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Cork composites for the absorption of impact energy

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ABSTRACT

In this article the authors analyse the characteristics, properties and behaviour of a new composite material, called Core-Y, resulting from the combination of granular cork and an epoxy resin. This article comprises three main parts. The first describes the manufacturing process of Core-Y. The second develops an experimental study of the material based on *quasi*-static axial compression test on cylindrical specimens of Core-Y. The results of the experimental tests are presented and analysed and the essential mechanical properties are determined. The third part presents a study of constitutive and numerical modelling, based on the experimental results. The main objective of this numerical study is to analyse the energy absorption capacity of metallic tubular structures incorporating Core-Y, aiming to study new applications for this composite material. A numerical model to simulate the tubular structures tested experimentally is developed, implemented and validated, using the finite element analysis software Abaqus. The overall results anticipate interesting expectations in terms of lightweight cork based composite materials and systems.

1. Introduction

The microstructure of cork positions this material in the class of natural cellular materials, which is gaining increasing importance in different fields of engineering. As the word implies, they are materials in which the presence of cells is predominant and in which these are responsible for their specific properties [1]. The mechanical properties of cork are poorly known. This fact has limited the expansion of its applications and impeded the technological development of the associated sector. In consequence, the use of natural cellular materials in industrial applications is still uncommon and deserving to be further investigated. However, once cork is a recyclable and reusable, ecological, hygienic, easy maintenance and high durability material, it can be expected to be able to meet requirements in several fields, namely, environmental, economic and concerning performance [2–5].

The aim of this work is to develop and study the characteristics, properties and behaviour of a new composite material resulting from the combination of granular cork and an epoxy resin. Therefore, it is a composite with a polymeric matrix – the epoxy resin – and a natural cellular reinforcement – the cork granules. The composite material is named Core-Y, which results from the combination of the names of its two components: CORk and EpoxY resin. The analogy with the word core is deliberate, since cork is the "core" of the material.

The incorporation of cellular materials in, for example, composite materials or sandwich structures, has been studied in recent decades and has proved very beneficial in improving the energy absorption capacity of structures in which they are embedded [6,7]. However, the use of natural cellular materials, such as cork, is still little explored and uncommon, deserving, therefore, to be further investigated. The fact that the incorporation of cork in composite materials is a little studied area limits the existence of specific literature on the subject.

The use of cork as a reinforcing material in Core-Y is due mainly to the fact that it has a crushing viscoelastic behaviour and, consequently, a greater capacity for energy absorption. Moreover, the function of the matrix material is to provide a stable shape to the composite material, to minimise clustering of the reinforcement, to protect it from damage and deterioration, to confer specific properties to composite material, such as tenacity and chemical resistance. Then, one tries to summarise and describe the work undertaken in recent years in the implementation and development of cork based materials. Although not directly linked to the material studied in this work, these studies demonstrate the versatility and the numerous possibilities of structural application of cork [8–14].

Castro et al. [15] refer to cork based agglomerates as being ideal as main components of lightweight sandwich structures, as used in aerospace applications. Static bending and dynamic compression

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studies show that the performance of cork agglomerates depends essentially on the size of its granules, on the density and on the bonding process. Optimised cork agglomerates have properties which support their good capacity as core material of sandwich structures, when compared with other conventional materials. Some of these properties are its low density and high specific properties, such as shear modulus, shear resistance and stiffness. Good acoustic and thermal isolation characteristics, high tolerance to damage to impact loads and good vibration damping are also relevant characteristics of these materials [16]. In the study by Castro et al. [15] several types of commercial clusters of cork (with different granular sizes) were tested, demonstrating a weak nuclear mechanical performance compared to conventional materials.

To improve the mechanical performance of cork, three new types of agglomerates of this material made with conventional granules were fabricated, using epoxy resin as matrix [15]. These clusters have quite reasonable limit values of shear stress, which reduces the possibility of crack propagation. All cork based sandwich structures have considerably higher load values than those obtained for other high performance material. There is also a good recovery ability, very typical of cork itself. Compared to high-performance foams, agglomerated cork sandwich components have a higher energy absorption capacity and therefore better resistance in case of impact.

Azis et al. [17] developed a specific type of concrete incorporating cork in three cement-aggregate ratios and believe that the values obtained for tensile and compressive strength are high when compared with lightweight concrete produced with other organic aggregates. Zbigniew et al. [18] tested samples with various percentages of cork, maintaining a constant water/cement ratio. Branco et al. [19] tested different compositions of concrete using aggregates made of natural and expanded cork. The results confirmed that the concrete loses strength with the increase of the volume fraction of incorporated cork and that the use of expanded cork leads to the most significant losses. Karade et al. [20] concluded that cork granules and cement are compatible, that this compatibility decreases as the proportion of cork increases and that coarser grain sizes are more compatible with cement.

Concerning other lightweight concrete mixtures made with the incorporation of cork granules, there are still references to studies of mechanical characterisation of lightweight polymer mortar incorporating granulated cork developed by Nóvoa et al. [21]. There are also studies relating to the development of composite materials of granulated cork, paper pulp and hemp fibre, cement, granulated cork, eucalyptus resin and pine developed by Pereira et al. [22,23]; and plaster and cork, developed by Hernández-Olivares et al. [24]. Silva [25] studied the improvement of the seismic response of structural walls using a composite matrix of mortar and dispersed cork elements.

Hernández-Olivares et al. [24] shows that there is a good interaction between a plaster matrix and granulated cork and that various materials can be developed through their mixture in different volume fractions. Oprea [26] studied the effect of cork as filler material in support structures made from polyurethane resin for insulation applications.

Recently, some authors studied the behaviour of cork when subjected to impact and the use of this material in energy absorption systems. Gameiro et al. [27–29] performed experimental and numerical studies on the dynamic behaviour of different types of cork when requested in compression at different strain rates. The authors concluded that the confinement of cork, in both geometries examined, leads to a significant increase in energy absorption capacity of the structure. Paulino and Teixeira-Dias [30] explored the ability of cork to act as a material for absorbing impact energy within automotive passive safety and crashworthiness applications.

2. Manufacturing process of Core-Y

In order to produce Core-Y one needs cork granules with a convenient size, in this case in the range of 4–7 mm. The cork granules will act as reinforcement element in the composite material. One still needs the epoxy resin that, in this case, was Biresin® LS resin that works as the matrix composite.

After several manufacturing experiments the process that produced the best results in terms of quality of the material is now described. Once having the mould, the first step in the manufacture of Core-Y is the preparation of a small amount of resin. The Biresin® LS resin is mixed 100:10 with the Biresin® LS hardener. The hardener proportion is intentionally smaller (about 1% less) to that specified by the manufacturer to guarantee a slower curing and thus to minimise the probability of retention of air bubbles and formation of porosity within the material. Subsequently, a small amount of granulated cork is placed in the mould and over this the resin is slowly poured. After the first cork layer is fully embedded in the resin, another granulated cork layer is poured. This procedure is repeated until the mould is full. To complete the procedure, the mould is closed, fixing the cover but taking care that sufficient openings are left on the cover in order to guarantee that air bubbles continue to leave during the first stage of the curing process — slow curing —, that must extend for at least 24 h. Once this stage is finished, the mould is taken to an oven at a temperature of 80 °C for 4 h, in order to guarantee that the resin achieves total curing, avoiding the possibility of remaining viscous zones. It is emphasised that both heating and cooling stages must be performed at low heating/cooling rates to prevent the formation of cracks caused by thermal shock. Generally, the process of demoulding presents no difficulty when the preparation is done in a plastic mould. The material obtained with this process was then machined and the resulting specimens are shown in Fig. 1.

3. Experimental analysis

3.1. Materials, experimental equipment and test conditions

In order to implement uni-axial compression tests on Core-Y, twelve identical cylindrical (height $h = 40$ mm and diameter $\phi = 40$ mm) specimens were used. In all tests, the specimens were centred on one of the two compressions discs and then axially compressed. Care was taken in order that the load supporting faces were as much as possible plain and perfect, guaranteeing in this way a homogeneous loading force and representative results. The tests were performed in the universal testing machine AG-50 ShimadzuTM KNG. A load cell of 50 kN was used.

In order to investigate the influence of the strain rate on the mechanical behaviour (for *quasi*-static strain rates), these tests were performed at three different compression velocities ($v = 2$, 20, 200 mm/min).

The Poisson ratio was determined on two specimens at two different velocities (2 and 20 mm/min) accompanied by successive measurements along the compression test in the regime considered elastic (about 8 mm displacement) with stops at intervals of 1 mm. At each stop, the diameter was measured, in two perpendicular directions (ϕ_1 and ϕ_2), as well as the corresponding axial displacement. The Poisson ratio was then determined by the ratio between the variation in diameter and displacement. During this test the applied load was registered against the axial displacement. With these data, stress–strain curves are determined and the fundamental mechanical properties of the material are analysed.

As will be seen later in this article, some dispersion will be observed fro the experimental results. this is a clean indicative that the manufacturing process still has room for improvement, mostly