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Comparative Study of Thermal Conductivity and Physical Properties of Typha Insulation Sheets with Different Piece Sizes

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Abstract

This research aims to study the properties of thermal insulation sheet made from Typha using different sizes of material pieces. Fresh Typha were shredded and dried, then sorted into 3 sizes: short pieces (< 5 mm), medium pieces (5 - 10 mm), and long pieces (> 10 mm). For each insulation sample was produced using 30 g of dried Typha mixed with 20 g of natural rubber latex (Typha : latex ratio of 1.5:1 w/w). The samples were formed using a hot-pressing method to make 10.0 cm insulation square sheets, with a thickness of 1 cm. The physical properties were investigated by the rate of water absorption and swelling. Thermal conductivity was measured using a heat conduction model HC-074-200, following the ASTM C518 standard. The study found that the short and medium Typha pieces were simple to form, with a consistent density, and bonded well. In terms of physical properties, the long pieces absorbed water at the lowest rate, followed by the short and medium pieces, respectively. All sample sizes show a more than 100% swelling rate, but they could all be submerged in water for a day without disintegrating. All sizes had good thermal conductivity, according to the thermal insulation testing results. The medium pieces had the lowest thermal conductivity (0.0431 W/m.K), followed by the long pieces (0.0453 W/m.K) and the short pieces (0.0539 W/m.K). Based on the analysis of both the thermal and physical properties, it can be concluded that the Typha insulation with medium-sized pieces had the lowest thermal conductivity and good formability, suitable to use as natural insulation material for further development as thermal insulation.

Keywords: Thermal Conductivity; Natural Insulation Sheet; Waste Utilization; Typha

1. Introduction

Building insulation had gained popularity due to rising air temperatures. However, most insulation materials are synthetic, which poses significant challenges regarding disposal and environmental impact. These materials are typically difficult to degrade and persist in landfills for extended periods. Furthermore, the chemicals used in synthetic insulation, such as polyurethane, can decompose into toxic gases like hydrogen cyanide (HCN) and hydrogen sulfide (H2S) when exposed to heat (Tantisattayakul *et al.*, 2018). Similarly, the use of gypsum-based materials may also lead to H2S emissions. Therefore, utilizing natural materials as performance-enhancing agents instead of synthetic fibers in building materials presents a promising alternative to mitigate these environmental concerns. Natural fibers offer several advantages, including low cost, lightweight properties, high strength, and environmental friendliness. Moreover, they can improve various material properties, such as thermal, physical, and mechanical characteristics, depending on the intended application. Various plant fibers have been widely adopted, but for high-performance applications, long, slender fibers with high cellulose content such as cattail, banana, jute, pandan leaves and coconut fibers are considered particularly suitable.

Typha is a common weed found in wetlands and swamps, known for its adaptability to various environments (Charoenphon *et al.,* 2021). It reproduces rapidly through seed dispersal, similar to invasive plant species. A single Typha plant can produce between 20,000 and 700,000 seeds on average (Grace, 1985). Due to these characteristics, Typha can cause significant environmental damage by obstructing sunlight penetration through water body, which reduces photosynthesis in aquatic plants, decreases oxygen production, and negatively impacts aquatic ecosystems (Penno *et al.,* 1999). Additionally, Typha can disrupt land use, interfere with drainage systems, and provide habitats for venomous animals and insects, such as mosquitoes, which are vectors of various diseases, including dengue fever, malaria, encephalitis, filariasis, and elephantiasis.

Despite its harmful impacts, Typha has been recognized for its applications in traditional medicine. Its flowers have been used to stop bleeding and heal wounds (Bajwa *et al.,* 2015). In modern medicine, Typha pollen has been found to treat certain internal disorders, such as kidney stones, menstrual irregularities, and diarrhea (Muntongkaw *et al.,* 2021). Typha also contains bioactive compounds, including sterols, terpenoids, flavonoid glycosides, cerebrosides, and long-chain hydrocarbons (Mitchell *et al.,* 2011). which exhibit immunosuppressive, anticoagulant (Williams *et al.,* 2002). and antimicrobial properties. (Jarchow *et al.,* 2009).

Moreover, Typha is notable for its fiber properties. The leaves of Typha are long, slender, and highly durable, with excellent thermal insulation capability due to their structural composition. Typha leaves consist of epidermis, diaphragm, partitions, and approximately 40% fiber content. The fiber composition includes 63% cellulose, 8.7% hemicellulose, and 9.6% lignin, along with porous foam-like tissues with around 96% porosity, resulting in low density. These properties make Typha fibers particularly suitable for use as thermal insulation materials in building applications.

This study aimed to develop thermal insulation materials using a mixture of natural rubber latex and Typha fibers, with a focus on the effects of different sizes Typha material pieces formation the insulation sheet. The physical and thermal properties of the resulting materials were evaluated to enhance the value of natural resources as sustainable alternatives to synthetic insulation materials. This approach contributes to minimizing construction waste issues by promoting the use of environmentally friendly materials.

2. Materials and methods

2.1 Materials

Typha (Typha angustifolia Linn.), was used as the primary material for thermal insulation. The Typha plants were sourced from a community wastewater treatment system, that were 70-100 cm in height from the base of the stem and had a body greater than 3 cm. The leaf tips were trimmed, and the plants were sun-dried for 4-5 days to reduce moisture content. After drying, the dried Typha were processed through a crushing machine to reduce their size. The shredded materials were sorted into three sizes: short pieces (< 5 mm), medium pieces (5-10 mm), and long pieces (> 10 mm). The materials were sorted through sieves with mesh sizes of 5 mm, 10 mm, and 20 mm, respectively. After sieving, the materials were washed to remove any dirt and then sun-dried. High ammonia latex (HA) was a latex which had 0.7% ammonia solution added to maintain lifespan of the latex. The latex used in this research was obtained from C.M. Laticase (Thailand) Limited Partnership and was used as a binder to hold the materials together.

Figure 1. Preparing the Typha materials

2.2 Sample Preparation

The samples were prepared with a Typha to latex ratio of 1.5:1 by weight. The Typha was mixed with rubber latex and stirred for 5 minutes. The mixture was poured into a mold with dimensions of 10 x 10 x 1 cm, and the surface was leveled for uniformity. The mold was placed in a heat compression molding machine set to a temperature of 150 ºC and a pressure of 90 MPa for 15 minutes. After the molding process, the samples were removed from the mold and placed in a hot air oven at 40 ºC for 4 hours, followed by drying in the shade. The samples were weighed and tested for their thermal and physical

2.3 The Thermal and Physical Properties Testing

1) The Density: The density of the samples was calculated using Equation (1) by dividing the weight (g) of the sample by the volume of the sample piece (m^3)

$$d = \frac{m}{v} \quad (1)$$

where; d = the density (g/m^3), m = the weight of the heat insulation sheet (g) and v = the volume of the heat insulation sheet (m^3).

2) The water absorption rate: The water absorption rate was determined by first weighing the sample and recording the initial weight. The sample was soaked in water for durations of 15 minutes, 60 minutes, and 1 day. After each specified time, the sample was weighed again, and the water absorption rate was calculated using Equation (2).

$$WA = \frac{(W1-W2)}{W1} x100 \quad (2)$$

where; wa = The water absorption rate (%), w1 = initial weight (before soak) (g) and w2 = weight after soak (g)

3) The swelling test of materials was done by measuring the thickness of the sample. Then, the sample was soaked in water with the edge of the sample away from the wall and bottom of the container for 1 day. After that, the sample was lifted up to absorb water and was left to air dry for 1 day. The thickness of the sample was measured and the swelling rate was calculated according to equation (3).

$$TS = \frac{(T2-T1)}{T1} x100 \quad (3)$$

where; TS = The swelling rate (%), T2 = The thickness after soaked (g) and T1 = The thickness before soaked (g)

4) Thermal Conductivity Test: The thermal conductivity test was conducted using a Heat Flow Meter (HC-074-200) following the ASTM C518 standard at the Centre of Building Innovation and Technology (CBIT). The sample with dimensions of 20 × 20 × 1 cm was placed between the hot plate and cold plate of the Heat Flow Meter. The device lid was closed to ensure direct contact between the sample and the plates. The temperatures of the hot and cold plates were set to maintain an appropriate temperature difference. The apparatus operated by transferring heat from the hot plate through the sample to the cold plate. The thermal conductivity of the specimen was recorded as the thermal conductivity coefficient (k), expressed in units of watts per meter kelvin (W/m·K).

3. Results and Discussion

3.1 Physical characteristics of different types of insulation sheets

Thermal insulation sheets were fabricated using three different Typha piece sizes: short (< 5 mm), medium (5 – 10 mm), and long (> 10 mm). The Typha pieces were mixed with natural rubber latex at a weight ratio of 1.5:1. All three sizes could be successfully formed into thermal insulation sheets. However, the short and medium-sized Typha exhibited good bonding with the rubber latex, resulting in smooth and flexible surfaces. These sheets could be easily bent without cracking, which was attributed to the diverse anatomical structures of Typha leaves, ranging from crescent to less concave shapes, enhancing the mechanical properties of the composites. (Muntongkaw *et al.,* 2021).

In contrast, sheets made from long Typha pieces displayed poor adhesion between the fibers and the rubber latex. This issue was likely due to the uneven latex distribution during the manufacturing process, as the latex could not fully penetrate the long fiber structures. Consequently, the latex only adhered to the material's surface, producing rough, inflexible sheets that were prone to cracking and difficult to bend (Charoenphon *et al.,* 2021).

3.2 Density of the Thermal Insulation Sheet

The density results showed that the thermal insulation sheet made from short pieces Typha had the highest density at 0.4112 g/m³, followed by long pieces at 0.386 g/m³, and medium pieces at 0.365 g/m³ as shown in Figure 2. This result was followed that the density of the thermal insulation sheet would decrease with the size of the Typha (Jakob Gößwald *et al.,* 2021). This relation could be attributed to the small and slender of the short pieces Typha, resulting in smaller pores and density consistency within the sheet. The small pieces had stronger internal bonding when compared to medium and long pieces of Typha sheet. Additionally, the smaller size of the Typha led to less material loss during the manufacturing process, contributing to a higher weight and density of the sample sheet.

3.3 Water Absorption Rate and Swelling Rate of the Thermal Insulation Sheets

Figure 3 showed that the thermal insulation sheets made from all three-piece sizes of Typha exhibited high water absorption rates, exceeding 100%. The sheet made from long pieces had the lowest initial water absorption rate of 102.98% within the first 15 minutes but reached the highest rate of

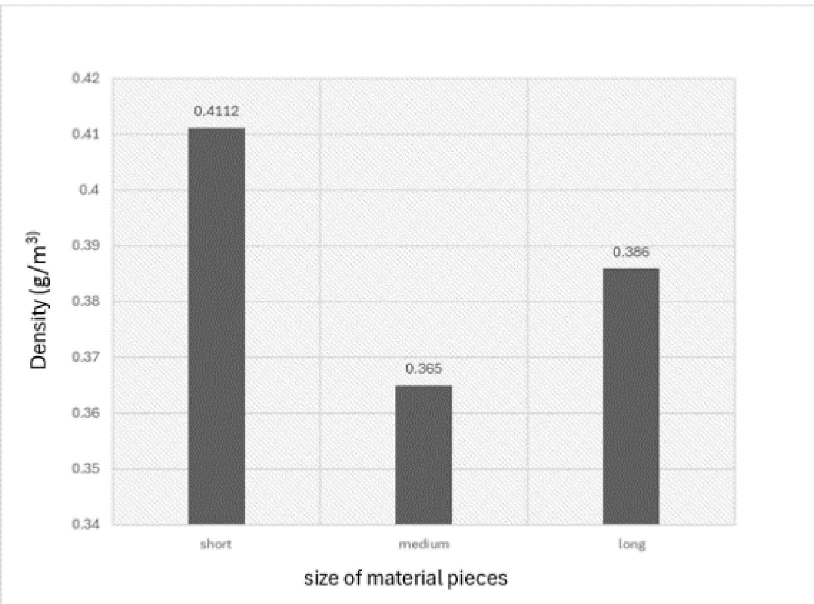

Figure 2. Density of the sample sheet

493.86% after 24 hours. This was the nature of the material, as the Typha fibers in the large sheet tended to separate and create larger gaps when submerged in water over time (Tserki V *et al.,* 2006). In comparison, the sheets made from short and medium pieces had water absorption rates within the first 15 minutes as 147.3% and 185.04%, respectively. This suggested that the water absorption rate increased with the amount of Typha used or, equivalently, with the density of the sheet (Zhao *et al.,* 2020). A comparison of the water absorption rate graph as shown in Figure 3 and the density graph (Figure 4) revealed that the water absorption rate increased with increasing density up to 60 minutes. Due to the sheets made from short and medium pieces reached saturation more quickly than the long pieces sheet. Additionally, the smaller Typha fibers did not disintegrate as much over time, resulting in a less significant increase in water absorption after 24 hours.

In terms of swelling rate, the thermal insulation sheets made from short and medium-pieces sized of Typha exhibited high swelling rates, similar to their water absorption rates, at 130% and 75%, respectively, as shown in Figure 5. However, when both sizes were soaked for a day, no detachment of Typha sheets was observed, as shown in Figures 6 and 7. This is in contrast to the thermal insulation sheet made from long pieces of Typha, where sheet detachment occurred, making it impossible to measure the sheet's thickness.

3.4 Thermal Conductivity of the Thermal Insulation Sheets

Thermal conductivity tests revealed that the thermal insulation sheets made from all three piece sizes of Typha exhibited thermal conductivity values within the range of 0.054-0.045, as shown in Table 1.

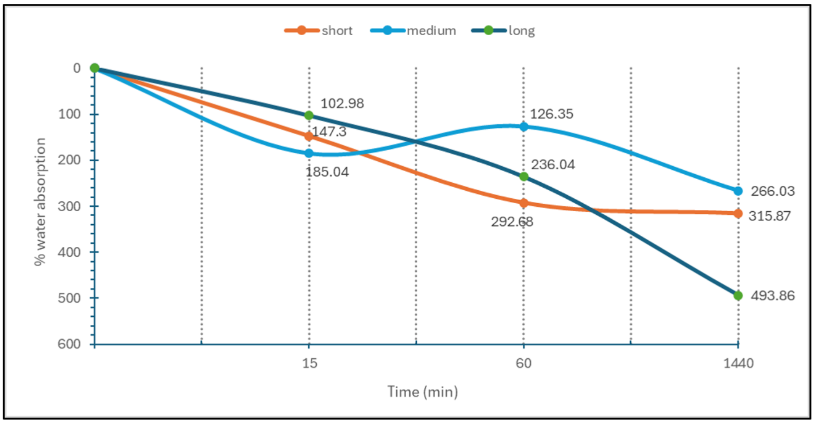

Figure 3. Water Absorption Rate

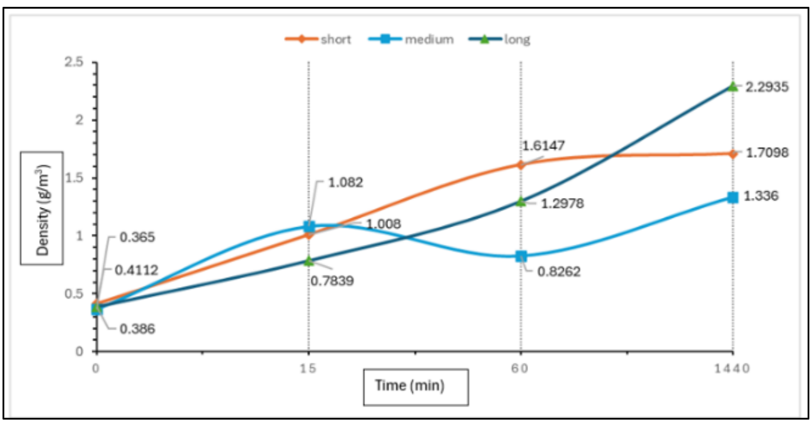

Figure 4. Change of Density after soaked in water for 15 min, 60 min and 1 day

Specifically, the sheet made from short pieces had the highest thermal conductivity coefficient of 0.0539 W/m.K, followed by the long pieces at 0.0453 W/m.K, and the medium pieces at 0.0539 W/m.K. These results indicate that the thermal conductivity of the insulation increased with density. This is because the smaller, thinner Typha fibers in the small sheet were compressed more during the forming process, resulting in fewer voids within the sheet compared to the other two sizes. Additionally, the smaller Typha fibers had better adhesion with the rubber latex, leading to a greater replacement of air gap by latex. Consequently, the thermal insulation sheet made from short pieces had a higher heat transfer rate compared to the other two sizes. This finding was related with the study by Pusit and Anchisa (2012) which showed that adding coconut and palm fibers to cement composites resulted in a decrease in thermal conductivity as the porosity of the sheet increased and its density decreased.

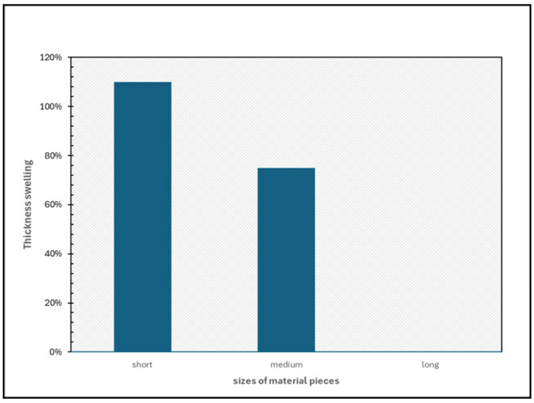

Figure 5. The swelling rate

Figure 6. Typha thermal insulation sheet

Figure 7. Typha thermal insulation sheet after soaked

Table. 1 Thermal Conductivity

Materials	Density (g/m^3)	Conductivity, K (W/mk)
Typha short pieces	0.4112	0.0539 ± 0.006
Typha medium pieces	0.365	0.04131 ± 0.007
Typha long pieces	0.386	0.0453 ± 0.007

4. Conclusion

To compare the qualities of Typha sheets made from three different piece sizes, it was observed that smaller pieces allowed the heat press to compact the material more tightly during the forming process. The small piece size of Typha enabled the latex to penetrate the voids within the material more effectively than in the medium and long pieces, resulting in a stronger, smoother, more flexible, and higher-density sheet.

Regarding physical properties, the use of Typha sheet in production led to high water absorption and swelling rates, attributed to the hydrophilic nature and high porosity of Typha. Among the three sizes, the medium pieces exhibited the highest water absorption rate, followed by the short and long pieces, respectively. In terms of thermal properties, the medium pieces had the lowest thermal conductivity coefficient, followed by the long and short pieces. This is because materials with lower density typically have lower thermal conductivity due to the presence of more air voids, which reduce heat transfer.

In conclusion, Typha sheets made from all three piece sizes were successfully used to produce natural thermal insulation sheets with favorable thermal properties. However, for optimal performance as a natural thermal insulation material, medium-sized Typha pieces are recommended due to their balanced characteristics and insulation properties.

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