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Properties of natural fiber cement materials containing coconut coir and oil palm fibers for residential building applications

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HIGHLIGHTS

- Natural fibers from agro-waste (coconut coir and oil palm fiber) were studied.
- Effects of natural fibers mixed in fiber cement materials were investigated.
- Natural fiber cement products yield acceptable physical and mechanical properties.
- Use of natural fibers in fiber cement materials can reduce thermal conductivity.
- Natural fiber cement products can be used to improve energy efficiency in building.

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ABSTRACT

This article presents an investigation of the properties of natural fiber based composite building materials that is applicable for hot and humid climatic regions. These materials were made of cement mortar containing coconut coir fiber and oil palm fiber, both waste products from agricultural manufacturing in Thailand. They are intended to be used as roof sheet and siding to reduce heat transfer through buildings and energy conservation. The investigation focused mainly on the effects of both cellulose fibers on the physical, mechanical and thermal properties of products. Test results showed that increasing the percentage replacement of natural fibers tends to reduce the density, compressive strength and flexural strength of the materials. Fiber cement products mixed with coconut fiber yielded lower density than that of oil palm fiber. The mixtures of fiber cement products containing up to 15% of both natural fibers by weight of binder yielded the acceptable physical and mechanical properties. Furthermore, the thermal conductivity of the natural fiber cement sheets was 60% less than that of the control specimen. The results of this research can be used as a guideline for using agricultural residues to develop fiber cement products for residential building applications.

1. Introduction

The roof is one of the most important parts of a building. In Thailand, there are currently many different types of roof sheets, made from various materials, which users can select according to their price and usability. At present, 60 percent of low- to moderate-income consumers use cement roof sheets, and of them 75 percent select asbestos cement roof sheets [29] as the price of an asbestos cement roof sheet is only 5 to 6 US Dollars per square meter [10] – an acceptable price for low- to moderate-income people in Thailand. In addition, these asbestos cement roof sheets provide good thermal properties and adequate fire durability, strength and flexibility. However, this type of roof sheet also contains toxic substances that enter the body through the respiratory system and can cause conditions such as Asbestosis, chronic lung disease, malignant pleural disease, tumors, and cancer of the lung and other parts of the body [30]. Alternatively, there are other types of roof sheet which are safer to human health, such as concrete roof sheets, ceramic roof tiles and fiber cement roof sheets with a range of prices and physical properties.

In terms of research, there has already been substantial work on the use of fiber cement products as insulation materials for roofs, ceilings and walls. Natural fibers have the potential to be developed into a highly effective material that does not generate pollution in its production process [13]. Moreover, natural fiber products in other countries can also be made using alternative types of fiber that are suited to the particular climate of the region. However, previous research in this area has mostly focused on the development of the mechanical properties of these products. Only

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a few of them have examined their thermal properties. There has been an increasing demand in the real estate market among low-to-moderate income home buyers in Bangkok and metropolitan areas, especially for single detached homes and townhouses [25,31]. These buildings use air conditioning units to provide comfortable indoor temperatures and humidity levels in Thailand's tropical climate. However, most of them lack consideration of the appropriate architectural design and building envelope materials that would reduce their energy consumption. As a result, electricity bills rise due to increased energy consumption due to higher cooling loads. This research therefore aims to develop natural fiber cement roof sheets with better thermal properties to reduce the amount of heat that goes into a residential building, and also to reduce energy consumption.

Coconut is one of the most common food and industrial crops, mostly found in the coastal provinces of Thailand due to its tropical climate. The coconut coir fiber can be removed from the coconut husk by hand or machine and is widely available to use as a raw material in fiber cement products due to its quantity, price, suitable mechanical properties, non-toxicity and chemical reactibility [3]. However, there is waste from coconut processing that when discarded or burnt may create problems for the environment. Brown and white coconut coir fibers are two commercially available types of coirs. Brown coir is extracted from fully mature coconuts, whereas white coir is obtained from green coconuts. Normally, the coconut coir fiber is 350 mm in length, 0.12–0.25 mm in diameter and 1250 kg/m^3 in density. Coconut fiber has one of the highest amounts of lignin coating, which makes it stronger than most other types of natural fiber: only banana fiber has a greater tensile strength. Its resistance to microbial degradation and salt water is also unique [15].

Thailand has many oil palm plantations in areas such as Krabi, Suratthani, Chumphon and other provinces, totaling around 3250 square kilometers with a productive capacity of around 700,000–800,000 tons of unprocessed palm oil annually. Due to its low price, demand for palm oil has been increasing continuously and the industry has grown steadily in response. Moreover, the processes and procedures in oil palm production started from sorting the quality of palm fruit bunch out of palm fruit. The waste oil palm residue extracted from the pure oil palm represents 12 percent of the oil palm bunch and can be used for other purposes, such as fiber production or fuel [12]. There are many other kinds of palms, such as Date and Raphia, but only the oil palm is important to the Thai economy because there has been continuous domestic growth. The characteristics of oil palm fiber waste have 20–100 mm in length, 0.2–0.8 mm in diameter, and 1300–1450 kg/m^3 in density. Moreover, it has similar mechanical properties to coconut coir fiber because the cell wall of fiber is relatively thick and so less susceptible to chemical reactions [16]. As a result, it must first be washed, boiled, and chemically treated before mixing it with other materials.

In research and development of fiber cement products primarily focused on the mechanical properties, most researchers investigated natural fibers with a length between 10–60 mm [21,2,26,4] to perform the compressive, flexural and other tests to meet the standards. This study focused on enhancing the thermal properties of fiber cement product, and the natural fibers with a length in the range of 5–10 mm were used. The longer fibers can create larger pores within the cement matrix which caused an impact on the thermal insulation properties of the product [18]. There are three main sources of electrical energy consumption in residential buildings in hot-humid climate, namely in descending order of energy consumed: air-conditioning, electric appliances and artificial lighting [23]. The aspect of residential buildings that most influences their reliance on air-conditioning is the building envelope components, particularly the thermal properties of wall and roof [20,11].

This research aims to study and develop fiber cement products made from natural materials, including coconut coir fiber and oil palm fiber, to be used as roof sheets and wall panels. The choice of material is expected to be widely used in the markets of Thailand, located in the tropical region, due to their lower production cost and the fact that they contain no harmful toxic substances. At present, commercially available fiber cement tiles are produced using combination of natural and synthetic fibers, which have similar properties compared with other types of roof sheets and are often more durable, with better impact resistance and heat insulation compared to asbestos cement roof sheets. Furthermore, the production of fiber cement roof sheets using natural fibers is still low. Therefore, once the use of these natural materials increases, the production costs will be reduced and natural fiber will be a viable alternative to synthetic materials, which waste both energy and resources in their production.

2. Experimental program

2.1. Materials

The materials used in this study included ASTM Type 1 Portland cement, limestone powder, sand, water and natural fibers at the levels of 5%, 10% and 15% by weight of binder. ASTM C494 Type G high-range water reducer was used to make the fiber uniformly distributed. The water-binder (w/b) ratio was 0.25, which is applicable for fiber cement materials in the manufacture of roof sheets and sidings [13]. Two types of natural fibers, coconut coir and oil palm fibers were cut into lengths of 5–10 mm. For pretreatment of fibers (Fig. 1), the raw fibers were washed with water until the pH was approximately 7, and boiled for 2 h in water to sufficiently reduce water soluble chemicals such as sugar, starch, fat, resin, quinines, tannins and phenols, and then oven dried at 100 °C for 24 h. The chemical and physical properties of both fibers were also studied. Mix proportions of natural fiber cement mortars studied are summarized in Table 1. OPC denotes the control cement mortar mixed with Portland cement Type 1. C(X) and P(X) denote cement mortars in which coconut coir fiber and oil palm fiber, respectively, were used as Portland cement replacements at X% by weight of binder. After the fiber cement mortar was properly mixed, it was cast into the molds for preparation of tests. The vibrating table was used to consolidate the fiber cement mixture.

2.2. Cement mortars

The physical and mechanical properties of cement mortars were performed in accordance with ASTM C20 and ASTM C109 standards [5,6] respectively to determine the optimal fiber-to-cement weight ratio of fiber cement mortars. The second experiment, following JIS R 2618 standards [17], examined their thermal properties. These were boiled and dried to treat the fibers and then, using fiber-to-cement weight ratios of 5%, 10%, and 15% as shown in Table 1, were cast into specimen cubes of 5 × 5 × 5 cm and 5 × 5 × 2.5 cm (for the thermal property tests).

In accordance with ASTM C20 standards, the cement mortars were tested for the following mechanical properties: volume of open pores and impervious portions, apparent porosity, water absorption, and bulk density. These were determined by weighing the cement mortar cube samples and then drying them at 100 °C for 2 h to gauge their dry weight (D) before soaking them in water for 12 h to measure their suspended weight (S). Finally, they were wiped with a dry cloth to absorb water droplets and then measured again for their saturated weight (W). The final results for the different cement mortars were derived from the average of 3 separate samples. They were then soaked in water for 28 days and then tested for their compressive strength.

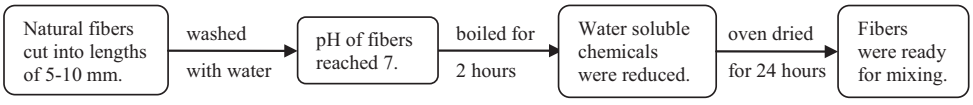

Fig. 1. Natural fiber pretreatment process.