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A novel approach to prepare aluminium-alloy foams reinforced by carbon-nanotubes

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ABSTRACT

This paper presents an innovative approach to prepare a new class of closed-cell reinforced (nano-composite) metal-foams that synergistically explores the remarkable properties of both metal-foams and carbon-nanotubes. This approach combines colloidal-processing (including freeze-granulation-lyophilisation) and powder technology, ensuring the retention of the tubular-structure of –COOH-functionalised multiwall carbon nanotubes (MWCNTs-COOH) and their uniform distribution in the metal-matrix. The microstructural analysis revealed non-agglomerated, well-dispersed, stretched and directionally-aligned MWCNTs within the Al-matrix of the foams. These conditions potentiate the reinforcing role of MWCNTs with Vickers microhardness increments $>100\%$.

1. Introduction

The present work combined the remarkable properties of metal-foams [1] and carbon nanotubes (CNTs) [2] in a new class of closed-cell metal reinforced foams. The closed-cell metal-foams have been regarded with much interest for commercial and military applications (e.g. bullet-proof vests and vehicles/aircraft) [3]. A high-number of processing techniques is available allowing to produce a variety of metal-foams [4]. The traditional powder metallurgy (PM) method comprises two main steps [5]. The first-step is the preparation of precursor by hot compacting a powder-mixture of the blowing agent (e.g. TiH_2) and the metal (e.g. Al-alloy) which is previously mixed using a conventional mixer. The second-step is the preparation of the metal foam itself through the foaming of precursor by heating. The metal expands, developing a highly internal porous structure of closed-cells due to the simultaneous occurrence of the metal melting and thermal decomposition of the blowing agent with the release of H_2. The liquid foam is then cooled in air, resulting in solid foams with closed-cells and with a very thin external dense metal-layer. CNTs have emerged as an important class of new materials for structural engineering and functional applications due to their high mechanical strength, electrical and thermal conductivities [2,6,7]. Their high aspect ratio and intrinsic properties make CNTs the most effective reinforcements to produce composite materials. The interest in using these nanotubes as reinforcements in the metal-matrix composites is encouraged by their successful incorporation into polymer-matrix composites of high performance [8]. But, incorporating CNTs in metal-matrices is rather difficult due to several reasons, such as their high tendency to agglomerate into clusters, their poor dispersion ability in the metal-matrix, poor wettability of carbon by molten metal due to a large difference of surface tensions and the formation of an interfacial reaction product [6,7]. Great efforts have been carried out by researchers for achieving uniform dispersion of CNTs in the metal-matrix using various processing strategies, mainly based on PM-method [6,7,9,10]. The results have shown that better dispersion of these reinforcement elements in the metal powder can be achieved using high-energy mixing process (e.g. ball-milling or mechanical-alloying) [6,7]. However, these processes cause structural damage and structural-integrity loss to CNTs. Dispersion improvements of CNTs in the Al-matrix with ball milling time have been reported together with their structural damage [9,10]. This is particularly serious for the single-walled CNTs since their tubular integrity is lost. The multi-walled CNTs (MWCNTs) even suffering damage in the outer-walls, the others may still provide the desired structural-integrity. The eventual formation interfacial-products (intermetallics) due to interfacial reactions between CNTs and molten metal under harsh conditions can also lead to loss of structural-integrity. Other studies attempted dispersing MWCNTs in liquid media (e.g. ethanol) [11] or in aqueous solutions of polyvinyl

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alcohol [12,13], but with a limited success. In both cases, clusters of agglomerated CNTs were reported. Till to present, researchers are still endlessly designing and developing novel processing techniques for manufacturing advanced nanocomposite with homogeneous dispersion of carbon nanomaterials, especially CNTs. Based on these reported works [8–10], and with the aim to improve the mechanical properties of current foams to make them competitive in relation with alternative products, including the existing foams, we propose a novel approach to obtain homogeneously dispersed functionalised MWCNTs-COOH in aluminium-matrix for preparing nanocomposite aluminium-foams.

2. Experimental procedure

2.1. Materials

Commercially available powders of gas-atomised Al–12Si having quasi-spherical or/and an oblong shaped particles with an average diameter of 32 μm and angular shaped TiH_2 with an average diameter of 6.9 μm were used as the main starting powders for preparing the closed-cell Al-alloy foams. Commercially available MWCNTs-COOH (purity > 95%, NanoAmor-USA) prepared by catalytic-chemical-vapour-deposition with an outer diameter of < 8 nm, an inner diameter of 2–5 nm, a length of 10–30 μm, a surface area of 350–420 $m^2\ g^{-1}$ and content of COOH of 3.67–4.05 wt% were used as reinforcement. Polyvinyl alcohol (PVA, Sigma-Dorset) and a proper commercial dispersant for MWCNTs (NanoSperse-AQ, NS, NanoLab-USA) were used as dispersant and surfactant, respectively.

2.2. Preparation of the aluminium foams reinforced carbon nanotubes

The proposed approach to prepare Al-alloy foams reinforced by MWCNTs-COOH is schematized in Fig. 1. It consists in adding a new colloidal-processing step to the traditional PM-method [5], being composed by three main steps instead of the traditional two steps process [5]: (i) the preparation of spherical granules; (ii) the preparation of foamable-precursor; and (iii) the preparation of reinforced Al-alloy foams. In the new first-step the homogeneous spherical granules were prepared through freeze-granulation (FG) using a well-dispersed aqueous suspension highly loaded in solids (Al-alloy + TiH_2 + MWCNTs-COOH) with appropriate rheological behaviour. For that, two initial aqueous suspensions of MWCNTs-COOH and of starting powder-mixture of Al-alloy and TiH_2, were separately prepared by dispersing the solids in an aqueous-PVA-solution (1.5 wt%) containing NS (0.96 wt%, ~4 drops to ~0.1 g of MWCNTs) under ultrasonic and mechanical-stirring. The powder-mixture was prepared by mixing the Al-alloy powders with pre-oxidised TiH_2 (0.6 wt%) through a tumbling mixer during 30 min. As-received TiH_2 was pre-oxidised into a pre-heated furnace at

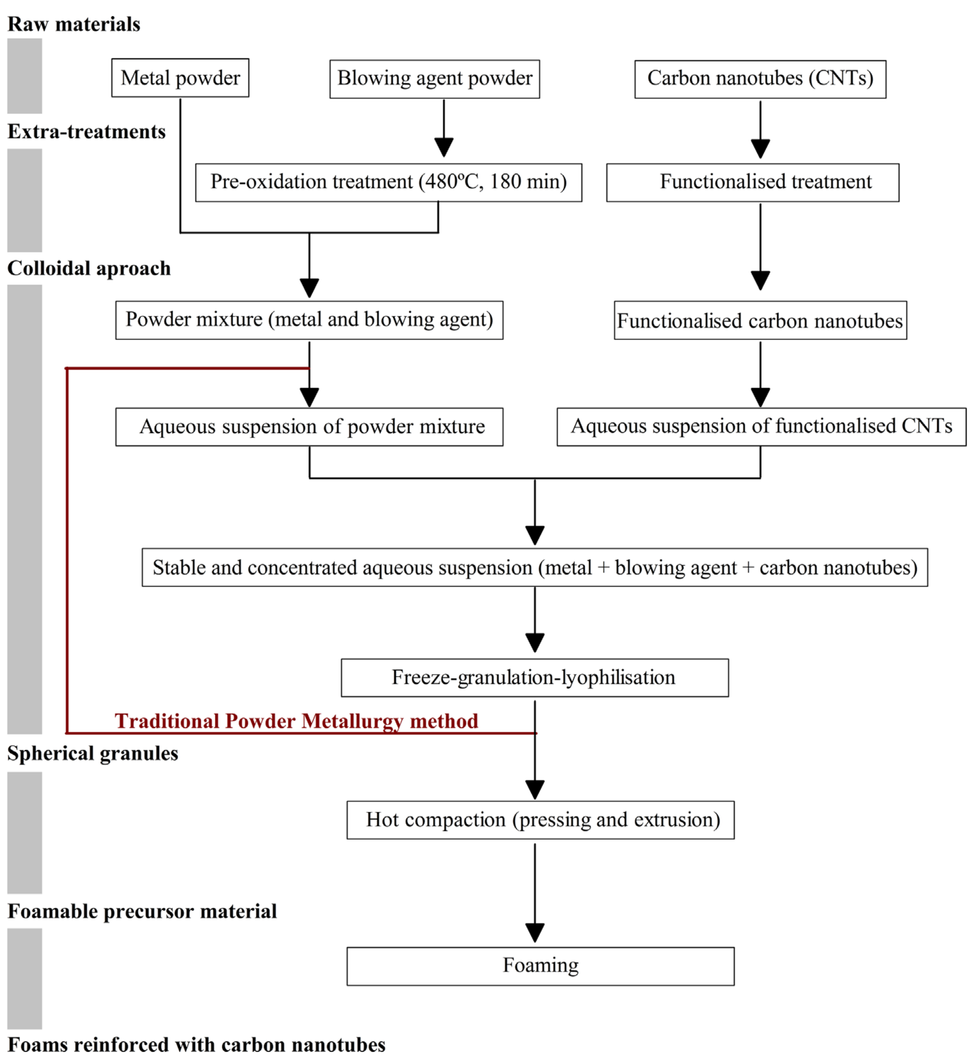

Fig. 1. A novel strategy developed for preparing metal-foams reinforced with carbon-nanotubes by combining the powder-metallurgy with colloidal-processing.