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Dynamic Mechanical Behavior of Reinforced Cork Agglomerate

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ABSTRACT

Agglomerated cork is today mainly used for its thermal insulation and acoustic properties. As cork is a cellular material, its absorbing properties at a dynamic regime are being considered for impact-absorbing applications as core material in sandwich structures. Therefore an optimization of this material would allow to strengthen its present applications and open new ones. Ranging from the container for the transport of sensible pieces to sports items and including lightweight aeronautic components, a wide range of applications is foreseen. Cork agglomerates with and without reinforcements at a quasi similar density were studied to compare their mechanical performances. This paper investigates the effect of these foreign reinforcements on the properties of agglomerated cork under a dynamic loading. The material behavior has been determined as a function of two parameters, charge presence and strain rate. The microstructure was first observed through optical and scanning electronic microscopy, spotting charges between each cork bead. The characterization of cork at different strain rates was then carried out. Agglomerated cork was tested on two specific machines. An electromechanical testing machine has been used to apply an uni-axial compression for quasi- static strain rates. These results were completed by those obtained with a specific set- up for the high strain rates assays allowing almost constant strain-rate during the loading. Results depending on the presence of charges at different strain rate regimes were obtained. Elastic modulus were compared afterward. Young's modulus increased between 22 and 36% for reinforced samples depending on the strain rate.

Keywords: Dynamic mechanical behavior, Cellular Material, Cork agglomerates, Compressive loading, Reinforcements

INTRODUCTION

Cellular materials can be found in a large range of application domains: transport, health, energy, sport. Their main characteristics are a low density, damping properties, thermal insulation and a capability to dissipate energy during an impact loading [1]. The last one is especially interesting considering passive safety applications. Depending on the stress level required, it is possible to tailor it [2]. However it is today mainly done by changing the density of the cellular material [3]. As potential lightweight materials, it is yet important to minimize the weight while enhancing the mechanical strength for specific applications. The introduction of reinforcements is one of the most commonly used methods to improve the mechanical properties in usual composite materials. Reinforcing cellular materials with short fibers has been done on syntactic foams [4]. Another option is to add fibers while expensing the foam. However the constitutive material of the foam and the fibers are not always compatible. Thus a surface treatment seems unavoidable. Furthermore, it is hard to control how fibers will arrange themselves in the material. To overcome this problem, multi-scale foams are investigated here. It consists in agglomerated beads composed of microscopic closed cells [5]. Before agglomeration, short fibers are added to the preparation but do not damage the cellular structure. This study focuses on the influence of these short fibers on the microstructure and the mechanical behavior of a multi-scale cellular material. Quasi-static and dynamic compressive loadings were applied. The material considered here is agglomerated cork beads.

BACKGROUND

Cork is a natural polymeric cellular material which displays a closed-cell structure [6]. It is formed by small anisotropic prismatic cells disposed in successive layers exhibiting a relatively homogeneous honeycomb structure. Two materials were studied: one without and one with short fibers. This last material will be called a composite foam. To obtain agglomerated cork, small beads of cork ($\phi=0.5/1$ mm) are mixed together with a thermoset resin ($\rho_{\text{resin}}=1128.5$ kg m⁻³). For the composite material, short fibers were added at this step. It is then uni-axially compressed into a 1000×500×150 mm³ block at a 0.42 density. A multi-scale cellular material is thus obtained. Fig.1 shows the three scales. First there is the structure scale, then the bead scale with millimetric lengths and finally each bead is made of a cellular material. Therefore by looking closer (with a scanning electronic microscope (SEM)) at the beads, cells can be spotted. This cells scale is at the micrometric scale. Each bead is characterized by a specific cellular orientation [7].

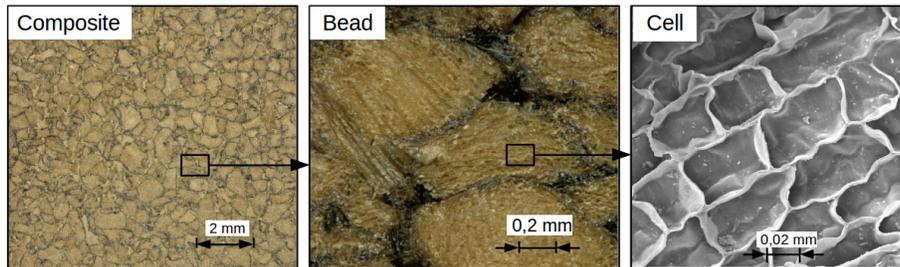


Figure 1: Agglomerated cork: a multi-scale cellular material.

An electromechanical traction/compression machine (Zwick Roell 250 from Allround-Line) with a load cell capacity of 250 kN is used. The loading speed is set at 5 mm min⁻¹ corresponding to an average strain rate of $4.2 \cdot 10^{-3}$ s⁻¹.

In order to reach the dynamic compression loading (around 70 s⁻¹), an original assembly was used (Fig.2). The fly wheel consists of a steel wheel with a high moment of inertia (77 kg m²). This ensures that the loading speed is considered as quasi-constant during loading. However, the speed of unloading is not controlled. Force/displacement signals during discharge were therefore not studied.

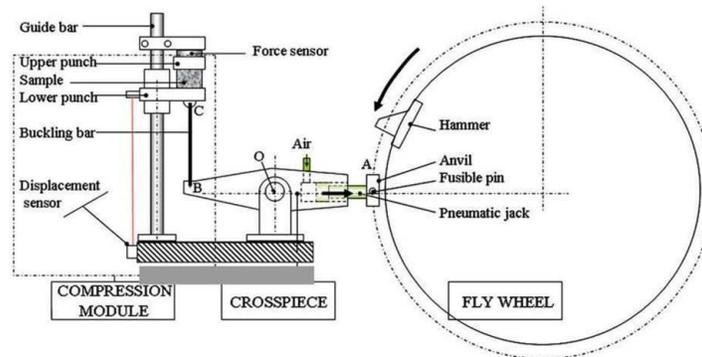


Figure 2: Fly wheel set-up scheme.

ANALYSIS

Interfaces between the foam beads are first observed with a SEM. Fig. 3a shows that for the agglomerated foam, interfaces are very thin. They are revealed by collapsed cells and resin. Furthermore the anisotropic nature of cork cells [6] can also help to distinguish one bead from another. On the other hand, interfaces in the composite material are thicker (around 20 μ m).

It seems that short fibers are well dispersed and are present between each bead. A closer look to the fibers (Fig. 3c) shows that short fibers seem to lay mostly tangentially to the foam beads.

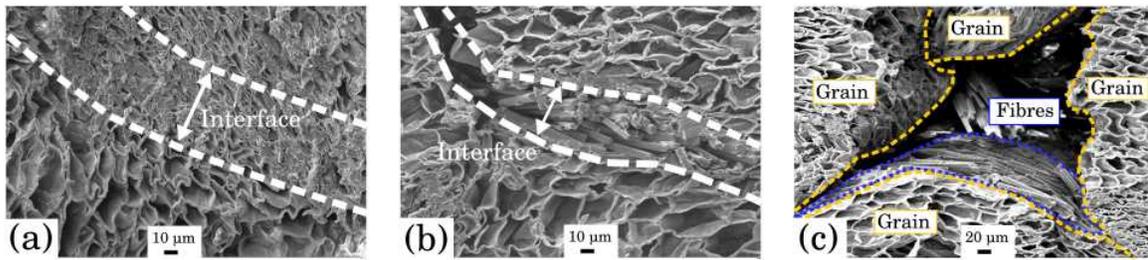


Figure 3: Interfaces between cork beads depending on the fiber presence.

Cellular materials are partly used for their energy absorption properties. The compressive behavior of the two material has then been studied for quasi-static and dynamic loadings. Fig.4 displays the stress/strain curves of each material tested in both direction for a mean strain-rate of $4.2 \cdot 10^{-3} \text{ s}^{-1}$. For both material, a typical foam-like behavior is noticed. For small strains, a linear behavior. It slopes is characterized by the Young's modulus E . After the stress increases slowly until large strains. This stage is called the plateau stage and is characterized by a plateau stress σ_p (where the stage starts) and a tangent modulus E_p . Finally the stress rises sharply and it is called the densification. The densification strain ϵ_d can be calculated to delimit it. Absorbed energy E_d was then calculated until densification.

Strain-rate effect on the compressive behavior

Young's modulus increases with the mean strain-rate for both materials (Fig. 5). Hence both cork agglomerates demonstrate a time-dependency at static and dynamic loadings. The viscoelastic behavior of cork had already be noticed [8]. Cork is made of several polymeric components as suberin, lignin, hemi-cellulose and cellulose and the composite contains also a polymeric resin. They demonstrate themselves viscoelastic behavior [9] though time dependency was not always detected in a given speed regime.

An increase in the strain-rate dependency is also noticed for both cellular materials. Several effects can drive the strength upward like this [3]. First the time dependency of the constitutive materials can change depending on whether the material is in the glassy state or the rubbery state. Another cause to this enhancement is the gas trapped in the closed cells. It was indeed shown that depending on the loading regime, different mechanisms concerning gas evacuation were activated [10]. Finally micro-inertia which is the inertia associated with rotation and lateral motion of cell walls when they buckle can also be cited.

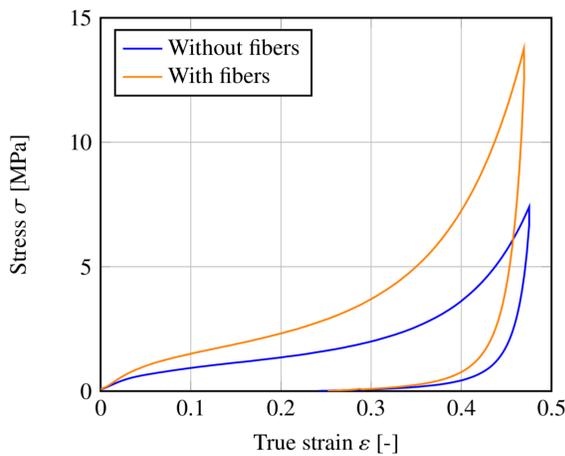


Figure 4: Experimental stress/strain curve of agglomerated cork and reinforced cork composite compressed at a mean strain-rate of $4.2 \cdot 10^{-3} \text{ s}^{-1}$.

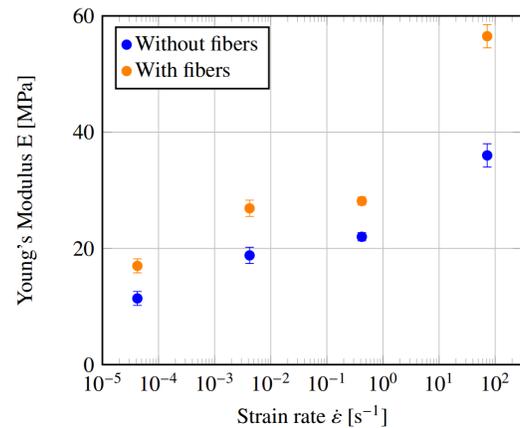


Figure 5: Young's modulus of cork agglomerates and reinforced composite material at several average strain-rates.

Reinforcement effect on the compressive behavior

The composite material is stiffer than the usual cork agglomerate at each tested strain-rate (Fig.4). Young's modulus is between 22 and 36% bigger. As SEM pictures show it, short fibers are placed between each cork beads. As the material is stiffer, it seems that these fibers allow to sustain higher stress by reinforcing interfaces between beads. A higher Young's modulus associated with a foam-like behavior implies that the composite foam will absorb more energy during an impact than the cork agglomerate.

CONCLUSION

In this article, the reinforcement of cellular material by short fibers was studied. The composite material consisted in beads of cellular material mixed together with a resin and short fibers then uni-axially compressed together before polymerization in an oven. By adding fibers to the mix of beads and resin, it seems that the fibers are mostly placed tangentially to the bead. Therefore after the compression process, they are most of the time at each interface. The compressive behavior of the composite foam was compared to a normal cork agglomerate on a wide range of strain rates: from quasi-static to dynamic compressive loadings. The composite foam keeps a mechanical behavior similar to a classical cellular material. Both materials were found to have a compressive behavior that depends on the strain-rate. An enhancement of this effect was noticed for dynamic loadings due to several elements (gas trapped, material dependence, ...). The initial rigidity described by the Young's modulus is increased between 22 to 36 % for the composite foam in comparison to usual agglomerated cork. This change in rigidity is likely caused by the short fibers. Being placed between each bead, they form a stiffer network with the resin. The composite material will then absorb more energy during a compressive loading. To conclude, short fibers appear as suitable reinforcements for multi-scale cellular materials.

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