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Experimental and environmental analysis of new sound-absorbing and insulating elements in recycled cardboard

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ABSTRACT

Paper and cardboard, made with recovered fibers obtained by recycling, are an attractive, sustainable material. Recovered paper and cardboard are mainly used for packaging purposes, even if, in recent years, various researches focused on the possibility to develop new products and proposed alternative applications.

This paper presents new designs of acoustic absorbers made of partially recycled cardboard, in order to reduce the environmental impact of the materials usually used for the acoustic correction on indoor environments. Some of these new designed absorbers are porous and make use of the visco-thermal absorption effects in the pore space. Other absorbers are based on the Helmholtz resonator principle.

Computer modeling software was used to predict the performance of the absorbers; in particular, different options of cardboard-based panels and paperboard tubes were investigated to identify the solutions with the best acoustic performance. A real-size prototype of a sandwich panel was then experimentally characterized in laboratory. The absorption coefficient spectrum of the prototype was measured according to the procedure indicated in the ISO 354 standard. The results show that the measured acoustic absorption coefficient of the material made using cardboard was higher than the one of traditional gypsum absorbers, giving in particular an increase of the acoustic absorption at mid and high frequencies in the order of 40%.

A Life Cycle Assessment analysis was also performed to evaluate the environmental advantages of these materials. The environmental impacts of the production of the cardboard-based panel were compared with the impacts of conventional acoustic materials. The analysis highlighted a potential reduction of both energy demand and greenhouse gas emissions during the production process of the cardboard-based acoustic materials.

The estimated CED and GWP values result 10% and 34% respectively lower than the impacts of a conventional gypsum board.

1. Introduction

The world recovered paper consumption increased in recent years [1–3]. Global data reveal constant progress in Asian production and a contraction in the Western World, thus confirming the on-going economic trends in the respective areas. Despite this, in 2013 the domestic selective collection of paper and cardboard in Italy reached 3 million tons [4] and 86% of packaging paper and cardboard collected from industries was recycled.

Recovered paper and cardboard show interesting properties and high potentialities and as a matter of fact they are used in the design of objects, in interior design and as building materials. However, the availability of recovered paper in Europe and in Italy is significantly higher than the needs and therefore it is important to find new applications in different sectors such as civil construction. In fact, it is necessary think of recycling as a total economic system. A good recycling loop has a product that can be sold back to industry [5–7].

Generally, the cardboard can be reused as packaging material. However, recycling it permits to avoid the depletion of new resources in other sectors, out of the packaging industry.

According to Brogaard et al. [8], the production of primary cardboard emits about 1.85 kilograms (kg) of carbon dioxide equivalents (CO_2 eq)/kg of material, versus 0.61 kg CO_2 eq/kg

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of produced secondary cardboard. The emissions of primary and secondary corrugated cardboard are equal to 1.14 and 0.82 kg CO_2 eq/kg respectively. These values are lower, if compared to other materials as aluminum or plastics.

On the other hand, Mercante et al. [9] said that the global warming potential of cardboard recycling is still under study, because wood products represent carbon storages. However, they noticed environmental savings from the cardboard recycling in the major part of the examined impact categories, such as ozone layer depletion, soil acidification or water eutrophication.

Some products made of recycled cardboard are already present in the building sector:

– honeycomb paperboard is used as a core material in the inner part of doors, partition walls and furniture panels;
– thermal–acoustic panels in cellulose fibers and flocks are used in floors and walls cavities;
– paperboard tubes are used as formworks for concrete castings.

Various artists, architects and designers make a large use of cardboard materials in their works, such as the Japanese architect Shigeru Ban [10]. However, these creations are unique pieces, real art; to find new uses, it is necessary to design components whose application possibilities are wider.

The acoustic comfort in offices, houses, classrooms, and conference rooms is very important [11–14]. The Guidelines for Community Noise [15], developed by the World Health Organization, seek to consolidate scientific knowledge on the health impacts of community noise and underline the necessity of a satisfactory indoor acoustical environment. Various studies demonstrated that a comfortable acoustic indoor environment assures a proper and intelligible communication, increases productivity, reduces illnesses of the occupants [11,16].

This study aims at evaluating and improving the acoustic performance of products made from cellulose fiber, already on the market (corrugated cardboard, honeycomb cardboard, paperboard tubes, cellulose fiber) [17–19] and to design new products obtained by assembling existing paper and cardboard products.

Secchi et al. [17] developed and evaluated the sound absorbing performance of sustainable acoustic absorbers produced using corrugated cardboard, paperboard tubes and cellulose fiber.

Yeon et al. [18] investigated and analyzed various physical properties and related parameters of cellulose sound absorbers produced from recycled paper (the NRC value, the thermal insulation, the weathering resistance and discoloration).

Arenas et al. [19] tested walls and floors with a single layer of loose-fill cellulose insulation in heavy timber construction. They concluded that the model predicts the acoustical performance of this material well and that the sound absorption properties of the material are similar to those of mineral fiber-based materials. Segments of paperboard tubes, corrugated cardboard, honeycomb cardboard and cellulose fiber flocks were investigated for possible use to improve the indoor acoustic comfort.

The aim of this study is to find good competitors to the conventional sound insulation and absorption products.

Traditional products for indoor acoustic correction, alternative to cardboard, mainly consist of gypsum perforated boards with a sound absorbent material in the cavity behind the gypsum. Others frequently used sound absorbent materials are made of polyester fibers, rock and glass wool or natural and recycled paper [20].

The performance of sound absorbing panels, installed on walls or ceilings, is significantly influenced by the diameter and shape of the holes and by the thickness of the plenum behind the boards themselves: high performance levels are achieved thanks to both the resonance phenomenon in the cavities behind the holes (Helmholtz effect) and the sound dissipation due to porous materials in the plenum.

On the other hand, cardboard based sound absorbing panels are not new, since they are some patents which date back to 1930s [21,22] and up to present days [23]; in recent years the European Commission has taken into consideration these materials and funded specific research on sustainable natural materials that can be used for noise absorption and insulation [24].

In recent years, concerns towards the environmental impacts of products and processes have increased, especially in the building sector. Attention focuses on energy consumptions and pollutant emissions released throughout the entire life cycle of buildings.

The production of building materials often requires a high energy demand for the extraction of raw materials and the manufacture phase.

Furthermore, the construction industry needs new techniques that allow to reduce emissions and waste in order to minimize costs of production and disposal [25–27].

Improving the sustainability of building materials can reduce greenhouse gas emissions and resources depletion.

Many LCA studies already confirm that the use of recycled materials, such as paper and cardboard, can be a valid way to achieve this objective in the packaging industry [28–32]. Koskela et al. [28] studied a delivery system using corrugated cardboard box. At the end of life, the recycling of cardboard to core board represents a benefit. It avoids emissions from the production process of core board, about 0.106 kg CO_2 eq/functional unit. This is more notable when it is compared to a delivery system using plastic crates.

González-García et al. [29] analyzed the life cycle of a wood box for wine storage. They aimed to identify the reduction of impacts obtained applying the eco-design principles.

Mourad et al. [30] examined the influence of the increasing rate of recycling in the life cycle of a carton of milk. They observed a significant reduction in overall impacts increasing the recycled rate of cardboard from 2% to 22%.

In a following study, Mourad et al. [31] have also analyzed the production process of cellulose packaging materials, that are folding box board and kraft liner paper.

They suggested some actions to improve the environmental performance. Among them, making changes to the consumption of the bleaching agent, since it is responsible of a notable impact to the process.

The influence of the sustainable materials are also studied by Takano et al. [32]. They noticed the importance of the material selection in the life cycle energy of building. The cellulose fiber insulations results one of the most environment friendly between the investigated products.

Various literature studies showed that natural or recycled building materials have a lower embodied energy than traditional ones [33,34].

Cabeza et al. [33] presented a review of LCA studies of residential and non-residential buildings. Among the several issues of LCA analysis, the embodied and operating energy of buildings were discussed. The researchers agreed that the use of sustainable and low-energy materials permit to reduce the share of the embodied energy of buildings, that is about 10–20% of total life cycle energy.

Asdrubali et al. [34] analyzed the life cycle of three types of buildings. Furthermore, the life cycle results are supported by the analysis of several scenarios, to optimize the building life cycle. For example, they analyzed the effect of the substitution of a mineral insulation material with a cellulose fibers slab in a multi-dwelling building. The results showed that an improvement of materials envelope reduce considerably the impacts of buildings.

For this reason, a Life Cycle Assessment (LCA) analysis was also performed, to evaluate the environmental advantages of these