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Rice husk panels for building applications: Thermal, acoustic and environmental characterization and comparison with other innovative recycled waste materials

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HIGHLIGHTS

- Rice husk panels for building applications were experimentally analysed.
- Thermal, acoustic and environmental performance were investigated.
- A comparison with other waste recycled materials was performed.
- A new experimental apparatus for thermal measurements was used.
- Primary embodied energy and greenhouse gas emissions were determined.

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ABSTRACT

In building applications, recycled waste materials are becoming promising acoustic absorbers and thermal insulating solutions in order to reduce the environmental impact. The aim of the research is to evaluate the thermal, acoustic, and environmental performance of recycled waste panels consisting of rice husk (RH) produced by gluing and pressing the raw material. Its acoustic and thermal performance were compared with the ones of six panels composed by other recycled materials (cork scraps, end-life tires, coffee chaff, waste paper, textile fiber mats, wool fiber scraps), assembled with similar techniques. Thermal resistance of RH is equal to 0.59 m^2K/W, in the same order of magnitude of many traditional systems. Sound absorption coefficients were measured by means of the impedance tube. All the panels present acoustic absorption comparable with traditional ones (peak values 0.87–0.99). RH peak value is 0.87, while the maximum values are obtained for cork and wool fiber scraps (1 and 0.97 respectively). Life cycle analysis, performed in compliance with ISO 14040 showed the best environmental performance for the production of 1 m^2 of RH and coffee chaff panels. Taking in account their acoustic and thermal behaviour, the wool fiber scraps presents a very good performance.

1. Introduction

The minimisation of carbon emissions resulting from the use of buildings increases relative importance of a building's life-cycle stages [1–3]. Thus, measures to control and reduce the environmental impacts of the entire construction chain have become a priority, in particular the production phase of building materials. The increased investment in near-zero buildings is also promoting the use of passive solutions for the envelope, resulting in increased insulation thicknesses of the walls all over the world [4]. As a consequence, the contribution of these materials to the life cycle environmental impact is also gaining momentum [5–7]. In addition, the growing environmental awareness throughout the world triggered a shift towards developing environment friendly materials from recycled ones [8,9]. Some non-conventional materials are emerging, especially the ones of natural origin, which still present rare applications in the building field. Volf et al. tested several materials such as raw sheep wool, wood fibre, hemp, flax, compressed straw bale in order to evaluate their thermal, moisture, and biological properties [10].

The novelty of this paper consists in presenting the results on thermal and acoustic characterization and life cycle analysis of an innovative recycled waste materials obtained from the discards

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of the rice processing (Rice Husk, named in the paper with the abbreviation RH). This material can be used for the fabrication of panels for building applications: its acoustic and thermal behaviour can be compared with other panels made of cork scraps (COR), end-life granulated tires (ELT), coffee chaff (CC), waste paper pressed and glued with polyethylene fibers mat (WP1), waste paper pressed and glued (WP2), and waste paper pressed and glued with wool fibers (WP3). Among these applications, cork and end-life granulated tires have been employed for years and they are included in the market as traditional building panes. Coffee chaff panels and the systems composed by waste paper glued and pressed are new materials and their properties are currently being analyzed.

Rice is the third most produced commodity in the world after sugar cane and maize, with more than 740 million tons per year [11]. Rice straw and rice husks were preliminary investigated by Izhar et al. and Sakamoto et al. [12,13] showing their useful characteristics of sound absorption. Yarbrough et al. [14] focused on thermal insulation performance of particleboards made of rice hulls, and found thermal conductivity values in the 0.046–0.057 W/mK range, comparable with the ones of coconut or sugarcane fibers. Yang et al. [15] analyzed the sound absorption coefficient of three composite materials made of rice straw and wood (10, 20, and 30% of rice in weight). The panel with 10% showed a sound absorption coefficient higher than particleboards, fiberboard, and plywood panels. None of the above mentioned studies on rice by products investigated the glued rice husks, which could be an innovative recycled material for the building sector. Recently, the rice husk ash was also inserted in Portland cement mortars in place of sea sand, in order to obtain improvement in terms of compressive strength [16]. Finally, another interesting study analyzed the potential of poppy (Papaver somniferum Linnaeus) husk for manufacturing wood-based particleboards [17]: poppy husk particles reduce the formaldehyde emissions and contribute to improve the physical and mechanical requirements of the panels.

Cork scraps deriving from the waste of the wine cops production are another valuable natural material for building applications [18]. Cork is very interesting from a sustainability perspective because it allows many environmental services such as forest preservation, biodiversity conservation, and wildfire prevention. Currently, in Sardinia (Italy) cork oak bark are only exploited about 20,000 km^2 of existing 36,000 km^2 [19]. Fernandes et al. [20] tested the fire resistance and the acoustic insulation of cork/HDPE (high density polyethylene) and cork/PP (polypropylene) composites, and found out that the presence of cork improves both properties. Experimental tests [21] were also carried out on samples composed by cork granules: they showed good sound absorption characteristics, low thermal conductivity, and low density, with best absorption results for the smallest granules. Vasconcelos et al. [22] investigated blocks made of cork and chalk for internal partition walls. Tests carried out by Tiuc et al. [23] on samples composed by a layer of cork of thickness of 3 mm, a layer of particles coming from the shredding of tires (diameter: 1–3 mm), and a polyurethane binder (15%) showed differences between the values of the absorption coefficient by changing the measurement side.

Leading car manufacturers are now producing vehicles which incorporate up to 20% of recycled waste [24,25], but end-life tires constitute a great proportion of total automotive waste. Different studies [26–28] showed that the absorption coefficient usually decreases by increasing the size of rubber granules. In particular, Maderuelo-Sanz et al. [26] found that the most appropriate size granules are in the 1–3 mm range. In the study conducted by Horoshenkov et al. [27], the relationship between percentage of binder and porosity is almost linear. Maderuelo-Sanz et al. [28] investigated the influence of the binder on the sound absorption and found the best results for samples made with 0.71–1 mm particle size granules, concentration of the 15% binder and 20% of degree of consolidation.

Coffee is one of the most widely consumed beverages [29], with a production of 8 million metric tons per year [30]. During the roasting process, the residual coffee chaff is completely removed and the ground roasted coffee beans are finally used for coffee beverage production. Coffee chaff is an industrial waste readily available in large amounts, waiting for a definition of its potential value-added uses [31].

Concerning the waste paper systems, insulation panels with cellulose as the main raw material were developed and analyzed in [32] and it was observed that they are suitable as acoustic correction systems, especially a panel type composed by waste paper and wool fibers. Natural fibers systems [33] showed acoustic properties strongly depending on the methods of production; their behaviour cannot be theoretically evaluated due to the lack of homogeneity. Yeon et al. developed a building material made from waste newspapers and magazines with good thermal insulation and sound absorption properties [34].

In the present paper rice husk (RH) panels were fabricated and studied from different perspectives and the results were related with the same performance of other traditional and innovative boards made with the same construction technique: the raw materials were glued and the panels were slightly compressed. The thermal resistance and the acoustic absorption coefficient were evaluated by means of two experimental campaigns. The thermal flux meter method [35] was used for the thermal analysis and the impedance tube method for the acoustic investigations, in compliance with ISO 10534-1, 2 [36,37]. Life Cycle analysis was also performed, in compliance with ISO 14040 series requirements [38,39]. A deep comparison analysis was carried out taking into account also the results obtained for other innovative waste materials in other experimental campaigns: all the aspects were investigated (thermal, acoustic, and environmental analysis).

2. Materials and method

2.1. Samples description

A company based in Lombardy (Italy) supplied rice husk, since it deals with rice derivatives production and distribution. Rice husk is deriving from the paddy rice husking process, the rough rice (unpolished) after threshing. The percentage of rice husk over paddy rice is variable depending on the variety, and it can be in the 17–23% range by weight. The used shells have a length of about 9 mm and a width of 1 mm. Rice husk contains 75–90% organic matter such as cellulose, lignin and mineral components, such as silica, alkalis, and trace elements [40]. Their content depends on rice variety, soil chemistry, climatic conditions, and even the geographic localization of the cultures [41].

All the tested samples were made in laboratory, in the form of disks of 2.9 and 10 cm diameter, for acoustic measurements, and as square panels of 300 × 300 mm for thermal ones (Fig. 1). For the realization of the samples, it was used a cold-water-based polyurethane glue, with a density of 1.000 kg/m^3 and a percentage present of 2.5% of the total weight. The percentage was determined after preliminary tests, in order to find the percentage necessary for an optimal consistence of the sample. The used polyurethane-based glue was a polyurethane adhesive in aqueous dispersion and it was found to be the ideal binder for bonding the type of used row material. In particular, this adhesive was found to be easily applied by spray technique and made it possible to achieve the desired results with low doses. Furthermore, two support panels of plasterboard (each thick 6 mm), one for each side of the recycled waste material, were employed for the thermal measurements'