HEATING TECHNIQUE INFLUENCE ON ELECTRICAL PROPERTIES OF CONDUCTIVE 3D PRINTED FILAMENT

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Introduction

3D printing is a widespread technology to design complex geometries . There are numerous methods that allow to implement the 3D printing process [1]. Among them Fused Deposition Modelling (FDM) is a common technique using filaments made by different materials such as thermoplastic, metal, wood or composite. The apparition of conductive filament allows the creation of electrical circuit inside a device for 4D printing application [2]. In this paper we will focus on a carbon particules reinforced-PLA filament (CP-PLA), one of the most widely used thermoplastics in 3D printing. The effect of Joule's heating and the oven heating on the electrical resistance of the CP-PLA composite below and above the glass transition temperature (Tg) has been studied. The results show that resistance evolution is highly dependent on the heating method and printing parameters such as layer height and printing direction. Indeed, the resistance was found to increase faster when heated by an oven than by Joule effect.

Materials & methods

Material & Sample preparation

For the present study, a commercial PLA filament with brand name Proto-Pasta supplied by the company Protoplant was selected. The filament is based on the natureworks 4044 PLA polymer with a melt point of 155 ºC and contains a significant percentage of carbon black filler to increase the electrical conductivity. Specimens were manufactured by a Prusa i3 MK3S FDM printer. A hot-end temperature of 225 ºC and a printing bed temperature of 60 ºC was used as recommended by the manufacturer. The filament was extruded through a 1 mm diameter nozzle, at 100% extrusion ratio. The size of the samples was 15x70 mm with a thickness of 2.4 mm. Three different layer heights of 0.05, 0.1 and 0.2 mm were selected. The filaments were laid down perpendicular (90°) or parallel to the printing direction (0°).

Electrical characterization

First, the self-heating behavior was investigated. A generator TENMA 72-2540 set on 30 volts DC was used for 5 minutes and the resistance change was logged using its software. For all samples, 5 minutes was enough for the resistance to stabilize. The temperature distribution was monitored with a FLIR A655SC thermal camera and registered with the ReshearIR software at the same time

Subsequently, the external heat source investigation was performed using a SciQuip oven-230HT. The specimens were initially heated to 50°C and afterwards temperature was progressively increased in steps of 5°C maintaining a constant temperature over a period of 5 minutes to ensure a homogeneous temperature distribution over the specimen. The temperature of the specimens was registered by thermo-couples, and the resistance was monitored with a TENMA 72-2540 generator set on 15 volts DC, low enough to avoid any self-heating Joule effect.

To analyse the evolution of electrical properties as function of the temperature, the parameter of Resistance Amplitude (RA) was introduced:

$RA = \frac{R_i - R_0}{R_0} \times 100$, where R_i stands to the registered resistance and R_0 stands for the initial resistance at room temperature (20°C). To ensure the statistical significance of the registered data, 5 repetitions of each experiment were conducted.

Results & Discussion

The layer height parameter has a significant effect on the electrical resistance evolution in 90° printing direction (figure 1a) meanwhile same trend was found regardless of the layer heights in 0° printing samples (figure 1b). For all cases, increasing the temperature increases the electrical resistance of the material, although the degradation of the electrical properties stabilizes once the Tg is reached.

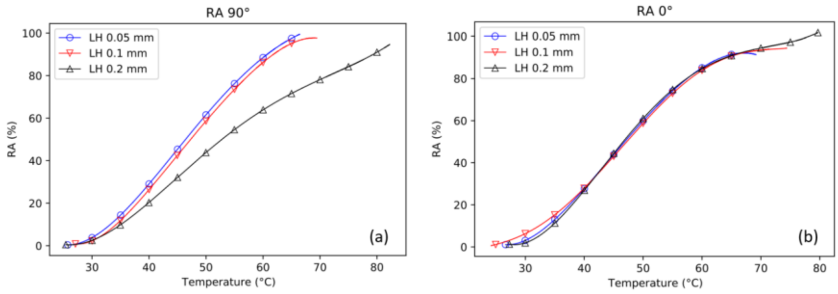

Figure 1: RA (%) of the samples printed at (a) 90° & (b) 0°

The heating technique analysis illustrates that an external source increases the electrical resistance faster than the self-heating method (figures 2a and 2b). The first hypothesis is the particle migration mechanisms differ when a current flows through them resulting in different percolation clusters.

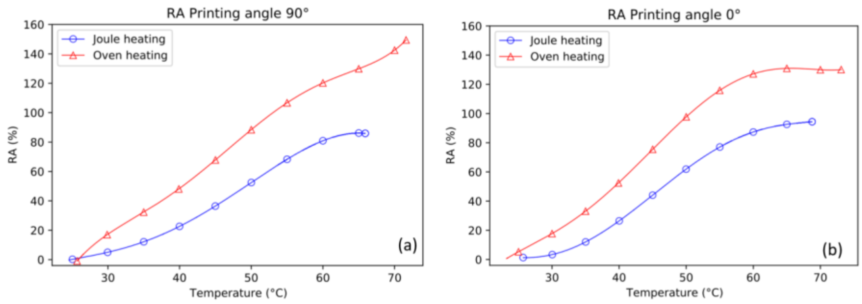

Figure 2: Oven heating & Joule heating samples printed at (a) 90° & (b) 0°, layer height of 0.05 mm

Conclusion

Electrical properties are influenced by the heating technique but also by the printing parameters such as the printing angle and the layer height. It is shown that when printed at 0°, samples are more reliable and have the same resistance evolution regardless of the layer height. In addition, samples printed at 90° take more time to reach the maximum resistance while sample printed at 0° tend to stabilize after 60°C. When heated in the oven, the resistance is increasing faster than the self-heating. Samples printed at 0° have the same trend regardless of the heating technique while samples printed at 90° take more time to stabilize.

Acknowledgements

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