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Characterizing Thermal, Acoustic, Water Absorption, and Flammability Performance of Pineapple Leaf Fibre Insulation: A Sustainable Alternative for Building Applications

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Pineapple leaf fibre, insulation material, thermal performance, acoustic performance, water absorption, flammability

Abstract

The sustainable usage of pineapple leaf fibre (PALF) for insulation applications on building components was studied. To prepare one-layer, two-layer and three-layer insulation samples, they have been cleaned, treated with alkali, ground, moulded and dried. Thermal, Acoustic, Water absorption and Flammability tests were performed on fabricated samples. The results indicated that the thickness of the layers increased, the insulation performance improved generally. The 3-layer configuration showed the best thermal performance with an average temperature difference of 0.56°C and the best acoustic performance with an average sound reduction of 14.37 dB. The three-layer sample had the longest ignition time of 67.67 s and shortest smouldering length of 2.0 cm in the flammability test, which meant that the sample had better flammability resistance. The water absorption increased as the insulation thickness increased, the three-layer sample has the highest water absorption value of 37.90%. Comparative performance assessment with the conventional insulation material showed that PALF insulation has competitive performance in terms of thermal and acoustics properties and has superior performance in terms of sustainability and environmental benefits. The comparison with conventional insulation materials was conducted using a qualitative performance scoring matrix based on the experimental findings and literature review rather than direct quantitative testing. The results showed that pineapple leaf fibre is an environmentally friendly alternative building materials insulation.

1. Introduction

Building insulation is of great importance to reduce heat transfer through building envelopes, enhance thermal comfort in indoor environment and to reduce energy consumption. Use of insulation materials can markedly improve energy efficiency and minimize cooling loads in buildings [1], [2]. Rock wool, glass wool and synthetic foam are examples of traditional insulation materials used in the construction industry for their excellent thermal insulation capabilities. The manufacture or disposal of these materials is often linked with environmental issues such as high energy consumption, non-biodegradable and carbon emissions [1], [3].

In recent years, agricultural waste materials have become more interesting as a sustainable alternative to insulations. Agricultural residues are renewable, biodegradable and readily available making them good candidates for eco-friendly construction materials [4], [5]. The use of agricultural waste helps in reducing pollution, waste valorisation and promotes circular economy [6].

Previous studies have shown that natural fibre insulation materials exhibit good thermal and acoustic characteristics. Different agricultural fibres including oil palm fibre, bamboo fibre, water hyacinth fibre, and other lignocellulosic fib res were researched for their application in building insulation systems [7] – [10]. Typically, these materials have low thermal conductivity and good sound absorption properties and are more environmentally friendly than traditional insulation products [11], [12].

Pineapple leaf fibre (PALF), one of the natural fibres of interest, is easily available in abundance and has a lower cost with good mechanical and thermal properties [13] – [21]. After harvest, large amounts of pineapple leaves are left as a by-product in agriculture and are rarely used. The high cellulose content and the renewable nature of PALF have been reported in previous studies as suitable for many composite and engineering applications [22], [23]. Pineapple leaves are a by-product of pineapple crop harvesting and can be used as a source of renewable natural fibre for insulation, as seen in Fig. 1.

Fig. 1 *Pineapple plant (Ananas comosus) as a raw material for sustainable production of pineapple leaf fibre (PALF) used in the production of sustainable insulation material*

Thus, the present study aims to explore the application of pineapple leaf fibre as a sustainable insulating material in the construction sector. Samples of insulation were prepared with various layer combinations, and tested for their thermal and acoustic properties, water absorption, and flammability [23]. The results help in developing eco-friendly natural agricultural waste-based insulators and reveal the suitability of pineapple leaf fibre for sustainable use in the construction industry [24] – [27].

2. Methodology

The approach used in this research was the preparation of pineapple leaf fibre-based insulation samples and the assessment of the performance of prepared samples by conducting various experimental tests. The entire research methodology adopted was sample preparation, thermal testing, acoustic testing, water absorption testing and flammability testing to evaluate the suitability of pineapple leaf fibre as an eco-friendly insulation material for building applications.

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2.1 Sample Preparation

Leaves of pineapples were harvested and prepared to manufacture the insulation samples by fabricating various processes. Collected leaves were washed to wash away dirt and impurities and were treated with alkaline solution of sodium hydroxide (NaOH) to enhance the quality of fibre and eliminate undesirable materials. The treated fibres were then washed, dried and broken up into small pieces before being formed into insulation samples. Three types of insulation samples (one-layer, two-layer, three-layer) were prepared and dried under control conditions before testing. The final samples of insulation were made of dimensions 15cm×21cm×3cm. To ensure consistency and reliability of results in thermal performance, water absorption, acoustic performance and flammability tests, a uniform sample size was utilized throughout the study. The standardized dimensions also enabled fair comparisons to be made of the insulation materials tested.

To provide a clear overview of the experimental procedures, the research methodology is presented in the form of a flowchart, as shown in Fig. 2. The flowchart illustrates the systematic sequence of the study, including sample preparation, fabrication of pineapple leaf fibre insulation, experimental testing, and evaluation of the obtained results.

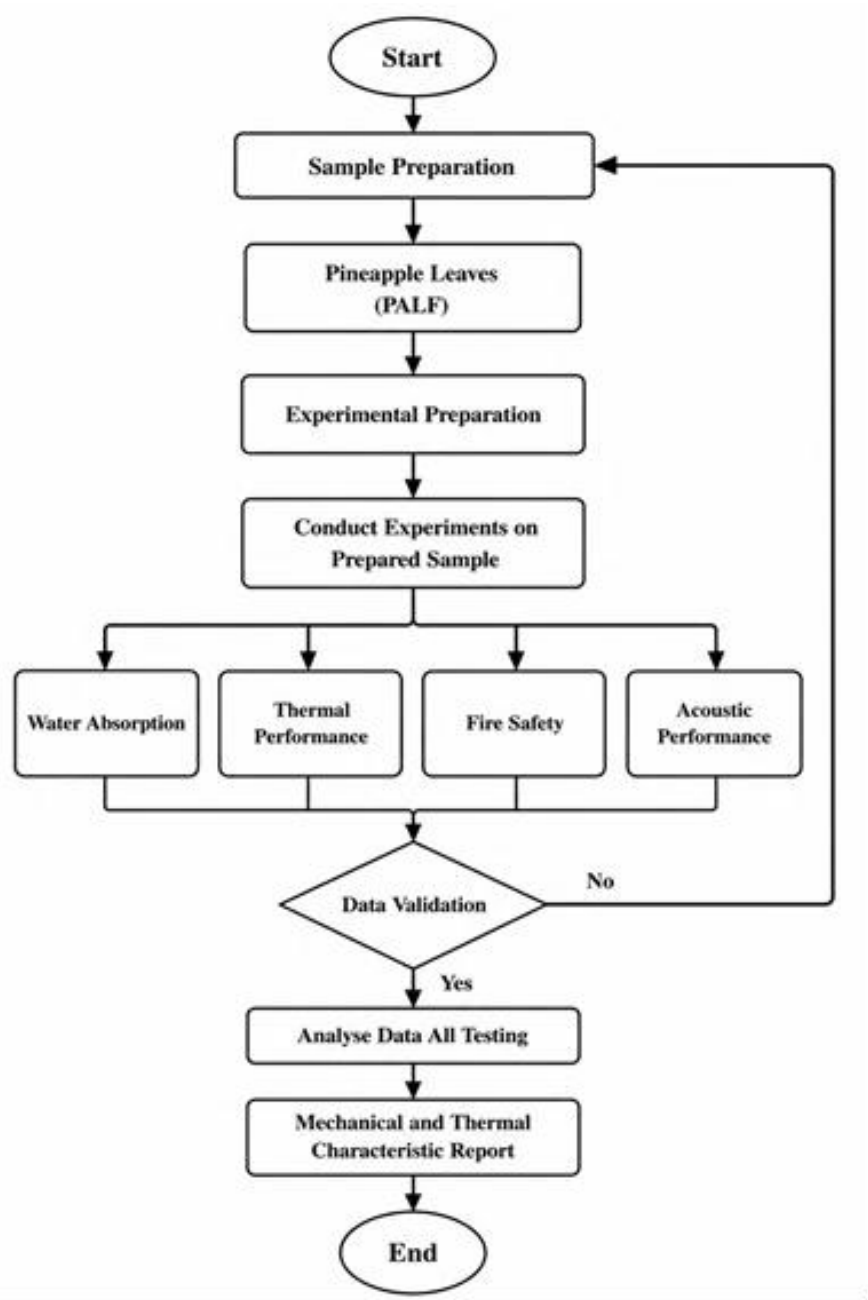

Fig. 2 *Research methodology flowchart for the fabrication and evaluation of pineapple leaf fibre-based insulation material*

2.2 Performance Evaluation

The fabricated samples were tested for thermal, acoustic, water absorption and flammability testing. Thermal performance was determined through the temperature difference between the external environment and internal environment of a test box. The sound level was measured in an outdoor and indoor environments inside the insulated enclosure, and the sound levels were compared. The water absorption characteristics were evaluated by placing the samples of insulation under water and measuring the volume of water absorbed after 15 minutes. The ignition time to the occurrence of burning and the maximum smouldering length of the insulation samples were used to determine the flammability performance. The experimental results of each test were analyzed to reveal the best insulation configuration and to assess the possibility of pineapple leaf fibre being used as a sustainable material of insulation in building applications.

3. Results and Discussion

Thermal, acoustic, water absorption and flammability performance of the fabricated pineapple leaf fibre samples were studied. The results obtained from experimental investigations are discussed in the following sections.

3.1 Thermal Performance

The average temperature difference (ΔT) obtained for each of the insulation types is shown in Fig. 3. The results indicate that the higher the thickness of insulation, the better the thermal performance. The one-layer configuration achieved an average temperature difference of 0.13°C, the two-layer configuration of 0.30°C and the three-layer configuration of 0.56°C.

The three-layer insulation sample showed the best insulation performance in all the samples tested. The added insulation had greater resistance to heat transfer creating a higher temperature differential between indoors and out. This means that the extra fibre layers helped to improve the thermal insulation properties of the material. In general, the findings indicate that pineapple leaf fibre insulation can be used to minimize the heat transfer and enhance the thermal comfort for building applications.

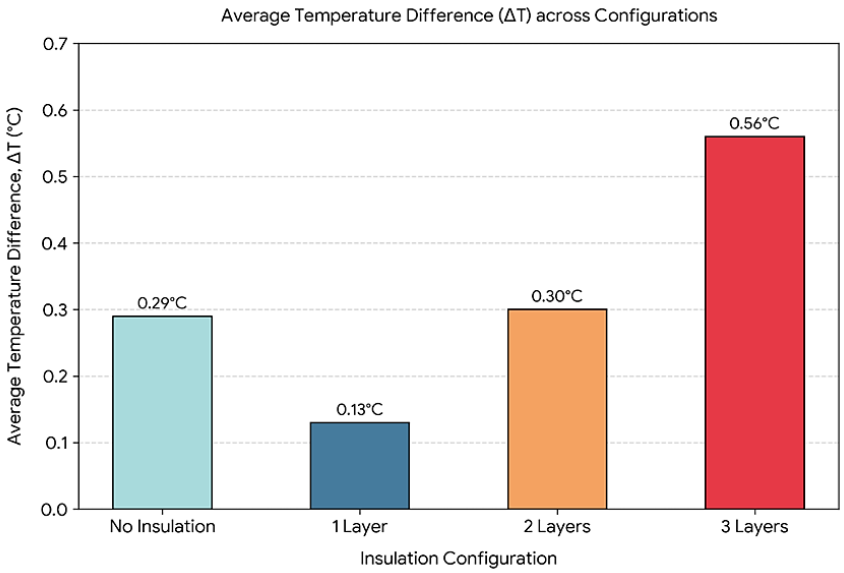

Fig. 3 *Comparison of average temperature difference (ΔT) for different pineapple leaf-based insulation configurations*

3.2 Acoustic Performance

Average sound reductions for each of the various insulation configurations are shown in Fig. 4. Results showed that increasing insulation thickness resulted in better acoustic performance. For the one-layer sample, the average sound reduction was 7.73 dB, whereas it was 10.03 dB and 14.37 dB for the two-layer and three-layer samples, respectively.

The three-layer configuration exhibited the best acoustic performance. The increase in the amount of fibre and thickness of the fibre insulation material likely accounts for the improvement in the sound reduction. The porous structure of pineapple leaf fibre also helped to reduce sound transmission in the pineapple leaf fibre

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insulation sample. The results indicate that pineapple leaf fibre-based insulation has good potential to enhance the acoustic comfort in building applications.

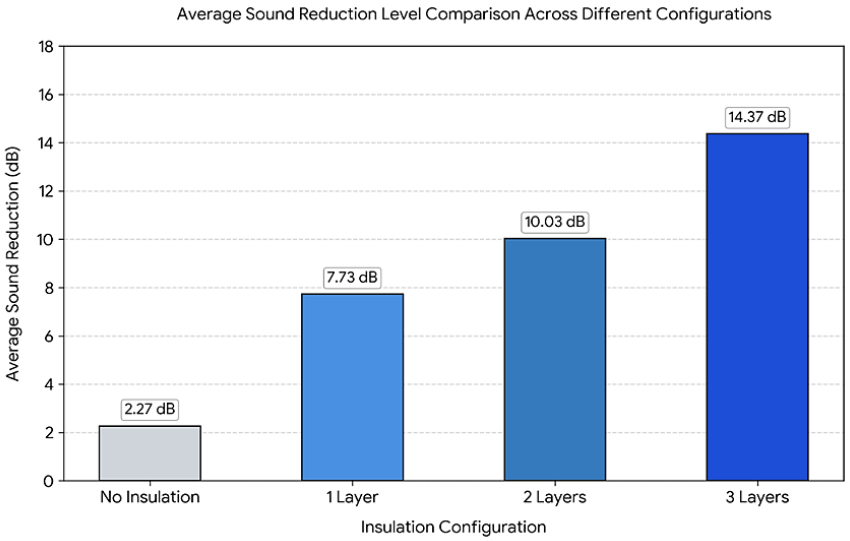

Fig. 4 *Comparison of average sound reduction for different pineapple leaf-based insulation configurations*

3.3 Water Absorption Performance

The water absorption percentage of pineapple leaf-based insulation samples after 15 minutes in water is shown in Fig. 5. Results indicate that the more insulation layers that were added, the more water was absorbed. The water absorption percentage is the lowest for the one-layer sample (20.47%) and is the highest for the two-layer and three-layer samples (35.73% and 37.90% respectively).

The greater absorption of water is due to the greater fibre content and pore volume found in thicker samples of insulation. More moisture was trapped inside the porous fibre structure as the number of layers increased, which led to more moisture absorption. This behaviour is similar to that of hydrophilic natural cellulose fibres. The results show that pineapple leaf fibre has a great capacity to absorb water because it is a natural fibre, though it may have an impact on its long-term durability in humid conditions. Despite the relatively high water absorption, PALF insulation may still be suitable for interior wall partitions, ceiling insulation, and other protected building applications where direct exposure to moisture is limited. For applications in humid environments, additional moisture-resistant treatments or protective surface coatings may be required to improve long-term durability.

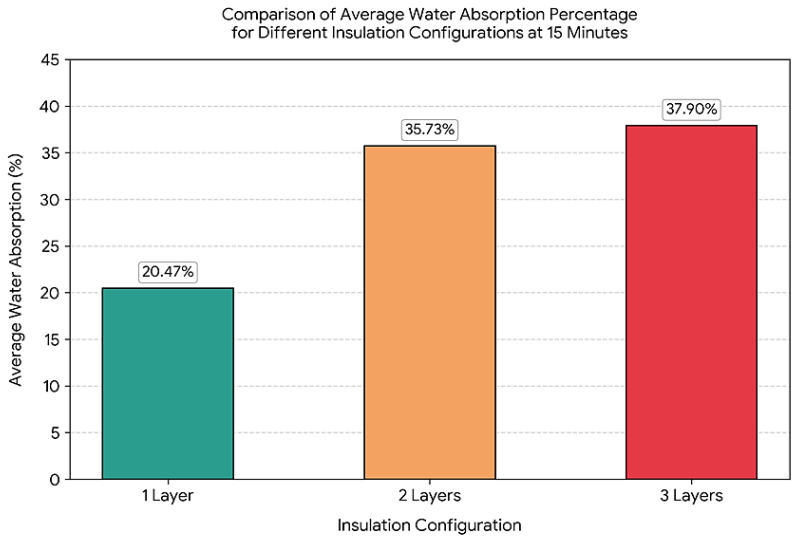

Fig. 5 *Comparison of water absorption percentage for different pineapple leaf-based insulation configurations after 15 minutes of immersion*

3.4 Flammability Performance

The ignition time and the maximum smouldering length of the pineapple leaf-based insulation samples are shown in Fig. 6. The results indicate that fire resistance improved with increasing insulation thickness. The one-layer sample had an average ignition time of 15.33 s while the two-layer sample had 44.33 s and the three-layer sample had 67.67 s.

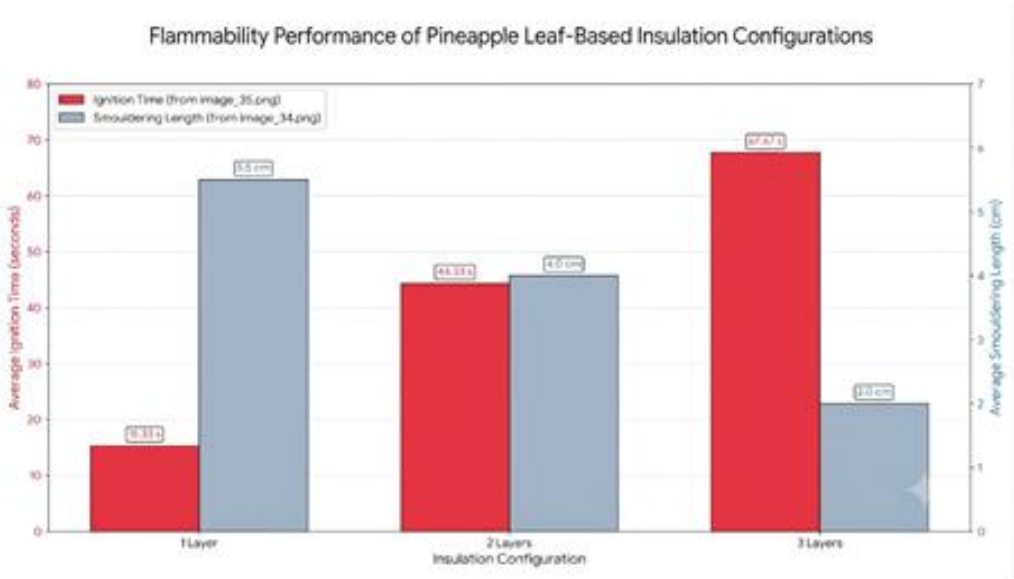

Fig. 6 *Comparison of ignition time and maximum smouldering length for different pineapple leaf-based insulation configurations*

The opposite was true when there were more layers of insulation, though, with the maximum smouldering length being shorter. One-layer recorded the longest smouldering length (5.5 cm) and two-layer (4.0 cm) and three-layer (2.0 cm) recorded. The shorter smouldering length was a result of an increase in the effectiveness of the thicker insulation samples in reducing the spread of smouldering combustion.

No flame propagation was observed in the test for any of the samples. Exposure to the ignition source resulted in only localized smouldering behaviour. The results show that the thickness of the insulation increased, the higher fire resistance performance of Pineapple Leaf Fibre based insulation materials was obtained and the suitability of the insulation materials was increased for building insulation applications.

3.5 Comparison with Conventional Material Insulations

The developed pineapple leaf fibre-based insulation material was compared with the conventional insulation materials including rock wool, glass wool and cotton wool. The overall level of performance of each material was judged using a qualitative performance criterion of 1 (very poor) to 5 (excellent) for thermal performance, acoustic performance, water resistance, fire resistance, sustainability, biodegradability and environmental impact. The scores presented in Table 1 were assigned based on the experimental results obtained in this study together with performance characteristics reported in previous literature. A score of 1 represents very poor performance, while a score of 5 represents excellent performance. The criteria used for each property are summarized below.

Table 1 shows that the scores for rock wool and glass wool were higher in terms of thermal performance, water resistance and fire resistance because the insulation properties and non-combustible characteristics of these are well established. Taking into account its renewable agricultural byproduct nature and less energy intensive processing, pineapple leaf fibre insulation proved to be even more sustainable, biodegradable, and environmentally friendly.

The developed pineapple leaf fibre insulation was better with a score of 28, higher than the rock wool (26), glass wool (24) and cotton wool (24). It was less resistant to water and fire as compared to mineral based insulation material, but the material had comparable thermal and acoustic properties and excellent environmental benefits. The results indicate that Pineapple leaf fibre is a promising sustainable natural fibre insulation material for building applications.

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Table 1 *Performance scoring comparison between pineapple leaf-based insulation and conventional insulation materials*

Property	PALF	Rock Wool	Glass Wool	Cotton Wool
Thermal Performance	4	5	4	3
Acoustic Performance	4	5	4	4
Water Resistance	2	5	5	2
Fire Resistance	3	5	5	2
Sustainability	5	2	2	4
Biodegradability	5	1	1	5
Environmental Impact	5	3	3	4
Total Score	28	26	24	24

*Note: Performance scores were assigned qualitatively based on experimental observations and supporting literature rather than fixed quantitative thresholds.

4. Conclusion

It is concluded that the pineapple leaf fibre (PALF) is successfully developed and evaluated with the desired characteristics in the production of insulating materials in building construction. The experimental results indicated that the insulation performance tended to be better for thicker insulations. The three-layer configuration yielded the highest average temperature difference of 0.56°C, sound reduction of 14.37 dB and the ignition time of 67.67 s. Water absorption increased as the thickness of the insulation layer was increased, however the thermal, acoustic and fire resistance properties of the material were found to be very promising. The comparison with traditional insulation materials also uncovered the considerable sustainability, biodegradability and environmental benefits of PALF insulation. The overall findings suggest that pineapple leaf fibre could be a viable and environmentally friendly alternative insulation material for use in building applications.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Nazrin Zamri, Mohd Azahari Razali;* ***data collection:*** *Muhammad Nazrin Zamri;* ***analysis and interpretation of results:*** *Muhammad Nazrin Zamri;* ***draft manuscript preparation:*** *Muhammad Nazrin Zamri, Mohd Azahari Razali, Norfakhira Mohd Nor, Nur Syafiqah Adha Narrudin, Masataro Suzuki, Mohd Azni Md Kasim. All authors reviewed the results and approved the final version of the manuscript.*

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