Materials and Design 31 (2010) 425–432

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Cork agglomerates as an ideal core material in lightweight structures

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ARTICLE INFO

Article history:
Received 6 February 2009
Accepted 29 May 2009
Available online 23 June 2009

Keywords:
Sandwich structures
Cork agglomerates
Impact
Flexural strength

ABSTRACT

The experiments carried out in this investigation were oriented in order to optimize the properties of cork-based agglomerates as an ideal core material for sandwich components of lightweight structures, such as those used in aerospace applications. Static bending tests were performed in order to characterize the mechanical strength of different types of cork agglomerates which were obtained considering distinct production variables. The ability to withstand dynamic loads was also evaluated from a set of impact tests using carbon-cork sandwich specimens. The results got from experimental tests revealed that cork agglomerates performance essentially depends on the cork granule size, its density and the bonding procedure used for the cohesion of granulates, and these parameters can be adjusted in function of the final application intended for the sandwich component. These results also allow inferring that optimized cork agglomerates have some specific properties that confirm their superior ability as a core material of sandwich components when compared with other conventional materials.

1. Introduction

The use of lightweight structures with high strength to weight ratio has been an enduring characteristic in the transport industry. The rising demand for new materials has induced a significant growth in sandwich composite technology, where sandwich core laminates are used to stiffen various composite applications such as boat hulls, automobile hoods, train structures and aircraft panels. The commonly used core materials are honeycombs, foams and balsa wood, but recent developments resulted into new alternatives, such as cellular core structures [1].

The properties of primary interest for the core materials can be summarised as: low density, high shear modulus, high shear strength, elevated stiffness perpendicular to the faces and both good thermal and acoustic insulation characteristics [1,2]. Some properties of cork agglomerates suggest that this natural material can evince some remarkable properties when performing as a core of a sandwich component, namely a high damage tolerance to impact loads, good thermal and acoustic insulation capacities and excellent damping characteristics for the suppression of vibrations [3,4].

Cork has an alveolar cellular structure similar to that of a honeycomb, and its cells are mostly formed by suberin, lignin and cellulose. This cellular configuration has a strong influence on the mechanical properties of cork-based materials [5]. Silva et al. [6] present a compilation of the main mechanical properties of natural cork obtained from different experimental tests. At a first glance, one could conclude that natural cork has a poor mechanical behaviour when compared with other types of core materials, such as synthetic foams. However, for some specific applications, cork can compete with these materials. In fact, when comparing the specific compressive strength (σ_c/ρ) against the specific modulus (E/ρ), cork has a better mechanical behaviour than flexible polymer foams and comparable to some rigid polymer foams. Also, its low thermal conductivity combined with a reasonable compressive strength make it an excellent material for thermal insulation purposes as well as for applications in which compressive loads are present.

The proper design and application of sandwich construction depends on a throughout characterization and understanding of the sandwich constituent materials (face sheets, core, and adhesive), and also of the whole structure under quasi-static and dynamic loading scenarios. In this latter case, sandwich structures are often susceptible to foreign object damages resulting from impacts [7]. Therefore, the performance of structural sandwich parts under impact loading has to be considered in many cases. Aircraft, rail and road vehicles can be exposed to local impact with small, but possibly heavy objects, such as runway/roadway debris, tool drops, hail, bird strikes, stones or ice, and also during the loading and unloading of cargo. Boats and ships can encounter loads on the hull in collision with floating objects when cruising or during manoeuvres in

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doi:10.1016/j.matdes.2009.05.039

the harbour. Horizontal surfaces, such as ship decks or aircraft floors can be subjected to impacts from almost any dropped object. Which object creates the most significant damage is a matter of circumstance. A small object dropped from a great height may create more damage than a large object dropped from only a few centimeters [8–11]. Sandwich beams are also being increasingly used in applications requiring high bending stiffness and strength combined with low weight [12].

The study herein presented lays stress upon in three-point bending tests of simply supported sandwich panels, consisting of carbon/epoxy face sheets and three different types of core materials: Nomex®, Rohacell® 71 WF rigid foam and cork agglomerates. At a first stage, three types of commercial cork agglomerates (with different granule sizes) were tested evincing a poor mechanical performance when compared to conventional core materials. In order to improve the mechanical behaviour of cork as a core material, three new types of cork agglomerates were fabricated with conventional cork granulates but using epoxy resin as adhesive element. A set of impact tests of different types of sandwich specimens were carried out, as well as thermal conductivity analysis, aiming the characterization of the new cork agglomerates on a comparative basis with other core materials having top mechanical performances.

2. Experimental procedures

2.1. Constituent materials and fabrication process

The face sheets of the sandwich panels were made of three 0°/45°/0° plies of carbon/epoxy prepreg (STA199-45-005 for the bending tests specimens and PN900-C08-45&D2358 for the impact test specimens), resulting in a final laminate with an average thickness of 1.3 mm and a fiber volume content of 54% (STA199-45-005) and 50% (PN900-C08-45&D2358), after autoclave curing. Table 1 lists the main mechanical properties of these carbon–epoxy composites.

Tables 2 and 3 present the density and main geometric parameters of eight types of core materials considered for comparative purposes, namely: Nomex® and Rohacell® (which are conventional core materials, each with high specific strengths within its class), commercial cork agglomerates (referenced as 8123, 8810, 8303, 8822 and NL30 from Amorim Cork Composites) and cork agglomerates developed in this work using epoxy resin (referenced as 2/3, 3/4 and Mixed, see Section 2.1.1). Table 3 also indicates the final sandwich panel dimensions for each of the previously mentioned materials. These dimensions (referred to Fig. 1) are not the same for all the specimens due to some discrepancies between commercial available materials and those agglomerates specifically developed in this investigation that, in turn, had to be constrained by the mould dimensions regarding the requirements of the flexural tests imposed by ASTM C393-00 [13]. Considering the simply supported sandwich beam loaded in a three-point bending configuration as sketched in Fig. 1, L is the beam length between the supports, c the core thickness, t the face thickness and d the panel thickness (b, not represented in this figure, is the width of the beam). The transverse mid point deflection is due to an applied transverse load P.

Six types of core materials with different densities were considered for the fabrication of the specimens used in the impact tests, namely: optimized cork–epoxy agglomerates (2/3, 3/4 and Mixed), conventional cork agglomerates (NL30, 8822) and Rohacell® 71 WF. The final sandwich panels were 150 mm square having a nominal thickness of 30 mm. These panels were fabricated by bonding the carbon–epoxy face sheets to the core material with a thermosetting modified epoxy structural adhesive in a film form (reference FM300-080PSF&09BV7). The face sheets and core were bonded together and cured in an autoclave following the fabrication cycle provided by the prepreg manufacturer.

2.1.1. Development of cork agglomerates with enhanced mechanical properties

As previously mentioned, one major goal of this investigation was to develop a new cork-based composite with improved mechanical properties when compared to similar cork products which are currently commercially available. Consequently, three new types of cork agglomerates consisting of cork granules and epoxy resin were fabricated in order to obtain a better overall specific strength. These agglomerates were based on different granule sizes being referenced as 2/3 (small granule size), 3/4 (large granule size) and Mixed (mixture of small and large granules, equal proportion). The challenge in the preparation process of the

Table 1
Main properties of carbon–epoxy laminates used in the face sheets.

Composite reference	Density (kg/m^3)	FVC standard (%)	Tensile strength (MPa)
STA 199-45-005	1760 ± 40	50	550
PN900-C08-45	1530 ± 30	54	540

FVC = Fiber volume content.

Table 2
Density of core materials used in three-point bending and impact tests.

Core material reference	Density (kg/m^3)
Rohacell® 71 WF	75
Nomex®	48
8123	270
8810	137
8303	224
8822	155
2/3	272
3/4	274
Mixed	162
NL30	266

Table 3
Main geometric parameters of sandwich specimens used in three-point bending tests.

Core material reference	b (mm)	c (mm)	d (mm)	L (mm)
Rohacell® 71 WF	50	15	17.6	270
Nomex®		12	14.6	
8123				
8810				
8303				
2/3	45	15	17.6	150
3/4		12.8	15.4	
Mixed		14.2	16.8	

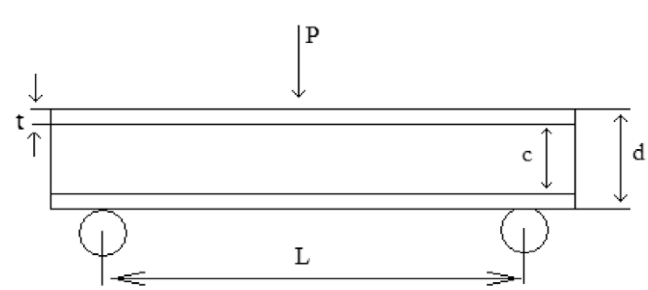

Fig. 1. Geometry of sandwich beam.