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Development and Characterization of Papaya and Modal Fibre Nonwovens for Thermal and Sound Insulation Applications

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***Abstract*— Growing demand for sustainable sound-absorbing materials has led to the creation of thermal-bonded nonwoven fabrics made from agricultural waste, specifically papaya stem bark fibres, modal fibres and low-melt PET fibres as a thermoplastic binder. In total, five unique thermal bonded nonwoven samples with various blend proportions were produced and characterized their physical, thermal and acoustic properties. The findings of the investigation significantly enhanced the structural and functional properties of the nonwoven materials. Additionally, optimized porosity and an interlinked porous structure enhanced sound absorption behaviour notably at medium and high frequency ranges. This confirms the feasibility of the newly developed nonwoven fabrics for environmentally friendly soundproof insulation applications.**

***Keywords*—Papaya, modal fibres, thermal bonded nonwoven, thermal insulation, sound absorption.**

I. Introduction

Noise pollution, defined as unwanted or excessive sound that can disrupt human or animal life, has emerged as a significant public health concern, particularly in urbanized and industrialized regions (Korlu, 2020; Mohammadi et al., 2024). Indeed, the World Health Organization estimates that 466 million people globally suffer from hearing loss, with a significant portion attributable to noise-induced hearing loss (Widjanarti et al., 2023). The escalating global concern regarding noise pollution, particularly in urban and industrial settings, necessitates the development of advanced acoustic materials to mitigate its detrimental effects on human health and environmental quality (Korlu, 2020). Conventional sound absorption materials, often derived from synthetic and petrochemical sources, present significant environmental drawbacks, thereby driving a critical need for sustainable and biodegradable alternatives (Mohammadi et al., 2024; Periyasamy et al., 2023). Traditionally, noise barriers and soundproofing have relied on synthetic materials like concrete, steel, and mineral wool however, recent advancements highlight the potential of natural fibre-based composites as eco-friendly alternatives for sound absorption and insulation (Dev et al., 2023; El-Basheer et al., 2023)

This imperative has spurred an extensive research into natural fiber-based composites, particularly nonwoven fabrics, as viable eco-friendly solutions for acoustic insulation (Namakka et al., 2025; Yalçın-Eniş et a.,, 2023). The porous nature of natural fibres, particularly their hollow lumen structures and interconnected voids facilitates the dissipation of sound energy through frictional losses and structural vibrations (Islam et al., 2018; Usta et al., 2025).

Furthermore, investigation into blending different natural fibres has demonstrated enhanced acoustic properties, with higher proportions of certain fibres and increased nonwoven thickness yielding superior sound absorption coefficients (Kumar et al., 2022). For instance, studies on various natural fiber composites, including sugarcane bagasse, have shown that increasing fiber content can significantly improve both sound absorption coefficients and transmission loss (Zulkarnain et al., 2024). Such materials are notably enticing to attract and shift towards utilizing renewable and biodegradable resources for acoustic insulation, moving away from less sustainable synthetic options (Krithika et al., 2022). These changes are essential, because traditional synthetic sound absorbing materials exhibit possible health hazards and considerable environmental impacts. Hence researchers move towards natural fibre substitutes (Prabhune et al., 2022; Yang et al., 2020).

The increasing demand for sustainable materials has led to significant interest in natural fibres, including those derived from the Carica papaya plant (kumar et al., 2017). This plant, particularly its waste products like stem bark and seeds, offers a promising source for developing eco-friendly materials through various extraction and valorization techniques (Feng et al., 2024). The efficacy of these techniques in yielding fibres suitable for composite applications is heavily influenced by the chosen extraction methods and subsequent chemical or physical modifications (Phiri et al., 2023). This review explores the methodologies employed for papaya fiber extraction and characterization, alongside the examination of their resulting mechanical, thermal, and chemical properties, crucial for optimizing their utility in diverse industrial applications.

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Specifically, the comparative analysis of different extraction methods, such as water retting versus alkali treatments, reveals distinct impacts on fiber purity, crystallinity, and thermal stability (Olembe et al., 2025).

Modal fiber, a regenerated cellulosic fiber, distinguished by its elevated wet modulus and tensile strength, exceeding that of conventional viscose rayon, attributed to its unique molecular alignment and crystallinity (Niresh et al., 2019). They are frequently blended with other natural fibres, such as cotton and tencel, to leverage synergistic properties like enhanced softness, breathability, moisture-wicking capability, and overall durability in knitted fabrics (Sangeetha & Riyas, 2025)

While several studies have explored the use of unconventional natural fibres for nonwoven development, no attempt has been made so far to develop nonwovens from papaya and modal fiber blends. Therefore, the investigator has undertaken this study to develop thermal bonded nonwoven fabrics from papaya, modal, and low melt PET fibres, to systematically investigate their physical, thermal, and acoustic performance.

Research objectives

- To develop sustainable thermal bonded nonwoven fabrics using blends of papaya, modal, and low melt PET fibres.
- To characterize and evaluate the physical properties of the developed nonwoven fabrics.
- To analyze the thermal performance of the nonwoven blends.
- To investigate the acoustic properties of the developed nonwoven fabrics for potential sound absorption applications.

II. Materials And Methods

Carica Papaya fibre is obtained through a manual retting process. Low melting point polyester (PET) fibre of length 38 mm and thermal bonding temperature of 115ºC with breaking strength of 3.6c N/dtex and 40.10 % elongation at break were sourced from Coimbatore District, Tamilnadu. Modal fibre was purchased from Pallava Textiles, Erode. Totally Five Thermal bonded nonwovens were produced from papaya, modal and low melt PET fibres by blending in different ratios, produced by air-lay web formation, needle punching and hot calendaring at 120℃. To meet ASTM standards nonwoven fabric were analysed for thickness, areal density, bulk density, porosity and air permeability.

Thermal conductivity, effusivity, transmittance and resistance were evaluated with C-Therm MTPS instrument. Sound absorption was assessed using an impedance tube following ASTM E-1050 standards. Table 1 shows the nomenclature of the samples produced.

Table: 1
Nomenclature of the samples

S.No	Sample Name	Sample Code
1	Papaya 80%+ Low Melt PET 20%	TBPLP1
2	Modal 80% + Low Melt PET 20%	TBMLP2
3	Papaya 60% + Modal 20 % + Low Melt PET 20%	TBPMLP1
4	Papaya 20% + Modal 60 % + Low Melt PET 20%	TBPMLP2
5	Papaya 40% + Modal 40 % + Low Melt PET 20%	TBPMLP3

III. Results And Discussion

3.1. Physical properties of thermal bonded nonwoven fabrics

Physical properties testing examines how nonwoven fabrics behave under different conditions and ensures they meet requirements and end uses. The physical properties of the developed thermal bonded nonwoven fabrics such as thickness, areal density, bulk density, porosity and air permeability is shown in Table -2

Table 2
Physical properties of thermal bonded nonwoven fabrics

Sample	Thickness (mm)	Areal Density (g/m^2)	Bulk density (Kg/m^3)	Porosity (%)	Air Permeability ($cc/s/cm^2$)
TBPLP1	4.604	615.27	133.6381	89.21	73.61
TBPMLP1	2.506	330.96	132.067	89.09	66.66
TBPMLP2	2.204	292.38	132.6588	88.54	52.77
TBPMLP3	2.882	483.15	167.644	85.84	59.72
TBMLP2	1.112	179.98	161.8525	85.73	38.88

3.1. Thickness

The thickness of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 1

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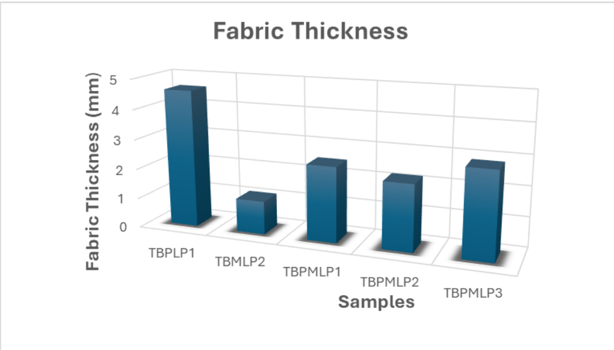

Figure:1 Fabric Thickness

Fabric thickness is a crucial factor to controlling both thermal insulation and acoustic performance. Thicker fibrous structure typically contains a greater volume of entrapped air which improves insulation properties. The thickness of developed thermal bonded nonwovens ranged from 1.112 to 4.604 mm. In comparison with produced samples, TBPLP1 showed more thickness (4.604 mm) whereas the sample TBMLP2 recorded the lowest thickness. The bulky nature of papaya fibres and the relatively open fibre network attributed to the highest thickness gained after thermal bonding techniques. Compared to this, compact fiber arrangement was found in TBMLP2 sample which leads to thinner fabric composition.

3.2. Areal density

The areal density of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 2

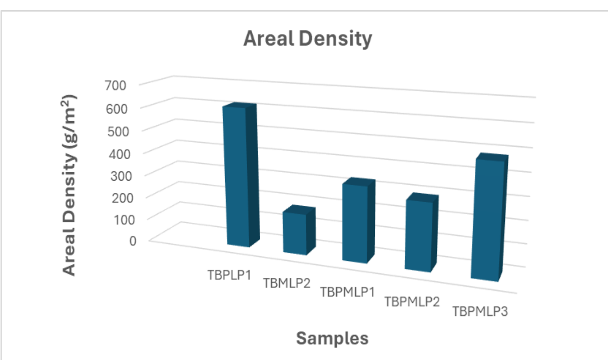

Figure:2 Areal Density

The areal density of the nonwoven samples oscillates between 179.98 to 615.27 g/m^2. The peak areal density was observed from the sample TBPLP1 (615.27 g/m^2) and the sample TBMLP2 showed the lowest value when compared to other nonwoven fabrics.

The greater areal density indicates high volume of fiber per unit area, which adds to the optimised structural stability and mechanical reliability of the nonwovens. Increased fiber mass stimulates the bulk characteristics and functional performance of standard insulation nonwoven fabrics

3.3. Bulk density

The bulk density of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 3

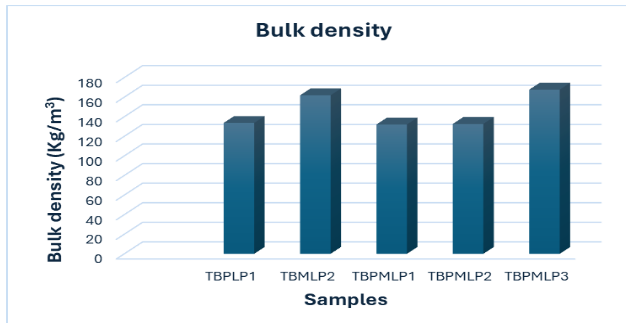

Figure:3 Bulk Density

The nonwoven bulk density is regulated by the fiber index and the internal volume occupied by the fibrous structure. A higher bulk density generally suggests a more compact fiber construction with reduced void spaces, while less bulk density indicates a bulkier structure with more entrapped air. The bulk density of nonwoven ranged from 132.07 to 167.64 kg/m^3 . The lowest bulk density was found in TBPMLP1 (132.07 kg/m^3) and the highest in TBPMLP3(167.64 kg/m^3). Lower bulk density generally associated with better thermal insulation ability.

3.4. Porosity

The porosity of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 4

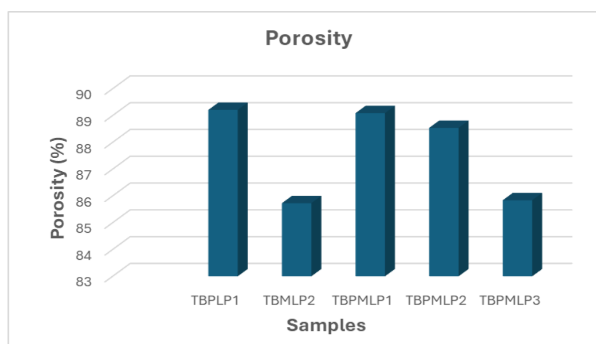

Figure :4 Porosity

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Porosity of the developed nonwoven samples is in the range of 85.73 to 89.21 %. The greatest amount of porosity was shown by TBPLP1 (89.21%) followed by TBPMLP1 (89.09%) while the lowest porosity was displayed by TBMLP2 (85.73%). A high porosity implies that a significant portion of the volume of the composites consists of interconnected spaces occupied by air, which decreases the conductive heat transfer and facilitates the dissipation of acoustic energy. Previous studies by Asanović et al. (2019) and Russell (2007) have proved that porosity is one of the foremost important structural parameter that regulate the thermal and sound absorption performance of nonwoven materials

3.5. Air permeability

The air permeability of the developed thermal bonded nonwoven fabrics in different ratios are shown in figure 5

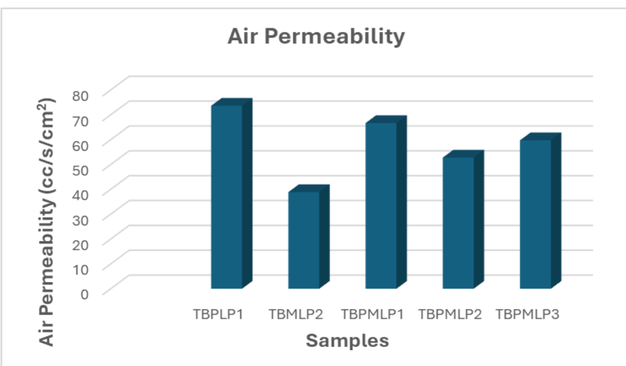

Figure:5 Air permeability

Air permeability metrics fluctuated between 33.88 to 73.61 cc/s/cm^2. TBPLP1 illustrated the highest air permeability in contrast to TBMLP2 which showed the minimum metrics. The high air permeability of the sample TBPLP1 is due to the greater fabric thickness and higher porosity, which results in deeper inter connected routes for airflow through the fiber structure. Conversely the denser structure of TBMLP2 inhibits the air movement due to reduced pore capacity and smaller interconnected spaces. Similarly Hearle et al. (2001) and Das et al. (2012) reported that increasing pore size and fibre openness considerably raises the airflow through the nonwoven structures.

IV. Testing Of Thermal Properties

Table 3 shows the thermal properties of thermal bonded nonwoven samples which comprises thermal conductivity, thermal resistance, thermal transmittance and thermal effusivity.

Table: 3 Characterization of Thermal properties

Sample	Thermal Conductivity (W/ (mK)	Thermal Resistance (m^{2}K)/W	Thermal Transmittance W(m^{2}K)	Thermal Effusivity (Ws^(1/2)/Km^2)
TBPLP1	0.03869	0.1189	8.4040	72.2010
TBPMLP1	0.04271	0.0586	17.0648	92.4601
TBPMLP2	0.04125	0.0534	18.7265	85.3613
TBPMLP3	0.04432	0.0650	15.3846	100.0354
TBMLP2	0.04445	0.0250	40	100.6614

4.1. Thermal Conductivity

The thermal conductivity of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 6

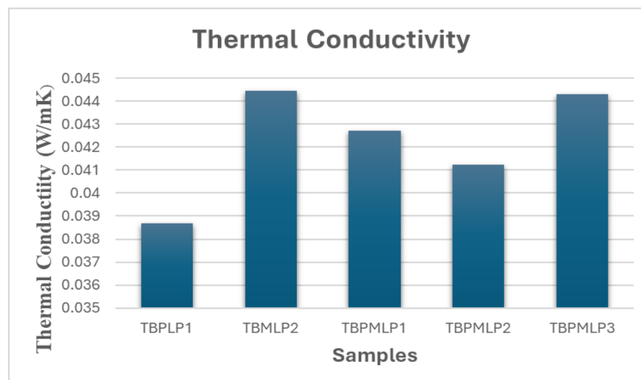

Figure:6 Thermal Conductivity

Thermal conductivity values were detected from 0.03869 to 0.04445 (W/mk) of the developed nonwoven samples. TBPLP1 exhibited minimal thermal conductivity at 0.03869 (W/mk), while TBMLP2 revealed the highest at 0.04445 (W/mk). The lower thermal conductivity of TBPLP1 signifies superior resistance to heat transfer, attributable to its bulkier and large fiber structure and higher volume of entrapped air in the nonwoven fabrics. The slight variance in thermal conductivity among the samples is mainly associated with difference in thickness and needle punching techniques.

4.2. Thermal Resistance

The thermal resistance of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 7

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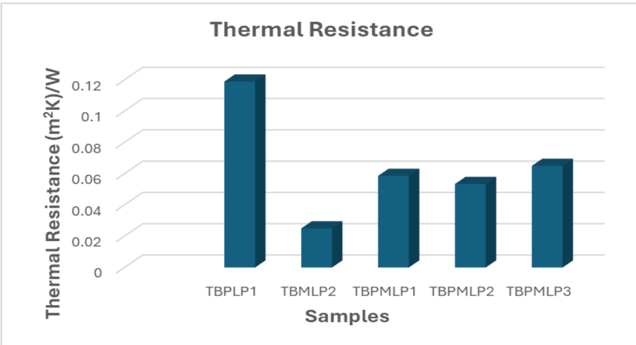

Figure:7 Thermal Resistance

The sample TBPLP1 indicate the highest thermal resistance, were as the sample TBMLP2 showed the lowest thermal resistance values fluctuating in-between 0.0250 (m^2K)/W to 0.1189 (m^2K)/W. Thermal resistance was improved because of effective thickness of the nonwoven fabrics. Similar behaviour has been reported for highest percentage natural fiber nonwoven insulations materials, where increased porosity and bulk density improve the resistance to heat flow by minimising convective heat transfer within the structure.

4.3. Thermal Transmittance

The thermal transmittance of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 8

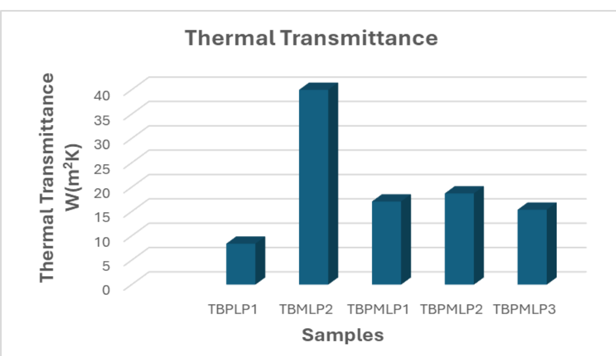

Figure:8 Thermal Transmittance

Thermal transmittance (U-Value) spanned from 8.4040 W(m^2K) to 40.0000 W(m^2K). The minimum value was recorded from TBPLP1 and sample TBPLP2 holds highest value when compared to other samples. Since the thermal transmittance is reciprocal of thermal resistance, the reduction in thermal resistance in TBPLP1 denotes a slower rate of transfer through the porous structures confirming its superior insulating efficacy. Conversely the U-Value of TBMLP2 shows more rapid heat transmission due to its lower thermal resistance.

4.4. Thermal Effusivity

The thermal effusivity of the developed thermal bonded nonwoven fabrics in different ratios are shown in Figure 9

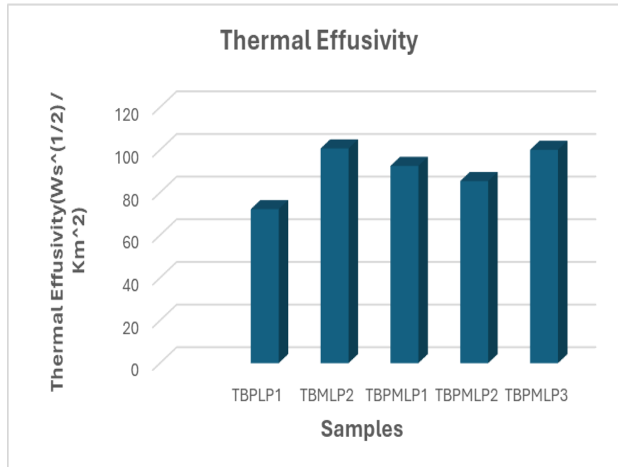

Figure:9 Thermal Effusivity

Thermal Effusivity represents the ability of nonwoven fabrics to exchange the thermal energy within the surrounding environment and governed by thermal conductivity, density and specific heat capacity. Thermal effusivity values were between 72.2010 (Ws^(1/2) / Km^2) and 100.6614 (Ws^(1/2) / Km^2). TBPLP1 proved the lowest thermal effusivity, while TBMLP2 had the greatest value. Nonwoven samples exhibiting lower thermal effusivity absorb and discharge heat less quickly, resulting in improved thermal comfort and enhanced insulation functionality. Therefore, TBPLP1 notably indicates better resistance to rapid heat fluctuations than the other nonwovens.

V. Effect On Sound Absorption Properties

Table :4 Sound absorption Coefficient Values

Sample	Frequency Hz					
	250	500	750	1000	1250	1600
TBPLP1	0.0782	0.0827	0.0773	0.0109	0.1152	0.1395
TBPMLP1	0.0505	0.0651	0.0614	0.0625	0.0780	0.0905
TBPMLP2	0.0578	0.0648	0.0701	0.1002	0.1009	0.1331
TBPMLP3	0.0654	0.0821	0.0834	0.0912	0.0994	0.1001
TBMLP2	0.0413	0.0467	0.0551	0.0687	0.0811	0.0825

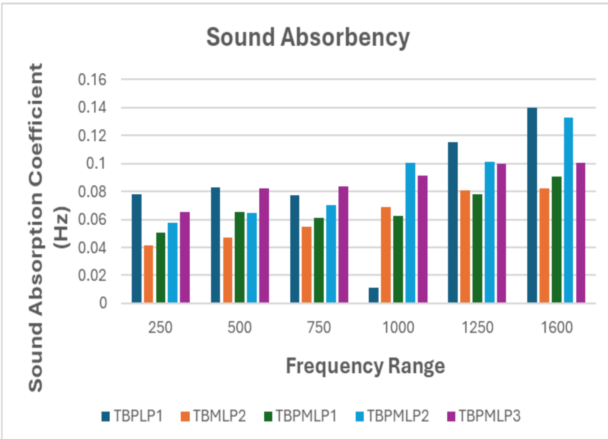

Figure:10 Sound Absorption Coefficient Values

Table:4 shows the sound absorption coefficients of the thermally bonded nonwoven fabrics ranging from 250-1600 Hz. The quantity of incident sound energy emitted within a nonwoven porous structure depends on its fabric thickness, porosity, bulk density, air permeability, areal density and fibre web laying method.

The sound absorption of the developed nonwoven fabrics was increased gradually with high frequency level and exhibited relatively low sound absorption at low frequencies (250-750 Hz). This performance depends on higher frequency sound waves undergoing greater viscous friction and thermal losses. Sound moves through the inter linked pores structure of fiber, so that acoustic energy dissipation is increased.

Among the developed samples, TBPLP1 gained the highest sound absorption coefficient at 1600 Hz (0.1395), followed by TBPMLP2 (0.1331). The favourable noise absorption TBPLP1 can be achieved by thickness (4.604 mm), high air permeability (73.61 cc/s/cm^2) and high porosity (89.21%), that creates a more tortuous sound wave propagation. Del Rey et al. (2017), Asanović et al. (2019), and Koizumi et al. (2002) reported that increasing fabric thickness and fabric porosity boosts the sound absorption performance of nonwovens made with natural fibres

The blended samples TBPMLP1, TBPMLP2 and TBPMLP3 produced moderate acoustic behaviour. Among these three samples TBPMLP2 showed a noticeable sound absorption beyond 1000 Hz. Papaya, modal and low melt PET produced a neutral pore structure capable of providing balanced acoustic energy dissipation across a broad frequency range.

VI. Conclusion

In this study, Carica Papaya fibre is denoted to have promising properties as a new natural textile fibre. In this work CPFS fibres are extracted from Carica Papaya stem barks blended with modal and low- melt PET fibres to develop thermal bonded nonwoven materials. The physical characterisation revealed that the sample Thermal bonded papaya 80 % and low melting point polymer (TBPLP1) demonstrated highest porosity, fabric thickness and maximum air permeability, lowest thermal conductivity, transmittance, effusivity and the highest thermal resistance indicating the formation of a bulkier and more open fibrous structure with enhanced air entrapment. Also it demonstrated promising sound absorption at high frequency level. The produced papaya fibre thermal bonded nonwoven fabrics provide a light weight and semi - biodegradable alternative for synthetic insulation materials. These nonwoven fabrics may be considered for application in building insulation, acoustic wall and ceilings interior sound proof applications.

REFERENCES

[1] Das, P.P., Chaudhary, V., Ahmad, F., Manral, A., Gupta, S. and Gupta, P. 2021. Acoustic performance of natural fiber reinforced polymer composites: Influencing factors, future scope, challenges, and applications. Polymer Composites, 43(3): 1221–1237.

[2] Dev, B., Rahman, M.A., Repon, M.R., Rahman, M.M., Haji, A. and Nawab, Y. 2023. Recent progress in thermal and acoustic properties of natural fiber reinforced polymer composites: Preparation, characterization, and data analysis. Polymer Composites, 44(11): 7235–7297.

[3] El-Basheer, T.M., Kh., H.H., Mohamed, G., Goines, L., Hagler, L., Eggermont, J., Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., Stansfeld, S., Mahmoud, D., El-Sabbagh, S., Moustafa, A., Barakat, M. and Zhang, P. 2023. Recent progress in acoustical materials and noise control approach., 3 (2): 32–41.

[4] Esposti, E.V.D., Bedon, C., Jonaitienė, V., Kazak, J.K., Liotta, L.F., Priniotakis, G. and Stachewicz, U. 2022. Smart textiles in building and living applications: WG4 CONTEXT insight on elderly and healthcare environments. Buildings, 12(12): 2156.

[5] Feng, X., Ameer, K., Jiang, G. and Ramachandraiah, K. 2024. Effects of extraction methods on the structural characteristics and functional properties of dietary fiber extracted from papaya peel and seed. Frontiers in Sustainable Food Systems, 8.

[6] Gboe, N.A. and Grubliauskas, R. 2025. Evaluation of life cycle assessment (LCA) and sound absorption properties of composite materials made from coconut and sugarcane fibers. Mokslas – Lietuvos Ateitis, 17: 1–6.

[7] Islam, S. and Alam, S.M.M. 2018. Investigation of the acoustic properties of needle punched nonwoven produced of blend with sustainable fibers. International Journal of Clothing Science and Technology, 30 (3): 444–458.

[8] Körlü, A. 2020. Waste in textile and leather sectors. Intech Open eBooks.

[9] Krithika, S.M.U., Mani, K., Thangavelu, S.K., Bharathi, C.M., Saravanan, K. and Prakash, C. 2022. Investigation of the physical properties and acoustic performance of composites developed from natural fibres. AATCC Journal of Research, 9 (4): 213–220.

[10] Kumaar, A.S., Kumar, A.S., Sornakumar, T., Saravanakumar, S.S. and Arthanariesewaran, V.P. 2017. Physicochemical properties of new cellulosic fiber extracted from Carica papaya bark. Journal of Natural Fibers, 16 (2): 175–184.

[11] Kumar, B.S., Bhuvaneshwari, M., Sangeetha, K., Pachiyappan, K.M. and Devaki, E. 2022. Influence of fiber blending on thermal and acoustic properties of nonwoven material. Journal of Natural Fibers, 19 (15): 11193–11203.

[12] Liao, J., Zhang, S. and Tang, X. 2020. Sound absorption of hemp fibers (Cannabis sativa L.) based nonwoven fabrics and composites: A review. Journal of Natural Fibers, 19 (4): 1297–1309.

[13] Mohammadi, M., Taban, E., Tan, W., Din, N.B.C., Putra, A. and Berardi, U. 2024. Recent progress in natural fiber reinforced composite as sound absorber material. Journal of Building Engineering, 84: 108514.

[14] Namakka, M., Rahman, M.R., Bakri, M.K.B., Karuppasamy, B.D., Ahmmad, M.S., James, A.A. and Rahman, I.M.M. 2025. Advancements in acoustic properties of natural waste biocomposites: Current trends, applications, and future perspectives. Advanced Composites and Hybrid Materials, 8 (5).

[15] Niresh, J., Archana, N., Karthink, T. and Tan, W. 2019. Physical, chemical, morphological and thermal characterisation of natural fibers for sound absorption. Tekstil ve Konfeksiyon, 29 (3): 219–227.

[16] Olembe, Y.R., Mewoli, A.E., Njom, A.E., Eyamo, V.J.E., Ndengue, M.J., Biyeme, F., Ndjock, G.A.B., Ayadi, M., Segovia, C., Essama, E.C., Momo, P.R.K., Ebanda, F.B., Meva'a, J.R.L. and Ateba, A. 2025. Comparative characterization of Carica papaya fibers extracted by retting and alkaline treatment for biocomposites. Advances in Polymer Technology, 2025 (1).

[17] Periyasamy, A.P., Karunakaran, G., Rwahwire, S. and Kesari, K.K. 2023. Nonwoven fabrics developed from agriculture and industrial waste for acoustic and thermal applications. Cellulose, 30 (11): 7329–7346.

[18] Phiri, R., Rangappa, S.M., Siengchin, S. and Marinković, D. 2023. Agro-waste natural fiber sample preparation techniques for biocomposites development: Methodological insights. Facta Universitatis Series Mechanical Engineering, 21 (4): 631.

[19] Prabhune, S., Munde, Y., Shinde, A. and Siva, I. 2022. Appraising the acoustic performance and related factors of natural fiber: A review. Journal of Natural Fibers, 19(16): 13475–13494.

[20] Sangeetha, M. and Riyas, J.M.M. 2025. Influence of fiber blends on the performance characteristics of weft knitted fabrics. International Scientific Journal of Engineering and Management, 4 (3): 1–7.

[21] Usta, C., Seyhan, A. and Gürarslan, A. 2025. Thermal insulation and sound absorption properties of poplar blend nonwovens. Cellulose, 32 (8): 5115–5129.

[22] Widjanarti, M.P., Probandari, A., Sumardiyono, S. and Sunarto, S. 2023. The acoustic performance of natural composites in reducing stress levels: Textile industry. Civil Engineering Journal, 9 (6): 1312–1328.

[23] Yalçın-Eniş, İ. and Sezgin, H. 2023. Investigation of structural parameters of acoustic panels produced from post-industrial textile wastes containing different raw materials. Progress in Rubber, Plastics and Recycling Technology, 40 (2): 121–135.

[24] Yang, T., Hu, L., Xiong, X., Petrů, M., Noman, M.T., Mishra, R. and Militký, J. 2020. Sound absorption properties of natural fibers: A review. Sustainability, 12(20): 8477.

[25] Zulkarnain, M., Irianto, I., Insdrawaty, M.I., Azman, M.I.F., Azmi, M.I.A. and Kusrini, E. 2024. Study on nature fiber composite for noise material control. International Journal of Technology, 15 (3): 618.