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Experimental study of expanded cork agglomerate blocks – Compressive creep behavior and dynamic performance

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HIGHLIGHTS

- Characterization of ICB when subjected to prolonged static and dynamic loads.
- ICB with low mass density can suffer large deformations under heavy loading.
- ICB specimens with lower mass density and larger thickness had better performance.
- Creep affects negatively the dynamic behavior in the initial stages of loading.
- ICB material is a more sustainable alternative to other commonly used products.

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ABSTRACT

The main goal of the present work is to experimentally evaluate the behavior of expanded cork agglomerate blocks subjected to static and dynamic loads. The study focuses on the compressive and creep effects and on the vibration isolation capability.

First, compressive creep behavior and deformation recovery capability (after loading) tests were performed on blocks made of expanded cork agglomerate. The dynamic characterization then involved performing transmissibility tests for different static and dynamic loading conditions and evaluating the dynamic transfer stiffness and damping ratio of the blocks. The resulting transmissibility curves indicate how much vibration is transmitted through the isolator to its base at a given frequency. These tests were also performed under different conditions of strain to better understand the effect on the dynamic performance of the material, and to assess whether it might be a limiting factor.

The results show that expanded cork agglomerate blocks, especially those with higher mass density, have physical and mechanical properties that provide this material with great potential for withstanding heavy static loads since small compressive creep effects and low permanent deformation was exhibited.

The results also indicate that expanded cork agglomerate can be a good option for mitigating vibration. It was found that specimens with lower mass density and larger thickness performed better, with higher vibration isolation and a wider range of frequencies isolated. However, this behavior is limited by the influence of compressive stress on the blocks.

1. Introduction

Cork features as one of the most versatile natural raw materials [1]. It is lightweight, elastic, flexible, impermeable to gases and liquids, imperishable and known to be a good electrical, thermal and sound insulator, as well as a vibration isolator [1–4]. The cork market has greatly expanded in recent years with the introduction of several cork based agglomerate products and composites. Furthermore, this material has huge economic, environmental and social importance to Portugal, where cork production and processing is mostly located, accounting for over 80% of the global market [5].

Of the various cork products applied in construction, expanded cork agglomerate, commercially known as insulation cork board (ICB), stands out in particular [6]. It is a 100% natural product made

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from cork by-products, and is completely recyclable [6,7]. It is fabricated without any additives since the cork particles are self-bonded by means of an autoclave process using their own natural suberin. ICB has the one of the smallest carbon footprints of most insulation materials currently available on the market, presenting a negative figure (-116.229 kgCO_2 equivalent per cubic meter of expanded cork agglomerate) [7].

Optimized for the construction sector, ICB has good mechanical strength, fire retardant behavior and robustness [6,8]. It is also resistant to freezing/thawing cycles and to water, is energy absorbent, and significantly resistant to chemical and biological agents, among other features [6,9]. Numerous applications are found for agglomerated cork materials, with the two principal uses being related to thermal insulation [10,11] and impact sound insulation [9,11–13].

In many of these applications, the materials used are subjected to complex static or dynamic loads and levels of strain. Depending on the mass density, a material may be more or less able to support large compressive stresses without exhibiting undue strain. The mechanical features of natural cork and other cork agglomerates have been studied previously and include the dynamic crushing behavior and the response under multi-impact loads [14–18]. The mechanical behavior of cork under compression shows stress-strain curves that are linear elastic up to about 7% strain, at which point elastic collapse gives a plateau which extends to nearly 70% strain when complete cell collapse occurs [19]. Additionally, the compressive properties of cork have been found to vary with density, cellular dimension, and quality [3]. Results found in the literature suggest that natural cork has a viscoelastic property, clearly evidenced in creep experiments [20,19]. In one of these studies, short-term creep experiments were performed at different temperatures in a first attempt to build master curves that could describe larger time-scale mechanical behavior under static loads.

In industrial applications, prolonged loading has been found to lead to increased stiffness and consequently to a loss of vibration isolation capability. Creep effect is of significant concern when choosing materials, particularly for structural applications. The underestimation of creep can lead to excessive deflection, cracking, and even to creep failure. Many experimental and theoretical studies have been performed to describe and predict the creep response of several materials, including cementitious products [21], refractory materials [22], granular materials[23], polymer composites [24,25], and plant fiber composites[26]. Even though the creep effect can be significant for some ICB applications, the behavior of expanded cork agglomerate under prolonged loading has not been studied thoroughly. Similarly, in the context of vibration isolation the dynamic behavior of expanded cork agglomerate has not been deeply studied either.

High level vibration is not only well known to be harmful to human health [27–32], but it also reduces the reliability and lifetime of machines, often leading to financial loss and equipment failure [33–35]. Additionally, vibration isolation blocks are usually made of non-sustainable materials such as synthetic rubber [36]. In fact, few works can be found on the development of new, more sustainable options for vibration isolation. Diego et al. [37] performed a numerical and experimental characterization of an elastomeric material based on end-of-life tires for anti-vibration use in railway applications. However, no studies using expanded cork, which could be an ecological alternative to the products currently on the market, have been performed so far.

Isolating vibrations is a problem that affects most engineering structures [38–40]. Even after decades of studies it remains a problem that is solved mostly on a case-by-case basis [41–42]. Suspension and damping elements, often called vibration isolators, are very often used as isolation systems. A parameter which is commonly used to quantify the effectiveness of such systems is transmissibility. For a conventional single-degree-of-freedom system this parameter is defined as the modulus of the ratio between the force transmitted to the host structure and the excitation force or, in the case of base excitation, as the ratio between the displacement of the payload and that of the base [43,44]. A decrease in transmitted force leads to a transmissibility (T) of less than one. The isolation effectiveness (IE) of a vibration isolator is then expressed as a percentage by $IE(\%) = (1 - T) \times 100$ [45]. The design of vibration isolation blocks depends on the excitation frequency and the static load. The static load due to the mass has an effect on the observed dynamic properties, and it is the only variable able to change the resonant frequency. Hence, experimental characterization is regarded as essential to better understand the isolator dynamics under different static and dynamic loading conditions [46].

In general, at the same time that people are spending more time inside buildings and expect improved thermal and acoustic comfort levels, there is also a growing concern about the scarcity of resources and environmental protection. This is leading the construction industry towards developing and adopting eco-friendly materials with less impact on the environment. In the European Union this strategy is explicitly addressed in the requirements and measures set out in Regulation (EU) No. 305/2011 regarding the marketing of construction products [47]. In particular, research in this field has tended to focus on materials used for thermal or acoustic insulation because of the pressing need to reduce energy consumption in buildings. A review of unconventional sustainable building insulation materials can be found in the paper by Asdrubali et al. [48], with emphasis on acoustic and thermal properties and life cycle analysis. Diverse materials such as sheep's wool [49], silkworm cocoons [50], crop by-products [51], jute, flax and hemp [52], date palm fibers with cornstarch resin [53] , other plant fibers [54], timber industry by-products [55], corn-on-the-cob waste [56], olive seeds with PVC and wood chips [57], and onion skin waste and peanut shells mixed with fly ash, pumice, perlite, barite, cement and gypsum [58] are all being considered and studied to enhance the sustainability of building insulation products.

In this work, compressive creep and dynamic loading tests were carried out to better understand the long-term behavior of expanded cork agglomerate under compressive loading, as well as to assess its vibration isolation capability. Experiments were carried out using expanded cork blocks of different mass density.

First, creep tests were carried out to predict the strain after a certain period of loading under different conditions of compressive stress. Compression tests were performed for comparison purposes. The data retrieved from the two tests were complementary. The deformation recovery capability of the expanded cork agglomerate blocks was also determined so as to find out what percentage of strain is recovered and what is permanent.

Then, the feasibility of using vibration isolators made of expanded cork agglomerate was evaluated by performing transmissibility tests. These tests were performed for different load masses to simulate different types of equipment or machines. The experiments enabled the determination of the isolation effectiveness (percentage IE), the dynamic transfer stiffness and the damping ratio of the material, as well as the assessment of the range of frequencies for which the material is most effective. It is well known that dynamic properties measured at high strain amplitudes cannot be used to design a vibration isolator that will work under low strain amplitudes, and vice versa [46]. To accurately take into account the exposure to load in the dynamic behavior of the material, transmissibility tests were performed on the samples at the instant of load application, and then repeated for the same samples that had been statically loaded over several weeks (higher levels of strain resulting from the compressive creep effect).