Transactions of the Materials Research Society of Japan 29[5] 1941-1946 (2004)

Development of construction materials with low thermal conductivity from agricultural waste

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The study on the use of young coconut fiber as natural fiber source to develop composite construction materials was carried out by mold compressing technique. The various amount of binder and fiber content were conducted. Their properties such as thermal conductivity, bulk density and water absorption were determined. Moreover, the heat transfer between outer and inner surface of simulated dwelling constructed from the fiber cement block was also investigated.

The result shows that the thermal conductivity and bulk density of composite specimen composed of young coconut fiber were lower than those of common mortar, commercial cement block and brick. The optimum fiber content of fiber cement block was about 25%. Its thermal conductivity and bulk density were 0.1893 W/mK and 1,065 kg/m^3 comparing to those of common mortar of 1.3970 W/mK and 1,888 kg/m^3 respectively. When using fiber cement block, commercial cement block and brick to construct simulated dwelling, it was found that heat transfer through fiber cement block was lower than that of commercial cement block and brick. It was also found that the average temperature different between outer surface and inner surface of fiber cement block was about 7°C while that of commercial cement block and brick was about 3°C. The result suggested that fiber cement block provide energy saving properties of the construction.

Key words: Low thermal conductivity, fiber cement block, energy conservation, composite construction materials, agricultural waste.

1. INTRODUCTION

Several papers [1-6] have reported the use of natural fibers, such as coir (coconut fiber), sisal, kenaf, jute, to produce natural composite materials in forms of reinforced corrugated slabs, medium density fiber (MDF) boards and roofing sheets. Those studies have aimed at value-added applications of natural fibers for lightweight construction materials for low cost housing.

Natural fibers are available abundantly in Thailand. Among the natural fiber sources, young coconut fiber has not been exploited yet and was left as agricultural wastes. This has resulted in more accumulation of municipal waste problem of the kingdom.

Due to the rapidly diminishing oil supply and increasing of oil price, energy concerns by all means of energy saving are paid attention closely. Recent studies [7,8] reported the fiber-matrix bonding and mechanical performance of the coir-Portland cement composites. In addition, *Cocos nucifera* was reported to be an efficient heat insulator for building materials. The previous work [9] suggested the possibility of the use of coconut fiber to form lightweight composite construction materials with low thermal conductivity. However, further investigation is required in determining the heat transfer surfaces of fiber cement composite block when being implemented.

The purpose of this study was to develop composite construction materials from young coconut (*Cocos nucifera*) fiber to be a light weight and low thermal conductivity materials. This fiber cement block was studied to determine its properties in terms of energy saving comparing to the commercial construction materials.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Young coconut (*Cocos nucifera*) fiber was used in this study as the source of natural fiber. Cement Type I and commercial lime and rubber latex as binder materials were used to form fiber cement block.

2.2 Preparation of fiber cement block

Before forming fiber cement block, young coconut fibers were prepared. In the preparation, young coconut hull was cut into small size.

It was then soaked in water and adjusted pH to 7-8. After being dried, fiber was classified its size by passed through U.S sieve No. 4. The fiber size of less than 5 mm was used in the study.

The setting time of portland cement-bonded wood composite boards could be reduced by the addition of additives or admixtures [10-11]. The admixtures are usually one of the following agents; aluminum sulfate (in combination of calcium hydroxide or lime water), calcium chloride, magnesium chloride or calcium acetate. In this study, lime water and latex were selected as admixture or binder to reduce its setting time for fiber cement block preparation. The properties of fiber cement block made with varying amount of binder (30% and 50%) and fiber content (10-25%) were determined.

Cement, young coconut fibers and binder were weighed according to the desired ratio. The mixture was mixed well and compressed in 150x300x50 mm^3 mold. In this present work, the fiber cement block was prepared by mold compressing technique in order to reduce water content in its mixture. The pressure applied in compressing was 100 kg/cm^2. The fiber cement blocks consisted of cement, various portions of fiber and binder were carried out.

The flow chart of fiber cement block preparation is shown in figure 1.

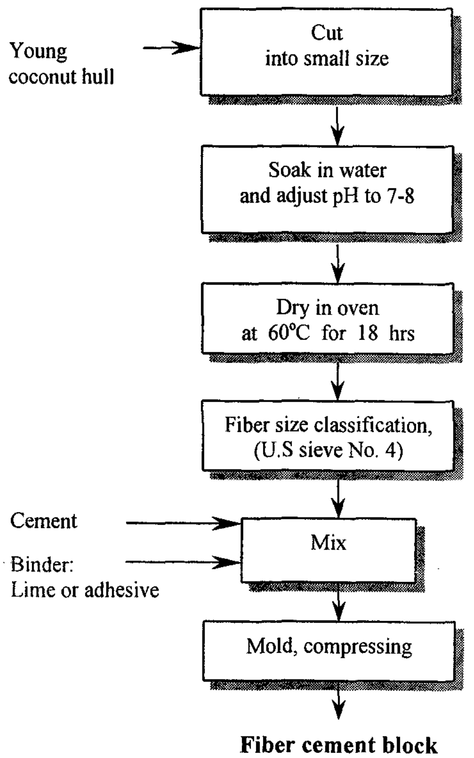

Fig 1. Flow chart of fiber cement block preparation.

2.3 Determination of thermal conductivity

Principally, thermal conductivity, k, can be determined from the following expression [12]:

$$q_c = \frac{2kA(\theta_1 - \theta_2)}{d} \qquad \text{..........(1)}$$

where

q_c = *rate of of heat flow over test area*
k = *thermal conductivity*
A = *test area normal to path of heat flow*
$\theta_1 - \theta_2$ = *temperature difference over the distance, d*
d = *mean thickness of specimen*

The measurement of thermal conductivity involves the measurement of heat flux and temperature difference of sample surface. As hot wire method is commonly used to measure refractory brick of low thermal conductivity [13], this method with sensor probe was applied in this study.

The thermal conductivity of the fiber cement blocks were determined according to ASTM C 1113 [13] by Hot Wire Method, Quick Thermal Conductivity Meter, Kemtherm KEM model QTH-500, with PD 11 sensor probe, dimension 110 W x 50 D x 100 H mm^3. Its measurement working range was 0.023 to 11.63 W/m K. The thermal conductivity value were taken and averaged from 5 measurements, lengthwise.

2.4 Determination of heat transfer surface

The simulated dwelling of one cubic meter were constructed by using fiber cement block, commercial cement block and brick as construction materials. They were constructed in the size of 1x1x1 m^3, covered with roof and exposed directly to sunlight. Three constructs were tested their heat transfer surfaces under the sun in summer. Their outer and inner surfaces were contacted with thermocouple Type K. The temperature were recorded continuously by Data Logger, Fluke 2280B, 100 channel, 1 sec time interval.

2.5 Determination of physical properties

Coconut fibers, or so-called coir, has a low elastic modulus and is sensitive to moisture change [14]. In the present study, the characteristic performance related to its sensitive properties such as tensile stress, water absorption and thickness expansion were determined. Water absorption and thickness expansion were determined after soaking the fiber cement blocks in water 24 hours.

3. RESULTS AND DISCUSSION

3.1 Thermal conductivity and physical properties of fiber cement blocks

Table I summarizes the properties of the fiber cement blocks from various mixtures. The relationships between fiber content and its properties were shown in figures 2-6.

From figure 2, the results show that higher fiber content resulted in lower thermal conductivity. The prepared fiber cement block with lower lime portion has lower thermal conductivity than those prepared with higher lime portion and with latex as binders. Likewise, higher fiber content and lower lime portion resulted in lower bulk density (figure 3). In other words, the lightweight material with lower thermal conductivity can be achieved with higher fiber content and lower lime portion in the fiber cement block prepared.

Table I. The properties of fiber cement blocks by mold compressing technique.

Sample No.	Mass ratio of Cement : fiber* : lime** : latex**	Thermal conductivity (W/mK)	Bulk density (kg/m^3)	Tensile stress (MPa)	Water absorption after 24 hrs (%)	Thickness expansion after 24 hrs (%)
C1	1 : 25 : 30 : 0	0.1500	850	0.8334	34.02	0.82
C2	1 : 25 : 50 : 0	0.1893	1,065	2.7464	32.04	0.50
C3	1 : 25 : 0 : 30	0.1676	828	0.2081	41.05	1.50
C4	1 : 20 : 30 : 0	0.1789	904	0.000	35.02	0.67
C5	1 : 20 : 50 : 0	0.2678	1,098	3.1155	29.81	0.36
C6	1 : 20 : 0 : 30	0.2274	1,028	0.000	35.84	1.00
C7	1 : 15 : 30 : 0	0.2414	1,148	1.3084	23.46	0.00
C8	1 : 15 : 50 : 0	0.2828	1,187	3.7717	23.62	0.00
C9	1 : 15 : 0 : 30	0.3075	1,222	5.1712	24.56	0.00
C10	1 : 10 : 30 : 0	0.3808	1,312	7.2838	14.13	0.00
C11	1 : 10 : 50 : 0	0.4008	1,848	12.4867	15.52	0.00
C12	1 : 10 : 0 : 30	0.3986	1,359	11.3703	18.93	0.00
Common mortar	-	1.3970	1,888	na***	na***	na***

* % of cement , ** % of fiber, *** not available

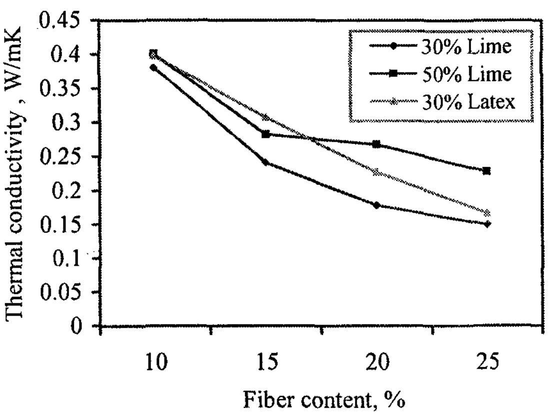

Fig. 2 Thermal conductivity of fiber cement block versus % fiber content for different binders.

Figures 4, 5 and 6 represent the tensile stress, water absorption and thickness expansion plotted as varying amount of binders and fiber content, respectively. As the fiber content increased, tensile stress decreased while water absorption and thickness expansion increased dramatically. It is interesting to note that there was no expansion in thickness when the fiber cement block containing of fiber content of less than 15%. However, their water absorption were still ranging from 14% to 23%.

The attempt was made to maximize the use of coconut fibers and also to reduce water content in the composite block. In addition, its properties must be suitable for energy conservation construction materials. Table II shows the k value of commonly used building materials. Generally, the material of lower thermal conductivity performs better insulation properties which leads to energy conservation.

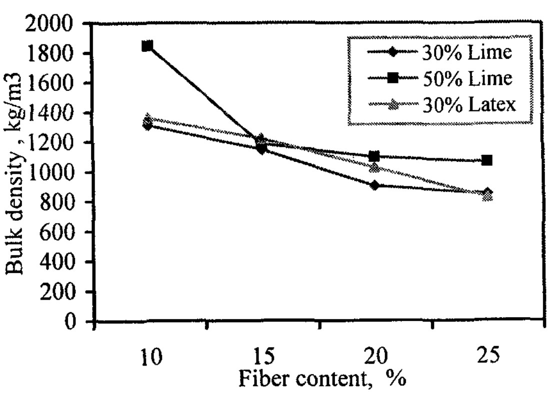

Fig. 3 Bulk density of fiber cement block versus % fiber content for different binders.

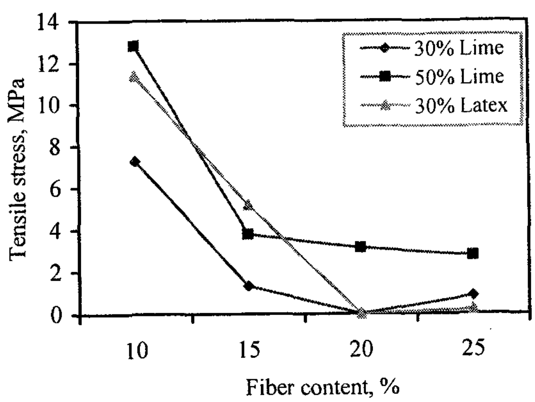

Fig. 4 Tensile stress of fiber cement block versus % fiber content for different binders.

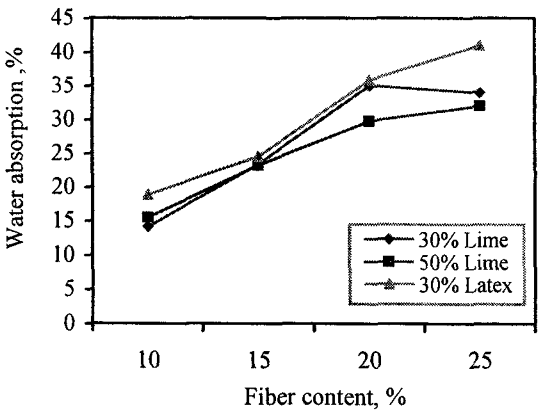

Fig. 5 Water absorption of fiber cement block versus % fiber content for different binders.

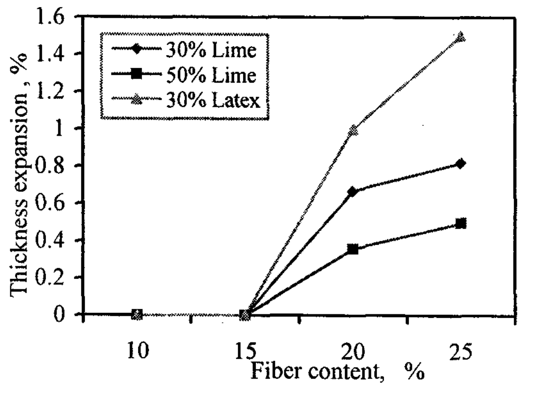

Fig. 6 Thickness expansion of fiber cement block versus % fiber content for different binders.

Judging from the experimental results and the mentioned consideration, the best mixture for the preparation of fiber cement block contained 25% fiber content with 50% lime water. Its thermal conductivity and bulk density were 0.1893 W/mK and 1,065 kg/m^3 comparing to those of common mortar of 1.3970 W/mK and 1,888 kg/m^3, respectively. It also suggested that the fiber cement block prepared was suitable for energy conservation construction materials such as panel, partition and wall for interior use where subjected to non-load bearing.

Table II. Thermal conductivity of construction materials [15,16].

Materials	Thermal conductivity (W/mK)
Brick (9% moisture)	0.80
Clay	1.28
Tiles	0.836
Concrete	1.10
Earth (Coarse gravelly)	0.52
Asbestos cement boards	0.65
Asbestos insulating boards	0.108-0.115

3.2 The heat transfer of the simulated dwelling

The heat conduction properties of the panels made from fiber cement block comparing with those from commercial cement block and brick were evaluated.

Figure 7 indicates the outer and inner surface temperature of test panels made from fiber cement block, commercial cement block and brick during 24 hours. It was found that the temperature difference between outer surface and inner surface of fiber cement block was higher than that of commercial cement block and brick along the testing duration. At the maximum temperature, it shows that the temperature difference between outer surface and inner surface of fiber cement block was about 7°C while that of commercial cement block and brick was about 3°C.

Table III shows the properties of experimental construction materials comparing to common mortar. It was suggested that fiber cement block was lighter than common mortar, commercial cement block and brick. Moreover, the heat transfer through fiber cement block was lower than that of commercial cement block and brick.

Figure 8 shows the comparison of outdoor temperature with the inside air temperature of test panel made from fiber cement block, commercial cement block and brick during 24 hours. Since the thermal conductivity of fiber cement block was lower than that of commercial cement block and brick, it was expected that heat transfer through fiber cement block would be a lot lower and resulted in its lower air temperature inside. The experiment showed that the inside air temperature of test panel made from fiber cement block was only slightly lower than those constructed from brick and commercial cement block at the daytime. It can be explained that once heat transferred through test panel, it was accumulated inside. In addition, the size of simulated dwelling constructed was too small to provide enough space for air circulation inside. This resulted in little difference in air temperature inside those three simulated dwelling constructions.

Table III. Properties of experimental construction materials comparing to common mortar.

Sample	Thermal conductivity W/mK	Bulk density kg/m3	To-Ti * (°C)
Common mortar	1.3970	1,888	na**
Fiber cement block ***	0.1893	1,065	7
Cement block	1.0895	1,230	3
Brick	0.3789	1,626	3

* *To-Ti is the temperature difference between outer surface and inner surface at maximum temperature.*

** *not available*

*** *composite made of young coconut fiber, 25% fiber content, 50% lime*

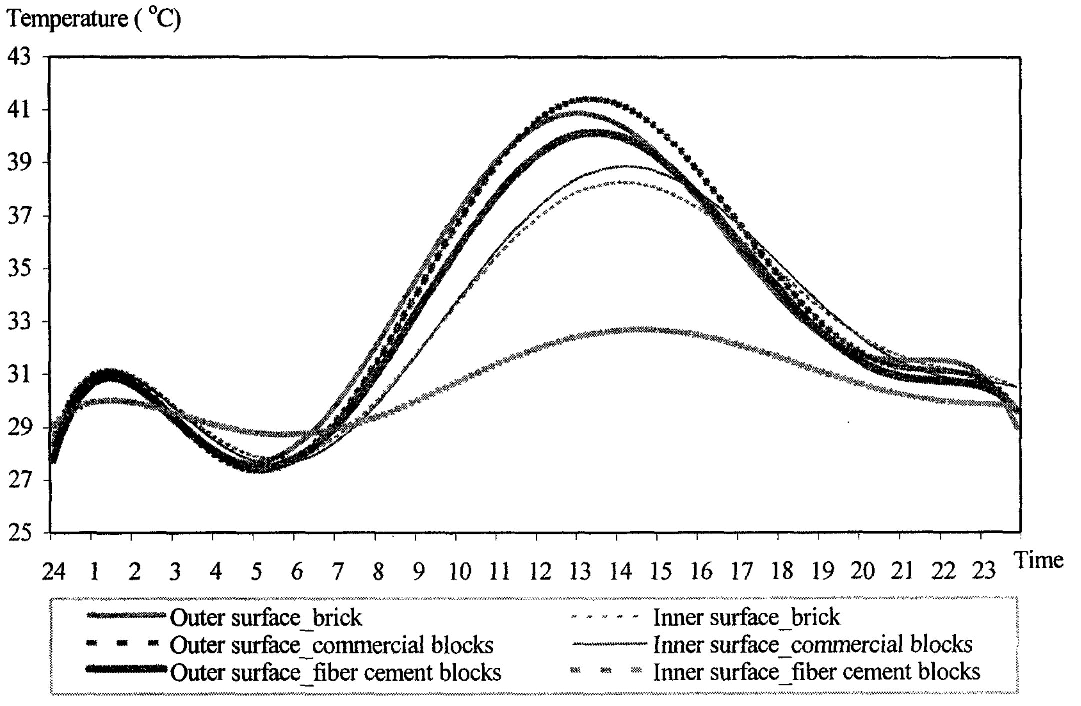

Fig. 7 The outer and inner surface temperature of test panels made from fiber cement block, commercial cement block and brick during 24 hours in April 7, 2002.

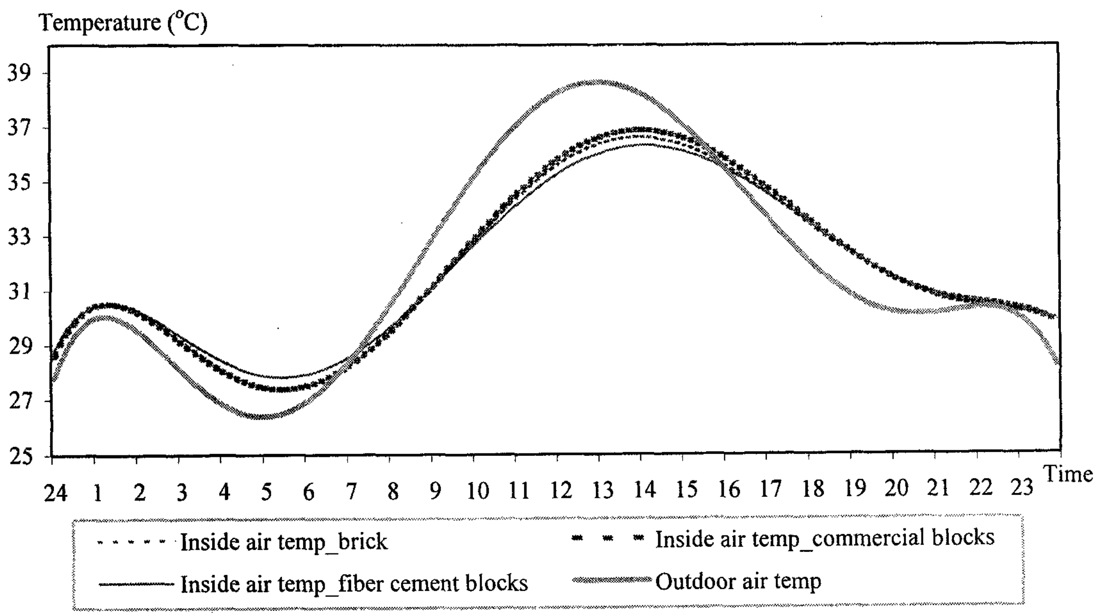

Fig. 8 Comparison of outdoor temperature with the inside air temperature of test panel made from fiber cement block, commercial cement block and brick during 24 hours in April 7, 2002.

4. CONCLUSION

- The thermal conductivity of composite specimen composed of young coconut fiber were lower than those of common mortar, commercial cement block and brick.
- The optimum fiber and binder content for the fiber cement block preparation was 25% and 50% lime. Its thermal conductivity and bulk density were 0.1893 W/mK and 1,065 kg/m^3 comparing to those of common mortar of 1.3970 W/mK and 1,888 kg/m^3 respectively.
- In the evaluation of the test panels made from fiber cement block comparing with those from commercial cement block and brick under outdoor exposure, it was found that heat transfer through fiber cement block was lower than that through commercial cement block and brick. The average temperature different between outer surface and inner surface of fiber cement block was about 7°C while that of commercial cement block and brick was about 3°C.
- The composition of fiber cement block prepared was suitable for energy conservation construction materials such as panel, partition and wall for interior use where subjected to non-load bearing.

ACKNOWLEDGEMENTS

Special thanks are extended to AIST and TISTR for the kind support and opportunity provided for the author to participate in the 6th International Conference on Ecomaterials (ICAM2003).

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(Received October 10, 2003; Accepted October 31, 2003)