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Environmental impacts and thermal insulation performance of innovative composite solutions for building applications

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HIGHLIGHTS

- Life Cycle Assessment method was applied to four composite systems for buildings.
- Thermal characterization of the materials under study was carried out.
- An eco-sandwich containing cork, plant derived epoxy resin and flax fibre is proposed.

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ABSTRACT

For buildings applications, an optimum material solution would have the essential structural properties of concrete but with lower thermal conductivity. The reduced thermal conductivity provides a better thermal insulation system that consumes less energy for cooling and heating in the use phase. In the present study, thermal conductivity analysis and environmental analysis were carried out for various materials that are intended for use as external walls for buildings. Life Cycle Assessment (LCA) methodology was applied to evaluate the environmental impacts of four different proposed systems.

An eco-sandwich material containing cork, flax fibres and bio-based epoxy resin as natural materials was manufactured and tested in order to evaluate the thermal conductivity. The use of the eco-sandwich in building structure seems to bring several advantages in terms of innovation, good insulation properties and light-weight structures. The LCA results show that when the eco-sandwich is used, the environmental performance is lower compared to other traditional materials, in the manufacture phase. Nevertheless, impacts due to material transportation and installation could be lowered due to the light weight and handling of the eco-sandwich.

1. Introduction

Eco-design and energy-efficiency are urgent concepts that express the need to search for new building solutions that are environmental friendly and lead to a reduction of materials and energy consumption. Polymer matrix composites polymers reinforced with natural fibres have received increasing attention during recent years since the environmental aspect has become an increasingly relevant issue in industrial applications. LCA applications to a large range of natural fibre composites demonstrate that these materials offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components [1–3]. Natural fibres from bast, e.g. [4–8] (i.e. plant stems, such as flax, hemp [9,10] and jute [11,12]), leaves (pineapple [13] and sisal), fruit and seeds (coir, cotton and palm [14]) or wood possess good reinforcing capability when properly compounded with polymers. These natural fibre-reinforced composites find a wide array of applications in the building and construction industry [15] and are suitable for eco-design. Another valuable natural material for building applications is cork [16] that is a product of great ecological value. It is very interesting from a sustainability perspective because, in addition to its low emissions and the great potential for capturing CO_2, it generates economic revenues, provides jobs

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and development in rural areas, and allows many environmental services such as forest preservation, biodiversity conservation and wildfire prevention. In a recent study, Fernandes et al. [17] tested the fire resistance and the acoustic insulation of cork/HDPE (high density polyethylene) and cork/PP (polypropylene) composites and found that the presence of cork improves both properties. Cork is also well known for its thermal insulation properties in building applications. The proper use of thermal insulation in buildings contributes in reducing the required air-conditioning system size, reducing the annual energy cost. According to Al-Homoud [18], the magnitude of energy savings as a result of using thermal insulation vary depending on the building type, the climatic conditions at which the building is located as well as the type of the insulating material used. The question is no longer should insulation be used but rather which type, how, and how much.

The aim of the present work is to find material solutions for building applications with low thermal conductivity and low environmental impacts. The study was divided into two steps: firstly, the thermal characterization of the materials under study and the calculation of the dimensions of innovative structures to be used for buildings' walls were carried out. The second step was the evaluation of the environmental impacts by means of the LCA methodology. LCA is a technique that provides a way of quantifying the diverse effects on the environment caused by products throughout their entire life cycle.

The third step will be the evaluation of the mechanical/structural properties, once the relative environmental burdens of the considered systems have been established (but that is beyond the scope of this paper). Structural insulated panels (SIPs) are an example of energy-efficient building technology that is increasingly used for walls, partitions, and flooring [19].

2. Thermal conductivity analysis

2.1. Terminology

ASTM [20] defines *thermal conductivity* (λ) as the time rate of steady state heat flow (W) through a unit area of 1 m thick homogeneous material in a direction perpendicular to isothermal planes, induced by a unit (1 K) temperature difference across the sample. Thermal conductivity, k-value, is expressed in W/m K (where m is metre) and is a function of material mean temperature and moisture content. Thermal conductivity is a measure of the effectiveness of a material in conducting heat. Hence, knowledge of the thermal conductivity values allows quantitative comparison to be made between the effectiveness of different thermal insulation materials.

Thermal resistance is a measure of the resistance of heat flow as a result of suppressing conduction, convection and radiation. It is a function of material thermal conductivity, thickness and density. Thermal resistance, R-value, is expressed in m^2 K/W.

Thermal transmittance is the rate of heat flow through a unit surface area of a component with unit (1 K) temperature difference between the surfaces of the two sides of the component. It is the reciprocal of the sum of the resistances of all layers composing that component plus the inside and outside air films resistances. It is often called the Overall Heat Transfer Coefficient, U-value, and is expressed in W/m^2 K.

2.2. Materials

Four different samples were tested:

(a) Syfar cork panel (commercial, supplied by Syfar srl, Italy).
(b) PVC foam board (commercial, purchased by Foam Seal Inc.).
(c) Cork eco-sandwich (manufactured in our laboratories). The sandwich panels were manufactured by resin infusion under flexible tooling (RIFT I) [21]. Syfar cork panels were used as core; Commercial flax fibres (Biotex, Composites Evolution, UK) and Entropy epoxy resin (SuperSap100, Ferrer-Dalmau, Spain) were used for the skin. Dimensions and weights of materials used are reported in Table 1. The density of each sandwich components was also evaluated because it is required for the thermal conductivity analysis.
(d) Cement-coated cork panel Bioverd (commercial, supplied by Coverd srl, Italy). Bioverd was approved by the EOTA (European Organisation for Technical Approvals) as "External Thermal Insulation Composite System with renderings for the use as external insulation to the walls of buildings" [22]. Bioverd is manufactured using the Syfar cork panel and a rendering system based of cement paste.

2.3. Equipment

Heat flow-meter HFM 436 Lambda (Netzsch) was used for measuring the thermal conductivity (λ). The heat flow meter is calibrated according to ASTM C518 [23] and ISO 8301 [24]. A sample sized $300 \times 300\ mm^2$ and 10 mm thick, placed between a hot and a cold plate and the heat flow created by the temperature difference is measured with a heat flux sensor. Thermal conductivity was measured 5 times for each samples. No significant differences were found among each measurements.

2.4. Thermal conductivity analysis

Table 2 reports the thermal conductivity (λ) evaluated at two different temperatures (T = 10 °C and 50 °C) in order to define the insulation properties in cold and hot weather conditions. As expected, PVC foam shows the lowest λ value 0.035–0.038 W/m K

Table 1
Eco-sandwich preparation: quantities and dimensions.

	Core	Skin		Eco-sandwich
	Cork	Epoxy resin	Biotex	Core + 2 skins
Weight of each eco-sandwich components (kg)	0.458	0.416	0.347	1.984
Dimensions (m)	0.4x0.4	0.4x0.4		0.4x0.4
Thickness (m)	0.015	0.005		0.025
Density ρ (kg/m^3)	191	1120	1500	1039[a]
Weight percentage of eco-sandwich components (%)	23	42	35	100

[a] The density of the sandwich was calculated as the sum of the density fraction of each component: $density_{sandwich}$ = ($density_{cork}$ *$\%_{cork}$) + ($density_{biotex}$ *$\%_{biotex}$) + ($density_{resin}$ *$\%_{resin}$).