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Mini Review

Future Prospects of Carbon Nanotubes Reinforced Metal Matrix Composite

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Abstract

Due to their high specific strength, and excellent thermal and electrical properties, carbon nanotubes (CNTs) reinforced metal matrix composites possess a huge potential to be widely used in structural and functional applications, such as automobile, aerospace, sports, microelectrochemical systems (MEMS), sensors, battery, and energy storage [1]. However, processing of CNTs reinforced metal matrix composite with advanced properties has been a challenge due to the difficulties in obtaining good dispersion of well-aligned and intact CNTs inside the matrix without chemical degradation. This review highlights the challenges and provides guidance for future research directions in CNTs reinforced metal matrix composite.

Mini Review

Carbon nanotubes (CNTs) have an excellent combination of mechanical, electrical, and thermal properties that make it a perfect reinforcement for composite material [2,3]. For examples, Young's modulus of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) are 2.8-3.6TPa and 1.7-2.4TPa, [4] respectively, which are approximately 10 times that of steel [5]. Electrical conductivity of CNTs is roughly 2 orders of magnitude higher than that of Ag, the best conductor in metals [6]. Application of CNTs as a reinforcement material for polymers has been well studied due to the ease of improving their electrical and mechanical properties [7], however, CNTs reinforced metal matrix composite has remained a challenge to a wide range of researcher because of the intrinsically good mechanical, electrical, and thermal properties of metals [8].

CNTs can be synthesized by, for examples, arc-discharge, laser ablation, gas-phase catalytic growth from carbon monoxide, and chemical vapor deposition (CVD) from hydrocarbons [3]. Although only a small fraction of CNTs (e.g., 1 wt.% (weight percent)) may be needed to significantly improve the properties of metal matrix if successful, large quantity of CNTs would be required for the purpose of industrial scale-up, which in turn requires an improvement in their production methods such as the arc discharge and laser ablation to make it cost-effective.

Fabrication Challenges

Figure 1 shows an example fabrication process of CNTs reinforced Cu matrix nanocomposite [9]. The challenges associated with CNTs reinforced metal matrix composite include CNTs' dispersion, damage (e.g., defects and metal carbides formation), interfacial bonding to matrix, and alignment. The first challenge lies in the fact that it is hard to disperse CNTs well inside the metal matrix to prevent formation of large CNTs clusters or aggregates due to their electrostatic and van der Waals forces as well as the density difference between CNTs and metal matrix [8]. Presence of CNTs clusters in processed composites, especially when CNTs are more than 1 wt.%, has often led to reduction in the properties instead of improvement. For example, effect of CNTs agglomeration on the conductivity of matrix has been studied by Taylton et al. [10]. They found that when the CNTs concentration is close to the percolation threshold, a more uniform CNTs distribution can be achieved and lead to an enhanced conductivity. Extensive efforts have been put to find effective techniques to improve dispersion of CNTs within the matrix including high energy ball-milling, surfactants, and metal encapsulated CNTs composite precursors (e.g., molecular-level mixing, electroless deposition, and electrochemical deposition) [8,9,11,12] Although some progress has been made, it is still a big challenge to get optimum parameters for these dispersion techniques in order to have uniform dispersion of CNTs in metal matrix while preventing degradation of CNTs.

A second challenge is to preserve an intact CNTs structure in the processed composite to maximize their reinforcement effects. For the purposes of clean and/or dispersion, pretreatments of CNTs by, for examples, acidic, thermal, mechanical, and chemical methods, are normally required prior to be used for composite fabrication [13]. This may cause significant damage to CNTs and subsequently reduce their unique properties [14].Therefore, optimum parameters of pretreatment need to be studied to address the tradeoff between advanced CNTs dispersion and CNTs damage. In addition, heat treatment processes, e.g. sintering, are normally required for fabrication of metal matrix composite, which may cause degradation of CNTs by, for example, formation of metal carbides such as aluminum carbide [15].

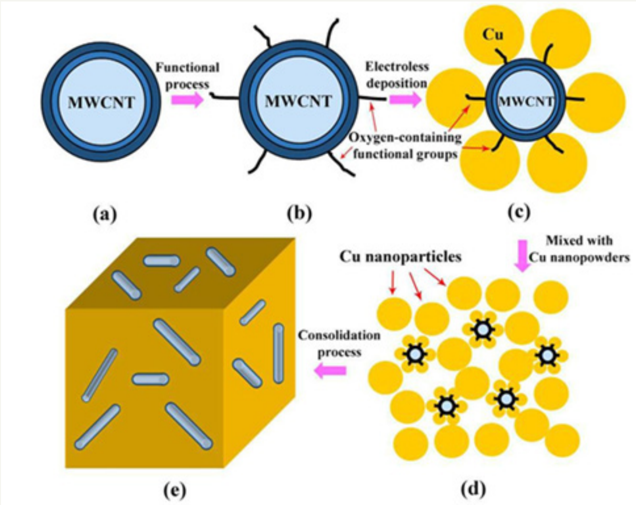

Figure 1: Schematics of fabrication processes of MWCNT reinforced Cu matrix nanocomposite.
a) Purified MWCNT,
b) Functionalized MWCNTs,
c) Cu encapsulated MWCNT,
d) Cu encapsulated MWCNT mixed with pure Cu nanoparticles, and
e) Fabricated MWCNT reinforced Cu nanocomposite [9].

A third challenge is to obtain an excellent interfacial bonding between CNTs and metal matrix. A CNTs-metal matrix bonding at or near the atomic length scale is normally required for good mechanical, electrical, and thermal performances of the processed composite, [16,17] otherwise debonding and subsequently increased phonon-electron scattering at the composite interface may occur during service to deteriorate the overall properties. The interfacial bonding between CNTs and metal matrix might be improved by pre-coating CNTs with, e.g., metals [18].

Another challenge is to achieve good alignment of CNTs in the metal matrix composite [8]. Well-aligned CNTs would bring a tremendous chance to improve the composite properties since the properties of CNTs along their axis are much better than those of their radial direction. For example, measurements have shown that an individual SWNT has a room-temperature thermal conductivity along its axis of about 3500Wm-1K-1, [19] but only about 1.52Wm-1K-1 in the radial direction [20]. Although some deformation processes techniques such as extrusion, rolling, and equal-channel angular processing, [1] may be able to align CNTs to some extent in the composite, more attention needs to be paid to explore successful processing techniques to achieve better CNTs alignment.

Future Prospects

Therefore, a successful development of a production process that promotes a uniform dispersion as well as alignment of CNTs in the matrix, without damaging them, is essential for obtaining metal matrix-CNTs nanocomposites with excellent mechanical and physical properties, and of course a significant advancement in the future manufacturing of CNTs reinforced metal matrix composite when compared to the current methods of powder metallurgy, melting and solidification, thermal spray, and electrochemistry [1].

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