Composites of 3D-Printed Polymers and Textile Fabrics*

Yasmin Martens*, Andrea Ehrmann*

*Bielefeld University of Applied Sciences, Faculty of Engineering and Mathematics, Working group of textile technologies, Bielefeld, Germany

Abstract: 3D printing belongs to the rapidly emerging technologies of our time. Due to its recent drawback – the technology is relatively slow compared with other primary shaping methods, such as injection molding –, 3D printing is often not used for creating complete large components but to add specific features to existing larger objects. One of the possibilities to create such composites with an additional value consists in combining 3D printed polymers with textile fabrics. Several attempts have been made to enhance the adhesion between both materials, a task which is still challenging for diverse material combinations. Our paper reports about new experiments combining 3D printed embossed designs, snap fasteners and zip fasteners with different textile base materials, showing the possibilities and technical limits of these novel composites.

Keywords: 3D printing; textile fabric; composite; snap fasteners; zip fasteners

1. Introduction

3D printing belongs to the additive manufacturing techniques. Three-dimensional shapes can be created, e.g., by selective laser sintering, stereo-lithography or fused deposition modeling (FDM), addressing a broad range of applications [1]. While some authors describe 3D printing as the base for a new industrial revolution [2,3], there are still drawbacks which must be taken into account, especially related to the durations necessary for printing a desired object. Especially printing large objects with high resolution requires long production times. This leads to the idea to combine 3D printing with other materials which are available on large scales, such as metals, plastics, or textiles [4].

The FDM technology is used by most inexpensive 3D printers and thus most interesting for industrial applications. Being developed by Stratasy [1], FDM printers melt polymer filaments in an extruder nozzle and deposit the molten material on the printing bed. After finishing the first layer, the bed is lowered, and the next layer is printed on top of the previous one [5]. Possible materials include PLA (polylactic acid), ABS (acrylonitrile butadiene styrene, PA 6.6 (polyamide 6.6, "nylon"), PC (polycarbonate), etc. [6].

Combinations of FDM printed polymers with textile fabrics have been examined in general to increase the adhesion between both partners or especially related to specific textile structures or yarns [7-9]. A more systematic study dealing with the adhesion of ABS, PLA and nylon on different textile fabrics was recently published, concentrating on the chemical adhesion between both partners of the layer system [10].
In this article we examine combinations of snap fasteners and zip fasteners with different textile fabrics with the focus on washing the samples which has not been investigated in earlier research projects.

2. Experimental

For the experiments, two different 3D printing filaments were used: FilaFlex, a very elastic filament with high elongation; and ABS. PLA, another typical 3D printing filament, is not suitable for washing due to its low glass transition temperature of \( \sim 45 \, ^\circ C \).

Printing was performed using the FDM printer Orcabot XXL, produced by Prodim (The Netherlands). The nozzle had a diameter of 0.4 mm, the layer height was 0.2 mm. The samples were fixed on the printing bed using double-faced adhesive tape at the borders and sandpaper in the middle area on which printing occurred, avoiding slipping of the textile fabrics. The printing nozzle temperature was 240 °C for ABS and 245 °C for FilaFlex; the printing bed was not heated.

As textile materials, a knitted fabric from 100 % polyester (PES) (thickness \( d = 0.79 \) mm), a woven fabric from 100 % PES (\( d = 0.27 \) mm), and a woven fabric from 100 % cotton (\( d = 0.19 \) mm) were used to examine man-made and natural fiber materials.

Washing tests were performed at 30 °C using a mild detergent, followed by a spin cycle with 1600 min\(^{-1}\).

3. Results

Firstly, FilaFlex layers were printed on the fabrics. This polymer is known to show strong adhesion on most textile fabrics. With such flexible materials, new three-dimensional designs would be possible on garments or other textile materials. 3D printing could be an alternative to iron-on appliqués, allowing individualization of clothing.

![Fig. 1. FilaFlex rectangle on knitted PES fabric.](image)

Printing was only possible at low printing speeds. It was necessary to adjust the distance between printing nozzle and textile surface to optimize the printing results. Ten rectangular samples of one or two layers height were printed on the textile materials (Fig. 1.). Washing did neither change the surface of the FilaFlex print nor the adhesion between both materials. Detaching the printed items from the textile by hand was impossible, too. Thus we can conclude that FilaFlex is in principle suited for creating novel 3D designs on textile fabrics.
Since printing with FilaFlex is not easy and snap fasteners require more rigid materials, the next tests were performed by printing with ABS on all textile fabrics. Fig. 2 depicts the results of 1 washing cycle and four washing cycles, respectively, performed on snap fasteners (upper and lower parts) printed using ABS on the textile materials. The snap fastener parts are always surrounded by a so-called skirt, a fine line which is printed before the actual
objects is started to ensure a constant material flow through the nozzle and avoid printing with a not completely filled nozzle. Here, the skirts were additionally used as an indicator of the adhesion quality – the fine lines can be assumed to be torn off the fabric first by washing or other mechanical impact before the snap fasteners with their larger contact area are influenced.

As Fig. 2 shows, the results of these washing tests are strongly dependent on the textile base material. After the first washing cycle, all snap fastener parts are still fixed on the fabric. The skirts, however, are partly damaged on the cotton fabric and twice even completely torn off from the PES woven fabric.

On the PES knitted fabric, all skirts are intact after one washing cycle.

The picture taken after four washing cycles shows a different picture: The partial damages of the skirts on cotton are identical with those already visible after the first washing cycle. Apparently, the skirt vanished in areas in which the printing process started, resulting in a lower adhesion or smaller amount of printing material. Although the fabric shows significant creases, the adhesion between polymer and textile fabric seems to be influenced only slightly by washing.

On the PES woven fabric, however, not only more skirts are vanished, but even snap fastener parts were torn off the fabric after the fourth washing cycle. The fabric shows creases, too, but less pronounced than the cotton woven fabric. Comparing the fabric thicknesses of both the cotton and the PES woven fabric, cotton is even thinner which is known from earlier investigations to lead to reduced adhesion forces for otherwise identical samples [11]. Thus we can conclude that the adhesion between ABS and cotton is higher than between ABS and the thin polyester fabric.

Nevertheless, on the thick PES knitted fabric, all snap fasteners and even all skirts are still intact and adhere to the textile fabric after 4 washing cycles. This finding can be attributed to the form-locking connection between the printing polymer and the textile material which can occur during printing on relatively open-pored, thick fabrics in which the polymer can penetrate [11].

A more quantitative analysis is given in Fig. 3, depicting the numbers of undamaged skirts and fixed snap fastener parts. For the polyester knitted fabric, all skirts and snap fastener parts are not influenced by washing. On the thin PES woven fabric, the numbers of undamaged skirts and still attached snap fastener parts decrease with each washing cycle. For the cotton woven fabric, nothing changes visibly after the first washing cycle.

![Fig. 3. Numbers of ABS snap fastener parts and brims, still attached to the textile fabrics after different numbers of washing cycles.](image_url)
Depending on the angle and the velocity of pulling both parts of the snap fastener apart from each other, it is nevertheless possible to damage the connection even between ABS objects and the PES knitted fabric on which all connections withstood the washing process. This problem is illustrated in Fig. 4.

Although the washing process – which was assumed to be the hardest challenge for the connection between 3D printed object and textile fabric due to the combination of mechanical and chemical impact in a warm environment – did not destroy the connections between ABS and the PES knitted fabric, stronger forces can apparently still damage this bond. Thus, for directly printing snap fasteners on textile fabrics, more research is necessary to identify suitable material partners with still increased adhesion forces between polymer and textile material.

To investigate whether larger printed areas are supportive or counteracting the adhesion between both material partners, additional tests were performed printing zip fasteners on the same textile materials. Fig. 5 depicts the results after the third washing test.

While washing could not influence the shape of the 3D printed snap fasteners, it destroys the zip fasteners printed from ABS. Since this material is quite rigid and not elastic, the mechanical forces during the washing process fold and thus break the snap fasteners which are also torn off the textile base fabrics in larger or smaller parts. Apparently it is not possible to print a complete zip fastener from one material.
Similar to usual commercial zip fasteners, the next test will be performed using a flexible material – such as FilaFlex – as a base for the connection with the textile fabric on which the necessarily rigid “teeth” are printed from another material, such as ABS.

4. Conclusion and Outlook

Combinations of 3D printed polymers on textile fabric were examined with respect to the interface adhesion after different numbers of washing cycles. While the adhesion between the flexible FilaFlex material and the textile materials under examination was not overcome by washing or mechanical pulling, ABS printed snap fasteners were partly torn off cotton and fine polyester woven fabrics. On a thicker polyester knitted fabric, the ABS printed objects stayed fixed but could be pulled apart by stronger mechanical forces. Printing zip fasteners completely from ABS resulted in several broken and lost parts after three washing cycles.

Future research will concentrate on dual-material zip fasteners with rigid “teeth” on a flexible base and on further increasing the adhesion between rigid printing polymers and different textile fabrics, e.g. by plasma pre-treatment or preparative coatings.

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