Available online at www.sciencedirect.com

ScienceDirect

Ciência & Tecnologia dos Materiais 29 (2017) e97–e101

Ciência & Tecnologia dos MATERIAIS

http://ees.elsevier.com/ctmat

Special Issue "Materiais 2015"

Effects of carbon nanotube modified adhesive layer on low velocity impact and flexural properties of cork core sandwich structures

I.A. Lopes[a], F.P. Macedo[a], A.J. Arteiro[a], A.L. Reis[a], P.R. Nóvoa[a,b,*], A.T. Marques[a]

[a]Department of Mechanical Engineering, Faculty of Engineering, FEUP Campus, Rua Dr. Roberto Frias s/n, 4200-465Porto, Portugal
[b]Composite Materials and Structures Research Unit, Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), FEUP Campus, Rua Dr. Roberto Frias 400, 4200-465 Porto, Portugal

Abstract

The traditional method of manufacturing sandwich structures using a structural adhesive to achieve face-sheets to core bonding maintains widespread use. Most research addressing experimental performance of sandwich structures focuses on core and face-sheet related parameters, and only marginal attention is directed to the mechanical properties of the thin, low content, adhesive layer – it usually suffices that it can provide effective face-sheet/core bonding. The present work studies sandwich structures with a cork agglomerate core and resin infusion processed skins consisting of +/-45º glass fibre fabric reinforced epoxy resin. A polyurethane structural adhesive was used to assemble the structure. The focus of the study was the influence on sandwich performance with respect to a modification of the adhesive with multiwall carbon nanotubes, exploring the possibility of an increase in both shear and adhesion strength of the modified adhesive. The sandwich structure was evaluated with respect to four-point bending and low velocity impact tests. In addition, scanning electron microscopy analysis was used to examine the adhesive layer morphology. The results were analysed to determine how the addition of ca. 0.4 wt.% of carbon nanotubes to the adhesive effectively influenced failure behaviour and damage events in both flexural and impact testing.

Keywords: Sandwich structure; carbon nanotube; cork core; adhesive; flexural properties; low velocity impact.

1. Introduction

Composite sandwich structures have found widespread application in automotive, aeronautic, aerospace, marine and civil industries, owing primarily to the high specific strength- and stiffness-to-weight ratios which can be achieved. They comprise a low bulk density core material and two comparatively thinner and rigid face-sheets. These are loaded primarily in tension or compression due to bending while the core resists most shear stresses [1].

When thermoset resins are involved, sandwich structures are usually constructed in either a two-step or a single-step process. The later involves a vacuum assisted resin infusion process (VARIM) where the impregnation of face-sheets and their bonding to the core is performed using the same resin. In the former and more traditional method, the face-sheets are processed in an initial independent step which is followed by bonding to the core using a structural adhesive.

Most research addressing experimental performance of two-step processed sandwich structures focuses on core and face-sheet related parameters. The interest on the adhesive component is generally confined to the materials selection phase where its elastic properties and adhesive bond strength to the main components are thoroughly analysed. Although there are tests specifically designed to address the face-sheet to core adhesion [2], the importance of the adhesive layer is

* Corresponding author.
E-mail address: prnovoa@fe.up.pt (P. R. Nóvoa)

http://dx.doi.org/10.1016/j.ctmat.2016.04.008

often overlooked, and studies addressing the face-sheet/core interface focus primarily on surface preparation [3].

In a previous work, some of the authors studied the performance of sandwich structures when cork agglomerates are used as core materials instead of typical polymer foams [4,5]. The sandwich structures had VARIM processed skins consisting of +/-45º glass fibre fabric reinforced epoxy resin, and a polyurethane structural adhesive was used to assemble the structure.

The present work used a similar sandwich structure, with one of the previously studied cork agglomerate cores. The focus of the study was the influence on sandwich performance with respect to a modification of the adhesive with multiwall carbon nanotubes (MWCNT), exploring the possibility of an increase in both shear and adhesion strength of the modified adhesive [6-8].

The sandwich structure was evaluated with respect to four-point bending and low velocity impact tests, and the results compared to those previously obtained with the same core material and neat adhesive [4,5]. In addition, scanning electron microscopy (SEM) analysis was used to examine the adhesive layer. The results were analysed to determine how the addition of *ca.* 0.4 wt.% of CNTs influenced failure behaviour and damage events in both flexural and impact testing.

2. Experimental

The two sandwich structures under consideration were constructed using the same facing material, core thickness and material, and adhesive layer thickness. The parameter under study was a modification of the adhesive layer material composition.

2.1. Materials

The matrix material used in sandwich face sheets was a very low viscosity (170 mPa s) two component Biresin® system (Sika®, Germany) based on epoxy resin CR83 and amine hardener CH83-6; the reinforcing material was Multifab® (Lintex®, PRC) E BX 600, a double biaxial (±45°) E-glass fibre fabric with areal weight of 612 g/m^2, which includes the contribution from polyester yarn stitching.

The core material was a 12 mm thick cork agglomerate CoreCork™ NL25 (Amorim Cork Composites S.A., Portugal) – a product developed for composite applications, with finer grain and narrower size distribution, and lower density (250 kg/m^3) than general purpose agglomerates, and a surface treatment to improve adhesion.

A structural two-component, fast-curing polyurethane assembly adhesive − SikaForce®-7888 L10 (Sika®, Germany) − was used to bond the face sheets to the core materials. The adhesive components are a mixture of filled polyols and isocyanate derivatives, respectively, which must be mixed in a 1:1 volume ratio.

Multiwall carbon nanotubes (MWCNT) with reference Baytubes® C 70 P (Bayer® MaterialScience, Germany) were used to modify the structural adhesive. (*cf.* C 70 P MWCNT's properties in Table 1).

Table 1. Properties of Baytubes® C 70 P.

C-purity (wt.%)	Outer mean diameter (nm)	Inner mean diameter (nm)	Length (μm)
> 95	~ 13	~ 4	> 1

2.2. Manufacturing

The sandwich structures were produced by sequentially producing the fiberglass/epoxy laminate face sheets by vacuum infusion, preparing the core, and bonding them together using the structural adhesive. Each fiberglass/epoxy facing had two layers of ±45° biaxial fabric. Two large laminates (*ca.* 2000×600 mm) were obtained by vacuum infusion, from which 500×200 mm face sheets were cut. These were bonded to the NL25 core using the two-component polyurethane-based neat adhesive in the sandwich structure previously characterized [4,5]. For the new sandwich structure, the adhesive was modified with the addition of 0.4 wt.% of MWCNTs. This was produced by adding the necessary amount of MWCNTs to the polyol component and combining sonication (UP200S, Hielscher Ultrasonics, Germany) at maximum amplitude and frequency of 0.5 Hz and mechanically stirring during two 4 min periods separated by a pause in sonication, to avoid excessive temperature build-up. Then the isocyanate component was added and manually mixed for about 1 min without further sonication, considering the low adhesive pot life (*ca.* 10 min) and the time required to evenly apply the adhesive to the face sheets prior to bonding. The procedure for MWCNT dispersion in the high viscosity adhesive was based on a previously developed one [9]. After assembly, weights were uniformly distributed on the sandwich structure so that a constant pressure was applied throughout adhesive curing/bonding, and adhesive layers with nearly constant thickness resulted along each of the sandwich