Combining 3D printed forms with textile structures – mechanical and geometrical properties of multi-material systems

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Abstract. The 3D printing belongs to the rapidly emerging technologies which have the chance to revolutionize the way products are created. In the textile industry, several designers have already presented creations of shoes, dresses or other garments which could not be produced with common techniques. 3D printing, however, is still far away from being a usual process in textile and clothing production. The main challenge results from the insufficient mechanical properties, especially the low tensile strength, of pure 3D printed products, prohibiting them from replacing common technologies such as weaving or knitting. Thus, one way to the application of 3D printed forms in garments is combining them with textile fabrics, the latter ensuring the necessary tensile strength. This article reports about different approaches to combine 3D printed polymers with different textile materials and fabrics, showing chances and limits of this technique.

1. Introduction

Several methods enable the additive production of 3D forms, such as stereo-lithography, selective laser sintering or fused deposition modelling (FDM) [1]. The FDM technique is based on resistively heating filaments in an extruder nozzle; the molten material is deposited on the printing bed line by line and then hardens there. The second layer is printed after the first one is finished and the printing bed is lowered [2].

FDM printers can handle filaments produced from several materials, such as Acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyamide, polycarbonate, polyethylene, polypropylene, or wax [3]. Additionally, special materials are available, e.g. wood or brick, which are especially useful for model makers in architecture. Soft materials can cause problems in the transport mechanism [4]. One possibility to overcome these problems is using special filaments, such as Lay Tekkks, produced by Kai Parthy from CC-Products (Cologne). The parts printed with this hard filament can be put into warm water for a certain time, which dissolves the hard parts and softens the sample [4].
Since the FDM technique is used in the most inexpensive 3D printers, this method is the most interesting one for small companies, allowing for testing the possibilities of this technology without the necessity of high investments. While previous experiments always concentrated on the possibilities to create textile-based structures from different polymeric materials by FDM printing [4] and to insert fibrous materials in 3D printed forms [5], this article examines possibilities to print 3D forms directly on textile fabrics.

2. Experimental
The 3D forms shown here were designed using the free CAD software SketchUp. The 3D elements were exported as standard template library (STL) files and imported in the repetier host which was used to slice the form into a layer model. This sliced result was sent to the 3D printer.

For the models depicted in this article, the FDM printer X400, created by German RepRap, was used.

The 3D printed additions to garments should be soft and not too brittle. Thus, instead of the commonly used ABS, which has shown insufficient mechanical properties if used in open structures [6], PLA soft was chosen as filament material. The filament diameter was 3.0 mm.

The extruder temperature was set to 211°C and the printing bed temperature to 63°C. The layer height was 0.3 mm. For filling the samples, a linear pattern was chosen.

3. Results
In a first test series, a pattern of 55 mm x 75 mm lateral dimension with 1.2 mm height (equal to 4 layers) was designed and printed on different textile fabrics. Figure 1 shows the results of printing PLA on cotton, wool, viscose, and a polyester net (from left to right), respectively.

![Figure 1. Floral pattern printed on cotton, wool, viscose fabric and polyester net (from left to right).](image)

While the printed forms can be easily stripped from the cotton and viscose fabrics, the adhesion on wool increases slightly due to the fabric’s rough surface. However, only for the polyester net, the printed material is really fixed on the fabric, since here the molten PLA flows around the single threads and encloses them, resulting in a mechanical connection of both parts.

To increase the adhesion strength of the printed pattern on a textile fabric, several tests using high temperature after treatments were performed. For this, a VEIT Kannegiesser fixation machine was used as well as an industrial steam iron VEIT HP 2003, allowing for combinations of pressure and temperature treatment. Since PLA has a softening temperature of about 50°C and should be processed at about 195-220°C, different temperatures between 120°C and 200°C were used in these tests. For an after-treatment at 200°C, a slight increase of the connection strength could be reached; however, the printed pattern could still be easily stripped from the textile fabric.

Thus, the next test concentrated on the idea of increasing the mechanical connection using “open” textile structures, such as different nets. Figure 2 shows the strip pattern which was used for the following examinations, with different strip heights (the largest one in the middle) and constant strip width. The textile layer was introduced between the first and the second PLA layer.
Figure 2. Strip pattern, designed in SketchUp, with strip heights of 0.9 mm, 1.2 mm, 1.5 mm, 1.8 mm, and 2.1 mm, a constant strip width of 2.5 mm and a length of 90 mm. The textile net is placed on the first layer.

This test sample was firstly tested using the Martindale Abrasion Tester Method according to standard ISO 12947-1. In this test, the abrasion of the sample under examination is tested by rubbing it against a worsted wool cloth abradent using a pressure of 9 kPa, and continuously changing the direction in a Lissajous-like figure.

As can be seen in figure 3, the polyester net fabric was not strong enough to stand the Martindale test, and was destroyed after 4,500 Martindale tours. The PLA printed pattern, however, was not influenced by the Martindale test – neither the surface changed visibly, nor the strips were pulled off from the base fabric. Apparently in this combination the connection between the textile and the surrounding PLA printed form is stronger than the textile net itself.

Next, the same PLA pattern was printed again, with one textile net between the first and the second layer, and another textile net between the second and the third layer. On this sample, a separation test according to standard ISO DIN 53530 was performed. For this, the polyester net layers were secured in the grip of a tensile testing machine and pulled apart with constant speed. In all cases – independent of the direction of the printed PLA pattern with respect to the grips – the test ended with the net fabric being destroyed (figure 4) for separation forces of ~ 2,600-3,700 cN. No separation between the PLA parts and the included net fabrics was detected.

Figure 3. Test pattern, printed with PLA on a polyester net fabric, after 4,500 Martindale tours.

Figure 4. Test pattern, printed with PLA on polyester net fabric, after test according to standard DIN 53530.
Figure 5. Microscopic pictures of cross sections of PLA printed strips with the textile net included.

To examine the connection between the printed layers and the included textile fabrics, cross sections of the printed PLA strips were prepared and inspected using a digital optical microscope. As figure 5 shows, the black net threads are well included in the white PLA matrix, building a reliable connection between both materials. The cross sections, however, also depict a typical problem of several inexpensive FDM printers: While the very first layer is printed on the hot printing bed, allowing for the first printed lines to fuse together and create one closed layer, the following layers still consist of clearly distinguishable lines whose connections seem to be reduced continually when the printed form becomes higher. This problem is connected with an undesired lateral shift of the layers with respect to their neighbours.

Figure 6. PLA strips with different warp knitted mesh structures as inlays: fishing net, pattern 89/232, by Karl Meyer, produced from 100% polyamide 6 (left panel), and sunscreen net, pattern DEMO 1134, by Karl Meyer, produced from 100% polyester (right panel).
In order to overcome these problems, future experiments will focus on adjusting the printing parameters, such as nozzle temperature, printing bed temperature, printing velocity, but also environment temperature etc., to enhance the layer-layer adhesion as well as the line-line adhesion.

Due to the insufficient mechanical properties of the polyester net used for previous experiments, several other textile fabrics with relatively open structures were tested as possible base layers. Figure 6 shows results of PLA strips, now all with an identical height of 1.5 mm, in which different textile mesh structures are inlayed.

While these textile structures are significantly stronger than the previously used fine polyester net, the connection between PLA strips and textile base materials now depends on the mesh-opening-diameter-to-thickness ratio of the net structures. Structures with large mesh openings (e.g. figure 6, left panel) can be fixed very well in the PLA strips, while thicker materials with smaller mesh openings (e.g. figure 6, right panel) cannot be completely interfused by the molten PLA due to its high viscosity. Thus, the latter is not perfectly surrounded by a PLA matrix, allowing for the PLA to be separated from the textile base layer by relatively low forces. Figure 6 (right panel) shows the results of a test to pull the strips off by hand, while the connection between PLA strips and the open-structure fishing net (figure 6, left panel) could not be destroyed by hand.

4. Conclusion
To combine the tensile strength of common textile fabrics with the creative freedom of printing different 3D forms, composites of different textile mesh structures with PLA printed matrices have been examined due to their mechanical properties. For several textile nets, the connection between both materials, generated by the printed material surrounding the single textile threads, is found to be sufficient for utilization in garments and appears promising for use in technical textiles.

Future tests will concentrate on enhancing the adhesion between the printed lines, with and without textile net structures embedded, by optimizing the printing parameters.

References
[1] Chua C K, Leong K F and Lim C S 2003 Rapid Prototyping: Principles and Applications, 2nd Edition (Singapore: World Scientific Publishing Co. Pte. Ltd.)
[2] Novakova-Marcincinova L 2012 Application of fused deposition modeling technology in 3D printing rapid prototyping area Manuf. and Ind. Eng. 11 35-7
[3] Noorani R 2005 Rapid Prototyping: Principles and Applications (New Jersey: John Wiley & Sons)
[4] Melnikova R, Ehrmann A and Finsterbusch K 2014 3D printing of textile-based structures by Fused Deposition Modelling (FDM) with different polymer materials IOP Conf. Ser.: Mater. Sci. Eng. 62 012018
[5] Richter C, Schmülling S, Ehrmann A and Finsterbusch K 2015 FDM printing of 3D forms with embedded fibrous materials, Proc. Int. Conf. on Design, Manufacturing and Mechatronics(Wuhan), accepted
[6] Passlack B, Ehrmann A and Finsterbusch K 2013 Mellian Textilberichte 94 224