Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 12 (2017) 89 – 95

Procedia MANUFACTURING

International Conference on Sustainable and Intelligent Manufacturing, RESIM 2016, 14-17 December 2016, Leiria, Portugal

Part specific applications of Additive Manufacturing

Imran Khan[a,b], Artur Mateus[a], Christina S. Kamma. Lorger[c], Geoffrey R. Mitchell[a]*

[a]*Centre for Rapid and Sustainable Product Development, Institute Polytechnic Leiria, Marinha Grande 2430-028, Portugal.*
[b]*Physics Department, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain.*
[c]*NCD beamline, Alba Synchrotron Light Source, Cerdanyola del Vallès 08290, Spain.*

Abstract

Additive manufacturing is one of the most important technological advances which has been implemented and recognised as a modern manufacturing technology with many advantages over conventional approaches. Fused deposition modelling is an additive manufacturing technology commonly used for modelling, prototyping, and production applications. In this work sample holding grips are designed and printed using fused deposition modelling. These are used in time-resolved experiments which require a dedicated system to study one to one structure-property relationships in electrically conductive nanocomposites under uniaxial strain. The grips serve not only to hold the sample during stretching but also have electrodes to measure the electric current and the voltage drop across the sample under uniaxial strain, as they are insulated from the rest of the tensiometer assembly. In such kind of experimental work, the success of the experiment strongly depends upon the grips as the fracture or slip of the sample during the experiment can ruin the data and lead to a loss of confidence on measurement. The use of additive manufacturing was a particular advantage in the optimization of the design of the grips.

Peer-review under responsibility of the scientific committee of the International Conference on Sustainable and Intelligent Manufacturing

Keywords: Additive manufacturing; Fused deposition modelling; electrode; grips; electrical conductivity.

---

* Corresponding author. Tel.: +351 244 569 441
E-mail address: geoffrey.mitchell@ipleiria.pt

Peer-review under responsibility of the scientific committee of the International Conference on Sustainable and Intelligent Manufacturing
doi:10.1016/j.promfg.2017.08.012

1. Introduction

Additive manufacturing (AM) is an advanced manufacturing technology in which three-dimensional objects are built through the addition of material in a layer-by-layer fashion. Common to all AM technologies is the use of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment and layering material. The processes take the information from a computer-aided design (CAD) using triangles and sliced data containing the information of each layer. Once a CAD file is produced, the AM equipment reads in the data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other form, in a layer-upon-layer fashion to fabricate a 3D object. This process continues until the entire model has been manufactured. The manufacturing of an object is an automated process, and a 3D manufacturing system does so without supervision. The machine places each layer upon the previous layer until the entire object is completed [1]. Most common additive manufacturing techniques include but are not limited to stereolithography (SLA), fused deposition modelling (FDM), selective laser sintering (SLS), and selective laser melting (SLM). Conventional manufacturing technologies are not only time consuming but material wastage, labour costs and post processing are some of the factors which encourage thinking about innovative technologies. Additive Manufacturing is a time, material and cost effective technology without the need for post processing with a benefit of the ability produce complex parts [2]. In other words, additive manufacturing offers a freedom to design and engineer parts. A complex-shaped model or piece to suit a specific function can be easily manufactured using AM through CAD [3]. Ideally, the manufactured part will have the properties suited for its application, such as enhanced mechanical or electrical properties or biologically compatible features depending on the particular part and its application. There are a variety of fields ranging from forming moulds, direct part manufacturing for aerospace, household appliances, automotive and biomedicine to which additive manufacturing can be applied [4].

The application of FDM to manufacture custom parts according to end-user requirements is becoming more popular day by day. This is also the case for experimental scientists with laboratory equipment. A test stand with sample grips has been printed using FDM to facilitate the infrared imaging of the machining process of zirconium oxide for dental prosthetic elements, in terms of determining best machining parameters [5]. Incorporating AM into the manufacture of consumer products can enhance the products in several ways, including increased geometric complexity, decreased system complexity, increased customization, and enhanced performance [6]. There are many devices in the medical field which can be manufactured such as low cost prosthetic parts, tissues with blood vessels, drugs, bone, ear cartilage and synthetic skin [7]. There are numerous other applications of additive manufacturing in daily life.

In our research work we are exploring the behaviour of nanoscale fillers in polymer matrices. It is important to know how the nano structures behave under deformation effects. Such kinds of experiments demand special arrangements to conduct experiments. For example, a literature survey shows very few reported studies were conducted to explore the consequences of the changes in the micro or nano structures on the electrical conductivity during deformation. In such experiments slipping of the samples from the cross heads holding the sample and poor electrical contacts are common drawback. Plastic insulating clips with a piece of wire threaded through and a ball of electrical solder on the end are reported in the literature [8. The experimental design was further improved through the use of steel and plastic screws to provide electrical contact and to hold the sample respectively. Gold coated brass plates have been used for electrical contacts and polytetrafluoroethylene (PTFE) was used to insulate the sample from rest of the assembly [8]. Silver paint with aluminium foils has been exploited to provide electrical contacts with an insulating material to keep the sample isolated from rest of the machine for uniaxially deformed sample [9]. Cyanoacrylate glue was used on the interface of the sample to provide a firm hold during uniaxial deformation [10]. We decided to design more efficient grips that not only serve efficiently but can be manufactured using additive manufacturing to facilitate and promote crucial experiments in material science.

1.1. Fused Deposition Modelling

FDM is an additive manufacturing process that builds production grade parts layer-by-layer from computer-aided design (CAD) files. The FDM system is consists of CAD software that processes the files generating a layer-by-layer model deposition to build up the overall model. By utilising sophisticated additive manufacturing software and hardware, high strength thermoplastics with significant throughput benefits for low-volume manufacturing can be achieved. The slice thickness of each layer is variable ranging from (0.178 – 0.356) mm and can be adjusted according to the requirements [11]. The working principle of the FDM technique involves a filament of material which is fed into an extrusion head where the filament material is melted and then deposited, then layer manufacturing creates the horizontal layers. Clearly, the adhesion between successive layers is critical. A schematic of a typical FDM system is shown in Fig.1.

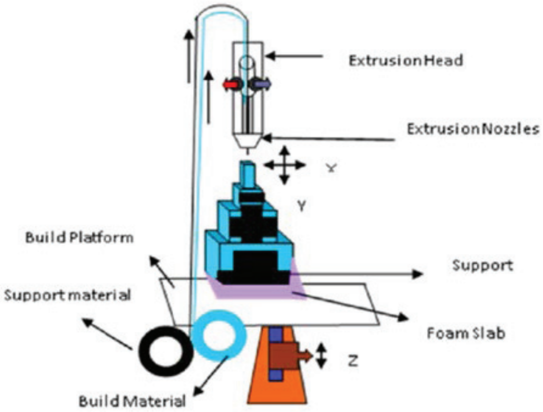

Fig.1. Schematics of fused deposition modeling system.

The build materials most frequently used in the FDM process are thermoplastics. Different types of feedstock materials are available for FDM including thermoplastic polyester based elastomers e.g. polycarbonate (PC), poly lactic acid (PLA), polyphenylsulfone (PPS), poly (acrylonitrile-butadiene-styrene) (ABS) and (PC/ABS) blends. ABS has been exploited for the rapid prototyping of electrically conductive components using FDM technology [12]. FDM is considered as a user friendly technology as it allows the production of samples in the local work place. Improved mechanical properties of parts were observed by fused deposition modeling processed under the exclusion of oxygen [13].

2. Case Study

In this work, we have designed sample holding grips which are produced using fused deposition modelling with the ability to hold samples without slipping and fracture and which facilitates the measure of electrical properties.

2.1. *Materials*

Acrylonitrile butadiene styrene (ABS) plastic is an amorphous thermoplastic polymer. It is the most widely used polymer to print prototypes as well as functional parts. ABS is a terpolymer made by polymerising styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene [14]. We used an ABS filament with a diameter of 1.75mm was used in the FDM machine to print the grips.

2.2. Computer aided design generation

Solidworks from 3D CAD software was used to design the grips. Afterwards, the CAD drawing is converted to a STL format file. The object is ready to manufacture after generating the STL file. Fig. 2 shows the top and bottom of designed grips generated using Solidwork software.

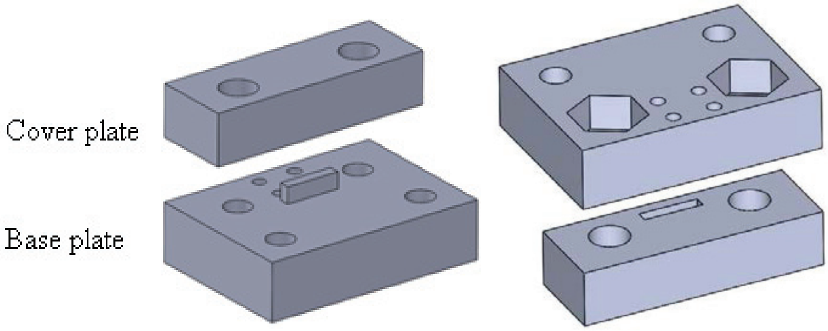

Fig.2. CAD model of the designed grips. Left) top view; Right) bottom view.

2.3. Build Process

A U-Print system, a commercial fused deposition modelling system from Stratasys, was used to manufacture the specially designed grips as shown in the Fig. 3(Left). We used the software called "Catalyst" to control the different manufacturing parameters to obtain high quality parts. These parameters include the nozzle size, the melt temperature, the manufacturing speed and the step between consecutive layers.

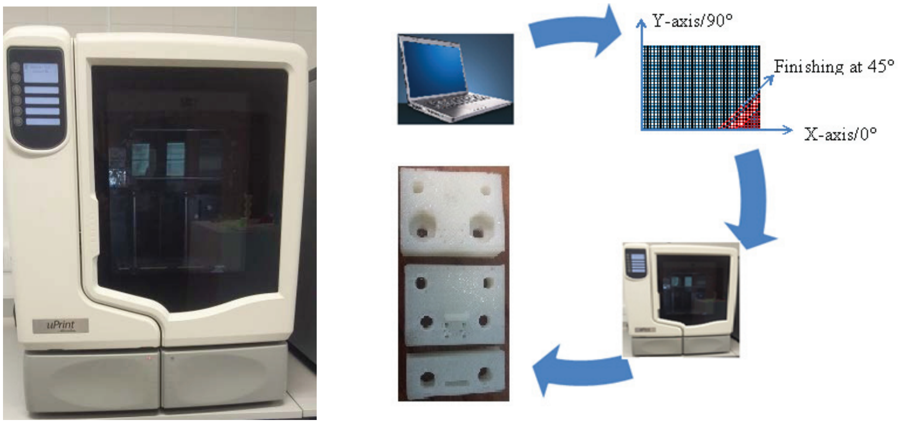

Fig.3. Left) U-Print Stratsys printing system used to manufacture the speciallydesigned grips shown in Figure 2. Right) Schematic of the build process using FDM.

Various aspects of the design such as the layer thickness, the outer finish, the layer alignment can be customised at this stage. The general schematic for the build process is shown in Fig. 3(Right). The final optimised grips with specific designations are shown in Fig. 4. We selected to use layers drawn at 0° and 90° to manufacture grips with a 45° finishing.

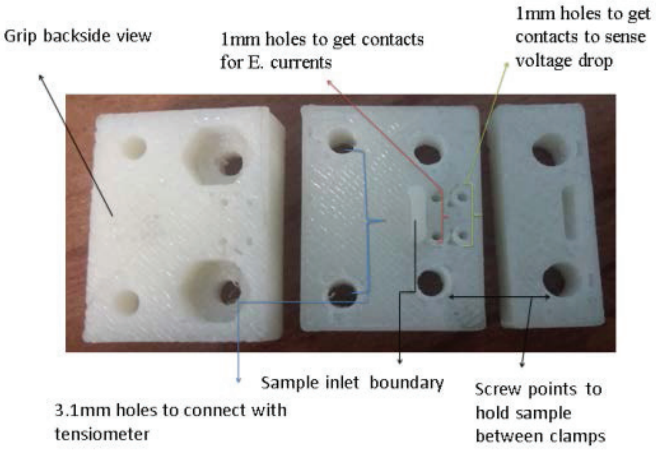

Fig.4. Final optimisedgrips manufactured using a ABS polymer filament together with the FDM system.

3. Grips mounting and experimentation

Two thin wires are used to sense the electrical current and the voltage drop within the conducting sample. The wires were soft and pliable so that easily can be bent or twist. The end points of the two wires are peeled to remove the insulation then fixed on their respective positions as shown in Fig. 5 (Centre). The electrode wires are fixed in their positions through a loop and knod. Since the sample is held between two grips, the same process was followed for the second grip. The other ends of the wires are connected to the measurement circuit. Fig. 5(Centre, Right) shows grips before and after mounting a sample on the tensiometer. The four probe method was used to measure electrical current and the corresponding voltage drop in the sample as shown in Fig. 5(left). The electrode wires are kept insulated from each other and from rest of tensiometer assembly using an adhesive tape.

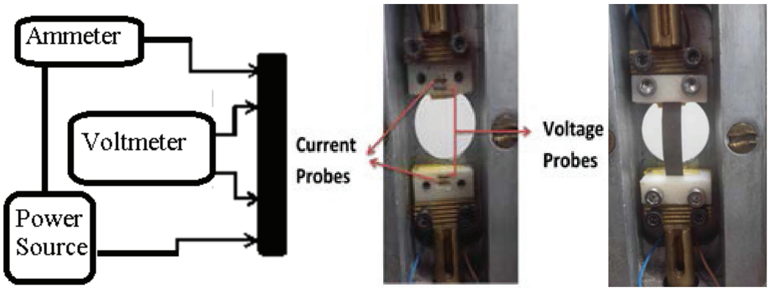

Fig.5. Left) Schematic of the four probe method used for the electrical conductivity measurement. Centre) grips mounted on tensiometer together with electrical contacts. Right) the grips after mounting the sample on the tensiometer.

Time resolved experiments are performed on electrically conductive nanocomposites under uniaxial strain. These samples are based on a thermoset polyurethane with multiwall carbon nanotubes as the conductive filler particles. The deformation of the macroscopic sample leads to a modification of the carbon nanotubes networks in the polymer [15]. This leads to a change in the electrical conductivity of the samples under test as shown in the inset of Figure 6(Right). Small angle x-ray data are collected simultaneously with conductivity and load measurements to study the changes in the nanoscale structure during uniaxial deformation as shown in Fig. 6(Right). This study provides invaluable data to develop an understanding of the network behaviour of carbon nanotubes under deformation in polymer nanocomposites. The schematic of the set-up used to measure electrical conductivity in the nanocomposites under uniaxial strain is shown in the Fig. 6(Left).

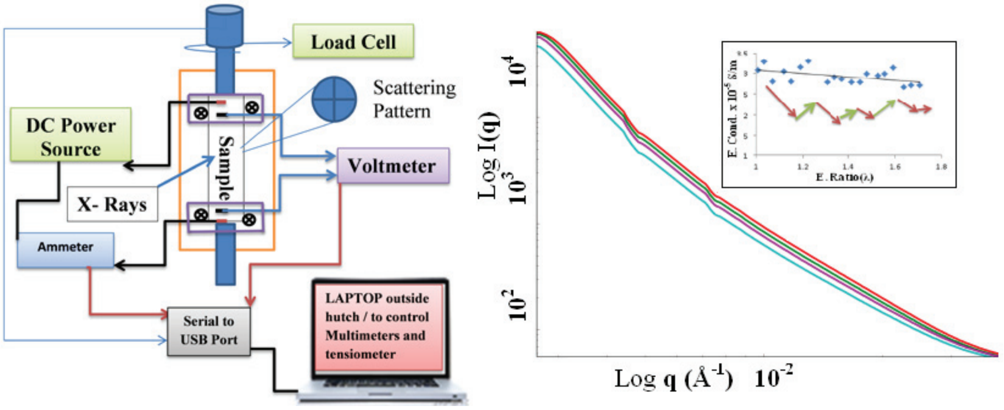

Fig.6. Left) Schematic of the experiments performed at beamline BL11 at Alba Synchrotron. Right) The results obtained through experimental work reported in [15] using the designed grips. Log-Log plot of scattering intensity I (**q**) vs scattering angle (**q**) of the nanocomposite sample under uniaxial strain. Inset shows variation in electrical conductivity with extension ratio.

3.1. Tests and validation

The numbers of samples were mounted in the specially designed grips to conduct the tests. The experiments run without problems as there is no sample slippage from the grips. The electrodes embedded within the grips are electrically isolated from tensiometer assembly. The grips did not fracture for 10-12 measurements. This indicates the success of the designed grips for simultaneous electrical and mechanical measurements. The tests reveal two important factors with regard to the grips. The first factor concerns the screws required to hold the sample between the base plate and cover plate. The screws should not be over tightened to avoid breakages of the plate. The second is the fracture of grips after testing 10-12 samples. The fracture is initiated from the holes used for voltage electrodes near the edge of the grip and they grow diagonally as shown in Fig. 7. The choice of mechanically stronger materials with an improved grip design can help to resolve these issues

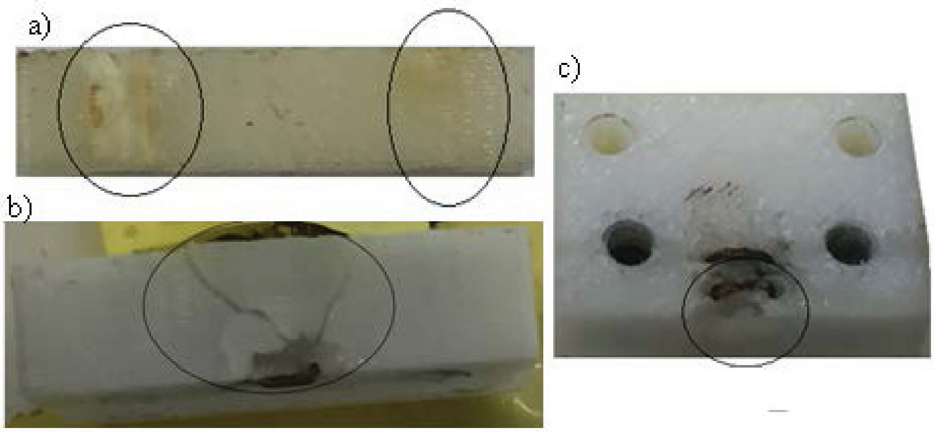

Fig.7. Fracture zones (circle) are observed in the grips after conducting 10 tests. a) Side view of covering plate with circle indicating fracture zone .b) Side view of base plate with fracture zone.c) Tope side view of base plate, circle indicates fracture zone.

Conclusion

Time resolved experiments to study electrical conductivity correlated with structural changes under the effect of mechanical deformation in polymer based nanocomposite materials require a specially designed system of measurement. Such kind of coupled measurements yield one to one structure property relationships. FDM was succesfully used tomanufacture the specially designed grips which serve not only to hold the sample during stretching but also have embedded electrodesto measure the electrical current and the corresponding voltage drop within the sample. The grips serve to insulate the sample from rest of the metal based tensiometer assembly. The success of the experiment is indirectly an indication that additive manufacturing is a useful technology to design complex parts within a experimental laboratory environment. We conclude that:

- Additive manufacturing has the ability to potentially solve problems in the part design and engineering in the context of a research laboratory.
- The case study of specially designed grips successfully served the purpose without failure for 10-12 samples, without sample slipping and fracture of grips during experiment indicating strong bonding between successive layers.
- The designed grips were used for static as well as dynamic experiments to measure electrical conductivity.
- A dimensional accuracy of 99% was observed for manufactured grips.
- A.M has the ability to produce parts for use in research laboratories in other scientific andfields.

Acknowledgements

This research work was supported by the Portuguese Foundation for Science and Technology (FCT) through the project reference UID/Multi/04044/2013. The x-ray scattering experiments were performed at the BL11 beamline at the Alba Synchrotron.

References

[1] S.H. Khajavi, J. Partanen, J. Holmström, Additive Manufacturing in the spare parts supply chain, Comp. Ind. 65 (2014) 50-63.

[2] M. Despeisse, S. Ford, The role of additive manufacturing in improving resource efficiency and sustainability, APMS 2015.

[3] K.V. Wong, A. Hernandez, A review of additive manufacturing, ISRN Mech. Eng. 2012.

[4] Y. Yongnian, L. Shengjie, Z. Renji, L. Feng, W. Rendong, L. Qingping, X. Zhuo, W. Xiaohong, Rapid prototyping and manufacturing technology: Principle, representative technics, applications, and development trends, Tsing. Sci. Tech. 14 (2009) 1 - 12.

[5] K. Żurowski, A. Piosik, R. Ciechack, FDM rapid prototyping method in the construction of portable test stand, J. Res. App. Agr. Eng. 58 (1) (2013) 199-202.

[6] J. Crane, R. Crestani, M. Cotteleer, 3D opportunity for end-use products: Additive manufacturing builds a better future, Deloitte University Press, 2014.

[7] T. Rulania, Impact and applications of 3D printing technology, Int. Jour. Com. Sci. Eng. 3 (8) (2016) 79-82.

[8] M.H.K. Peace, G.R. Mitchell, Conductive Elastomeric Composites, J. Phys.: Conf. Ser. 183 12011 2009.

[9] L. Flandin, Y. Brechet, J. Y. Cavaille, Electrically conductive polymer nanocomposites as deformation sensors, Comp. Sci. Tech. 61 (2001) 895-901.

[10] M.C. Robitaille, R. Zareian, C.A. DiMarzio, K.T. Wan, J.W. Ruberti, Small-angle light scattering to detect strain-directed collagen degradation in native tissue, Int. Foc. 1 (2011) 767-776.

[11] C.K. Chua, K.F. Leong, C.S. Lim, Rapid Prototyping: Principles and Applications, 3rd ed., World Scientific publishing company, Singapore 2010.

[12] J. Czyzewski, P. Burzynski, K. Gavel, J. Meisner, J. Mat. Proc. Tech. 209 (2009) 5281-5285.

[13] F. Lederle, F. Meyer, G.P. Brunotte, C. Kaldun, E.G. Hubner, Improved mechanical properties of 3D-printed parts by fused deposition modeling processed under the exclusion of oxygen, Prog. Addit. Manuf. 1 (2016) 3–7.

[14] J.G. Drobny, Polymers for electricity and electronics:Materials,properties,and applications,1st Ed., John Wiley and Sons, New Jersey, 2012.

[15] I. Khan, G. Mitchell, A. Mateus, C.S.K. Lorger, Time resolved strain dependent morphological study of electrically conducting nanocomposites,J. Phy. Conf. Ser. 646 (2015).