Materials and Design 89 (2016) 323–334

Contents lists available at ScienceDirect

Materials and Design

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

Processing of a new class of multifunctional hybrid for electromagnetic absorption based on a foam filled honeycomb

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ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 21 September 2015
Accepted 22 September 2015
Available online 28 September 2015

Keywords:
Nanocomposite
Foam filled honeycomb
Electromagnetic absorption
Multifunctional structure

ABSTRACT

A multifunctional hybrid material class in the form of a sandwich panel has been developed towards the combined optimization of mechanical and electromagnetic absorption performance. The faces of the panel are made of glass fibre reinforced epoxy composites and the core is made of carbon nanotube reinforced polymer foam filling a metallic honeycomb. The different processing strategies and options tested to fabricate the core material are described as well as the associated scientific and technological issues. The most efficient processing route is by foaming the nanocomposite with a chemical foaming agent directly inside the honeycomb. This route offers a good surface finish and the operation can be achieved in one step. But, in order to produce large panels with a semi-continuous process, thermo-mechanical insertion of the foamed nanocomposite with supercritical CO_2 can be more suitable. The characterization of the electromagnetic absorption of the panels produced by different routes shows that the performance is not much sensitive to processing defects making possible upscaling to mass production.

1. Introduction

The reduction of electromagnetic (EM) pollution and electromagnetic interference is a major technological issue considering the widespread use of wireless applications. The protection of living cells or the preservation of the operation of sensitive electronic devices and systems constitutes prominent examples. In most applications, the unwanted radiation is either confined at the source or the device is shielded by a metallic enclosure that reflects the incident radiation. Most of the time, such a simple approach provides a cheap and effective solution. But for some specific applications shielding based on true absorption of the incoming EM energy with no reflection and no transmission is needed or, at least, preferred. One example is radar stealth, which consists in reducing the detectability of a target by cancelling reflection of a radar signal incident to the surface. Usually radar absorbing materials are made of thick foams with a topology designed for wide band absorption [1]. Alternatively, thin multilayered coatings can be used but with operation over a narrow frequency band [2]. None of these two solutions integrate both EM shielding and structural function.

A new class of multifunctional hybrid material (see Fig. 1) has been recently developed based on a multiscale architectured material approach towards combined optimization of mechanical and electromagnetic (EM) absorption performance [3,4,5]. The strategy involves, at the nanoscale, the use of a CNT reinforced polymer which is foamed with sub-millimetre cell size. The foam has an electrical conductivity in the range of 0.1 to 10 S/m with 0.1 to 2 wt.% of fillers while keeping the permittivity low. The foam is inserted in a millimetre scale metallic honeycomb lattice which acts as a waveguide. The combination of the metallic honeycomb and of the polymeric foam provides enhanced crushing performance. Indeed, the presence of the foam positively impacts the buckling of Al honeycomb faces by forcing instabilities to develop later and with small wavelengths involving more energy dissipation [6]. At the centimetre scale, the hybrid is used as the core of a sandwich panel, obtained by the addition of one or two EM transparent face sheets made of glass fibre reinforced polymers. The sandwich configuration provides good bending stiffness. A careful design of face sheets preserves and even improves the EM absorption performance of the hybrid in a specific frequency range. A level of absorption of around 90% has been achieved in the 10–40 GHz frequency band for 8.8 mm thick sandwich panel [7]. By 90% absorption, it is meant here that only 10% of the incoming radiation power is not dissipated (and thus partially reflected and partially transmitted). This class of hybrids involves a wide range of

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http://dx.doi.org/10.1016/j.matdes.2015.09.129
0264-1275/

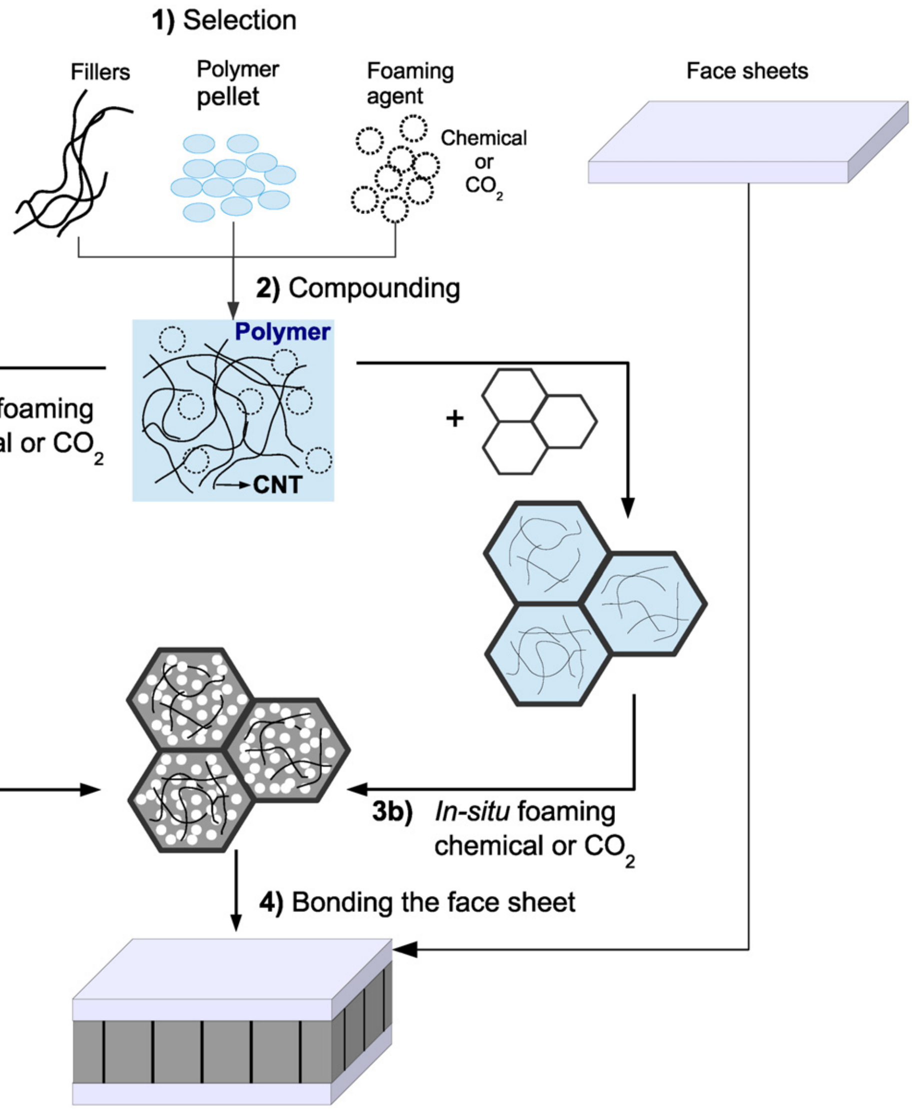

Fig. 1. Schematic view of the key steps of the two main processing routes: ex situ process (i.e. mechanical insertion of foamed compound into honeycomb), or in situ process (i.e. foaming of the compound inside the honeycomb cells).

parameters. Even though models and optimization procedures have been set up to design the best solution with respect to a list of requirements [3], selecting the best processing routes as a function of the application and of the expected characteristics of the hybrids remains an open question and could be the limiting factor in the development of this class of hybrids, as for many other hybrid systems [8,9].

Earlier studies focused on the performance of different material configurations around the same concept, involving modelling and testing, in order to validate that high EM absorption is attained in certain ranges of frequency and to explain the underlying physics, while also addressing other properties such as thermal conductivity and mechanical strength. The present contribution focuses on the processing aspects which have been presented only in an isolated way in earlier reports without critical cross-comparison of the different options and without addressing the possible problems related to processing defects. This is an essential aspect for any future possible deployment of this class of materials to large-scale real applications.

This paper presents and critically discusses the different processing strategies that have been attempted and assessed for the fabrication of the hybrids in order to provide constraints for the optimization as well as guidelines for possible future upscaling to larger panels or to mass production. The paper is divided into two parts. In the first part, the reinforcement, the polymer matrix and the foaming method are selected and the compounding method and honeycomb filling process are set up based on the selected materials. In the second part, the filler dispersion and the foam microstructure are analysed. The overall quality of the fabricated samples is verified. Finally, the EM absorption performance is studied as a function of the different processing routes.

2. Selection of the materials and processing methods

Fig. 1 shows the different steps of the process which are described in this section.

1. The fillers, polymer matrix, foaming agent, honeycomb and face sheets are selected based on the expected set of elementary properties (electrical conductivity, permittivity, porosity, strength). The choice is guided using different electromagnetic and mechanical models presented in several references [10,3,7].
2. Compounding is performed in melt phase.
3. Foaming is performed either ex situ followed by insertion within the honeycomb or in situ in the honeycomb (HC).