Possible Applications of 3D Printing Technology on Textile Substrates

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Abstract. 3D printing is a rapidly emerging additive manufacturing technology which can offer cost efficiency and flexibility in product development and production. In textile production 3D printing can also serve as an add-on process to apply 3D structures on textiles. In this study the low-cost fused deposition modeling (FDM) technique was applied using different thermoplastic printing materials available on the market with focus on flexible filaments such as thermoplastic elastomers (TPE) or Soft PLA. Since a good adhesion and stability of the 3D printed structures on textiles are essential, separation force and abrasion resistance tests were conducted with different kinds of printed woven fabrics demonstrating that a sufficient adhesion can be achieved. The main influencing factor can be attributed to the topography of the textile surface affected by the weave, roughness and hairiness offering form-locking connections followed by the wettability of the textile surface by the molten polymer, which depends on the textile surface energy and can be specifically controlled by washing (desizing), finishing or plasma treatment of the textile before the print. These basic adhesion mechanisms can also be considered crucial for 3D printing on knitwear.

1. Introduction

3D printing is regarded as one of the key technologies in future production processes. In the field of additive manufacturing 3D objects are produced in layers using starting materials from liquid to solid and corresponding technological principles of model building named, e.g., stereolithography (SLA), selective laser sintering (SLS) or fused deposition modelling (FDM) [1].

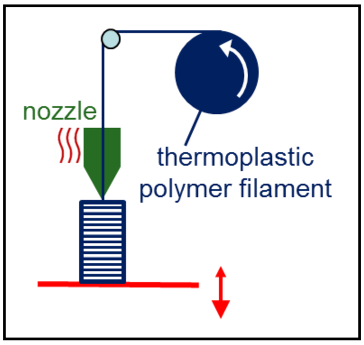

Figure 1. Schematic depiction of fused deposition modelling (FDM) technology.

The latter one is of special interest for SMEs due to its relatively low initial costs and easy operation compared to other 3D printing techniques. At FDM a wire-shaped thermoplastic filament is molten in an extruder nozzle and deposited in layers on a heatable printing bed, which is lowered according to the selected layer thickness each time one layer was printed. In this way the 3D element according to a previously designed CAD model is built up step by step (Fig. 1).

Combining FDM printing of thermoplastic polymers with textiles, new possibilities of individual product and process design arise. Previous investigations focussed on embedding fibrous materials [2] or woven fabrics [3] in 3D printed forms or printing on textile net structures creating new multicomponent textiles [4]. FDM printing on textile substrates, regarded as new kind of textile functionalization, offers production of individualized or customized products by freedom of shape and design concerning the fields of functional textiles as well as apparel. In addition to textile applications like buttons, accessories or 3D structured elements for home textiles (roller blinds, curtains) the possibilities to integrate a local reinforcement and protection function for sportswear as well as protection clothes can be considered as application fields.

While the adhesion characteristics of only FDM printed hard and stiff materials like acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) and polyamide (PA) on different types of fabrics have recently been under investigation [5, 6], the current article concentrates on the flexible printing materials Soft PLA and a thermoplastic elastomer (TPE). As a result the influence of different chemical and physical surface properties of the textiles on the adhesion of the prints is depicted.

2. Experimental

3D printing experiments were performed using the FDM printer X400 manufactured by German RepRap GmbH. The selected nozzle diameter was 0.5 mm processing filaments with 3 mm diameter.

When testing the adhesion strength rectangles were created as CAD models, exported as stl files and imported in the Repetier-Host software for slicing. Rectangle dimensions for the prints usually were 150 mm x 50 mm. The layer thickness was set to 0.3 mm. Two layers were printed selecting a rectilinear infill pattern and a fill angle of 45°.

Soft PLA (shore hardness ≈ 43 D, purchased by German RepRap) and NinjaFlex (TPE filament, shore hardness ≈ 33 D) were used as printing filaments. The temperatures of the nozzle / printing bed were set to 210 °C / 70 °C (Soft PLA) and 220 °C / 35 °C (NinjaFlex). When printing the first layer it was ensured that the nozzle moves in close contact to the textile surface.

Adhesion tests were performed according to DIN 53530 (test for separating layers of laminated woven fabrics) using a Zwick Roell testing device. For evaluation the average peak values of the tensile forces in the recorded stress-strain-diagrams were given following the standard specifications.

Washing and desizing of textile samples were performed 45 min at 60 °C adding the enzyme amylase and the washing agent Kieralon CD (BASF).

Low pressure plasma treatments (50 Pa, 2.45 GHz microwave discharge) of textile samples were performed under carbon dioxide, argon and nitrogen atmosphere. The parameter settings are as following: 600 W (power), 250 sccm (gas flow), 30 s (duration of treatment).

3. Results and Discussion

Figure 2 shows maximum adhesion forces for both flexible Soft PLA and TPE filaments printed on different woven fabrics which can be mainly categorized by the textile material, weave and thickness. Obviously, the adhesion forces are more dependent on the textile substrate than on the printing material. A better adhesion can be obtained if the textile surface is roughened or hairy as shown for the rough polyester (PES), cotton (CO) and wool (WO) samples. Additionally, in case of the thicker fabrics also better adhesion forces can be acquired. These good adhesion results can be attributed to the provided form-locking connections of the printed polymer to the fibres on top of the textile as well as inside the textile structure, which should offer sufficiently open areas for the molten polymer to penetrate inside.

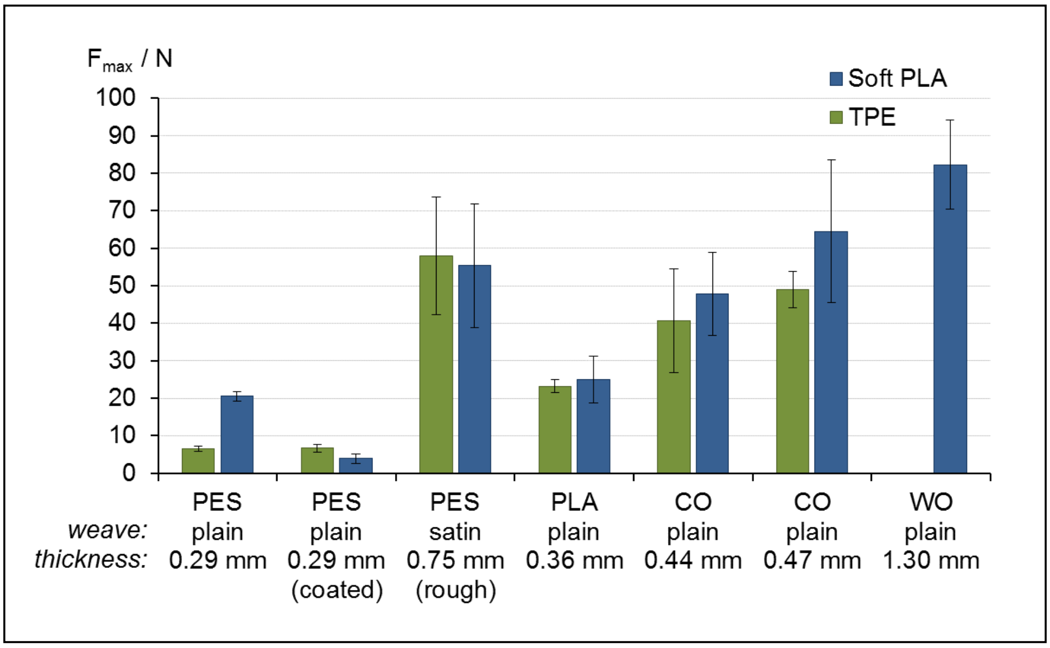

Figure 2. Maximum adhesion forces F_{max} of FDM prints (350 mm x 50 mm) on different woven fabrics – polyester PES, polylactic acid PLA, cotton CO and wool WO.

Apart from structural and topographical properties of the textile, the influence of the chemical properties of the textile surface providing, e.g., hydrophilicity or hydrophobicity on the adhesion strength was investigated. Figure 3 depicts the adhesion strengths of printed Soft PLA on different cotton and polyester fabrics for technical textile applications with similar thickness (0.21-0.33 mm) either unwashed or washed before the FDM printing process.

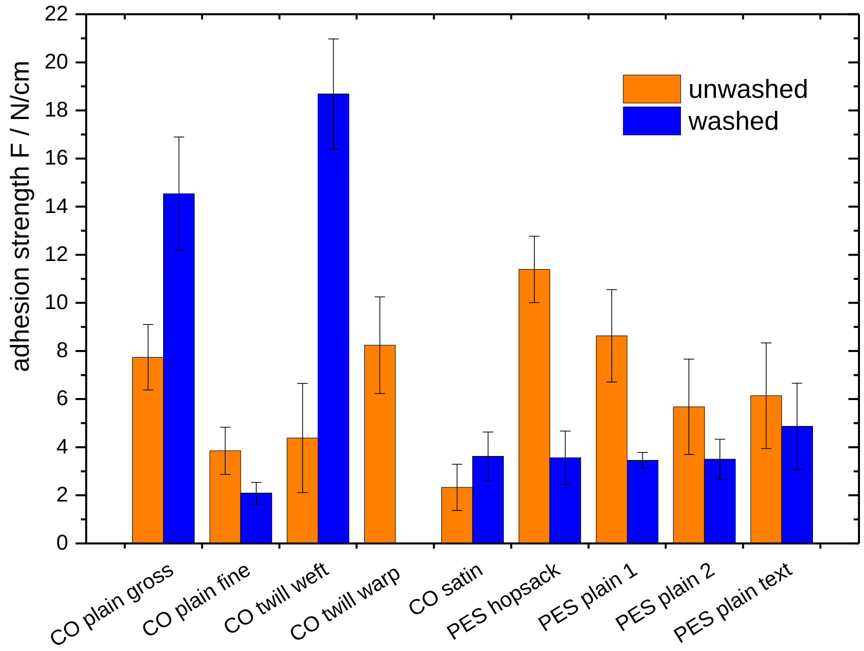

Figure 3. Adhesion strengths of Soft PLA prints on different unwashed and washed cotton CO and polyester PES fabrics.

During washing cycles, sizes and chemicals used for textile finishing should be removed. Looking at the cotton CO samples first, the determined values for the adhesion strength vary widely due to different textile surface structures. Except for CO plain fine, after washing and desizing the adhesion strength increases. For CO twill the adhesion strength even gets four times higher than without washing, so that it becomes impossible to remove the print by hand without fabric destruction. As proven by water droplet test, after washing the CO surface becomes hydrophilic owing to removal of waxes or lubricants. As a result the wettability of the textile surface and therewith the textile surface energy is enhanced.
In contrast to CO fabrics, washing treatment of PES fabrics led to hydrophobization of the PES surface, so that surface energy and wettability were reduced. This resulted in an adhesion strength reduction to similar values of around 4 N/cm. For this, it can be assumed that the formerly applied hydrophilic finish acts as a penetration and adhesion promoter.

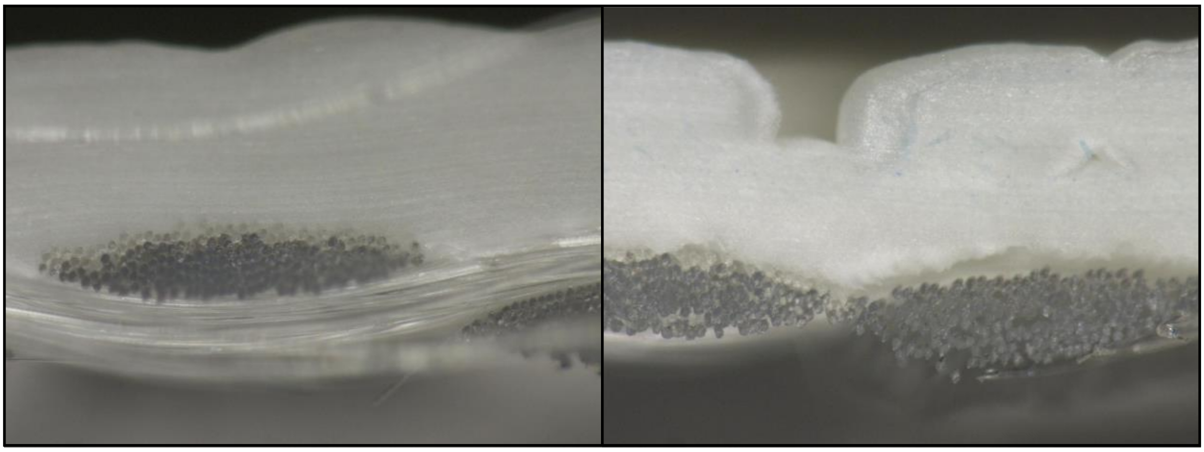

Figure 4. Cross section light microscope images of polyester PES samples without (left panel) and with argon plasma treatment (right panel) printed with Soft PLA on the top.

Low pressure plasma treatment of the polyester fabrics before the print led to different effects: Both argon (Ar) and nitrogen (N_2) plasma treatment drastically reduced the adhesion strengths for printed Soft PLA. Apparently, this kind of treatment only had a cleaning effect on the textile surface removing the hydrophilic finish and no polar groups were created. The resulting bad adhesion strength values of below 2 N/cm can be visualized by a cross-cut microscope image of the print revealing an air space at the interface between textile and printed polymer (Figure 4, right panel).
In case of carbon dioxide (CO_2) plasma treatment of the polyester fabric made of texturized yarns the hydrophilicity and wetting behaviour could be enhanced leading to almost two times higher adhesion strength for Soft PLA.
Using a Martindale testing device, various abrasion resistance tests with textile cotton and polyester samples printed with small squares of 2-3 layers of Soft PLA demonstrated, that the textile surface can be well protected against abrasion by FDM printed structures.

4. Conclusion

Deposition of polymers onto textiles using FDM printing technology can contribute to new textile applications and individual manufacturing of functional products. In this study the influence of textile surface properties on the adhesion strength of printed flexible polymers was examined considering mechanical / physical and chemical adhesion mechanisms. Basically, FDM prints on cotton and polyester textiles can result in great adhesion properties. The obtained adhesion strength is decisively influenced by the form-locking connections of the molten polymer with the textile substrate. These connections can occur on the textile surface (if roughened and hairy) and in the textile structure itself corresponding to the type of yarns and weave. Another important factor which affects the adhesion strength is the wettability of the textile surface and so the textile surface energy. This is or can be specifically controlled by washing (desizing), finishing or plasma treatment of the textile before the print.

These basic principles resulting in good adhesion properties should also be valid for corresponding 3D printing processes on knitted structures, which will be the topic of further investigations.

5. References

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