \times R \times d \times (2h + r)}{A \times (T_1 - T_2) \times (2h + 2r)} [w/(mk)]$$

Where, K- Thermal conductivity of sample (w/(mk)); M-Mass of lower disk (800g); S-Specific heat of the material of disc (370 J/Kg/s); R-Rate of fall of temperature (Kelvin/s); h-Thickness of the lower disc (m); r- radius of the lower disc (m); d-thickness of the sample (m); A- area of cross section of the sample (m^2)

2.7.8 Characterization of Sound Absorption of developed samples

The developed headliner materials were evaluated for sound absorption using the impedance tube method in accordance with ASTM E1050 / ISO 10534-2. The specimen was placed at one end of a cylindrical impedance tube, while a loudspeaker generated sound waves at the opposite end. The sound waves reflected from the specimen were measured inside the tube using microphones. The ratio of absorbed sound energy to incident sound energy was used to determine the sound absorption coefficient. The noise reduction coefficient (NRC) was calculated as the average sound absorption coefficient of the material at four specified frequencies (Hz), as expressed in the following equation.

$$\text{NRC} = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4}$$

Where, α_{250}, α_{500}, α_{1000} and α_{2000} denote the sound absorption coefficient at incident sound frequencies of 250 Hz, 500 Hz, 1000 Hz and 2000 Hz respectively.

3. Results and Discussion

3.1 Fibre Characterization using Fourier Transform Infrared Spectroscopy Analysis

Fig. 3 shows the FTIR spectra of untreated and alkali-treated hemp fibres in the wavenumber range of 500–4000 cm^{-1}. The peak observed around 1700 cm^{-1} corresponds to the C=O stretching vibration associated with hemicellulose and lignin components[24,25]. The

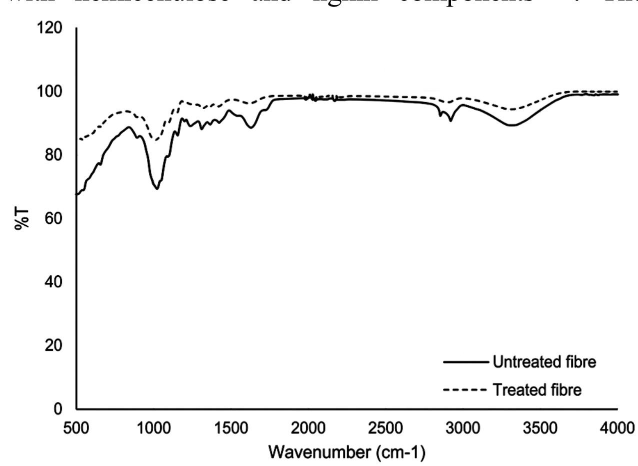

Fig. 3 — FTIR spectra of untreated and treated fabric samples

peaks at 1637 cm^{-1} and 1223 cm^{-1} in the untreated fibres decrease in intensity and, in some cases, disappear (notably at 1223 cm^{-1}) after alkali treatment. The reduction in peak intensity at these wavenumbers indicates the removal of hemicellulose and lignin components[26,27]. The peak at 1026 cm^{-1} is attributed to xylan and glycosidic linkages of hemicellulose in the fibres[28]. After alkali treatment, this peak shifts to 1024 cm^{-1} and 1063 cm^{-1}, which may be associated with structural modifications resulting from the removal of hemicellulose.

Similarly, the characteristic peak at 1026 cm^{-1} is attributed to aromatic C–H in-plane deformation and C–O stretching of lignin. Following alkali treatment, this peak shifts by approximately 4–6 cm^{-1} with a reduction in intensity. The peak at 1710 cm^{-1} corresponds to conjugated carbonyl stretching associated with lignin[29]. This peak is absent in the alkali-treated fibres, indicating the removal of lignin components. The spectral analysis confirms that alkali-treated fibres exhibit a higher degree of reactivity due to the elimination of hemicellulose and lignin constituents.

3.2 Thermal Analysis of Fibres Using Differential Scanning Calorimetry

The thermal behaviour of recycled polyester (r-PET) and low-melt polyester fibres was analysed using Differential Scanning Calorimetry (DSC). The DSC results indicated that the glass transition temperature (T_g), melting temperature (T_m), and degradation temperature (T_d) of r-PET were in the ranges of 110–120 °C, 250–255 °C, and 370–455 °C, respectively. Similarly, the T_g, T_m, and T_d of the low-melt PET fibre were observed at 40–45 °C, 110–120 °C, and 365–465 °C, respectively. The lower melting temperature of the low-melt fibre confirms its suitability as a binding matrix for the production of thermally bonded nonwoven fabrics intended for headliner applications.

3.3 Air Permeability of Thermal Bonded Nonwoven Fabrics

The air permeability of r-PET nonwoven fabrics at three different areal densities was measured using an air permeability tester in accordance with ASTM D737, at a pressure of 125 Pa and a test area of 38 cm². The air permeability values of the developed samples are presented in Fig. 4. As shown in Fig. 4, the 500 GSM sample exhibited lower air permeability (142 ft³/ft²/min), which may be attributed to the reduced number of voids or pores between the fibres. In contrast, the 300 GSM sample showed higher air permeability due to its relatively lower fibre packing density, resulting in a greater number of interconnected pores that facilitate airflow. The results indicate that air permeability decreases with increasing areal density of the polyester fibres. Air permeability is a critical parameter influencing the thermal conductivity and acoustic performance of the developed samples

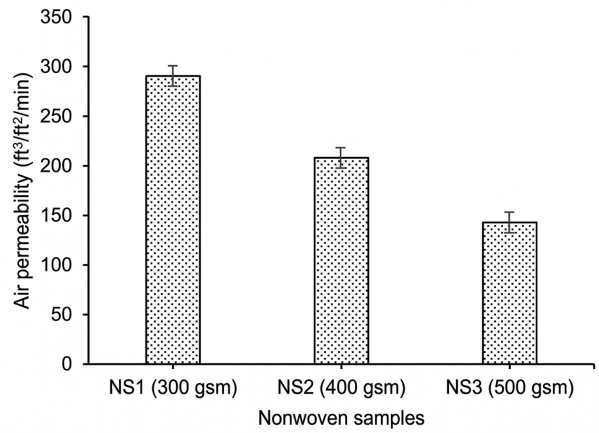

Fig. 4 — Air permeability of r-PET thermal bonded nonwoven fabric

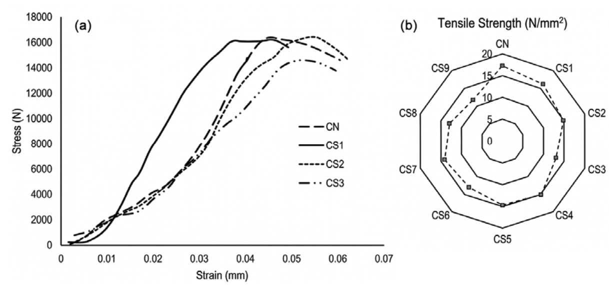

Fig. 5 — Tensile strength of developed headliner board (a) Composites with 50% FWF (b) Composites with 50%, 40% and 30% FWF

3.4 Tensile Testing of Headliner Boards

Tensile strength is a critical parameter governing the mechanical performance of composite materials. The tensile behaviour of the developed headliner composite boards was evaluated using a Zwick/Roell Universal Testing Machine in accordance with ASTM D3039. The tensile properties of the developed composites are presented in Fig. 5. As shown in Fig. 5a, composite CS4 exhibited lower tensile strength compared to the other composites with 50% fibre weight fraction (FWF). This reduction may be attributed to the presence of a higher number of surface serrations (3 serrations per 2 cm), which act as stress concentration sites. In comparison with the

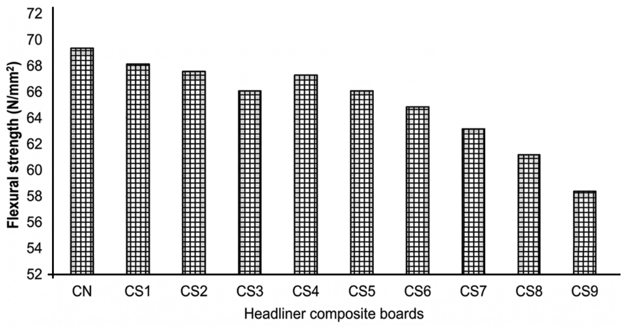

Fig. 6 — Flexural rigidity of developed composite samples

neat composite (CN), the introduction of serrations resulted in a decrease in tensile strength due to localized stress concentration effects. However, the tensile strength of the serrated composites remained above 10 N/mm², which satisfies the minimum strength requirement reported for commercial automobile headliner boards manufactured using 10% glass fibre mat reinforced polyurethane (4.51 Mpa) systems[30]. Furthermore, as illustrated in Fig. 5b, an increase in fibre weight fraction led to an improvement in tensile strength, rising from 11.56 to 17.32 N/mm². Therefore, the composite composition can be selected based on the specified mechanical performance requirements.

3.5 Flexural Rigidity and Impact Strength

The three-point flexural test of the samples was conducted using a flexural testing machine in accordance with ASTM D790. The flexural properties of the developed composite boards are presented in Fig. 6. As shown in Fig. 6, the CS4 sample exhibited lower flexural strength due to the higher number of serrations per unit length. In contrast, the CS2 sample, containing 50% fibre weight fraction and one serration per 2 cm, demonstrated higher flexural strength. An increase in the number of serrations resulted in a reduction in flexural strength, as the serrations act as stress concentration points. Furthermore, an increase in fibre weight fraction enhanced the flexural strength of the composites. Among the serrated composites, CS1 exhibited the highest flexural strength of 68.12 N/mm². This improvement is attributed to the higher fibre content in CS1, which enhances the load-bearing capacity and overall structural stability. These results indicate that increasing the fibre content improves the flexural performance of the composite.

The impact strength of the developed composite boards was also evaluated. Table 5 presents the Izod impact strength results of the headliner boards. The CS1 composite exhibited higher impact strength compared to the other serrated composites, owing to its higher fibre weight fraction and fewer serrations, which contribute to improved structural integrity. In contrast, when the fibre weight fraction was reduced to 30%, the impact strength decreased to 1.1 J. This reduction is attributed to the lower fibre content and the presence of more serrations on the composite surface (e.g., CS9). The overall trend indicates that impact strength decreases with decreasing fibre content in the composite boards.

Table 5 — Impact strength of the composite samples

Sample	Impact strength (J)
CN	4.8
CS1	4.4
CS2	3.8
CS3	3.1
CS4	3.6
CS5	2.9
CS6	2.1
CS7	2.6
CS8	1.8
CS9	1.1

3.6 Thermal Conductivity of Headliner Assembly

The thermal conductivity of the developed headliner boards, r-PET nonwoven fabrics, and headliner assemblies was determined using Lee's disc apparatus in accordance with ASTM D7340–07. The results are presented in Fig. 7. As shown in Fig. 7a, the CS3 composite exhibited lower thermal conductivity compared to the composites containing 50% fibre weight fraction (FWF). This reduction is attributed to the higher fibre content and increased number of surface serrations. Since hemp fibre possesses lower thermal conductivity and the serrated surface generates more air pockets, heat transfer between the fibre and matrix is reduced, thereby decreasing the overall thermal conductivity of the composite. In contrast, at lower fibre weight fractions, r-PET contributes more significantly to heat transfer, resulting in comparatively higher thermal conductivity, particularly in samples with fewer serrations.

For the thermally bonded nonwoven fabrics, the lowest thermal conductivity (0.0245 W/(m·K)) was observed for the NS1 sample (300 g/m²). This may be attributed to its lower fibre packing density and higher proportion of voids and entrapped air, which restrict heat transfer. Conversely, the NS3 sample (500 g/m²)

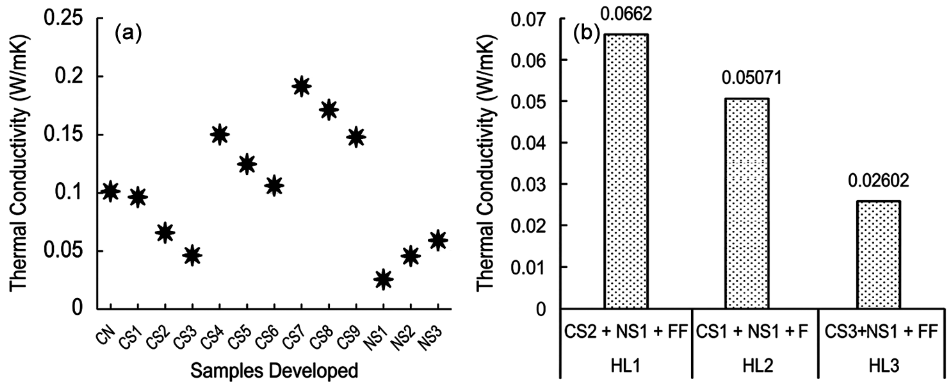

Fig. 7 — Thermal conductivity of (a) composite panel and nonwoven fabrics (b) Headliner assembly

exhibited higher thermal conductivity (0.0595 W/(m·K)) due to increased fibre content, reduced porosity, and fewer air gaps. These results indicate that thermal conductivity increases with increasing areal density of the nonwoven fabric. The headliner assembly was fabricated by combining the composite board, r-PET nonwoven fabric, and knitted facing fabric. The thermal conductivity of the assemblies is shown in Fig. 7b. For headliner applications, the assembly must provide adequate mechanical strength along with effective thermal insulation. Based on these requirements, the CS1 composite was selected as the outer rigid board, and the r-PET nonwoven fabric (NS1) was used as a substitute for conventional foam. The layers were bonded using adhesive and finished with a knitted facing fabric to obtain the final headliner structure. As observed in Fig. 7b, the HL1 assembly exhibited lower thermal conductivity due to the higher number of voids and air gaps created by the serrated composite surface, which enhances heat trapping and reduces heat transfer. In contrast, the HL2 assembly showed higher thermal conductivity owing to reduced air cavities and fewer serrations, resulting in diminished heat retention within the structure. Therefore, the headliner design can be optimized based on the required balance between mechanical performance and thermal insulation.

3.7 Sound Absorption Behaviour

The sound absorption coefficients (SAC) of the headliner assemblies were evaluated using the impedance tube method. As described in the previous section, three different headliner assemblies were tested, and the results are presented in Table 6. From Table 6, it is observed that sound absorption is higher at high frequencies compared to low frequencies. Among the samples, the HL3 headliner assembly exhibited the highest SAC value of 0.8 at 2000 Hz. This improvement may be attributed to increased dissipation of sound energy at the composite–nonwoven interface, facilitated by a greater number of serrations that enhance internal friction and energy loss.

Table 6 — Sound absorption behaviour developed headliner assembly

Frequency (Hz)	Sound Absorption coefficients		
	HL1	HL2	HL3
250	0.04	0.04	0.06
500	0.08	0.08	0.09
1000	0.3	0.23	0.4
2000	0.4	0.7	0.8
4000	0.46	0.48	0.55
6300	0.65	0.68	0.75

Based on the SAC values, the noise reduction coefficient (NRC) was calculated for all three assemblies. The NRC values of HL1, HL2, and HL3 were 0.21, 0.26, and 0.34, respectively. The highest NRC value (0.34) was recorded for the HL3 assembly, which is comparable to that of conventional acoustic foam and carpet materials (0.30-0.45)[31]

4. Conclusion

A sustainable headliner was developed by incorporating recycled polyester and hemp fibre–reinforced composites. To enhance the thermal and acoustic insulation performance of the headliner, serrations were introduced on the composite boards during fabrication. Composites with fewer serrations exhibited superior mechanical properties, including tensile, flexural, and impact strength, compared to highly serrated composites. In contrast, composites with increased serrations demonstrated lower thermal conductivity due to enhanced air entrapment within the serrated structure. Accordingly, composites with three levels of serration were selected for final headliner development. Among the nonwoven samples, NS1 exhibited higher air permeability owing to its lower areal density. It also showed lower thermal conductivity as a result of its higher porosity and greater air content. The increased porosity further contributed to improved sound absorption performance. Therefore, NS1 was selected for incorporation into the headliner assembly. Among the three headliner variants, HL3, comprising the CS3 composite board, NS1 nonwoven fabric, and knitted facing fabric, demonstrated superior thermal insulation and sound absorption properties. With respect to mechanical performance, the thickness of the headliner board and its fibre weight fraction can be tailored to meet specific vehicle requirements. The developed headliner thus presents a sustainable and effective alternative for automotive applications.

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References

1 Hong Y H, *J Korea Academia-Indust Coop Soc,* 14 (2013), 3089.
2 Chen Y, Sun L, Chiparus O, Negulescu I, Yachmenev V & Warnock M, *J Polym Environ*, 13 (2005) 2.
3 Shahzad A, *J Compos Mater*, 46 (2012) 8.
4 Manaia J P, Manaia A T & Rodriges L, *Fibers*, 7 (2019) 12.
5 Liao J, Zhang S & Tang X, *J Nat Fibers*, 19 (2022).
6 Yamamoto T, Medina L & Schledjewski R, *Adv Compos Lett*, 14 (2005) 1.
7 Oksman K, Skrifvars M & Selin J F, *Compos Sci Technol*, 63 (2003) 9.
8 Christian S J & Billington S L, *Compos Part B Eng*, 42 (2011) 7.
9 Hu R & Lim J K, *J Compos Mater*, 41 (2007) 13.
10 Masirek R, Kulinski Z, Chionna D, Piorkowska E & Pracella M, *J Appl Polym Sci*, 105 (2007) 1.
11 Saricam C & Okur N, *In Polyester—Production, Characterization and Innovative Applications*, edited by N O Camlibel, InTechOpen, Zagreb/Croatia, 2018, pp. 69–85.
12 Antolinc D & Filipič K E, *Polymers (Basel)*, 13 (2021) 18.
13 Thirumurugan V & RameshKumar M, *Fibers Polym,* 21 (2020) 12.
14 Muthukumar N, Thilagavathi G & Karthikka M, *J Nat Fibers*, 19 (2022) 3233.
15 Sadeghi B, Marfavi Y, AliAkbari R, Kowsari E, Borbor Ajdari F & Ramakrishna S, *Mater Circ Econ*, 3 (2021) 1.
16 Savic V & Hector L G, *SAE Tech Pap,* 2011, 2011-01-0463.
17 Shishoo R, *Textile Advances in the Automotive Industry*, Woodhead Publishing in Textiles, Cambridge, England/Boca Raton, FL, 2008, pp. 356
18 Kumar R S, *Textiles for Industrial Application*s, CRC Press, Boca Raton, FL, USA, 2016, pp. 406
19 Mosomi E K, Olanrewaju O A & Adeosun S O, *Eng Rep*, 6 (2024) e12909.
20 Girisha L, Saravanan R, Kumarasan T, Pitchandi P, Sakthi S, Nanthakumar S & Girimurugan R, *Hemp fibre-reinforced polylactic acid composites: a sustainable material for engineering and industry, in Polymer Composites: Fundamentals and Applications*, Springer Nature, Singapore, 2024, pp. 217
21 Shahzad A, *J Compos Mater*, 46 (2012) 973.
22 Yüksel Y E, Korkmaz Y & Kaynak H K, *Indian J Fibre Text Res*, 50 (2025) 31.
23 Atakan R, Sezer S & Karakas H, *J Ind Text*, 49 (2020) 835.
24 Abraham E, Deepa B, Pothan L A, Jacob M, Thomas S, Cvelbar U et al., *Carbohydr Polym,* 86 (2011) 4.
25 Chen W, Yu H, Liu Y, Chen P, Zhang M & Hai Y, *Carbohydr Polym,* 83 (2011) 4.
26 Olsson A M & Salmén L, *Carbohydr Res*, 339 (2004) 4.
27 Kabir M M, Wang H, Lau K T & Cardona F, *Compos Part B Eng,* 53 (2013) 362.
28 Sunny T, Pickering K L & Lim S H, *Cellulose*, 27 (2020) 5.
29 Kabir M M, Wang H, Lau K T & Cardona F*, Appl Surf Sc*i, 276 (2013) 13.
30 Kobiela-Mendrek K, Bączek M, Broda J, Rom M, Espelien I & Klepp I, *Mater*, 15(2022) 3139.
31 Elkhateeb A, Adas A, Attia M & Balila Y, *Appl Acous*t, 105 (2016) 143.