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Application of rice husk in the development of new composite boards

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HIGHLIGHTS

- Rice husk waste is an abundantly accumulated agro-industrial waste product.
- Composites made from rice husks, expanded cork and recycled rubber granules.
- Weighted reduction in impact sound pressure level ranging from 20 dB to 27 dB.
- Thermal conductivity varying from 0.060 to 0.074 W/(m.°C).

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ABSTRACT

The main objective of the paper is to propose a new composite material incorporating rice husk. This paper reports an experimental study on the mechanical, thermal and acoustic performance of new composite boards made of rice husk waste intended for construction applications. In this study, rice husk was mixed with expanded cork granules or recycled rubber granules in 50/50 and 75/25 (weight percent) proportions. A TDI-based polyurethane pre-polymer was used as binder in 20% of the mass of the fillers. A sufficient number of small boards were produced to perform small-scale tests and assess properties such as compressive strength, thermal conductivity, dynamic stiffness, improvement in impact sound insulation, sound absorption and transmission loss.

The results are very interesting, in particular: the thermal conductivity, at 10 °C, varies from λ_{10} = 60.0 mW/(m.K) to λ_{10} = 74.3 mW/(m.K); the weighted reduction of the impact sound pressure level, ΔL_w, ranges from 20 dB to 27 dB; the noise reduction coefficient (NRC) ranges from 0.15 to 0.45, with maximum sound absorption coefficient of 0.96 for composite B1. These results suggest that optimized construction solutions based on these composite materials could improve the thermal and acoustic performance of buildings.

1. Introduction

In general, a large amount of resources is consumed over the life-cycle of a building, including the exploitation of raw materials and manufacture of construction products in the design, construction, use, renovation and demolition stages. This is responsible for significant negative impacts on the environment and people. According to a Communication from the European Commission [1], about half of all extracted materials and energy consumption in the EU are accounted for by the construction and use of buildings. The sector also generates about one third of all waste. This is why authorities and researchers have been advocating the design of more sustainable materials and buildings. Furthermore, several authors have suggested that one of the most effective approaches to reducing resource consumption in buildings would be to incorporate recycled materials, materials made from waste and renewable materials [2–4].

Safiuddin et al. [5] presented a comprehensive review of the major solid waste products (e.g. agro-industrial, industrial, mining/mineral) and the potential for their use as alternative construction materials, which would help to improve environmental performance and to reduce construction costs. Agrawal et al. [6] presented a more specific review of using industrial waste in concrete and mortars by partially replacing cement and fine aggregates, and the impact of this on the mechanical properties. Examples of analysed waste materials include rice husk ash, fly ash, sewage sludge ash, paper mill sludge ash, quarry powder, rub-

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ber granulate, and granulated blast furnace slag. A review of the use of various agro-industrial residues in the development of different sustainable construction materials can be found in Madurwar et al. [7]. More recently, a review of the use of various recycled and natural materials for building insulation has been presented by Asdrubali et al. [8], where the most relevant thermal, acoustic and environmental properties were identified. These recycled and natural materials include reeds, corncobs, cotton stalks, pineapple leaves, straw and rice husk, and bales of straw. Different types of waste biomass for use in building material have also been studied, including recycling poppy husk biomass and pine wood to produce particleboards [9], and using coffee chaff as sound insulation and absorption material for the building industry [10].

All these research works show that the development of building materials based on agro-industrial wastes has been gaining attention in recent years, possibly driven by the environmental concern with the massive production of these kind of waste materials.

In this context, it should be noted that rice husk is one of the agro-industrial waste products that is most abundantly accumulated. Annual rice production worldwide is over 700 million tonnes and Portugal produces over 160 thousand tonnes per year [11]. Rice husk accounts for 20% of paddy weight and it takes up a lot of space. It is usually burnt or transported to landfill, with relevant environmental impacts. The recovery of this waste material would improve the sustainability of this agricultural activity and help reduce the environmental impact of other means of disposing of it. So far rice husk has been recycled only for low-value applications, although some studies have described the incorporation of rice husk in materials, particularly in thermal insulation [12,13], plastic composites [14] and lightweight concrete [15]. Regarding the potential environmental performance of this type of material, note should be taken of a previous life-cycle assessment (LCA) carried out by some of the authors of this article on the product stage (A1–A3, according to EN 15804:2012) of wall panels made from rice husk [13]. That study suggested that rice husk provides a better environmental performance for almost all the impact categories (CML – IA v4.1) than conventional insulation materials, such as the rock wool. One exception to this conclusion is the impact on the category "depletion of abiotic resources – elements" caused by the exploitation of the soil in rice farming. However, this impact may be neglected given that rice husk corresponds to a waste product. Low values of incorporated energy (128–145 MJ) were also obtained for the rice husk panels studied.

This work aims to add value to rice husk by developing a sustainable material with improved thermal and acoustic features. The rice husk was combined with expanded cork granules and recycled tyre rubber granules to enhance the performance of the material without compromising the environmental goal.

Expanded cork granules are a by-product of the manufacture of expanded cork agglomerate. Cork is a raw material obtained from the bark of the oak tree, *Quercus suber*, which mainly grows in the Mediterranean basin, particularly in the southern regions of the Iberian Peninsula [16]. Portugal is still the world's main cork producer. Cork granules, both expanded and non-expanded, have been used in the manufacture of cement based products, notable in concrete and light screeds [17–20].

Council Directive on the Landfill of Waste 1999/31/EC banned the disposal of tyres in landfills [21]. The Waste Framework Directive (Directive 2008/98/EC) requires member states to take measures that lead to the reuse, recycling and recovery of materials [22]. The life of used tyres can be extended by retreading them and when they reach the end of life they can be used as an energy source or the material can be recovered. Several applications for the construction industry can be found in the literature, such as in cementitious composites to produce lighter, flexible mortar and concrete, in resilient mats used to attenuate the impact sound in buildings, and in rubber-modified asphalt concrete [23–27].

The present work presents an initial investigation aimed at evaluating the potential of composite materials made from rice husks, expanded cork granules and recycled rubber granules for use in building construction. Two different composites were designed, one using rice husk and expanded cork granules and the other using rice husk and recycled rubber granules. Two compositions were studied for each composite, one with 50% rice husk and 50% of the other filler (cork or rubber granules), and the second with 75% rice husk and 25% of the other filler (percentages in mass). Non-industrial mixes were made to produce boards measuring 1 m × 1 m, from which small samples were cut for testing purposes. Properties such as thermal conductivity, compressive strength, dynamic stiffness, impact sound insulation improvement, sound absorption and transmission loss were determined. The next section describes the materials and compositions used and the test set-ups for the different experiments. Section 3 presents and discusses the results of all the tests, and the final section indicates some conclusions.

2. Materials and methods

2.1. Materials and composites

Rice husk was obtained from the rice cultivation in Baixo Mondego (Portugal). The loose rice husk has a bulk density around 105 kg/m^3. The expanded cork granules, with a granulometry of 3/8 mm and a bulk density of 65 kg/m^3, were provided by Amorim Isolamentos, a business unit belonging to the Portuguese holding company Corticeira Amorim SGPS, SA. The recycled tyre granules, with a granulometry of 0/0.8 mm and a bulk density of around 350 kg/m3 were from Biosafe. Two different composites were produced, one with rice husk and expanded cork granules (see Fig. 1) and the other with rice husk and recycled rubber granules (see Fig. 2). Two mixes were made with each composite (Table 1): the first with 50% rice husk and 50% of the additional filler, and the second with 75% rice husk and 25% of the additional filler (in weight). The fillers were agglomerated with a TDI-based polyurethane pre-polymer in a proportion of 20% of the solid mass of the fillers. Boards of 1 m × 1 m were moulded in a thermal press such that those made from the first composite were 17 mm thick and those made from the second composite were 25 mm thick.

2.2. Thermal conductivity

A Lambda-Messtechnik GmbH Dresden apparatus, single-specimen Lambdameter EP-500 model, was used to measure the thermal conductivity as per EN 12667:2001 [28] and ISO 8302:1991 [29] (see Fig. 3). This apparatus provides a one-dimensional heat transfer in a metering area of 150 × 150 mm^2 at the centre by means of a "hot ring". The equipment ensured null heat flows across the lateral boundaries.

The sample size used for measurement was 500 mm × 500 mm × (specimen thickness). Before testing, the specimens were conditioned at a temperature of (23 ± 2) °C and relative humidity of (50 ± 5)%. Then the test specimen was placed between the Lambda-meter plates, the test was repeated for three different average temperature levels, 10 °C, 25 °C and 40 °C and keeping a temperature difference of 15 °C between the Lambda-meter plates. The thermal conductivity at 10 °C was calculated by a linear regression applied to the three measured values. Three test specimens were tested for each composite.

2.3. Compressive strength

The compressive strength was measured at 10% deformation, as is usual for thermal insulation materials. A universal testing machine, Instron 5884, with a load cell of 30 kN equipped with a displacement sensor appropriate for the test was used (see Fig. 4). The compressive force was applied at a constant rate of displacement [0.1 thickness (mm)/min]. The sample consists of three test specimens with dimensions of 150 mm × 150 mm × (specimen thickness). Prior to the test, the specimens were stabilized at a temperature (23 ± 2) °C and (50 ± 5) % relative humidity. The test was performed according to the procedures recommended in EN 826: 2013 [30] (used for thermal insulation).

2.4. Dynamic stiffness

The dynamic stiffness was evaluated according to ISO 9052-1:1989 [31]. The procedure determines the apparent dynamic stiffness per unit area using a resonance method (see Fig. 5). The resonance frequency, f_r, of the fundamental vertical