Correlation between heat transfer of polyester textiles and its adhesion with 3D-printed extruded thermoplastic filaments

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Abstract

FDM technology used for printing functionalized layers on textiles brought new challenges such as the understanding and the improvement of the adhesion performance of the thermoplastic filaments on synthetic textile materials. In addition to the impact of printing parameters, the correlation between the heat transfer and structure of the textile material and the adhesion performance after varying printer platform temperature was an important parameter considered in this paper. A factorial design, using material density, direction, and structure and platform temperature as factors, was followed. 3D-printed materials made of PLA filaments deposited on polyester woven and knit materials were manufactured on a dual-head printer and their adhesion was measured according to DIN EN ISO 13937-2 and ISO 11339 and the heat transfer of the fabrics according to ASTM D4966-98, ISO 6330 and ISO 22007-2. The findings showed that the heat transfer and structure of textile materials affect the adhesion properties of the 3D-printed material.

***Keywords*—3D-printing, Fused Deposition Modelling (FDM), Polyester textile, PLA filament, Heat transfer, Thermal conductivity, Adhesion, Additive Manufacturing (AM)**

I. Introduction

Fused Deposition Modelling (FDM) is the deposition of extruded thermoplastic filaments layer-by-layer called also Additive Manufacturing (AM). This technique becomes more and more interesting for smart textiles applications. Various approaches have been attempted in order to understand the influence of 3D printing process parameters on the adhesion and suggest solutions for its improvement [1-10]. For instance, it has been demonstrated by R. Sanatgar *et al.* (2017) that an increase of extruder temperature and the printing speed increased linearly and quadratically the adhesion performance between Poly (lactic acid) (PLA) extruded filaments on PLA woven textile materials respectively. T. Spahiu *et al.* (2017) showed that raising the platform temperature of the 3D-printer could improve the adhesion between the printed track and the textile. However, textile materials have different thermal and mechanical properties mainly linked to their structure and composition that might affect the properties of the final 3D-printed textiles. The main focus of this article is to correlate heat transfer of both textiles and extruded filaments with their adhesion.

Many studies of heat transfer of textile materials focused on comfort application purposes. They investigated the impact of the textile properties on the capacity of the textiles to carry heat or resist it [11-18]. Heat transfer can be defined by two parameters: thermal conductivity and thermal resistance. For PET and cotton plain weaves, the thermal resistance increases with an increase of both thickness and weight of fabric and a decrease of porosity [13]. The heat transfer of nonwoven material is driven by the conduction through solid fibers, the conduction through air in the inter-fiber spaces and the convection and radiation due to the structure. An increase of porosity and pore size in a nonwoven structure results in increasing radiative heat transfer and eventually, the total heat transfer (effective

thermal conductivity). Yet, the thickness of the nonwoven does not significantly affect the heat transfer [15]. Thermal conductivity of knitted textile increases with an increase in thermal conductivity of the fibers and a decrease in porosity [11].
Density and air permeability of interlock knit fabrics are parameters that highly influence thermal properties.[17] Furthermore, the relative porosity and moisture regain are the first parameters that affect thermal conductivity of fabrics of cotton/polyester/rayon blend simple rib, cotton, cotton/viscose blend, polyamide 1-1 interlock and polyester double rib. These results aid in understanding the behavior of the textile when it is heated by the printing build platform during 3D printing. However, in order to anticipate and optimize the mechanical performances of the final 3D printed fabric, both heat transfer of the textile and melt flow characteristics of the extruded filaments need to be combined to understand the interface filament/textile properties. PLA, ABS and PCL are the main filaments used in 3D printing applications and cannot be used in the same way due to their melt flow.

The chamber, the extrusion head temperatures, pressure drop and velocity influence the melt flow of polymers such as PLA, ABS and PCL [19-29]. In the extruder, the polymer is at unsteady state and has a complex behavior because of its phase change (from solid to liquid) and its non-Newtonian character (i.e the shear stress is not directly proportional to its velocity speed). In contact with neighboring material, the semi-molten filaments solidify immediately after deposition. The mechanical properties of the final printed part can be guaranteed only if bonding is sufficient. The semi-molten filament particles adhere to each other and form a homogeneous part due to surface tension and thermal energy actions [21]. However, due to their molecular structure, each polymer has a unique behavior. For instance, modelling shows that PLA filament with specific specifications (viscosity, diameter…etc.) melted completely crossing two/third of the middle section of the extruder. The melt flow behavior was influenced by the rheological properties of the polymer, especially the viscosity.

The aim of this paper is to study the influence of the build platform temperature and the heat transfer of different PET fabrics and PLA filaments on the adhesion properties of 3D-printed materials.
PET fabrics with different structures and different build platform temperatures were selected and used for the experiment according to a factorial design of experiment. Their adhesion was measured according to DIN EN ISO 13937-2 and ISO 11339 and their thermal properties according to ASTM D4966-98, ISO 6330 and ISO 22007-2. These findings are of great importance for novel printed and smart textiles.

II. Methods and procedures

Polyester woven and knit textiles were manufactured in University of Borås and nonwoven materials were purchased from different companies. ECO-PLA monofilament from Creative tools was used for the experiments. For each type of material a general statistical design of experiments of four distinct factors was created randomly in Minitab 17 software. The 3D printing manufacturing process was performed in a room with controlled temperature (20 °C ± 0.2) and humidity (65% ± 5). Rectangular samples of woven material were placed at the middle of the metallic build platform without any intermediate film between the platform and textile prior to printing process. After, rectangular track made of ECO-PLA, 1.75 mm monofilament, designed first on a Rhinoceros CAD software and then imported into Simplify 3D software, was printed on each different woven material. The infill percentage, the Z offset, the printing speed and the extruder dimensions were constant during the experiment.
The adhesion performance was determined according to DIN EN ISO 13937-2 and ISO 11339.
Additionally, two methods were used to measure the thermal conductivity of textiles. The first one was called "Alambeta" method and the tests were performed according to standard SS-EN 31092/A1:2012, updated version of ISO EN 31092-1994. Textile samples were conditioned in a controlled temperature and humidity room (20±2°C and 50±5%). For each set of trials, three samples were tested to obtain an accurate average value of these parameters: thermal conductivity λ, specific heat transfer and thermal resistivity. Therefore, the second method used to measure the thermal properties of textile was Hot Disk Method (TDA-501). This method consisted in a thin disk-shaped sensor (hot-disk sensor) which measured the thermal conductivity. At least three measurements were performed for each material to ensure the repeatability of the measurement results. The sample surface tested was 100 mm2. The specimens were compressed at 2 kPa and the hot disk was positioned according to ISO 22007-2 [30].

III. CHALLENGES AND CONCLUSION

The findings of this article are very promising and support the manufacturing of smart textiles by using FDM process. It was shown that the build platform temperature as well as the heat transfer and structure of both polyester fabrics and PLA filament have an effect on their adhesion properties. Thus, in order to reach the adhesion performance required, 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 still exist in the manufacturing process to demonstrate fully repeatability and be applicable for any textiles considering the difference in heat transfer and structure of the substrate.

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