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Electrically conductive nanocomposites for fused deposition modelling

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ABSTRACT

An acrylonitrile-butadiene-styrene (ABS) matrix was melt compounded with various amounts (from 1 to 8 wt%) of multi-walled carbon nanotubes (MWCNT) predispersed in an ABS carrier. The resulting materials were then i) compression molded (CM) to obtain plaques or ii) extruded in filaments used to feed a fused deposition modelling (FDM) machine. 3D printed samples were obtained under three different orientations.

The nanofiller addition within the ABS matrix caused a remarkable increase of both stiffness and stress at yield of the bulk samples, accompanied by a strong reduction of the elongation at break. The mechanical properties of 3D printed samples resulted to be strongly dependent on the printing orientation. The addition of CNTs was very effective in improving the electrical conductivity with respect to neat ABS even at the smallest filler content. The FDM process determined a partial loss in the electrical conductivity of ABS nanocomposites, with a marked dependency on the printing orientation. For CNT amounts higher than 4 wt%, CM samples manifested a rapid heating by Joule effect, while the process was less efficient in the printed samples. CNT addition has high impact on thermal properties, resulting in a decrease of specific heat and a increase of thermal diffusivity and conductivity. Like observed for electric conductivity FDM also influences properties of thermal diffusivity and conductivity, resulted by a possible orientation of CNT.

1. Introduction

In the last years, polymer matrix nanocomposites have attracted a remarkable interest because nanoscale affects the potential to lead significant improvements in properties such as impact resistance [1], elastic modulus [6], thermal stability and fire resistance [2–5] compared with those of neat polymers. It is well known that conventional polymers offer significant resistance to electrical conduction [7] and several methods have been explored to increase their electrical conductivity values [8,9]. One of the most promising methods is to add conductive fillers such as carbon black, CNTs or metal particles to polymer matrices. In fact, above a critical concentration (i.e. percolation threshold), it is possible to observe the formation of a conductive path within the polymer matrix constituted by uninterrupted clusters of connected filler particles [10–12]. These materials can be used in applications where charge dissipation and electrical conductivity are desired, such as films for packaging of sensitive electronics components or materials subjected to corona treatments. Considering that an inhomogeneous dispersion in filled polymers can lead to problems such as heavy process dependency, the control of the filler dispersion quality represents one of the most critical and challenging technical issue.

Fused deposition modelling (FDM) is an emerging technology, and represents one of the most common techniques for prototyping and personal additive manufacturing [13]. This is an extrusion based system, in which a thermoplastic polymer is supplied as a continuous solid filament. It is pushed into a heating chamber by a tractor wheel arrangement and it is heated until softening or melting. The extrusion pressure is given by the portion of filament pushed into the chamber that forces the softened material through the nozzle. The extruder head is able to scan on a horizontal plane as well as starting and stopping the flow of material; in addition the deposition bed can move in the vertical direction. In fact, once a layer is completed, the bed moves the part downwards, so that a further layer can be produced. In order to obtain a flow of material with constant rate and constant cross-section diameter, the extrusion pressure and the travel speed of the nozzle across a depositing surface must remain as constant as possible during all deposition phases. The technical improvements

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obtained for this technology over the last 25 years attracted a strong interest from both academy and industry [14]. The relative easiness of use and the affordable cost for entry-level machines gave this technology the ability of changing the common conception of how things can be produced, opening new possibility of manufacturing complex products with limited economical investments. As other additive manufacturing processes, this technology allows to produce small complex parts at low volumes, reducing the need of moulds or tools. Therefore, it can compete on cost and delivery speed with traditional manufacturing processes for products that need short production runs. Various polymeric materials have been explored for application in FDM, however commercial FDM machines mostly use acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA).

In literature is well reported how the electrical conductivity of ABS could be strongly increased by nanofiller addition. As an example, in a paper of Saleh et al. [15], a nanocomposite with carbon nanotube (CNT) dispersed in a ABS matrix was prepared by solution mixing. The good dispersion and selective localization of CNT in the styrene acrylonitrile styrene (SAN) phase of the ABS matrix allowed to prepare nanocomposites with a percolation threshold of only 0.06 vol%. Moreover, the addition of nanofillers to ABS has recently emerged as a possible tool to increase the mechanical properties of filaments for FDM applications [16–19].

On the basis of these considerations, the objective of the present work is to investigate the mechanical, electrical and thermal behaviour of ABS/CNT nanocomposites for FDM applications. A comparison between the properties of the bulk (compression molded) and 3D printed samples (along different orientations) was carried out, in order to underline the role of the filler content and of the manufacturing procedure on the physical properties of the prepared materials. Furthermore, the possibility to heat 3D printed parts by Joule effect has been experimentally proven.

2. Experimental part

2.1. Materials

A Sinkral PD L 322 ABS, produced by Versalis-Eni (Mantova, Italy) using a continuous mass polymerization process, was utilized as polymeric matrix (density 1.04 g/cm^3, MFI at 220 °C 10 kg 23 g/10 min). An ABS/CNT masterbatch, Plasticyl ABS1501 produced by Nanocyl S.A. (Sambreville, Belgium), was utilized. According to the manufacturer this masterbatch contains 15 wt% of NC7000 multi-walled carbon nanotubes (MWCNTs) produced by Nanocyl S.A. (Sambreville, Belgium).

2.2. Samples preparation

In this work, two different manufacturing processes were used for the production of the samples. The bulk materials were produced through a melt compounding process followed by compression molding, while 3D printed materials were prepared by using a FDM machine starting from extruded filaments. ABS pellets and masterbatch were preliminary dried at a temperature of 80 °C for 4 h with an air flow of 7 m^3/h by using a Moretto X Dry air drier. Nanocomposite samples were then melt compounded in a Thermo Haake Polylab internal mixer at 190 °C for 15 min, setting a rotor speed of 90 rpm. A compression molding process was then performed at 200 °C with a pressure of 3.8 MPa for 10 min, in order

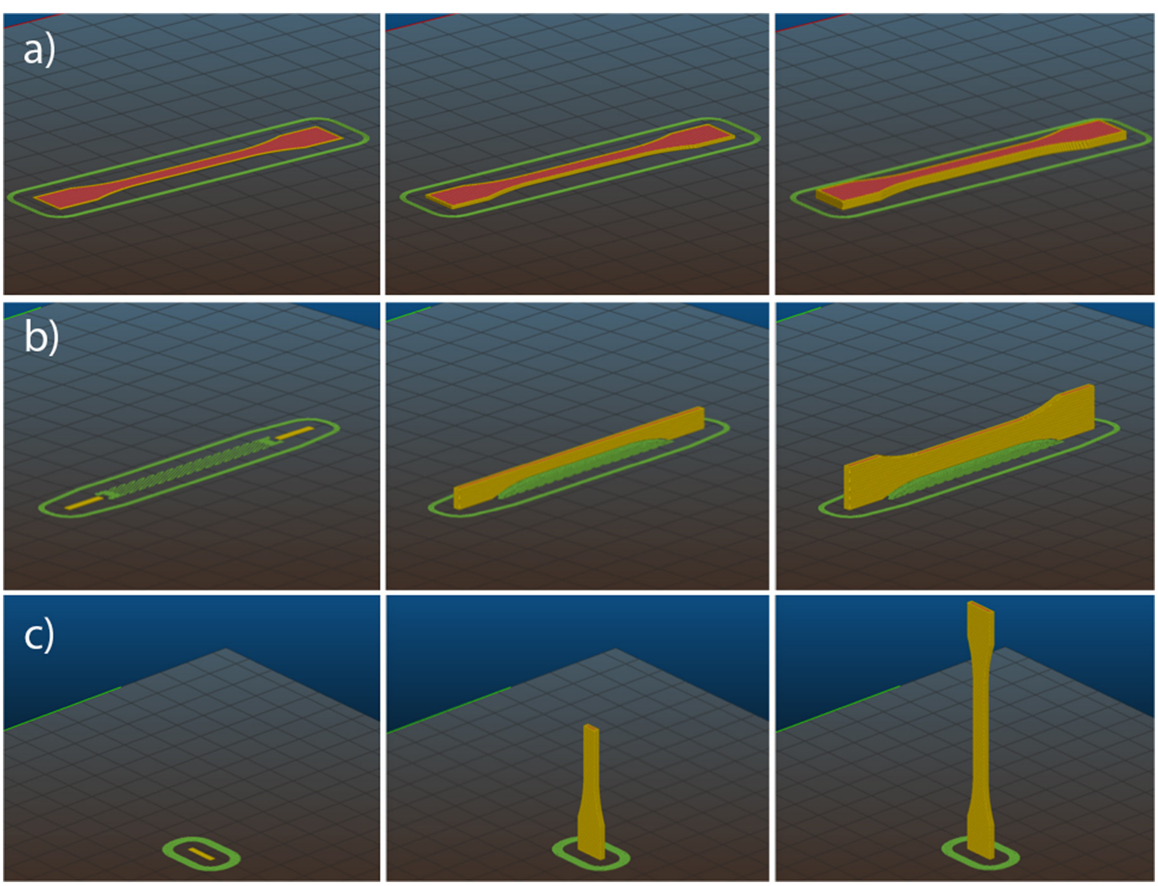

Fig. 1. Rendering of the 3D printing of samples in different directions: a) horizontal (HC), b) vertical (VC), c) perpendicular (PC) building orientations.