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Development of Cellulose Panels with Porous Structure for Sustainable Building Insulation

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Abstract**—**The study and development of an innovative material for building insulation is really important for a sustainable society in order to improve comfort and reducing energy consumption.

The aim of this work is the development of insulating panels for sustainable buildings based on an innovative material made by cardboard and Phase Change Materials (PCMs).

The research has consisted in laboratory tests whose purpose has been the obtaining of the required properties for insulation panels: lightweight, porous structures and mechanical resistance.

PCMs have been used for many years in the building industry as smart insulation technology because of their properties of storage and release high quantity of latent heat at useful specific temperatures [1] - [2].

The integration of PCMs into cellulose matrix during the waste paper recycling process has been developed in order to obtain a composite material.

Experiments on the productive process for the realization of insulating panels were done in order to make the new material suitable for building application. The addition of rising agents demonstrated the possibility to obtain a lighter structure with better insulation properties.

Several tests were conducted to verify the new panel properties. The results obtained have shown the possibility to realize an innovative and sustainable material suitable to replace insulating panels currently used.

Keywords**—**Sustainability, recycling, waste cardboard, PCM, cladding system, insulating materials.

I. INTRODUCTION

THE reclaim of wastepaper to produce other recycled paper is a consolidated industrial process that also brings proven economical and environmental advantages [3]. However, the current production and collection of recycling paper is marked by excess, which is difficult to make use of materials and products currently made [4].

This project plans on providing a sustainable answer to those problems.

Fibers derived from recycled paper were used as a matrix in order to create a composite material. This cellulose matrix has been loaded and modified to achieve specific properties and functionalities. The sustainable building has been identified as an appropriate application field for this material.

There are many different kinds of materials for thermal insulation realized in different ways: the choice of the correct material depends on the type of the application and on the physical and thermal expected properties [5].

After preliminary studies and tests of materials with low thermal conductivity, the idea to achieve thermal insulation has been coupled with the possibility to create passive solar heating systems using latent heat storage facilities. The energy storage in walls, roofs and floors can be achieved by integration of appropriate phase change material (PCM) in building materials. The PCMs have been used for the production of various building structures (plasterboard panels, insulating panels, et cetera); by choosing the appropriate PCM transition temperature, the final result is nearly an isothermal system. Although these materials have demonstrated benefits, one of the still unsolved problems is related to the dispersion of them in a matrix [6].

In this work, a process for the production of an insulating cellulose panel made of waste cardboard and PCM has been developed in order to obtain innovative products for sustainable buildings.

The pulp obtained was foamed to create a lightweight and porous material. The porosity confers to the material better thermal insulation properties.

Experiments done in the laboratory have shown that this composite material can modulate the hot spikes due to the environmental thermal shocks.

II. EXPERIMENTS

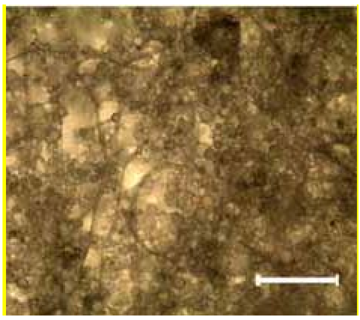

Fig. 1 Optical micrographs of cellulose fiber matrix with 50% of PCMs

Cardboard panels have been obtained by mixing cellulose pulp and a PCM suspension [7]. An aqueous solution of cellulose pulp (5% w/v) has been obtained by grinding commercial paperboards (Ghelfi Ondulati, Italy). Commercial Micro-encapsulated Phase Change Materials (PX 28 HC, Rubitherm, Germany) were used as they were. PCM microcapsules were dispersed in distilled water (5% w/v) and this suspension was mixed under stirring with an appropriate

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amount of paperboard suspension, to obtain a specific pulp/PCM (w/w) ratio: 50% cellulose pulp, 50% PCM (Fig. 1).

Different processes (chemical, mechanical or physical modification) have been tested in order to increase the porosity of the composite material.

A. Foaming Agents

The first process has consisted in the addition of rising agents into the mixture before the drying phase. Different substances have been tested (brewer's yeast, baking powder, $NaHCO_3$) in various concentrations (Fig. 2).

Fig. 2 Samples of panels obtained with rising agents. *A and F* without additives, *B* with brewer's yeast , *C* with baking powder, *D* with 30% of $NaHCO_3$, *E* with 50% of $NaHCO_3$

A good porous structure has been obtained by dispersing 30% of $NaHCO_3$ in the cellulose pulp and drying it at 100°C for 24h. As shown in Fig. 3, the panel obtained presents a porous matrix.

Fig. 3 Porous matrix obtained with 30% of $NaHCO_3$

B. Cellulose Flakes

The second process has consisted in the use of cellulose flakes obtained by the scratching of dried panels. Flakes were arranged in layers with glues or binding agents obtaining a soft fibrous panel (Fig. 4).

Fig. 4 Soft fibrous panel made with cellulose flakes and PCMs

C. Freeze-dry Process

The third process has consisted in the use of a freeze-dry method. The operating principles of this experiment are shown in Fig. 5. Cellulose matrix containing water has been frozen in order to create ice crystals with higher volume. A laboratory freeze dryer has been used to reach very low pressure (less than 4,58 mmHg) and obtain water sublimation. In this way, air particles remained inside the solid material and a soft panel has been obtained (Fig. 6).

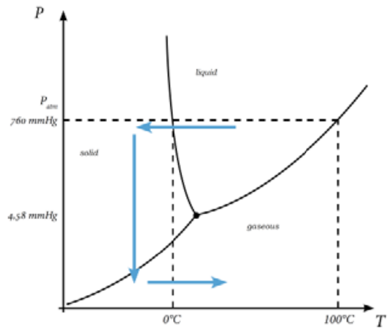

Fig. 5 Freeze-dry process scheme

Fig. 6 Sample obtained with freeze-dry process

D. Perforated Panels

The fourth process has consisted in the realization of geometrical perforated structures. Cylindrical metal inserts have been placed into the wet pulp before the drying process and removed from the solid panels. The result is shown in Fig. 7.

Fig. 7 Perforated panel

III. Characterization

The different panels obtained have been characterized and compared with standard panels commonly used in the building insulation industry in order to verify their properties. Comparison is shown in Table I.

A. Thermal Conductivity

Thermo-fluximeter tests (Fig. 8) allowed the calculation of thermal conductivity, according to the processing software SUBB [8]. Results, listed in Table I, have underlined that the realization of a porous material helps to achieve better thermal insulation properties.

Fig. 8 Thermo-fluximeter Test

B. Flexural Strength

Mechanical tests (Fig. 9) were carried out in order to evaluate the mechanical resistance of the panels.

Results, listed in Table I, have demonstrated that panels made by cellulose matrix present lower flexural strength value compared with standard panels, because of their porosity structure. However, the mechanical properties evaluated are acceptable for the application considered in this work.

TABLE I
Materials Properties Comparison

Material	Density	Thermal conductivity	Flexural strength
	kg/m³	*W/(m K)*	*kPa*
50% paper – 50% PCM	215	0.063	390.25
30% paper – 30% PCM - 30% Rising agent	180	0.052	170.75
50% paper – 50% PCM - Perforated panel	215	0.055	375.80
50% paper – 50% PCM – Freeze-dry process	105	-	-
50% paper – 50% PCM – Cellulose flakes	62	-	-
Expanded Perlite	260	0.060	650.50
Expanded Perlite with cellulose fiber	145	0.050	282.95
Polystyrene foams	20	0.031	158.80

Fig. 9 Three points bending device used for mechanical Tests

C. Thermal Cycles Simulation

Environmental thermal cycles were performed in order to test and verify the behavior of the panels. The temperature variation was measured and recorded using a system of thermocouples (National Instrument System acquisition NI cDAQ 9172) to evaluate the heat transfer.

The diagram in Fig. 10 shows the results obtained: panels made with cellulose matrix, PCMs and rising agents, have better thermal insulation properties compared to standard panels common used in construction (perlite panels). As shown in the diagram, when the external temperature is increased innovative panels present a better temperature control compared with standard panels.

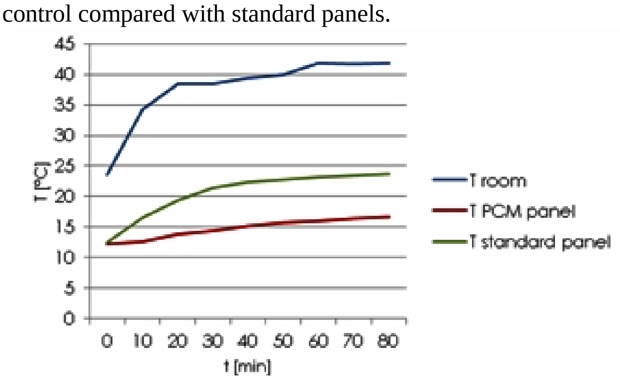

Fig. 10 Temperature variations recorded on the surface of innovative composite panels and standard panels

The results obtained are related to the amount of PCMs integrated into the cardboard. Because of their great capacity to absorb and slowly release the latent heat, the PCM addition in building panels increases the thermal energy storage capacity of the material. The use of PCMs allows a delay in the rise of temperature during the transition process: heat storage, occurs over a fairly narrow temperature range (around the PCM transition temperature). A panel with PCM exposed to hot temperatures slowly increases its temperature in a process governed by sensible heat: when it approaches the phase-change temperature, the building behind the panel is held at a nearly constant temperature, due to the latent heat absorbed by PCM. Once the PCM have changed phase, the temperature finally increases up to the external temperature [9].

IV. Conclusion

In the present work an innovative sustainable material for insulating building panels has been developed and results in a new panel with equal or better properties than standard products commonly used (perlite panels).

In addition, special attention has been given to environmental sustainability. A new material has been obtained by the recovery and recycling of waste paper and its functionalization.

The panel developed presents a porous structure, contains PCMs with heat storage properties and shows high thermal insulation performance.

All the highlighted characteristics have confirmed the possibility to obtain an innovative and sustainable product. Moreover it is possible to improve the performance of the material by adding special additives such as anti-humidity or flame retardant and confering significant improvements for building applications. This material presents the requirements necessary to be a good alternative to the insulating panels currently used.

Acknowledgment

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