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Potential of Pineapple Leaf Fibers as Sound and Thermal Insulation Materials in Thailand

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Abstract

The objectives of this research were to create a database of botanical characteristics including fiber morphology, chemical composition and physical properties of pineapple leaf fiber (PALF) from different areas of Thailand. Production efficacy and potential of PALF panel as sound and thermal insulation material were also investigated. Information on the botanical characteristics and morphology of Batavia pineapple leaf fibers from different areas of Thailand and commercial sound and thermal insulation products made from various materials was collected and used as primary and secondary data for business feasibility analysis as technique, cost and market. Results showed that thermal properties of PALF composites were better than commercial composites containing asbestos and PET fiber and similar to glass fiber composites. The sound absorption property of PALF composites was lower than polyester fiber but better than glass fiber and comparable with asbestos. The noise reduction coefficient (NRC) value of PALF composite products was lower than sound insulation materials made of PET fiber, a similar type of material to PALF composites. The developed PALF sound absorption and heat insulation panel showed promise as a commercial product in terms of production technology, market trend and competitive cost.

Keywords: Environmentally friendly products, Pineapple leaf fiber, Sound absorption, Thermal insulation, Business feasibility

1. Introduction

The natural fiber market has recently become more attractive. Pineapple leaf fiber (PALF) shows potential with high cellulose content and low microfibrillar angle (1). PALF fiber can be used to develop structural and non-structural industrial products with outstanding toughness and durability as good quality materials that are also environmentally friendly. PALF has been used for various applications in the automotive, infrastructure and biomedical industries as furniture, textiles and packaging. Utilization of PALF reduces pollution caused by agricultural waste and also increases the value and applications of pineapple fiber.

The global insulation market showed gradual growth from 2015 to 2020 with a value of US $65 billion in 2020 (United Nations Industrial Development Organization (2). Suitable thermal insulation and sound absorption material must have low conductivity (K) with a high noise reduction coefficient (NRC). Common insulation materials are asbestos, glass, polyethylene terephthalate (PET), polypropylene

(PP) and polyethylene (PE). Natural materials such as wood and natural fibers generate public interest as a result of environmental and health concerns. Global trends in building and construction materials show rapid growth and utilization of agricultural and agro-industry wastes as raw materials to reduce environmental and health problems.

Pineapple (*Ananas comosus*) is cultivated in tropical and sub-tropical countries. Thailand is one the largest global producers, contributing 12% of the world's pineapple production at 19 - 20 million tons per year. After fruit harvesting, pineapple leaves are a by-product remaining in the fields, estimated at 6,000 kg of leaves per rai. Pineapple leaf fiber (PALF) can be extracted from leaves with a 2% yield using a manual decorticating machine. PALF is a fine, good quality fiber with 70-80% cellulose content and high crystallinity, resulting in high tensile strength and modulus of 400-1600 MPa and 59 GPa, respectively (3). PALF has been utilized as reinforcing material in thermoplastic composites (4-7) and as fiber for textile and packaging applications. Fiber reinforcement in composites has recently gained popularity. Natural fibers have high strength, low density, good thermal properties and also undergo decomposition.

Sound-absorbing and insulating materials are mainly made from glass, asbestos or PET fibers. However, both glass and asbestos fibers impact the health and body of the user by touching or inhaling fiber dust, causing diseases such as emphysema, cancer, pleural or bronchial cancer (8). Utilization of natural fibers to replace glass and asbestos fibers as sound-absorbing and thermal insulation materials has recently attracted increased interest as these fibers have low density with good mechanical properties, easy production process, user safety, high volume and less environmental impact compared to synthetic fibers (9-10). Natural fiber insulation products commercially available in Europe are made from cotton, straw, hemp, wood and wool (11-12).

Sound-absorbing or heat insulation natural fibers are applied for trendy designs of new or renovated buildings as new concepts of reducing energy consumption with efficient resource utilization, and requiring low-energy building standards. This study developed thermal insulation and sound absorption materials from PALF fibers and analyzed the business feasibility of natural PALF fibers in the green building and construction industry and markets.

2. Materials and Experiment

2.1 Data acquisition

Characteristics of Batavia pineapple leaf fiber (PALF) from different cultivation areas of Thailand were analyzed. The samples were collected from northern regions (Lampang Province, Phitsanulok Province and Uthai Thani Province), north-eastern regions (Nong Khai Province) and southern regions (Chumphon Province) of Thailand, with morphological properties of the fibers observed under an optical light microscope (Leica, LM750, Germany). The fiber morphology of PALF collected from different provinces was measured and calculated following the reference method (13), as shown in Figure 1.

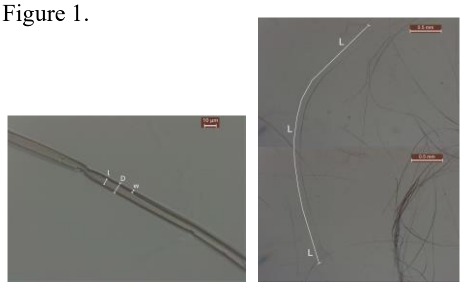


Figure 1 Fiber morphology of PALF under light microscope a) Fiber diameter (D), lumen (l), cell wall thickness (w) and b) Fiber length (L).

Primary data (production costs and product characteristics) of PALF insulation prototypes were collected by interviews and questionnaires from the first step of fiber preparation until the end of pilot scale production of PALF sound and heat insulation material. The insulation material was prepared as follows: PALF was extracted using a conventional decorticating machine and mixed with recycled PET fiber (*r*-PET) as a product prototype using a pilot non-woven manufacturing process. The thermal conductivity (K value) and noise reduction coefficient (NRC value) of the sample were evaluated.

Thermal conductivity of each sample material was analyzed with Heat Flow Meter Instruments (HC-074, EKO instruments, Japan) following the standard method ASTM-518-1. The nonwoven sample was cut into 20x20 cm^2 and placed between the hot and cold plate. The heat flow was transferred from hot plate to nonwoven sample and though to cold plate and was measured with a heat flux sensor.

Also, sound absorption of nonwoven samples was measured following standard method ASTM E-1050 by Acoustic Material Testing Single-Sided (Type 3560 B-T72/X72, Bruel & Kiaer, Denmark) based on the impedance tube. This PULSE template provides measurement and calculation procedures for the determination of the normal incidence sound absorption coefficient and related acoustic properties of nonwoven samples sized 3mm and 10 mm diameters using a two-microphone impedance tube. A computer was used for evaluating the sound absorption coefficient from the measured transfer function data.

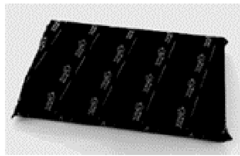
Secondary data as market trends and prices of various insulators were collected to compare and assess business feasibility.

2.2 Content and data analysis

PALF insulation material prototypes were analyzed and compared with commercial products in Thailand and abroad with the same specifications of density and thickness. Production costs, product properties, production processes, market trends and price information are shown in Table 1.

The business feasibility of PALF composite was assessed under the three main aspects of production technology, market trend and competitive cost to determine progress to the next stage of product development.

Table 1 Specifications of the PALF composite and commercial sound absorption and thermal insulation products.

Sample
 A / PALF insulated material PALF:recycled PET:low melt PE = 30:60:10 Density (Kg/m^3) /Thickness (mm) = 53 / 46
 B / PET insulated material Density (Kg/m^3) /Thickness (mm) = 43 / 56
 C / Glass fiber insulated material 1 Density (Kg/m^3) /Thickness (mm) = 35 / 48
 D / Glass fiber insulated material 2 Density (Kg/m^3) /Thickness (mm) = 40 / 50
 E / Asbestos fiber insulated material 1 Density (Kg/m^3) /Thickness (mm) = 41/ 46
 F / Asbestos fiber insulated material 2 Density (Kg/m^3) /Thickness (mm) = 65 / 50

3. Results and Discussion

3.1 Basic information about pineapple fiber production

The sound absorption coefficient of natural fiber depends on its diameter and porosity, and is measured in lumens size. Smaller fiber diameter and larger lumen size affect the friction between sound waves and the fiber surface, which changes sound energy to heat energy. Moreover, the lumen width of the fiber influences the heat transfer ability of the material (14). When comparing the morphology of Batavia pineapple leaf fiber cultivated in different areas of Thailand, PALF from Pluak Daeng, Rayong and Ban Kha, Ratchaburi had the largest fiber diameter and lumen width, giving better sound absorption and heat transfer properties as insulation materials. The long fiber length of PALF from these two areas had higher combination ability with another component fiber as a result of the more tortuous path within the composites that promoted sound energy change to heat energy due to higher airflow resistance or friction between the soundwaves and the material (15).

3.2 Business feasibility study on production of PALF composite as sound-absorbing and thermal insulation materials

The market for energy-saving and environmental conservation of buildings using biodegradable green thermal insulation and sound-absorbing materials is growing, and market feasibility of products developed from this research is consistent with the trend. PALF extracted from the prototype automatic decorticating machine showed competitive product ability with reduced cost compared to commercial thermal insulation and sound-absorbing products in the same market segment.

A preliminary assessment indicated that the thermal insulation and sound-absorbing materials developed in this research had business feasibility in terms of properties and price competition. Three aspects as technical, marketing and cost data were used to assess the initial business feasibility of sound-absorbing and thermal insulation of PALF composites. Details of fiber morphology are shown in Table 2.

Table 2 Morphological indices of Batavia pineapple mycelium in different cultivation areas.

Area	Fiber Length / Diameter (mm/) µm)	Lumen Width (µm) [M1]	Fiber Wall Thickness (µm)
BanRai, Uthai Thani	3.94/ 8.32	4.86	1.73
HuaiKhot, Uthai Thani	3.86/ 7.82	4.63	41.59
Pluak Daeng, Rayong	3.82/ 8.99	4.95	32.02
Ban Kha, Ratchaburi	3.92/ 8.46	4.69	41.89
Sri Chiang Mai, Nong Khai	2.76/ 5.38	2.88	41.25
PhoTak, Nong Khai	2.50/ 5.14	3.08	41.03
Nakhon Thai, Phitsanulok	3.07/ 4.25	2.30	40.98
Chattrakarn, Phitsanulok	2.75/ 4.57	2.56	1.00
Mueang Lampang, Lampang	2.74/ 5.76	3.55	31.11
ChaeHom, Lampang	2.53/ 4.27	2.24	41.02
ThaSae, Chumphon	2.30/ 5.17	2.80	41.18
Pathiw, Chumphon	2.58/ 6.19	3.55	41.32

3.3 Technical assessment

Main cultivation areas produce PALF composite from Batavia pineapple leaves are Ban Kha District, Ratchaburi Province and Pluak Daeng District, Rayong Province. To study the efficiency of PALF composite material for thermal and sound insulation, its thermal conductivity (K) and noise reduction coefficient (NRC) values were compared with commercial insulation materials including PET, glass and asbestos composites. Lower K values indicated that PALF-r-PET composites (A) exhibited better heat insulation performance than PET (B) by 18% and asbestos commercial composites (E-F) by 5-12%, while the sample had lower heat insulation properties than products made from glass fiber composites (C-D) by 2-16% (Table 3).

The PALF composite had a lower NRC value compared to other commercial sound-absorbing materials (B, D and F products) by 11-18% with sound absorption property similar to C and E products. The PALF material showed better sound-absorbing property than material made from wood wool composites (NRC 0.4) (16). This data confirmed that PALF composite, produced from natural PALF fibers and recycled PET fibers as a green material, could be used in sound absorption applications.

Table 3 Thermal conductivity (K) and Noise reduction coefficient (NRC) properties of PALF composite and other commercial sound-absorbing and insulating panels.

Code	Thermal conductivity (W/mK)	NRC
A	0.0333^{b}	0.60^{b}
B	0.0393^{d}	0.71^{a}
C	0.0326^{b}	0.57^{c}
D	0.0277^{a}	0.67^{ab}
E	0.0373^{c}	0.62^{b}
F	0.0352^{c}	0.70^{a}

*Different letters a, b, c, d within the same column indicate statistically significant differences at the 95% confidence level.
** A = PALF insulation, B = PET insulation, C = Glass fiber insulation 1, D = Glass fiber insulation 2, E = Asbestos fiber insulation 1, F = Asbestos fiber insulation 2

3.4 Marketing assessment

The building thermal insulation market was valued at US$23.89 billion in 2016 and is projected to reach US$29.62 billion by 2022, at a Compound annual growth rate (CAGR) of 3.65% from 2017 to 2022 (Figure 2) (17).

Building thermal insulation is used to reduce the amount of power required to heat or cool a home and minimize heat escape in winter and hot air penetration in summer. Building insulation is the most cost-effective measure in climates that have a wide range of annual average temperatures. In this report, 2016 is considered the base year, with 2017-2022 selected as the forecast period to estimate the size of the building thermal insulation market.

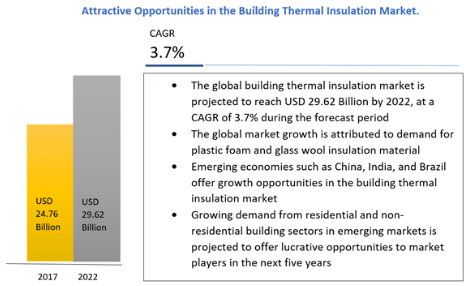


Figure 2 Building thermal insulation market by material (Glass Wool, Stone Wool, Polystyrene), Application (Flat Roof, Pitched Roof, External Wall, Internal Wall, Cavity Wall, Floor), Building Type (Residential, Non-residential) - Global Forecast to 2022 (17).

The global market was valued at US$ 28 billion in 2022, better than the projection by 13% and is projected to reach US$ 35.3 billion by 2027 at CAGR 4.7 % (18).

Most thermal and sound insulators are made from petrochemical materials, mainly polystyrene, natural glass and rock wool, consuming high fossil energy in production. The global building sector from construction to demolition emits greenhouse gas amounting to 33% of the planet (19) or 13.5 $GtCO_2$ (20). Therefore, eco-friendly product designs are encouraged in the construction industry because of the severe effects of global warming. Natural and recycled materials have attracted attention as raw materials to develop thermal and acoustic insulators in green buildings. Leadership in Energy and Environment Design (LEED) certification promotes reduced environmental impact and lower CO_2 emissions using sustainable building materials. One of the standard conditions is that the acoustic and thermal insulation product contains more than 60% of recycled material (21). Our PALF thermal and sound insulated prototype which contained 30% PALF : 60% recycled PET : 10% low melt PET met the requirement of the LEED certificate standard and aligned with market demand to offer functional business value in terms of product variety and standard compliance.

3.5 Cost assessment

The estimated cost and selling prices of PALF insulation material were 317 baht and 397 baht per square meter, respectively. Selling prices of PALF insulation material and other commercially available materials with the same range of density and thickness are shown in Table 4. The selling price of PALF insulation material was higher than commercial glass and asbestos fiber insulation composites but comparable with PET composite materials and competitive with other similar materials in the market.

Table 4 Price of PALF composite and commercial sound-absorbing and thermal insulation products.

Code	Price per square meter (Baht)
A	397
B	400
C	277
D	230
E	108
F	329
G	700

A = PALF insulation, B = PET insulation, C = Glass fiber insulation, D = Glass fiber insulation, E = Asbestos fiber insulation, F = Asbestos fiber insulation, G = Wood wool insulation (14)

4. Conclusions

Batavia PALF from different areas of Thailand was appropriate for use as sound absorption and thermal insulation materials, and showed promise as a commercial product in terms of production technology, market trend and competitive cost. The production supply chain should be developed to promote pineapple fiber as a new raw insulation material on a commercial scale. The trend of heat and sound insulation development is leaning toward sustainable insulation material due to global warming, and compliance with standards and regulations that will be more strictly enforced in the future.

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Declaration of conflicting interests

The authors declared that they have no conflicts of interest in the research, authorship, and this article's publication.

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