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Thermal conductivity of coconut fibre filled ferrocement sandwich panels

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HIGHLIGHTS

- ▶ The potential use of coconut fibre as thermal isolating filler for ferrocement panel walls.
- ▶ Ferrocement sandwich panels filled with coconut fibre exhibit lower thermal conductivity than the extreme cases tested.
- ▶ Ferrocement sandwich panels filled with coconut fibre present lower thermal conductivity than traditional materials.
- ▶ Coconut fibre loading content has some influence on thermal conductivity.

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ABSTRACT

This study evaluates the potential use of coconut fibre as thermal isolating filler for ferrocement panel walls in sandwich configuration of schools and houses' roofing in Puerto Escondido, Oaxaca, Mexico. Thermal conductivity measurements were performed to compare the thermal behaviour of ferrocement panel walls filled with coconut fibre to other typical building materials of the region. Measured thermal conductivities for red clay brick, hollow concrete block and lightweight concrete brick panel walls are 0.93, 0.683 and 0.536 W/m K respectively. Thermal conductivity of the proposed configuration is 0.221 W/m K and that is lower than typical materials used for home-buildings in this region.

1. Introduction

In the coast of southern México, specifically Puerto Escondido, Oaxaca the climate is hot and semi-humid presenting an average daytime temperature of 28 °C but can reach peak temperatures up to 34 °C during the summer. This location is situated 60 m above sea level at geographic coordinates 15°51′43″N, 97°4′18″W in the southern coast of Oaxaca [1,2]. The dominating vegetation type is medium subdeciduous forest and lowland deciduous forest with annual rainfall that normally varies from 500 to 1500 mm [3,4]. In order to have certain comfort under such circumstances, air coolers that normally consume an important amount of energy are used. This energy consumption can be reduced making use of construction materials with biodegradable fibres as an alternative to reduce energy consumption in house living, waste isolating materials and help to preserve ecological surroundings. On the other hand, in the last decade, grow of industrial sector from the construction point of view has experienced a significant development with the inclusion of new materials and advanced properties. This development presents also an important disadvantage in the surroundings since most of the materials used are inorganic and cause environmental contamination for not being degradable [5]. Activities such as rebuild and refurbish buildings and structures generate waste isolating materials and contamination for the environment and to recycle these materials is difficult for developing countries because of their lack of infrastructure to carry out these processes.

In this sense, biodegradable fibres like coconut have taken a growing importance for economical and environmental reasons [6]. Research in previously mentioned organic fibres, either mixed with cement, mortar or concrete indicate that an improvement in some mechanical properties such as impact strength, tension, flexure and bonding [7–11] is achieved. Reduction of 30–40% in cost of the composite material makes them an alternative to be considered. Some studies carried out using Durian and coconut fibres for panel boards have shown promising results, registering low thermal conductivities in the range of 0.054–0.1854 W/m K, making it possible to use them as thermal isolating materials [12–15]. Khedari et al. developed coconut fibre based soil–cement blocks with light weight and low thermal conductivity [16].

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Now a days ferrocement sandwich panels are attracting attention in the production of building components. Sandwich panels provide an economic method of providing structural requirements and thermal insulation [17–20]. The faces of the sandwich panel provide protection to the core material and withstand the imposed loads acting as tension and compression elements.

Ferrocement encased aerated concrete core sandwich composites have been investigated in terms of ultimate compression and flexural strength and compared to solely aerated concrete. The ferrocement encasement transforms the brittle behaviour of aerated concrete in ductile failure mode reducing weight and increasing flexural and compressive strength [21]. Raj et al. [22–24] have developed bamboo-based ferrocement slab elements for roofing/flooring purpose in low cost housing with good mechanical properties and light weight, while Yao and Li [25] carried out flexural strength studies on bamboo-fibre-reinforced mortar sandwich plates with remarkable improvement.

The work presented in this paper is focused on exploring the potential use of coconut fibre as thermal insulation filler of ferrocement sandwich type panel wall components and compare its performance with panel walls made of typical building materials used in roofing at schools and houses in hot climate of Puerto Escondido Oaxaca, Mexico.

2. Materials and methods

In this section, a description of materials and details related to fabrication of the panels used in the experimental measurements are presented.

2.1. Properties of materials used in panels

Ferrocement is a construction material composed of reinforced concrete and various layers of steel wire mesh, either electro-welded or hexagonal, distributed uniformly through a transversal section [26]. Normally a mortar rich of cement, sand and water is used. This material is thin (10–35 mm width) and with high resistance and flexibility besides of being a low cost material. Ferrocement constructions present weight reduction compared to traditional building materials.

Panel walls prepared and tested in this study were fabricated of (a) two ferrocement panels, 0.025 m thick, plus long coconut fibres, 0.1 m thick, in sandwich configuration, and the thermal conductivity measured and compared to three typical materials highly used in house building in south of Mexico, like (b) panel wall of hollow concrete block, 0.15 m thick, (c) panel wall of lightweight concrete brick, 0.15 m thick, (d) panel wall of red clay brick, 0.15 m thick, and two additional tests of extreme cases were conducted, (e) panel wall exclusively of solid ferrocement, 0.025 m thick, and (f) two ferrocement panels with air space, 0.1 m thick, in-between, instead of coconut fibre (see Fig. 1).

For mortar preparation in this study, Portland cement type 1 was used since it fulfils all requirements of ASTM C-150-89 standard. Cooperativa La Cruz Azul S.C.L. in Mexico fabricates this cement. Natural sand, clean and free from organic substances, sieved with sieve 8 (2.38) ASTM was used. Average grain size was 0.7 ± 0.145 mm. Water from the main distribution line in the region was taken to prepare the mixture. Mechanical properties of mortar used in this study are summarised in Table 1 [27].

Coconut fibre used as thermal insulator filler in ferrocement panels was bought in the local market. Moisture content, W_m of coconut fibre was determined by Eq. (1) as the ratio of the mass of absorbed water to the total fibre mass. Coconut fibre (0.5 kg) was thoroughly washed in a soap solution for 24 h to eliminate impurities and completely rinsed in tap water, it was let to drip off for 1 h and weighted in a precision scale balance. Then the fibre was sun dried for 5 days and weighted again. Then that fibre was introduced in an electric oven set to temperature of 45 °C for 5 h to be finally weighted.

Table 1
Properties of mortar.

Property	Measured value	International standard
Cement:sand:water	1:3:0.67	–
Compression strength of cylinders	25.29 MPa	ASTM C39/C39M-03
Compression strength of cubes	23.03 MPa	ASTM C109/C109M-02
Elasticity modulus	16.3 GPa	ASTM C469-02
Poisson ratio	0.11	ASTM C469-02

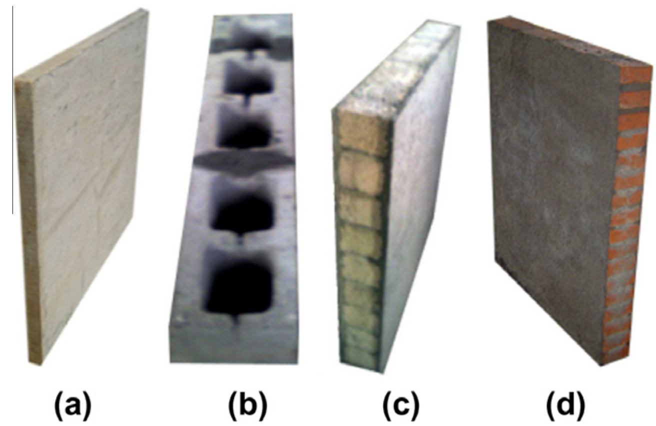

Fig. 1. Materials used for thermal conductivity tests: (a) panel wall of ferrocement, (b) panel wall of hollow concrete block, (c) panel wall of lightweight concrete brick, and (d) panel wall of red clay brick.

Fig. 2. Coconut fibres used in the experiments as thermal isolating material.

Table 2
Physical and mechanical properties of coconut fibre.

Property	Typical value	Ref.
Specific density	1.15 kg/m^3	[28]
Tensile strength	≈150 MPa	[29]
Modulus of elasticity	≈3 GPa	[29]
Thermal conductivity	0.046–0.068 W/m K	[30]

$$W_m = \frac{(M_h - M_o)}{M_h} \times 100 \tag{1}$$

where M_h is the mass of coconut fibre before drying and M_o is the mass of coconut fibre after drying (oven-drying).

A 24 h water absorption test was carried out firstly weighting on a scale balance the fully dried coconut fibre and immersing it in 20 °C water at 15 min time intervals up to 24 h in a flat bottom container. Water absorption is expressed as the percentage of the weight of water absorbed by the coconut fibre by the dry weight of the coconut fibre. Water absorption, O is then calculated by using the following equation:

$$O = \frac{(M_2 - M_1)}{M_1} \times 100 \tag{2}$$

where O is the water absorption (%), M_1 is mass of coconut fibre before immersion (g), and M_2 is the mass of coconut fibre after immersion (g)

After dried, coconut fibre was chopped in 9 cm long as indicated in Fig. 2 and its diameter was measured with a calibrated micrometre saw gauge resulting an average of 0.51 mm. More than 100 individual fibres were measured in this way for a representative value. Physical and mechanical properties typical of coconut fibre, taken from references, are indicated in Table 2.