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An experimental study on the use of waste aggregate for acoustic attenuation: EVA and rice husk composites for impact noise reduction

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HIGHLIGHTS

- It is possible to use waste from other sectors in civil construction elements.
- The use of EVA waste and rice hulls in the construction of underfloors enable the decrease of impact noise.
- Underfloors are identified as an opportunity to use waste with the benefit of reducing the total load of a building.

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ABSTRACT

The civil construction sector is one of the areas that most generates waste and consumes raw materials. To mitigate this environmental damage, is possible to use waste from other sectors to reduce raw material or by minimizing the generation of waste with materials of satisfactory durability. One of the main points to be evaluated is how such materials behave to the loads application and other mechanical stresses, and how it affects their acoustic performance. These mechanical tests usually are performed only in industrial materials. Still, the search for building performance is increasingly based on the sustainability, safety and habitability. Habitability requirements include acoustic performance, which is vital in buildings because its absence could cause stress, insomnia, hearing loss and other problems. So, this article proposes the use of EVA waste and rice husk in subfloors to decrease impact noise, replacing natural fine aggregates in the contents of 25, 50 and 75%. Compressive creep, dynamic stiffness and impact noise tests were performed. The results show that the use of both natural and artificial waste can represent gains in the efficiency of impact noise acoustic insulation for subfloors when used in larger proportions.

1. Introduction

The use of materials mixed with waste can be a significant contribution to the environment by the construction supply chain. The main benefit of these materials usage is the reduction in the consumption of energy that would be spent in manufacturing new inputs, in addition to direct reduction of the volume of waste in landfills and the impact related to waste degradation time.

The waste used in construction can be natural or artificial, according to the type of processing of the original product. Wastes generated from agricultural or extractive activities are classified as natural and, because they are organic, they are subject to more rapid degradation. Artificial wastes are generated after the process of industrialization of other materials such as metal and plastic [1,2], deriving, for example, from scraps of sheets and parts.

The type of material that is recycled is indicative of the socioeconomic context of each region, by verifying which productive activities generate products for final disposal. Thus, the sustainable nature of using waste is based on the insertion of processes within a regional reality for the solution of contemporary problems [1].

Civil construction consumes a significant amount of inputs with a high impact on the environment and the materials used in acoustic insulation of buildings are a relevant example of the use of products of difficult degradation and/or high energy consumption in their manufacture. Coelho and Brito [3] studied the environmental impact of three buildings by analyzing different life cycle stages, for several waste and material management options. In this study, the materials used in thermal and acoustic insulation made a significant contribution to the impact on the environment, resulting from their transportation and disposal after the building was

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demolished. This transport-related impact is due to the low density and significant volume of the waste, together with the presence of toxic substances in its composition, which results in increased trip cycles and longer distances to be traveled for disposal, which is usually in areas farther from urban perimeters.

For acoustic insulation of buildings, the principle governing the efficient behavior of a building system depends on the medium of sound transmission, which can be by air or by the structure and other solid elements of the building. The sound transmitted by the structure, called impact noise, is treated by damping the mechanical excitations in the floor, thus reducing vibration propagation. The materials used to attenuate this type of sound have elastic properties to cushion the mechanical impact and, consequently, to make the acoustic insulation of a floor system more efficient [4].

The theoretical prediction of the acoustic insulation efficiency of floor systems can be applied when the materials characteristics that compound the layers of floating floors are known, and several aspects can be studied for the qualification proposals preparation still in the design phase [5]. However, composite materials based on new materials still require an experimental characterization.

2. Previous studies

In this context of waste utilization, several researches have been carried out with the purpose of analyzing the acoustic performance of composite materials made from the addition and/or substitution of waste materials, both natural and artificial. The influence of variables, such as particle size of the material incorporated to different types of composites, differs according to the material type, because the smaller the particle size, the greater the efficiency of the material in impact noise insulation [6–8]. Another factor that can determine the efficiency of the impact noise insulation is the deformation capacity of the input at constant load, for which it becomes important to perform accelerated compression creep tests. Creep is the deformation of a viscoelastic material at constant load, with a strong relationship between time, deformation and applied stress [9], therefore, this property allows evaluating the performance of the system over time at use loading rates.

D'Alessandro et al. [7] tested lightweight concrete subfloors made from polymers used in electrical wire covering. The authors argue that although the subfloor with lightweight aggregates is not considered a traditional resilient material, depending on the method of manufacture, increasing the polymer content makes it sufficiently elastic. The study showed that it is possible to use polymer waste in a new product with efficient acoustic and thermal performance compared to conventional lightweight subfloors. Moreover, the material's reduced dynamic stiffness (s') was the most important variable for the reduction of impact noise.

Branco and Godinho [8] evaluated mortar mixes made of lightweight expanded polystyrene aggregates, expanded cork and expanded clay granulates with two different particle sizes in each material. The purpose was to investigate, through laboratory tests, the acoustic performance and to compare the impact noise reduction provided by the three different aggregates used. The mortar produced with these aggregates showed different acoustic behavior. Samples made with conventional mortar and expanded clay did not perform satisfactorily regarding impact noise reduction. On the other hand, the samples with expanded cork and expanded polystyrene presented a satisfactory behavior, as compared to the other test specimens. In this study, both materials provided increased impact noise reduction at high frequencies, and at the frequency of 3150 Hz reduction reached 40 dB.

In a comparative study developed with lightweight mortar with EVA waste, Zuchetto et al. [10] tested five different EVA waste proportions (20%, 40%, 60%, 80% and 100%) to verify the acoustic performance of subfloors based on compression creep and dynamic stiffness tests. The samples made of 80% and 100% EVA had the lowest dynamic stiffness, 26.74 and 28.13 MN/m^3 respectively, both with an estimate of ΔLw of 24 dB.

António et al. [11] studied mortar with cement and cork at three different cement proportions, three sample thicknesses, with the purpose of reducing impact noise in floors. In this study, impact sound insulation reduced with increased cement content, particularly when the mortar was tested as floor coating. The best results were obtained for the 3 cm thick sample, with lower consumption of cement. It was observed that the samples with lower specific mass presented the best results.

Brancher et al. [12] analyzed the efficiency of micronized EVA composite subfloors in test specimens of 3, 5 and 7 cm thickness and three polymer addition contents. Samples with 50% micronized EVA showed better impact insulation efficiency with $\Delta L'_{nT,w}$23 dB. Scanning electron microscopy (SEM) analyses allowed verifying that the system efficiency is explained by the preservation of porosity of polymer grains because of the type of interface formed with the cement paste, reinforcing what had been observed by António et al. [11].

António et al. [11] also studied the characteristics of materials made of cement, sand and cork in different proportions, with cork replacements of up to 80%. In this work, the authors found s' of 599.56 MN/m^3 for the samples with the highest proportions of cement and 148,75 MN/m^3 for the samples with larger amounts of cork in their composition. Authors used the standard ISO 9052.

Tutikian et al. [13], when studying lightweight concrete with replacement of natural aggregate by recycled EVA aggregate to evaluate the reduction of impact noise, found that the use of this material can reduce impact noise levels by up to 15 dB and the increased percentage of coarse EVA aggregates did not increase the acoustic performance. The authors analyzed the relationship between impact noise and voids and found that increasing the number of voids leads to better acoustic performance in accessible slabs and covers.

Petroleum coke waste was used by Olmeda et al. [14] for the production of lightweight mortar. The authors identified that at frequencies below 400 Hz the material presented little impact noise insulation efficiency and that the greatest reductions occurred at high frequencies, where the most significant differences occurred from 1600 Hz, reaching 14 dB at 5000 Hz.

Although it has potential to be used for impact noise reduction in floor systems, natural waste is still not widely exploited for this purpose. Several studies have already demonstrated the efficiency of composites in sound absorption, such as jute [15], rice husk [16], bamboo fibers and sisal [1]. In addition, other studies have been carried out with composites using wood-waste with used tire rubber [17] and with high density polyurethane grains [18]. António and Tadeu [19] developed a composite consisting of rice hulls, expanded cork granulate and polyurethane to verify the potential of this composite as a material for acoustic insulation in buildings through tests of dynamic stiffness, reduction of the transmission of percussion sounds, among others.

The authors found of dynamic stiffness values between 71 and 100 MN/m^3 and ΔLw of 20 dB. According to António and Tadeu, the results obtained were very promising and future developments should enable this material to be applied in the construction industry. There is a lack in studies evaluating the acoustic properties of the material concomitantly with its behavior through mechanical tests, though it is known that stresses may affect acoustic efficiency.

Considering this scenario, the general objective of this paper is to investigate the acoustic efficiency of 3 and 5 cm thick subfloors produced with replacement of coarse aggregate by rice hulls (RH)