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The influence of natural reinforcement fibres on insulation values of earth plaster for straw bale buildings

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ABSTRACT

This work aimed to measure the thermal conductivity of some natural plaster materials that could be used for straw bale buildings. Thermal conductivity is very important to determine the insulation value and other thermal parameters for natural plaster materials. Plaster materials consisted of soil, sand and straw. Straw is used as a reinforcement fibre for plaster. Three types of fibres were used such as wheat straw, barley straw and wood shavings. The results indicated that the thermal conductivity of all materials decreased with increasing straw fibre content and decreased with increasing sand content. The straw fibres have greater effect on the change of thermal conductivity than the effect of sand. The results also revealed that plaster reinforced by barley straw fibres has the highest values of thermal insulation.

1. Introduction

There is a growing interest in using earth as a building material which exhibits excellent physical properties with respect to ecological design, and fulfils all strength and serviceability requirements for thermal transmittance. This development is also due to the present concerns for sustainable development that have arisen out of extensive environmental problems (such as climate change and impoverishment of resources) and also rapid pace of technological development within the building sector. Most building regulations have increasingly laid down strict criteria for the thermal performance of buildings rather than the theoretically possible level of performance derived in the past. This has become necessary because the energy efficiency of building depends on the ability of the whole building envelope to retain internal heat, and also considers other factors such as heat loss and moisture movement through the walls. Understandably, the need for energy efficient structures in the built environment is increasing. Residential buildings use the largest proportion of energy, where heating and cooling are the predominant forms, and this is exacerbated by the adoption of air-conditioning, which has increased dramatically in recent years [1].

Studies on the thermal conductivity of building and insulating materials have increased in recent years. New materials are being developed and new uses for existing materials are being found. Today it is often not enough to obtain approximate data from text books, but measurements of real samples are necessary. Rapid technological developments in recent years have resulted in increasing effort to expand our knowledge of the transport properties of construction materials [2].

On the other hand, faced with the worldwide shortage of forest resources, industry is showing increased interest in the production of particle board from agricultural residues [3]. Wheat straw contains a large amount of fibre with the potential to replace wood for particleboard fabrication. Particleboard with a density range from 0.59 to 0.8 g/cm^3 is designated as medium-density particleboard [4]. It has broad applications for both structural and non-structural uses. Also barley straw is a significant raw material used in cellulose production as an energy resource [5–11].

Furthermore, thermal conductivity of wheat and barley straw bales ranged from 0.0414 to 0.0486 and 0.0353 to 0.0539 W/mK for all bale densities at different temperature for wheat and barley straw bales respectively. The average values of thermal conductivity and thermal resistance at both 20.7 and 34.2 °C were much higher than those of at 10.3 °C. The differences in the thermal conductivity and thermal resistance values as temperature changed from 10.3 to 20.7 °C is higher than when temperature changed from 20.7 to 34.2 °C [12]. McCabe [13] measured the thermal conductivity of wheat straw bales was found to be 0.046 W/mK. The

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lightweight straw loam with density of 750 kg/m^3 gave a k-value of 0.20 W/mK whereas a lightweight expanded day loam with a density of 740 kg/m^3 gave a value of 0.18 W/mK. The specific heat for the same material was 1.0 kJ/kg K [14].

Thermal expansion coefficients of plaster made from heavy loam were 0.0043–0.0052 mm/mK. Thermal expansion coefficients for mud brick masonry were up to 0.0062 mm/mK, and for sandy mud mortar has a value of 0.005 mm/mK, and strong cement mortar 0.01 mm/mK, the same as a concrete [15].

In addition the insulation is rated by R-value, the resistance to heat flow. The R-value of wood is 1 per inch (0.15 W/mK), brick is 0.2 (0.734 W/mK), fibre glass bats are 3.0 (0.05 W/mK). Straw bale buildings are thermally efficient and energy conserving, with R-values significantly better than conventional construction, depending on the type of straw and the wall thickness [16]. While Stone [17] estimated the insulation value for the straw bale walls. The R-value for the bale walls was R-44 (0.04 W/mK).

The thermal properties of sustainable earth materials were measured by using a novel thermal probe technique involving an iterative method of data analysis for determining simultaneously the thermal conductivity and diffusivity [18,19].

The viability of using coconut fibre as thermal insulation was explored by conducting thermal conductivity tests on 200 × 400 × 60 mm thick slab-like specimens. The thermal conductivity was 0.058 W/mK occurred at an optimum density of 85 kg/m^3 at 38 °C temperature [20].

The effect of adding wood shavings to sand concretes was studies. Results demonstrate that the inclusion of shavings into sand concretes reduces material density to a considerable extent, whilst the structure remained homogeneous with a strong wood–matrix adherence; furthermore, thermal conductivity has been improved [21].

Gatland et al. [22] described a unique guarded hot box designed for thermal testing of fenestration products incorporates several new design concepts from guarded hot plates, namely wall and edge guards. The wall and edge guarded hot box was built to meet the test methodologies specified in the American Society for Testing and Materials (ASTM) Standard Test Methods C 236-89 [23]. Our article presents an investigation into the thermal conductivity of earth plasters reinforced with different natural fibres such as wheat straw, barley straw and wood shavings under different mix ratios.

2. Materials and methods

2.1. Materials tested

Three different materials are used, i.e. cohesive soil, sand and reinforcement fibres. The composition of the cohesive soil texture is as follows: 31% clay (<2 μm), 22% silt (20–63 μm) and 47% sand (63–2000 μm). Three different fibre types, barley straw, wheat straw and wood shavings are used. The average length of straw particles is about 5 cm, while the length of wood shavings is about 2 cm.

2.2. Sample preparation

At first, the oversized gravels and organic matter (grass root) were removed from the natural cohesive soil. The soil was then oven dried at 105 °C to obtain a constant mass. After the drying process, the hard soil lumps were broken up with a hammer. The natural fibres were also oven dried at 105 °C to constant mass.

Different recipes of earth plasters with different compositions of cohesive soil, sand and fibre were used for testing. The dosing of different materials was controlled by volume with given density. This was done by compressing the materials in a mold. The densities of wheat straw, barley straw and wood shavings are 103.6 kg/m^3, 106.9 kg/m^3 and 111.4 kg/m^3 respectively. The densities of soil and sand are 1666.8 kg/m^3 and 1974.4 kg/m^3 respectively. The amount of soil and the fibre of a given recipe were placed in a container and mixed by hand without water until the different materials are homogeneously distributed. Afterwards, 2 L of water was sprayed over the materials and the materials were mixed by hand for about 15 min until a homogeneous mixture was obtained. The soil–fibre mixture was left to rest for about 30 min and then manually mixed for about 15 min. Earth plaster of four different recipes combined with three different natural fibres used in the thermal conductivity tests are given in Table 1. The compositions of the materials in Table 1 are given in volume percentage with the average material densities mentioned above.

The soil–fibre mixture was poured into a steel mold placed on a wood board. The square steel mold has a side length of 30 cm and a depth of 5 cm (see Fig. 1). The surface was leveled and compressed with a loading plate under a force of about 50 kg, which simulates the plaster operation on site. Afterwards, the steel mold was lifted leaving an earth plaster sample on the wood board.

The samples were allowed to dry slowly to avoid any cracks. This was done in a climate chamber under the temperature of 30 °C and the humidity of 40% for 60 days. The temperature and relative humidity inside the climate chamber can be controlled. A

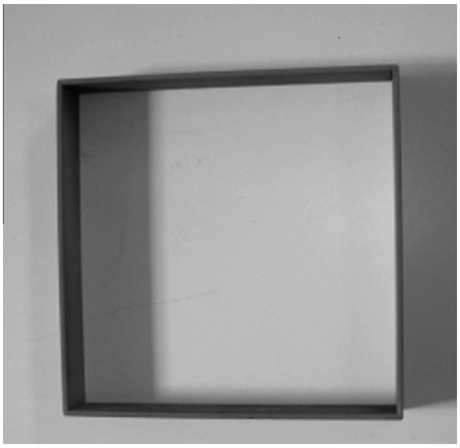

Fig. 1. Steel frame for samples preparation.

Table 1
Four earth plasters with three natural fibres.

Earth plaster recipes	Wood shavings			Wheat straw			Barley straw		
	Soil (%)	Soil (%)	Reinforcement fibres (%)	Soil (%)	Soil (%)	Reinforcement fibres (%)	Soil (%)	Soil (%)	Reinforcement fibres (%)
A	25	0	75	25	0	75	25	0	75
B	25	25	50	25	25	50	25	25	50
C	25	50	25	25	50	25	25	50	25
D	25	75	0	25	75	0	25	75	0