Adhesion of 3D printing polymers on textile fabrics for garment production

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Abstract. Applications of 3D printing in fashion industry are numerous, including 3D printing geometries on textile fabrics, printing parts of the garments, or even the entire garment. A crucial point of making such polymer/textile combinations usable is the adhesion between both materials. Investigations related to this adhesion, however, are still scarce. Similarly, the influence of 3D printed patterns on the geometries and the mechanical parameters of textile fabrics are only rarely examined. Continuing our previous research, the experiments shown here illustrate the influence of different printing parameters on the adhesion between fabrics and 3D printing polymer. These results will support other researchers as well as fashion designers in developing new 3D garment shapes by combining common textile fabrics with the relatively new possibility of 3D printing.

1. Introduction

3D printing is an innovative technology with applications in different areas of production. These applications include the fashion industry, where examples can be found in various case related to 3D printing geometries on textile fabrics, printing parts of the garments or whole garments. Even though combinations of 3D printed objects and textile fabrics are innovative for the fashion industry, they are still rare compared to the traditional fabrics. Applications for footwear products are more often found than garments. This is related to the polymers which are more often used in footwear products for sole production [1-3].

Applications of 3D printing on textile fabrics strongly depend on a high adhesion of the 3D printed polymers on the textile fabrics. Investigations related to this adhesion, however, are still scarce [4-6]. Only few research groups have conducted investigations on the impact of textile and printing parameters on the adhesion between both materials. Especially the distance between nozzle and printing bed was found to significantly influence the adhesion [6], while other researchers underlined chemical influences or pretreatments of the textile fabrics [5,7,8]. In another study, several printing parameters were found to weakly influence the adhesion of an imprinted polymer [9]. More comprehensive investigations, however, correlating the different parameters, are still missing.

Similarly, the influence of 3D printed patterns on the geometries and the mechanical parameters of textile fabrics are only rarely examined [10]. This is why this paper depicts results of adhesion tests on different textile fabrics typically used for garments and shows some possibilities to create new 3D forms by adding 3D printed patterns to common textile fabrics.
2. Methods and Materials
In this work printing was performed using an FDM (fused deposition modelling) printer Orcabot XXL (Prodim International). The following printing parameters were used: nozzle diameter 0.4 mm, layer thickness 0.2 mm, nozzle temperature 200 °C or 230 °C, and printing bed temperature 60 °C or 100 °C. The distance between nozzle and printing bed was varied.

As printing materials, was used PLA, which has shown to have the highest adhesion in textile fabrics in previous investigations [6].

Different cotton woven fabrics of varying thickness and areal weight were used as the base for printing. Table 1 depicts the fabric parameters. Since for 3D printing with a fine nozzle on the fabric, the thickness measured by a micrometer caliper is more important than the value measured with the usual textile thickness tester, both values are given here. Opposite to the tests performed earlier [8], the fabrics are raw and were not chemically or mechanically pre-treated.

Table 1. Parameters of the fabrics used in this study. \(d_{\text{micro}}\) and \(d_{\text{textile}}\) depict the thicknesses measured with a micrometer caliper and with a textile testing instrument (according to DIN EN ISO 5084), respectively. The areal weight is measured according to ASTM D3776.

| No. | Weave  | \(d_{\text{micro}}\) / mm | \(d_{\text{textile}}\) / mm | Areal weight / (g/m²) |
|-----|--------|---------------------------|---------------------------|----------------------|
| 1   | Plain  | 0.32                      | 0.49                      | 144                  |
| 2   | Plain  | 0.27                      | 0.37                      | 127                  |
| 3   | Plain  | 0.31                      | 0.39                      | 154                  |
| 4   | Twill 2/1 | 0.56                      | 0.74                      | 276                  |

Rectangles of 250 mm x 25 mm area with a nominal height of 0.4 mm, i.e. two layers, were printed on the fabrics for the adhesion tests, using three printed samples per parameter set. Autodesk Inventor was used for 3D designing of the rectangles. The exported .stl files were imported in the repetier host for slicing them.

Adhesion tests were performed according to DIN 53530 and results were evaluated according to ISO 6133 defining the analysis of multi-peak results obtained in adhesion force investigations. The method for more than 20 peaks was used due to our experimental results.

Microscopic images were taken using a digital optical microscope VHX-600D (Keyence, Neu-Ulmenburg, Germany) with a nominal magnification of 50 x.

3. Results & discussion
Fig. 1 depicts one z-distance dependent measurement series (samples printed with a nozzle temperature of 200 °C and a printing bed temperature of 60 °C). The shape of the curve is typical for printing PLA on diverse woven fabrics [6]. With decreasing distance, the adhesion force increases, until in a certain distance (here: -0.2 mm) when the filament is blocked too strongly and cannot be transported to the nozzle anymore, so that printing stops. It should be mentioned that the z-distance of 0 mm means that nozzle and printing bed are in contact before the textile fabric is placed on the printing bed, i.e. the nozzle is printing inside the textile fabric to press the polymer with enough force into the open pores of the woven fabric.
To investigate the influence of the textile fabric thickness and weave, the same test series was performed with the other three woven fabrics under examination, using the same nozzle and printing bed temperatures. The results are depicted in Fig. 2, showing the z-distance dependent adhesion force (Fig. 2a) as well as the derivative, i.e. the slope of the curve (Fig. 2b).

Firstly, it becomes visible that the graph of sample 4 – which is 0.25-0.3 mm thicker than the other fabrics – is shifted to higher z-distances, what could be expected. On the other hand, the slopes of the graphs differ. This is best visible by calculating the derivatives dF/dz (Fig. 2b).

For sample 2 – with the smallest areal weight – and sample 4 – with the highest areal weight, the largest absolute values are reached, i.e. the strongest changes of the adhesion force with the z-distance. Apparently, there is no correlation between the maximum of the derivative and the areal weight or the thickness.

Another possibly interesting value can be calculated by taking into account the different thicknesses, measured by the textile testing instrument and the micrometer caliper. If the ratio d_{micro}/d_{textile} is defined as compression, the following compressions can be calculated for the samples used in this study: 0.65 (sample 1), 0.73 (sample 2), 0.79 (sample 3), and 0.76 (sample 4). Obviously, for sample 1 which can be compressed most strongly, the derivative has the smallest value. The less compressible samples have correspondingly higher maximum values of the derivatives. It should be mentioned that
printing on sample 3 with a z-distance of -0.1 mm resulted in clearly visible problems in the first layer. Here setting the z-distance to -0.05 mm may have led to a similarly high absolute value of the derivative as for samples 2 and 4.

Due to the relatively low amount of different compressibility values, it can only be estimated that the slope of the z-dependent adhesion force curve is correlated to the compressibility. This idea has to be investigated in more detail in the future.

Another interesting parameter is the temperature of the printing bed and the nozzle. The influence of increased temperatures was tested with sample 3 and is depicted in Fig. 3.

In an earlier investigation [11], we found a strong dependence of the adhesion force on the printing bed temperature as well as the nozzle temperature while letting all other parameters constant. Fig. 3 now reveals the reason for this finding. Apparently, the maximum possible adhesion force is not increased, and even the slopes of the curves of both temperature situations are nearly identical (Fig. 3b). Instead, the curves are shifted along the z-distance. It must be mentioned that after changing the temperatures, the distance between nozzle and printing bed was carefully re-adjusted to avoid erroneous modifications of this parameter.

This finding means that by increasing both temperatures and thus decreasing the viscosity of the molten PLA during printing, it is possible to print in an increased distance to the textile fabric. In this way, however, it is not possible to increase the maximum adhesion force since the z-distance in which the nozzle is clogged is also shifted to larger values.

Finally, Fig. 4 shows a comparison of the back of the 3D printed layer on sample 3 after the adhesion tests, comparing the maximum and the minimum distance. When printing in the maximum z-distance, the typical diagonal stripes of the printing process are clearly visible, with only a slight modification by the textile fabric below. Only a few fibers are stuck on the polymer. Oppositely, the back of the polymer printed in the smallest distance is fully covered with fibers, and in the polymer, the structure of the woven fabric is clearly visible. These images show clearly how strongly the z-distance influences the first printed layer.

It should be mentioned that the large amount of fibers visible in Fig. 4b suggests printing on a fabric woven from a filament yarn where – opposite to the cotton fabrics used here – the filaments cannot be pulled out of the fabric easily. In this way, it may be possible to further increase the adhesion between a 3D printed object and the textile fabric below.

Figure 3. z-distance dependence of the adhesion force of PLA on sample 3, printed with different temperatures, (a) and corresponding derivatives dF/dz (b). For the calculation of the derivative, the smallest z-distance was ignored.
Conclusions

3D printing on textile fabrics can be used to create composite garments in new 3D shapes. A crucial point is to ensure sufficient adhesion between both materials, making previous tests with the materials in use necessary. The results of our study give an overview of the most important printing parameters. The z-distance, i.e. the distance between the nozzle and the printing bed, is very important for the adhesion on textile substrates. With decreasing distance, the adhesion force increases until the minimum distance is reached in which the filament does not clog the nozzle. By reducing the z-distance, the nozzle presses the 3D printing polymer with higher forces into the open pores of the woven fabric.

Other important parameters tested in this work are the temperatures of the printing bed and the nozzle. By increasing both temperatures and thus decreasing the viscosity of the molten PLA during printing, it was possible to print in an increased distance to the textile fabric. In this way, however, the maximum adhesion force could not be increased since the z-distance in which the nozzle was clogged was also shifted to larger values.

These results will support other researchers as well as fashion designers in developing new 3D garment shapes by combining common textile fabrics with the relatively new possibility of 3D printing.

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