

Comparative study on nanotubes reinforced with carbon filaments for the 3D printing of mechanical parts

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ABSTRACT: Additive manufacturing (AM) has attracted a lot of interest lately. While different types of materials can be used in AM, their properties, such as strength, electrical conductivity and thermal conductivity typically have inferior properties compared with conventionally manufactured counterparts due to the anisotropy caused by the layer-by-layer approach. Nanoparticles, such carbon nanotubes (CNT) are of particular interest for incorporation into AM media because of their unique properties. In this work a comparative study on nanotubes reinforced with carbon filaments for 3D printed mechanical parts was carried out. Regarding the educational benefits of 3D printing, it is considered to be an innovative way of combining technology, design and engineering allowing students to involve in creative uses of 3D printing through an accessible and rather economic process of rapidly producing tangible prototypes of mechanical parts.

INTRODUCTION

Additive manufacturing (AM) is the name given to a group of emerging technologies that create objects from the bottom-up by adding material one cross-sectional layer at a time [1]. A three-dimensional solid object of virtually any shape can be manufactured from a digital model. The adaptation of such a technology will result in engineers having to invest less time dealing with manufacturing constrains and will give them almost unlimited design freedom. However, up to now, despite all positive aspects, no single 3D printer has been able to print using different materials.

Additionally, while various materials can be used in AM, their material properties, such as strength, electrical conductivity and thermal conductivity typically have inferior properties compared with conventionally manufactured counterparts due to the anisotropy caused by the layer-by-layer approach. Many studies have reported on the incorporation of nanoparticles for the creation of new printing materials for AM. Metal nanoparticles [2], nano-sized carbon black powder [3], carbon nanotubes [4] and ceramic nanoparticles [5] have been used in the past.

However, significant gaps still remain in the knowledge relating to the introduction of nanomaterials to AM. Standardisation of printing processes and blending methods for different nanomaterials have to be addressed. A lot of work has to be done, but the benefit from the integration of nanotechnology with AM will result in a new era of manufacturing.

METHODOLOGY

As nanotechnology and nanoparticles are expected to play an important role in composite materials, this article presents a discussion about the implementation of carbon nanotubes in 3D printing materials in order to overcome the aforementioned problem of poor properties. Carbon nanotubes are allotrope forms of cylindrically-shaped carbon. They exhibit exceptional mechanical, thermal and electrical properties that have been proved by experimental and computational means and, therefore, they were selected [6].

The methodology presented in this work consists of building filaments with different carbon nanotube concentrations and conducting a comparative mechanical properties study between conventional manufacturing methods (injection moulding) and 3D printing. The 3D printing technique that has been used is fused deposition modelling (FDM) [7][8]. It extrudes and deposits thermoplastic filament materials in layers on a platform. The thermoplastic material is heated above its melting point so that it solidifies immediately after the extrusion.

A commercially available thermoplastic material was selected (ABS - acrylonitrile butadiene styrene) for this study and samples according the ASTM standard were manufactured. For the manufacturing, an injection moulding machine was used and a low cost commercial 3D printer. Furthermore, the ABS was reinforced with carbon nanotubes by using an extruder and it formed a filament with a diameter of 1.75mm for the feeding of the 3D printer. Additionally, the ability of 3D printing to form in situ composite materials during manufacturing is being explored.

IMPLEMENTATION

For the implementation of the project, two methods were used for comparison reasons: conventional manufacturing processes (injection moulding) and 3D printing. Samples were prepared using the two methods and they were evaluated in terms of mechanical strength. The strategy followed consists of the following steps:

As a reference, samples were prepared using net thermoplastic (ABS) with injection moulding and 3D printing. For the printing procedure the thermoplastic had to be reformed in a filament shape.

Extrusion techniques were used for the mixing of thermoplastic (ABS) with carbon nanotubes. The resulting material provided the raw material for the preparation of samples with injection moulding and 3D printing. To create a more comprehensive study, several percentages of CNT concentrations (0.5%, 1% and 3%) were prepared. Furthermore, a commercial filament with a colour additive was used for comparison reasons (Figure 1).

To expand the abilities of 3D printing, carbon fibres (CF) were incorporated into 3D printed specimens during the printing with net and composite ABS. In addition, carbon fibres with CNTs grown on them were used into 3D printed specimens.

All the specimens produced were subjected to mechanical stresses and the results were evaluated.

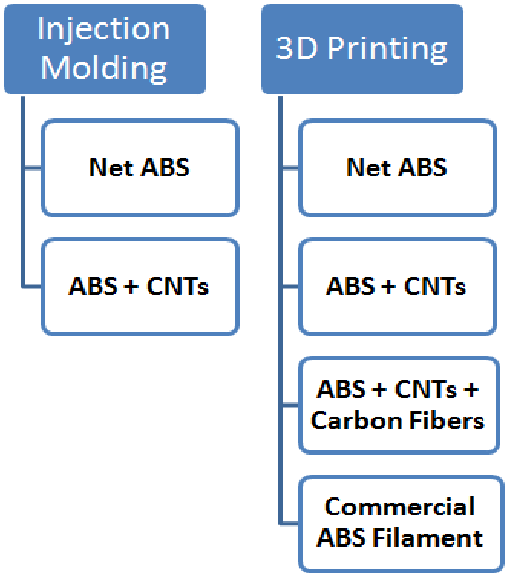

Figure 1: Schematic implementation of the comparative study between injection moulding and 3D printing.

IMPLEMENTATION TESTS

Tensile tests were conducted using an Instron 1122 Testing System with a 10kN load cell. Tests based on the ASTM D638 standard and a test speed of 50 mm/min were conducted. Tensile strength values were calculated from the highest load experienced.

Table 1 and Table 2 show the results for injection moulding and 3D printing respectively, while Figure 2 and Figure 3 represent the increment of the mechanical strength graphically. The comparison between the two methods is presented in Figure 4.

Table 1: Results of ABS net and composite samples manufactured with injection moulding.

Injection moulding	Young modulus	Increase (%)
ABS	1,528.00	
ABS 0.5% CNTs	1,532.80	0.30
ABS 1% CNTs	1,520.80	-0.40
ABS 3% CNTs	1,693.30	10.00

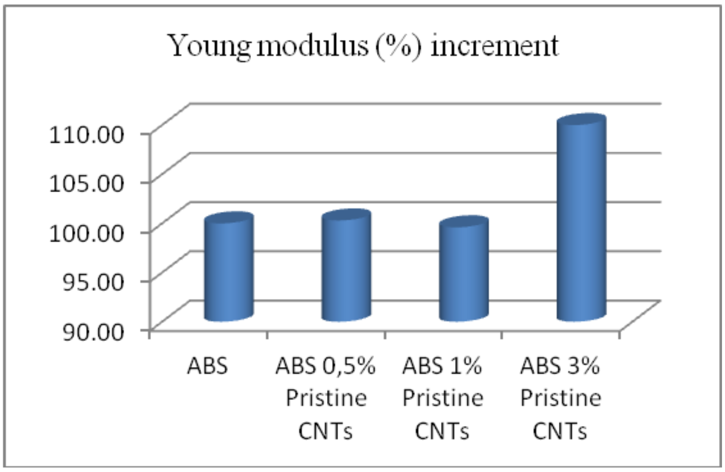

Figure 2: Young modulus increment for samples manufactured with injection moulding.

Table 2: Results of ABS net and composite samples manufactured with 3D printing.

3D Printing	Young modulus	Increase (%)
ABS	1,247	
ABS 0.5% CNTs	1,327	6
ABS 1% CNTs	1,320	5.5
ABS 3% CNTs	1,481	16

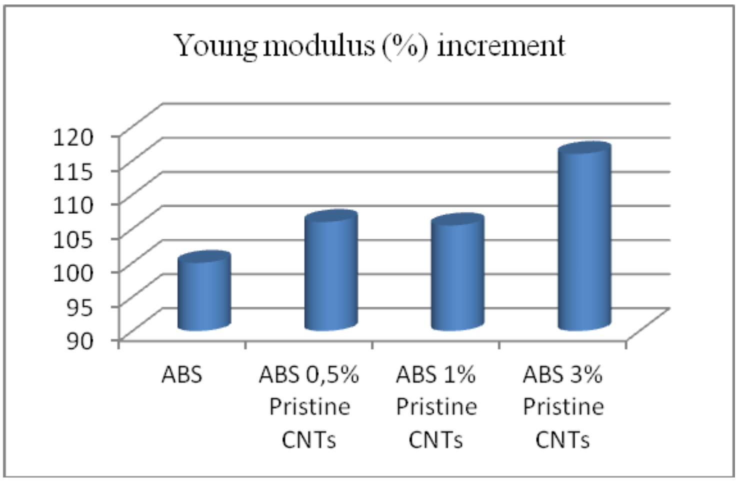

Figure 3: Young modulus increment for samples manufactured with 3D printing

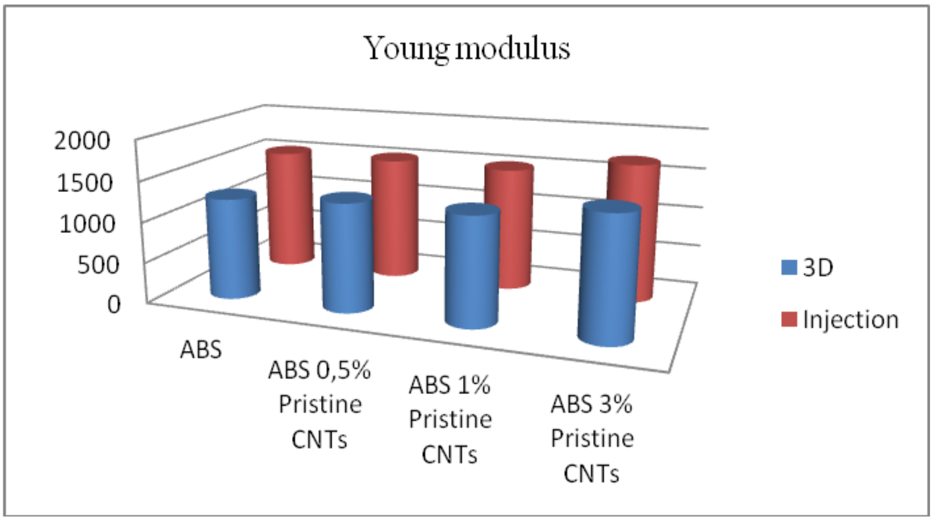

Figure 4: Comparison of young modulus values exhibited from samples manufactured with 3D printing and injection moulding.

Table 3 shows the results from the in situ implementation of carbon fibres and carbon nanotubes in the printed object.

Table 3: Young modulus values obtained from 3D printed samples with embedded carbon fibres and commercial filament.

3D printing	Young modulus	Increase (%)
ABS	1,247	0
ABS + CF	2,868	56.5
ABS 0.5% CNTs + CF	3,052	59.1
ABS 1% CNTs + CF	3,036	58.9
ABS 3% CNTs + CF	3,406	63.0
Commercial filament	605	0 (-50% in comparison with Net ABS)
Commercial filament with CF	1,383	56 (10% in comparison with Net ABS)
Commercial filament with optimised printing settings	1,255	51 (0,6% in comparison with Net ABS)

IMPACT ON ENGINEERING AND TECHNOLOGY EDUCATION

Apart from its extensive use in research, industry and manufacturing, 3D printing has most recently become of high value in the field of education. The educational benefits of 3D printing refer to the innovative way it combines technology, design and engineering. Regarding mechanical engineering, the main advantage of 3D printing is rapid prototyping tangible replicas of mechanical parts, while allowing students to interact with their products [9][10].

The incorporation of nanotechnology is providing an opportunity to study and test the properties of the prototypes under more realistic conditions and facilitates the introduction of modifications in order to improve the final product.

Therefore, future engineers will be trained to cope with real challenges through authentic problem solving. It is suggested that 3D printing can be adopted as a useful tool for engaging students in learning by being actively involved in an accessible and rather economic process [11]. The significance of experimental learning through 3D printing lies in the creative inquiry of complex notions and critical thinking, opposed to academic learning.

CONCLUSIONS

The effect of incorporating nanoparticles in materials being used in 3D printing applications was presented in this work. The comparative study between conventional manufacturing methods and additive manufacturing resulted in rather interesting results. Injection moulding produces more rigid structures, while 3D printing needs improvement on the mechanical strength side. Nanoparticles are a move in the right direction, helping to improve the strength of the printed objects, since mechanical property enhancements were observed in the composite material, nearly equating its behaviour with those of the injection moulded. This brings 3D printing to the frontiers of rapid prototyping by producing realistic objects, which can be tested under real conditions of operation.

The amount of the mechanical improvement varied with the carbon nanotube concentration and the incorporation of carbon fibres. The manufacturing flexibility that 3D printing provides made possible the in situ incorporation of carbon fibres; this is not possible with conventional techniques. The improvement was significant in that it reveals that not only is research on new materials important, but also that new materials incorporation methods or printing settings can be applied in order to improve the final result of a 3D printing procedure.

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