STUDY OF THE ELECTRICAL RESISTANCE OF SMART TEXTILES MADE OF THREE-DIMENSIONAL PRINTED CONDUCTIVE POLY LACTIC ACID ON POLYESTER FABRICS

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ABSTRACT

In this study, conductive tracks are integrated onto textiles through Fused Deposition Modeling (FDM) process and the correlation between the FDM process parameters such as platform temperature and speed, the textile properties such as porosity, pattern, roughness, density and structure, and the electrical resistance of the smart textiles made of conductive poly lactic acid polymer printed on fabrics is investigated.
In addition to study and understand the electrical properties of these conductive materials deposited onto textiles, they are maximized to guarantee their use in smart textiles field. The surface resistance measurements of the materials were carried out using a concentric ring probe technique. Findings are promising and important in the development of functionalized textiles as they demonstrate the feasibility of enhancing the electrical conductivity of textile composite materials through theoretical models based on the experimental data.

Key Words: 3D PRINTING, ELECTRICAL CONDUCTIVITY, TEXTILE STRUCTURE, NANOCOMPOSITE, POLYMER

1. INTRODUCTION

Over the past few years, 3D printing technology using Fused Deposition Modeling (FDM) process has demonstrated great potential in the development of smart textiles for various applications [1–5]. This technique, defined as a deposition of extruded thermoplastic filaments layer-by-layer, is part of the Additive Manufacturing (AM) processes. Some researchers have investigated the mechanical properties (adhesion, deformation and tensile strength) of these materials and highlighted their challenges [1–7]. For instance, it has been demonstrated by R. Sanatgar *et al.* (2017) that increasing the extruder temperature and the printing speed led to increase linearly and quadratically the adhesion performance between Poly (lactic acid) (PLA) extruded filaments on PLA woven textile materials respectively. Besides, raising the platform temperature of the 3D-printer and the use of open and rough textile materials could improve the adhesion between the printed track and the textile [1, 2]. However, few studies have been focused on understanding and optimizing the electrical properties of such materials. Scientists have studied the electrical conductivity of polymers composites using incorporation of conductive fillers such as carbon black or carbon nanotubes–polymer composites and the effect of the 3D printing process parameters, such as extruder temperature, on the electrical properties [6, 8–13].
Campbell *et al.* (2013) approached nanomaterials-based additive manufacturing as a new potential for added functionalities in nanocomposite materials field. In that case, 3D printing

technology using FDM could be a better alternative solution to obtain greater control over material properties across deposited materials. Two main ways exist to integrate metals into matrix: the first method is to introduce them during the 3D printing process of the host matrix by mean of periodic stoppages [2] and the second method is to blend them into the host matrix (wet or melt process). Nano fillers such carbon black particles or carbon nanotubes are commonly dispersed into polymeric matrix through extrusion process. Nevertheless, there are still many fundamental challenges to overcome for nanocomposites to be commonly processed by additive manufacturing such as reliable methods and standard to assess their properties and performances. Although many studies in the field of conductive polymer nanocomposites are done or on going, controlling the morphology of nanocomposites like shape, distribution, size and melt flow to control the properties of the 3D printed nanocomposites on fabrics, remains the main challenge. For this reason, few researchers started working on this topic. As an example, R. Sanatgar *et al.* (2018) successfully developed PLA-based conductive monofilaments with two types of nanofillers, Multiwall carbon nanotubes (MWNT) of surface area of 250 m^2/g and high-structured carbon black (Ketjenblack) of surface area of 1400 m^2/g and investigated their morphological and electrical properties to guarantee their use in smart textiles through 3D printing [2].
The aim of this paper is to study the influence of the build platform temperature and the structural properties of different PET fabrics on the electrical conductivity properties of 3D-printed conductive polymers on textile materials.
The materials and process parameters were selected and used for the experiment according to a factorial design of experiment. Their electrical conductivity was measured and correlated to their structural properties. These findings are of great importance for novel smart textiles development through 3D printing and assessment of their durability.

2. METHODS AND PROCEDURES

2.1 Materials

Polyester woven and knit textiles were manufactured in the weaving and knitting departments of the University of Borås and nonwoven materials were purchased from different companies. For each type of material a general statistical design of experiments of distinct factors was randomly created through Minitab 17 software.

2.2 Manufacturing of conductive polymers

The extrusion process of the conductive nanocomposite PLA monofilaments was carried out in a controlled temperature (20 ˚C ± 0.2) and humidity of (65% ± 5) room. First, 2.5wt.% of carbon black (CB) fillers were incorporated into virgin PLA pellets (ref: 6202D from NatureWorks), and then dried in an oven. In order to guarantee a homogeneous dispersion of the CB in the PLA, a rotating and inter-meshing twin-screw extruder was used at a constant speed and at a set range of temperature.

2.3 3D printing processes

The 3D printing process using Fused Deposition Modelling (FDM) technique was achieved in a room with controlled temperature (20 °C ± 0.2) and humidity (65% ± 5). Rectangular shaped woven materials were placed at the middle of the metallic build platform without applying any intermediate film between the platform and textile prior to printing process.

After, 50 mm x 50 mm square shaped track made of conductive PLA, designed first on Rhinoceros CAD software and then imported into Simplify 3D software was printed on each different fabric. The infill percentage, the Z offset, the printing speed and the extruder dimensions were constant during the experiment.

2.4 Electrical conductivity measurements

The electrical conductivity of the 3D printed conductive PLA on textiles was determined by first measuring their surface resistivity through the measurement of the associated current of an applied voltage potential across the surface of the material sample. The surface and volume resistivity measurements of the materials were executed using a 6517A Electrometer Keithley coupling with the 8009 Resistivity Test Fixture [9]. As the composites PLA+2.5% CB printed onto PET Textiles using 3D printing are semi-conductors, the surface resistance is calculated by using Eq. (1) and the Ohm's law equation (2):

$$Surface\ resistance(Ohm) = c \times R \tag{1}$$

and,

$$R(Ohm) = \frac{I(A)}{U(V)} \tag{2}$$

where c is a constant value of 53.4 linked to the 8009 Resistivity Test Fixture machine, *I* is the current through the semi-conductor material in units of amperes, U is the voltage measured across the semi-conductor material in units of volts, and R is the resistance of the semi-conductor material in units of ohms. Only the linear portion of the current-voltage curve is considered for the calculation of the resistance for a voltage range of [0.5V;2V].

3. CHALLENGES AND CONCLUSION

The findings of this article are very promising and support the manufacturing of smart textiles by using FDM process by studying the influence of textiles' structures and properties and 3D printing process parameters on the conductivity of the 3D printed conductive PLA onto PET fabrics. It was shown that the build platform temperatures as well as the properties of both polyester fabrics and conductive PLA filament have an effect on the electrical conductivity (or resistivity) properties. Thus, in order to reach the electrical conductivity performance required or/and be able to tune it, it could be possible to adjust the FDM process parameters according to the textile substrate used or modify the properties of the textile materials.
Finally, various challenges and further work still exist in the manufacturing process to demonstrate fully repeatability and be applicable for any textiles.

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