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Thermal analysis, microstructure and acoustic characteristics of some hybrid natural insulating materials

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HIGHLIGHTS

- Thermal and microstructure of hybrid fibers are obtained.
- Hybrid specimens have a good potential to be used as acoustic absorbent materials in buildings.
- Thermal conductivity of the proposed insulation material are 0.0418–0.0568 W/m-K.
- TGA and DTGA shows degradation and decomposition agave fibers starts at 221 °C.
- DSC is performed for agave fibers and the endothermic transition starts at 292–357 °C.
- Cornstarch is used as a resin to bind the fibers which makes the insulation material totally natural.

GRAPHICAL ABSTRACT

Five hybrid new insulation materials were made of palm trees surface fibers (PTSF) and Apple of Sodom fibers (AOSF) of different densities and one was made of agave fiber (AF) and Apple of Sodom fibers as seen in the figure below. Cornstarch, glue (wood adhesive) and white cement were used as binders for the fibers. Thermal conductivity measurements were conducted for all samples at temperature ranging from 10 °C to 50°C which resulted in average values of 0.04234–0.05291 W/m K. The acoustic measurements were reported for the specimens and show good values of absorbent coefficient. The proposed tested hybrid samples are all natural, safe for human beings, utilize the wasted material and biodegradable therefore, they are good for saving our environment and could be used in buildings as thermal insulating and acoustic absorbent materials.

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ABSTRACT

Hybrid new insulating materials are proposed using different binders such as cornstarch, glue (wood adhesive) and white cement. Five hybrid samples were produced from date palm trees surface fibers (PTSF) and Apple of Sodom fibers (AOSF) for different ratio of mass and densities. One hybrid sample was produced from AOSF and agave fiber (AF) using glue (wood adhesive) as a binder. Thermal conductivity measurements were conducted for all samples at temperature ranging from 10 °C to 50 °C which resulted in average values of 0.04234–0.05291 W/m K. Microstructure analysis was conducted for AF using the scanning electron microscope (SEM) which resulted in an average diameter range of 170–259 µm. Infrared (FT- IR) Fourier transformation spectra of AF showed ranges of wavenumber functional groups. Thermogravimetric analysis (TGA and DTGA) was obtained for AF and showed that the fibers start to degrade and decompose at about 221 °C where the fiber loses 5% of its original mass. The Differential Scanning Calorimetry (DSC) analysis is also reported for AF and shows a broad endothermic transition range of 292–357 °C with a peak at 353 °C. Sound absorption coefficients were obtained for the hybrid samples and indicate the potential of using these samples for sound absorption. The current tests indicate the feasibility of using such hybrid samples as insulating materials for heat as well as sound absorption.

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1. Introduction

Energy efficiency and sustainability has been a priority for almost all engineering applications for decades. Almost all fields of engineering are witnessing plans to cut down on energy consumption and increase sustainability. The European Union plans to reduce emission levels from aviation and power industries by 21% compared to 2005 emission levels. While for residential, transportation, agriculture waste by about 20% compared to 2005 emission levels [1]. Further proposals are reported to reduce greenhouse emission by 30% compared to 2005 emission levels from residential and construction industries by 2030 [2]. Moreover, The European Union issued a directive in 2010 targeting energy performance of buildings labeled "EPBD" that requires all new buildings to be nearly zero-energy buildings "NZEB" by December 31, 2020 [3]. Since nearly 40% of energy consumption and 36% of greenhouse emissions are due to residential and other commercial buildings [3], research into new thermal insulating materials have gained further attention. Natural occurring unconventional materials are being considered for thermal insulation since they are found naturally and, more importantly, they are less harmful than synthetic materials. Reviews of conventional and unconventional insulation materials can be found in [4] and [5], respectively. Unconventional materials reviewed by Francesco et al. [5] included natural materials like reeds, bagasse, cattail, oil palm, date palm among others and recycled material such as glass foam, plastics, textile fabric and others. Thermal, acoustic as well as lifecycle assessments were compared for all materials. It was concluded that some of the unconventional insulation materials reported to have same thermal and acoustic properties as available commercial ones. However, there is a lack of comprehensive characterization for such materials.

Ali and Zeitoun [6] have developed a novel thermal insulation material from the fiber extracted from the seedpods of the Apple of Sodom plant using cornstarch as a resin for the fiber. Experimental data showed low thermal conductivity levels at different densities. The advantage of this material is that it is natural and bio-degradable. Asia Research News has acknowledged Ali's discovery in a written article [7]. In addition to that a complete details about this discovery was patented by Ali [8]. The morphology, sound absorption characteristic, and thermal properties of the Apple of Sodom (Calotropis Procera) fibers have reported by Ali [9] including the Fourier Transformation- Infrared (FT-IR) analysis, Thermogravimetric analysis (TGA) and the differential DTGA, and the energy dispersive X-ray (EDX) spectroscopy.

Agoudjil et al. [10] analyzed palm wood for thermal insulation applications. They measured the microstructure as well as chemical composition and thermal conductivity of palm wood growing in Biskra oasis in Algeria. They reported that the test specimens' surfaces were irregular containing many filaments as well as impurities, cells and pores. It was concluded that fibers' orientations affected the relative permittivity. Their results also show that date palm wood retains its insulation capability at lower pressure levels. Chikhi et al. [11] developed a bio-composite material for thermal insulation composed of a gypsum based material with the addition of date palm fibers (DPF) with different concentrations. They studied the effect of DPF on thermal conductivity, water absorption as well as mechanical properties. Their results showed that increasing DPF concentration enhanced the thermal insulation of gypsum based materials while flexural strength was reduced to certain extent. However, their results also show an increase in water absorption with increase in DPF concentration. Zach et al. [12] and Korjenic et al. [13] investigated ways to modify thermal insulation material based on industrial hemp with the objective of reducing water absorption. They used a hydrophobic treatment, a sol-gel method and a combined treatment. They concluded that hydrophobic coating reduced absorption significantly as well as reduced the increase in thermal conductivity due to moisture content. Wei et al. [14] developed a thermal insulation material from rice straw using hot-pressing applied with high frequency. They investigated the effect of moisture content, heating frequency, board density, particle size as well as ambient temperature on thermal insulation material properties. It was shown that lower densities resulted in lower thermal conductivity and higher heating frequency resulted in shorter pressing time as well as stronger internal bonding.

Tůmová et al. [15] investigated the thermal conductivity of cut and uncut straw using different amounts of casein adhesive. Thermal conductivity was reduced at lower doses of casein adhesive. The benefit of using this particular adhesive is that it is natural and fully bio-degradable.

Oushabi et al. [16] studied the effect of adding date palm particles (DPP) to a polyurethane insulation material on thermal conductivity and mechanical properties with the aim of reducing the amount of polyurethane used. It was concluded that increasing the date palm particle increased the thermal conductivity modestly which means less petrochemical material used. However, increasing DPP above 20% wt degrades the mechanical properties of the material.

Braiek et al. [17] investigated the addition of date palm fibers (DPF) to gypsum boards insulation material. Their experimental results showed a significant decrease in thermal conductivity when 20% DPF are added to gypsum boards with comparable thermophysical properties of current insulation materials.

Boumhaout et al. [18] studied experimentally the thermomechanical properties of DPF and mortar composite material. They measured the thermal conductivity as well as mechanical properties of the composite material with DPF concentration up to 51%. The experimental results showed a decrease in thermal conductivity by as much as 70% as the DPF content is increased to 51%. In addition the density is also decreased which made the material lighter.

Ali and Abdulkarem [19] reported on the thermal characteristics and microstructure of an insulation material extracted from date palm surface fibers (DPSF). Samples were produced using a cornstarch resin as a binder. Thermal conductivity was measured as well as a Thermogravimetric analysis (TGA) was performed for each sample. Reported thermal conductivity ranged between 0.0475 and 0.0697 $W m^{-1} K^{-1}$ while the TGA analysis showed that the fibers lost 50% of its original mass at about 364 °C. Methods of extracting Agave fibers (AF) was studied by Cheikh et al. [20] and physical and mechanical characteristics of Agave fibers were also reported.

Acoustic properties of natural materials are also being investigated for the same purpose of using more environmentally friendly materials. Very often acoustic insulation material are also good thermal insulators [21]. Berardi and Iannace [22] performed an acoustic characterization of natural fibers for sound absorption