New Application for Recycled Functionalized Cellulosic Fibers in Buildings

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EXECUTIVE SUMMARY

The reclaim of wastepaper to produce other recycled paper is a well consolidated industrial process that also brings proven economical and environmental advantages. However, the current production and collection of recycling paper is marked by an enduring offer excess, which is difficult to take in for materials and products currently made.

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

We used fibers derived from recycled paper as a matrix in order to synthesize a composite material. This cellulosic matrix has been loaded and chemically modified to achieve specific properties and functionalities. The appropriate application field identify for this material is the sustainable buildings.

Fibers chemical modifications are done in order to improve the manufacturing process, the modulation of the mechanical properties and their stabilization in time as a function of proper application. The use of some suitable additives allows to improve the thermal and acoustic insulation properties, the resistance to fire and humidity.

There are a lot of different kind of materials for thermal insulation realized in different ways: the choice of the correct material depends on the type of the application, physical and thermal expected properties, as well as the combination of the same with properties of building materials.

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 realized integrating appropriate phase change material (PCM) in building material.

The PCM 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 a nearly isothermal system. Although these materials have demonstrated benefits, one of the still unsolved problem is related to the dispersion of them in a matrix such as building and structures composite materials.

In this work we developed a process for the dispersion of PCM and other additives in a recycled paper matrix in order to obtain innovative products for sustainable buildings.

After that, the pulp obtained was expanded to create a lightweight and porous material, with constant thickness of few centimetres. The porosity gives to the material better thermal and acoustic

insulation properties.

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

INTRODUCTION

Approximately 22% of the total waste mass is made of paper or cardboard: the current production and collection of recycling paper is marked by an enduring offer excess. A possible approach to the solution could be the development of a composite material, based on cellulosic matrix, that combines the mechanical properties of cardboard with other smart properties for innovative applications. We identify, as a promising application field for this material, the building sector.

In the last years, the building sector has been undergoing significant changes as concerns both building techniques and energetic strategies. This trend is confirmed by EU directives; in particular, the 93/76 Directive regarding the emission of CO_2, estimates that over 40% of the global energy consumption can be attributed to the Building Construction sector. Moreover, the sector contributes heavily to Greenhouse Gas (GHG) emission. The positive aspect is that there are many possibilities to improve the energetic performances of buildings, using technologies that are already available, such as thermal insulation, efficient glazing, ventilation systems with heat recovery, and so on. The mentioned Directive affirms that through the exploitation of renewable sources and the optimization of the buildings' thermal behaviour it could be possible to reduce the consumption level to 22%. On the other hand, performance requirements are growing higher because of both more stringent regulations and higher comfort requirements by the users – the spreading use of air conditioning systems, also in houses, is just an example of this trend. These two issues mean that a deep reconsideration of how buildings are designed and built is required, in order to provide high performance levels with a limited environmental impact – which is simply the definition of sustainable development applied to buildings (Imperadori, Masera, Iannaccone, 2006).

The building surface is the mediating element between the inner of a building and the environment in which it is located. In fact, it is subject to several physical phenomena coming from the external environment, which can be climatic, meteorological or social phenomena, and it constitutes the barrier of protection or isolation from them. Its role is therefore ensure the comfort inside the building through the control of thermal, acoustic and light flows. In recent years, the attention to building design and projects has increased even more as a result of the need to achieve sustainable buildings and rehabilitated (Allen, 1990).

The main requirements, that building coatings must have, are: thermal and acoustic insulation, fire resistance, umidity resistance, impact resistance, machinability and sustainability. For each requirements there are regulations and normatives that list the minimum acceptable values and specific characteristics.

There are many types of building coatings that can be classified through various criteria: structural or non-structural surface, one-layer or multilayer surface, transparent or not, active surface or passive surface (Brunoro, 2007).

We decided to investigate the possibility to develop a new material for pre-fabricated panels. Pre-fabricated panels are a class of facing for building, with non-structural, multilayer and not transparent surface, that are mounted directly on the outer wall of buildings as a final layer. They are made by an external layer in mortar cement and an inside layer generally in polystyrene. In recent years, many companies have tried to replace the polystyrene layer with other material, such as perlite, in order to obtain a better energy classification.

We worked in order to realize an innovative material, based on wastepaper, as a possible solution to replace polystyrene layer with a more sustainable material. The idea to develop a composite material has been chosen.

Composite materials are made by combining two or more materials that have quite different properties such as mechanical, thermal, electrical behaviour. The different materials work together and give to the composite unique properties, but within the composite you can easily decouple the different materials – they do not dissolve or blend into each other. They remain separate and distinct at the macroscopic or microscopic scale within the finished structure. The great advantage obtainable by the use of a composite material is related with the capability to combine different properties and characteristics that single material does not allow.

Here, we focused on the development of a composite material based on the use of cellulosic matrix, obtained from paper and cardboard recycle, conveniently loaded and/or chemically modified to convey specific functionalities. The chemical modification of the fibres aims at improving the manufacturing process, at the modulation of the mechanical properties and their stabilization in time on the basis of the new applications. The use of some suitable additives aims to the improvement of the thermal insulation properties, fire resistance and humidity.

One possible approach to control thermal insulation and to maintain a desired temperature, for a limited period of time, is represented by thermal energy storage approach (Melone, Altomare, Cigada, De Nardo, 2011). Along this direction, large quantity of thermal storage/recovery can be achieved in the form of melting/freezing latent heat by using phase change material (PCM) (Günther, Hiebler, Mehling, 2005).

PCMs are materials that undergo a phase change, e.g. from solid to liquid state, at a specific temperature near envisaged application. In such systems, energy is stored during melting and recovered during freezing. The latent heat is the thermal energy that needs to be absorbed or released when PCMs change phase which are hence capable to store or release large amounts of energy. PCMs are usually used in separate forms (single removable bricks or flexible compartment wraps) that are generally not designed to be part of an integrated panel system. For these main reasons, shape-stabilized PCMs, that comprise mainly polymers as supporting materials and paraffin as latent heat storage media, have been actively promoted during the recent past. However, shape-stabilized approach results in some challenging problems. An alternative approach is based on microencapsulated PCMs blended with different supporting materials, to prepare form-stable phase change materials. Via such an approach, the encapsulation and low thermal conductivity problems of paraffin or other organic solid–liquid PCMs can simultaneously be solved. The Phase Change Materials have been studied by several research group since 1980, and over the past 20 years they have been experimented in research laboratories. By Choosing appropriate PCM transition temperature, the final result is a nearly isothermal system. Some authors have demonstrated that concrete filled with PCM have an improvement of storage temperature up to 300% (Kuznik, Virgone, Roux, 2008). Although these materials have benefits, one of the unsolved problem is related to the incorporation of them in matrix materials and structures. A possible solution can be offered by macro- and micro-encapsulation (Tyagi, Kaushika, Tyagi, Akiyamac, 2010).

Here, we propose a simple method for the stable incorporation of PCM microcapsules in a paper matrix and characterized their thermo-physical properties, in order to realize PCM cellulosic composites as novel active building material.

The development of an innovative composite material for smart packaging has included the

evaluation of the possibility to recover and recycle materials and energy consumption.
After the preliminary analyses we proceeded with the laboratory experimentation.

MATERIALS AND METHODS

Cardboard and cardboard/PCM panels have been obtained by mixing pulp and PCM suspension via an easy process. A water-based pulp solution (5% w/v) has been obtained by mechanical grinding commercial paperboards (Ghelfi Ondulati, Italy). Commercial Micro-encapsulated Phase Change Materials (MPCM6D, Microteklabs, USA) were used as received. PCM microcapsules were dispersed in distilled water (5% w/v) and this suspension was mixed under stirring with an appropriate amount of paperboard suspension, to obtain pulp/PCM (w/w) ratio: 50% pulp paper (50 PCM). During this process is also possible to introduce special additives in order to confer flame retardant (boron salts) and anti-umidity properties (Basoplast Basf).

Finally, the obtained pulp has been added with various foaming agents in order to obtain porous panels and dried for 24h at 100°C.

After the development of the productive process we realized a sampling of panels in order to test their functionality in laboratory.

We simulated variuos possible environmental thermal cycle in order to test and verify the behaviour of the new composite panels. Thermal maintenance of innovative panels was compared with perlite panels.

To record the temperature variation a system of thermocouples was assembled and linked to each panels. Temperatures were recorded using a National Instrument system acquisition NI cDAQ 9172. The system of thermocouples has recorded temperature variations for 24 hours with an acquisition time of 10 minutes.

Thermal insulation has been also evaluated using a thermo-fluximeter in order to calculate material thermal conductivity.

The water permeability of the material has been calculated through tests regulated by Normative UNI 12087. Flame retardant properties have been evaluated measuring the flame delay time. Mechanical characteristics were tested through flexural strength tests.

Optical microscope observations were performed in order to investigate the microcapsules distribution in the paperboard.

RESULTS AND DISCUSSIONS

Through this research we have obtained an innovative composite material made by a porous cellulosic matrix. A good porous structure, as shown in Figure 1, has been obtained by dispersing 30% w/v of $NaHCO_3$ inside the cellulosic pulp.

Figure 1 Porous composite material obtained

A simple process for PCM incorporation in cardboard and their possible applications in building panels has been developed: via a conventional filtration process it is possible to design and realize composite materials based on PCM microparticles dispersed into a cardboard matrix. We integrated PCM microcapsules in the cardboard during the productive process of the panels. Through this technique it is possible to recover and recycle cardboard scraps and functionalized the material by using PCMs. During the recycling process we have also tested the integration of additives in order to modulate other relevant properties, such as, anti-umidity and flame retardant.

Optical microscope analysis (Leica DMLM) have allowed us to evaluate the homogeneity of the composite material. In Figure 2 optical micrographs of PCM microcapsules (Figure 2a) and paper specimen (Figure 2b) are shown. PCM microcapsules are characterized by a uniform distribution of dimensions (Figure 2c), with an average diameter in the range of about 10–30 μm as declared by the producer. The incorporation of PCM microcapsules into paperboard matrix results homogeneous, with a regular distribution of particles in paper matrix, moreover the microcapsules maintain their shape without damaging.

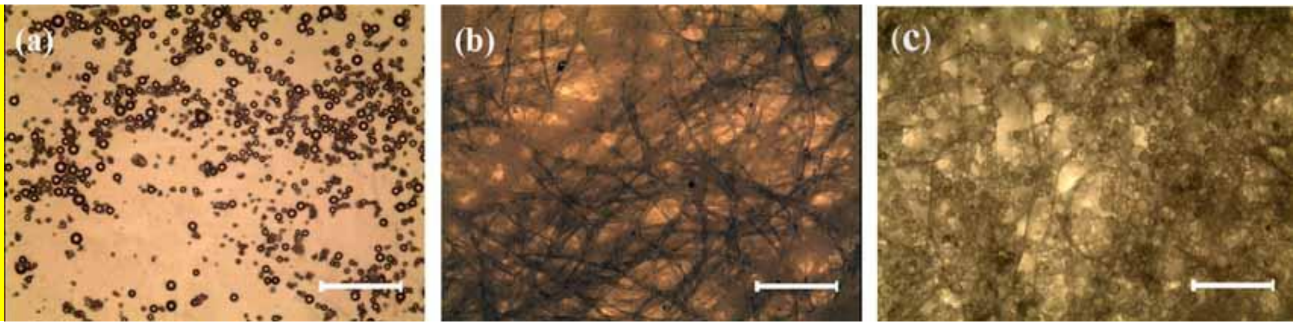

Figure 2 Optical micrographs of (a) PCM particles as received and specimens of (b) Paperboard (0 PCM); (c) 50 PCM. Scale bar 200 μm

The processing of recorded data done by the system of thermocouples has enabled us to evaluate the heat transfer. The diagram in Figure 3 shows the results obtained: panels made with cellulose matrix and PCM 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 increasing, innovative composite panels are able to better control the rise of temperature compared with standard panels.

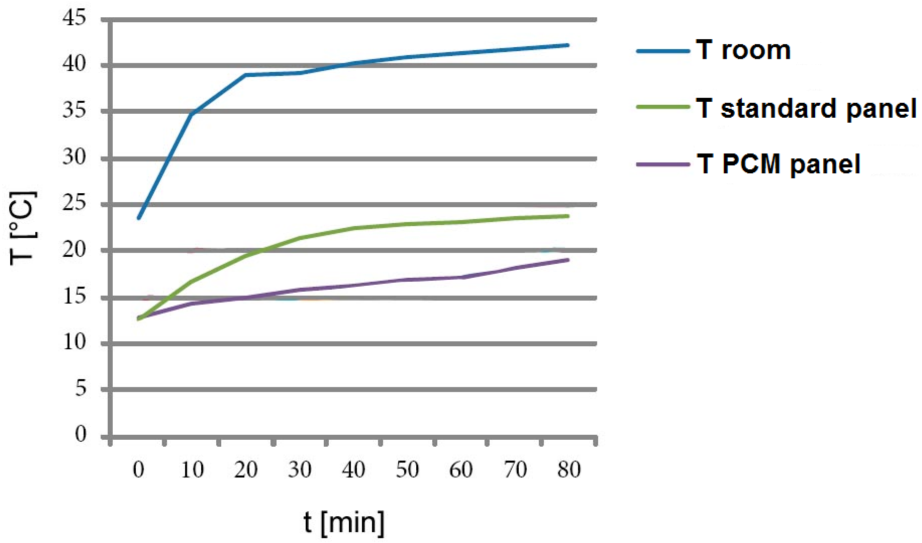

Figure 3 temperature variations recorded on the surface of innovative composite panels and standard panels (perlite)

The results obtained are related to the operation of the PCM integrated into the cardboard (as a composite material). Because of their great capacity to absorb and slowly release the latent heat, if a PCM is added to the interior of building panels, it increases the thermal energy storage capacity of the material, representing the most ideal solution to thermal insulation. The use of PCM allows to obtain little or no change in temperature during transition processes: heat storage, in facts, occurs over a fairly narrow temperature range (the transition zone). A panel exposed to hot temperatures, hence, slowly increases its temperature in a process governed by sensible heat: when it approaches the phase-change temperature, the building surface behind the panel is held at a nearly constant temperature, due to the latent heat adsorbed by PCM. Once the material has changed phase, the temperature finally increases up to the ambient temperature (Melone, Altomare, Cigada, De Nardo, 2011).

Tests done using a thermo-fluximeter have allowed us to calculate the material thermal conductivity: innovative composite panels are characterized by thermal conductivity value of λ=0,052 W/mK, while standard panels are characterized by thermal conductivity value of about λ=0,060 W/mK.

Water dipping tests, as shown in Figure 4, have verified the good functionality of anti-umidity additives in cellulosic matrix. The addition of 15% w/v of anti-umidity additives is enough to guarantee the same water resistant performance as standard panels (perlite).

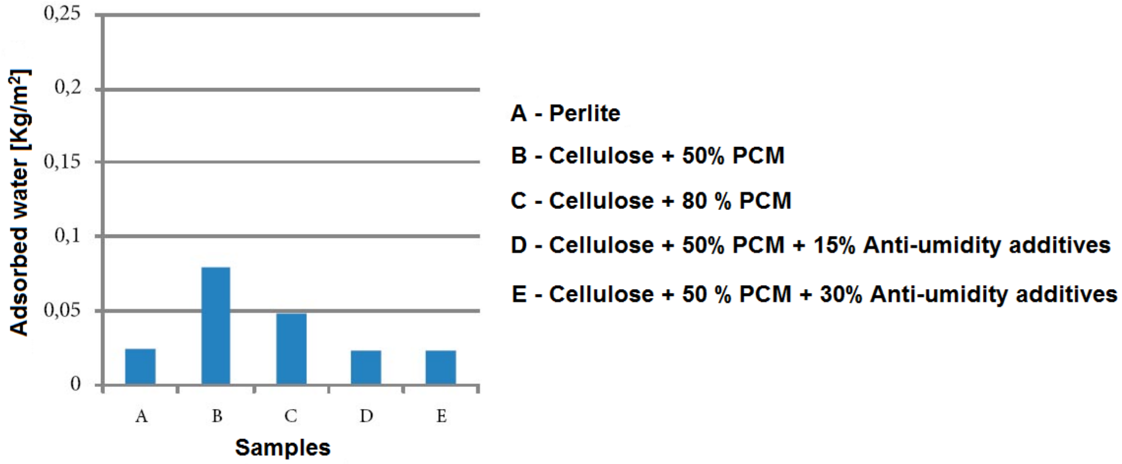

Figure 4 Results of the water absorber tests, (normative UNI 12087)

Through the fire resistance tests we verified that boron salts are able to reduce paper combustibility but it's also necessary to control the fire tendency of PCMs. In order to solve this problem we tested different concentrations of boron salts and finally we obtained good flame retardant characteristics using 30% w/v of additives.

Mechanical tests were carried out in order to evaluate the mechanical resistance of the panels. The results obtained demonstrate that panels made by cellulosic matrix present lower flexural strength value compared with standard panels, because of their porosity structure. Flexural strength of porous cellulosic panels is around 170 KPa, while flexural strength of standard panels is around 280 KPa. However, the mechanical properties evaluated are acceptable for the application considered in this work.

CONCLUSION

In the present work an innovative material for insulating building panels has been developed. We developed a kind of panel presenting similar or better characteristics than standard panels commonly used. In addition, special attention has been given to environmental sustainability.

Through laboratory experiments we have obtained a material starting from the recovery and recycle of waste paper to re-use them in building applications. The composite material has a porous structure and it is made by a cellulosic matrix filled with: PCMs in order to obtain high thermal insulation performace, anti-umidity additives in order to garantee water resistance and boron salts for flame retardant properties. All the additives are uniform integrated inside the matrix. This material has demonstrated to have better properties compared with standard panels used in buildings (perlite). Only mechanical characteristics are not better because of its porous structure; however, they are acceptable for the considered application.

All the highlighted characteristics have confirmed the possibility to obtaining an innovative and sustainable material. It was possible to improve the performance of the material simply by adding special additives and to confer significant values for building applications. This material presents the requirements necessary to be a good alternative to insulating panels currently used.

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