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Embedding carbon fibre structures in metal matrixes for additive manufacturing

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Abstract

It is possible to reinforce structures and components using carbon fibres for applications in electronics and medicine, but most commonly used in reinforcing resin fibre composites for personal protection equipment and light weight constructions. Carbon fibres act as stress redistributors while having increased electrical and thermal conductivities. These properties could also be utilized in metal matrixes, if the fibres are properly fused to the metal and the structure remains intact. Another recently developed high potential carbon structure, carbon nanotube- (CNT) yarns, has similar but even greater mechanical properties than common carbon fibres. Via laser cladding, these reinforcing materials could be used in a plethora of applications, either locally (or globally) as surface treatments or as structural reinforcements using multi-layer laser cladding (additive manufacturing). The challenges of embedding carbon fibres or CNT-yarns in a CuAl mixture and SnPb solder wire using lasers are here investigated using high speed imaging and SEM. It is revealed that the carbon fibres have very high buoyancy in the molten metal and quickly degrades when irradiated by the laser. Wetting of the fibres is shown to be improved by a Tungsten coating and embedding of the structures after processing are evaluated using SEM and Raman spectroscopy.

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Keywords: Laser cladding; additive manufacturing; CNT yarns; Carbon fibres; metal matrix

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1. Introduction

Most commonly used to reinforce resin fibre composites for equipment for e.g. personal protection or lightweight constructions, carbon fibres (CFs), Fig. 1a, could also be used to reinforce structures and components in the electronics and medical fields. Carbon nanotubes (CNTs) have been shown to have excellent properties (e.g. E-modulus strength of 1 TPa and yield strength of 10-150 GPa and high electrical and thermal conductivities), with applications in electronic devices and bullet proof vests. These can have multiple walls (MWCNT) or even be spun into CNT-yarns, having even greater properties than CFs. These yarns can be used to reinforce metals to achieve improved properties, such as higher strength (enabling weight reduction) and stress redistributors, possibly stop crack propagation, while having increased electrical and thermal conductivities, if they are properly fused to the metal and having intact structure. It is of high interest to be able to produce parts using additive manufacturing (AM). Built parts could also be locally reinforced to reinforce structures where needed.

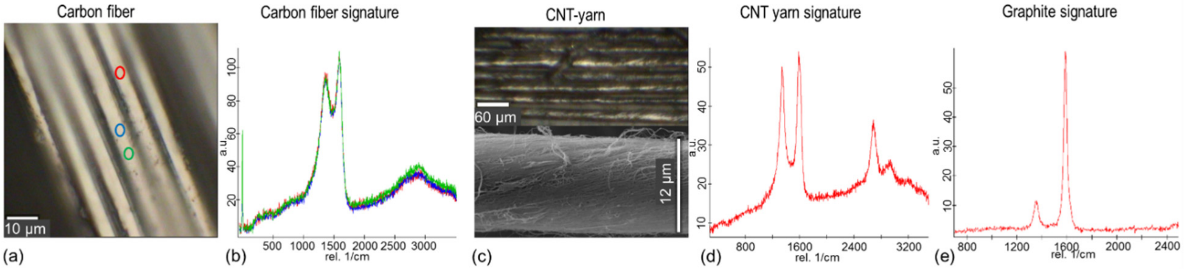

Fig. 1. Enlarged (a) Carbon fibre and (c) CNT-yarn, with (b)(d) respective Raman spectroscopy profiles; (e) Raman spectroscopy signature for graphite.

Laser cladding, recently studied by (Roehling et al., 2017), is a common technique for reinforcing surfaces and is a basis for AM techniques. Using laser cladding and embedding CNT-yarns to reinforce structures, could be applied in a plethora of applications. CNT metal matrixes have excellent properties (Bakshi et al., 2010), and MWCNTs have also previously been shown to be sintered into Ti using lasers by (Savalani et al., 2012), but processing is complex and even distribution is difficult (Cha et al., 2005). Besides the frequently studied embedding of CNT particles in metals by various techniques (Bakshi et al., 2010), it has also recently been shown to be possible to embed CNT-yarns into a CuAl matrix (Kaplan et al., 2012). One important insight is that a positive linear impact of the composite on tensile stress requires C-structures with higher E-modulus than the metal matrix as high strength alone is not sufficient and only affects the fracture limit. Highly twisted CNT-yarns has an E-modulus of 100 GPa, while Al-alloys has E-modules of ~70 GPa. Successful embedding of CNT-yarns and fabrics in metals can form a new kind of composite material, enabling creative design solutions and strategies for application and structure designed materials.

Here the challenges of embedding CFs or CNT-yarns metals using lasers are further studied, investigated using high speed imaging (HSI), scanning electron microscopy (SEM) and Raman spectroscopy. By adjusting the energy of projected light, energy can be transferred into a sample so that the vibrational or rotational modes can be identified which provides a unique "fingerprint" of a molecule (Bokobza and Zhang, 2012). Each structure of carbon has its own unique characteristics that can be identified by an experienced technician. Relevant signatures using Raman spectroscopy are shown Fig. 1b,d,e. It has earlier been reported that bonding of the CNT structure and the metal matrix is crucial and also suggests using chemical coating with e.g. Ni (Chou et al., 1985). Wetting of various metals to graphite has also been studied by Mortimer and Nicholas (Mortimer and Nicholas, 1970). Challenges to overcome when embedding the CNT structures using lasers are reported by (Kaplan et al., 2012) to involve thermal degradation and wetting in metal for proper fusion, which can be solved by coating the CNT-yarns with a metal. It is known that CFs can degrade at above ~300-400 degrees in air (depending on resin type), whilst MWCNTs are reported to suffer from thermal decomposition at ~400-500 degrees in air (Li et al., 2006). Another aspect to consider is diffusion, of C