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Sandwiching textiles with FDM-printing

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ABSTRACT

3D printing on textile fabrics has been investigated intensively during the last years. A critical factor is the adhesion between the printed polymer and the textile fabric, limiting the potential areas of application. Especially safety-related applications, e.g. stab-resistant textile/polymer composites, need to show reliable adhesion between both components to serve their purpose. Here we investigate the possibility of sandwiching textiles between 3D-printed layers, produced by fused deposition modeling (FDM). We show that adding nubs to the lower 3D-printed layers stabilizes the inner textile fabric and suggest future constructive improvements to further enhance the textile-polymer connection.

1 Introduction

Originally used for rapid prototyping, 3D printing techniques have increasingly entered into the application areas of rapid manufacturing and rapid tooling [1-3]. Many typical 3D printing polymers, e.g. poly(lactic acid) (PLA) often used for fused deposition modeling (FDM) printing, do not have sufficient mechanical properties for applications in which large forces work on them. This problem is reinforced by the layered production process of common 3D printing techniques. Several research groups are thus investigating potential solutions to improve the mechanical properties of 3D-printed objects [4-7].

One approach is to modify the filament by developing new printable polymers, adding nanoparticles or fibers [8,9]. Thermal post-treatment can also be used to improve the mechanical properties of FDM-printed objects [10,11]. A completely different idea is to form composites from 3D-printed polymers and textile fabrics, combining the rigidity of the first with the tensile strength of the latter and in this way creating objects with new and often favorable mechanical properties.

Several research groups have studied the adhesion between 3D-printed polymers and textile fabrics, mostly for the FDM process [12-14], but recently also for stereolithography (SLA) [15]. Potential adhesion improvement techniques include optimizing the nozzle-fabric distance as most important parameter [16,17], but also modifying nozzle and printing bed temperature [18], chemical pretreatment of the textile fabric [19,20] or thermal post-treatment of the composite [21,22].

Generally, most studies show that building interlocking connections between both parts of the composite by printing “through” the textile fabric is the best way to reach reliable adhesion [23]. This is especially true in case of sandwiches consisting of a textile fabric between an upper and a lower layer of 3D-printed material, where the textile fabrics, yarns or fibers are placed on the lower polymer layer before the upper polymer part is printed [24,25].

Here, we investigate the behavior of FDM printing/textile sandwiches with flat-printed layers compared to a system with small nubs on the lower layer. We show that even such small modifications can stabilize the composite due to improved friction and suggest next constructional improvements for further increased stability of such sandwiches. Such composites could be used, e.g., for stab-resistant garments. Often, such stab-resistant body armor contains textile fabrics fully embedded in resin, making the system very stiff. On the other hand, it is well known that fixing the fibers to the fabric is very important in order to increase the stab-resistance of a protective garment [26,27]. Our recent approach aims at finding a compromise between the fully fixed, rigid composites and completely loose stacks of polymers and fabrics, as the textile fabric is partly fixed to the nubs on the lower layer.

2 Materials and methods

Samples were produced with an FDM printer Anycubic i3 Mega S (Shenzhen, China) with a nozzle diameter of 0.4 mm and a layer height of 0.2 mm, printing subsequent layers in ± 45° orientation. Solid Edge 2020 was used for CAD, Ultimaker Cura 4.6.1 for the printing settings and creating the G-code.

Two different filaments were used: Eryone Silk Silver (PLA) and S Sienoc Orange TPU (thermoplastic polyurethane) with shore hardness 95A. TPU has the advantage of higher flexibility compared to PLA and is thus well suited for many applications in combination with textile fabrics. TPU needs printing at higher temperature and with reduced speed. The printing settings for the filaments are listed in Table 1. Temperatures were chosen at the upper limits of the filaments in order to compensate for the unevenness of the textiles with better flow properties.

Table 1. Printer settings.

Heading	PLA	TPU
Nozzle temperature	210 °C	230 °C
Bed temperature	60 °C	70 °C
Printing speed	50 mm/s	20 mm/s

Two different plain-weave fabrics are used for sandwiching: a cotton fabric with a thickness of 0.33 mm, and an aramid fabric with a thickness of 0.61 mm. These fabrics differ strongly in terms of thickness and bending rigidity and are thus chosen for this proof-of-principle as examples of fabrics with quite different mechanical properties so that potential problems with especially thick and rigid fabrics, as they are often found in the area of technical textiles from high-performance yarns, can be detected.

In this study, the textile fabric is sandwiched between filament layers. First, a layer of the filament is printed on the printing bed. A pause of the print after the first layer height is programmed in the G-code. The next step is to place the textile, which is cut to fit precisely, on the printed layer. To fix the textile, it is glued to the printed layer with a glue stick containing resin and poly(glycoside ether). In order to investigate whether the flat 3D printing or the nubs are capable of keeping the textile in its position with respect to the lower 3D-printed part, only the corners were glued. Generally, full-layer gluing can be considered an alternative if a sufficiently flexible glue is available; however, in this study, tests without an additional layer of glue are performed. Then printing is continued to build a second layer on top of the textile fabric.

As shown in Figure 1, sample dimensions are 102 mm x 52 mm. The upper and lower layers are joined with a 1-mm edge. The layer thickness and the gap for the cotton fabric are 0.2 mm each. The gap size can be varied depending on the thickness of the textile.

One possibility of ensuring that the textile cannot move inside the sandwich is to fix the textile inside the sandwich construction with nubs. These are elevations within the sandwich construction that ensure that the textile is squeezed against the printed material. In order to find the best way of fixing the textile fabric, the shapes, sizes and distances of the nubs are varied. Square and round nubs with a diameter/side length of 0.8 to 1.5 mm and a spacing of 5–17 mm are tested. The nubs for cotton are depicted in Fig. 2a. Due to the low thickness of the cotton fabric, there is no space between nub and top layer. Instead, the cotton fabric is squeezed between nub and top layer.

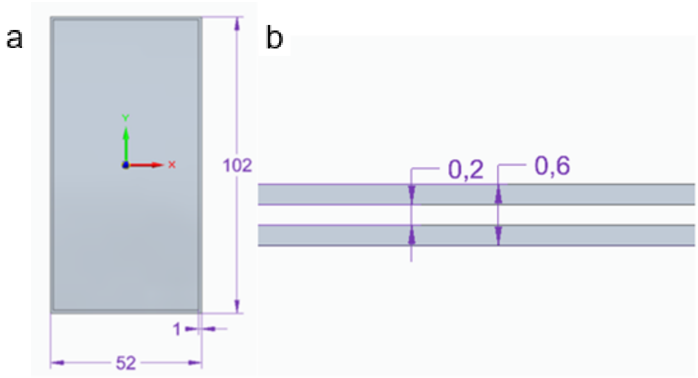

Fig. 1 Sample dimensions: (a) general view; (b) cross-section.

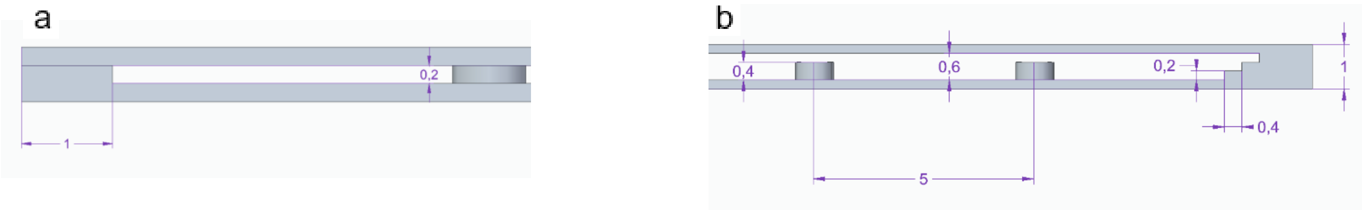

Fig. 2 Embedded nub construction: (a) cotton fabric; (b) aramid fabric.

The construction must be revised for sandwiching the aramid tissue. The gap for the textile is set to 0.6 mm, according to the aramid fabric thickness. The nubs have a diameter of 0.8 mm and a height of 0.4 mm. In this case, due to the thickness of the textile, a gap of 0.2 mm for the aramid fabric is left between the nubs and the top layer. In addition, the end of the construction is adjusted because the thickness and unevenness of the fabric can cause problems when connecting the top and bottom layers. Therefore, the edge has steps to allow for a better transition. The dimensions can be found in Figure 2b.

Qualitative analysis of the results was performed by photographic images and microscopic images, taken by a digital microscope Camcolms2 (Velleman, Gavere, Belgium).

3 Results and discussion

The result of a print without nubs is visible in Figure 3. Sandwiching ensures that the textile is embedded in the 3D print. The cross-section (Fig. 3b), however, shows that the textile fabric is not firmly fixed between the printed layers, as it is not oriented in parallel to the top and bottom layers. Instead, apparently its height between both polymeric layers varies. This allows the textile to move inside the sandwich.

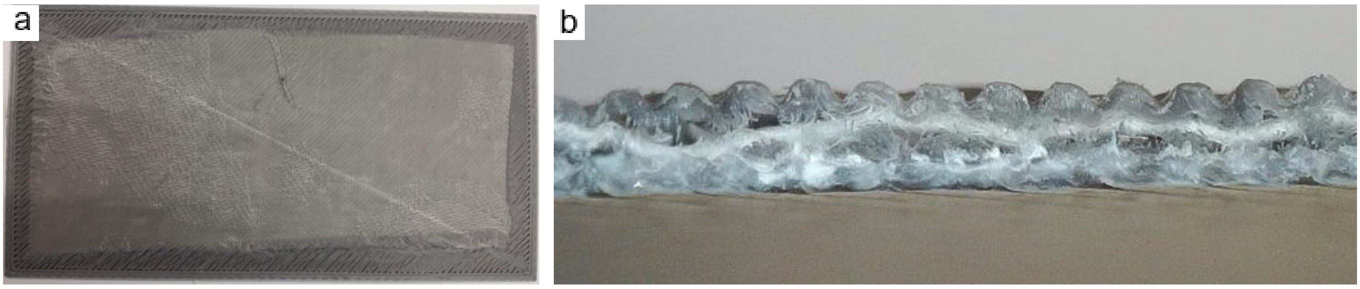

Fig. 3 PLA sample: (a) entire sample; (b) cross-section.

Next, trying to overcome this problem, samples with nubs are printed. It turns out that small nubs with a small spacing are best suited for cotton fabrics. The shape does not play a noticeable role in this size range. In Figures 4a and 4b, the nubs are visible before the textile has been placed on them and after the second layer is printed. The textile is visible in the areas of the nubs because the upper print layer is tapered. This indicates that the textile was firmly pressed inside the print so that the nubs kept it in position. This is also visible in the cross-section of a nub (Fig. 4d). The results of the PLA and TPU print are both promising; however, the results of the TPU sandwich (Fig. 4c,d), which is usually more difficult to print, is better than that of PLA in terms of flexibility and thus usability for a potential stab-resistant garment.

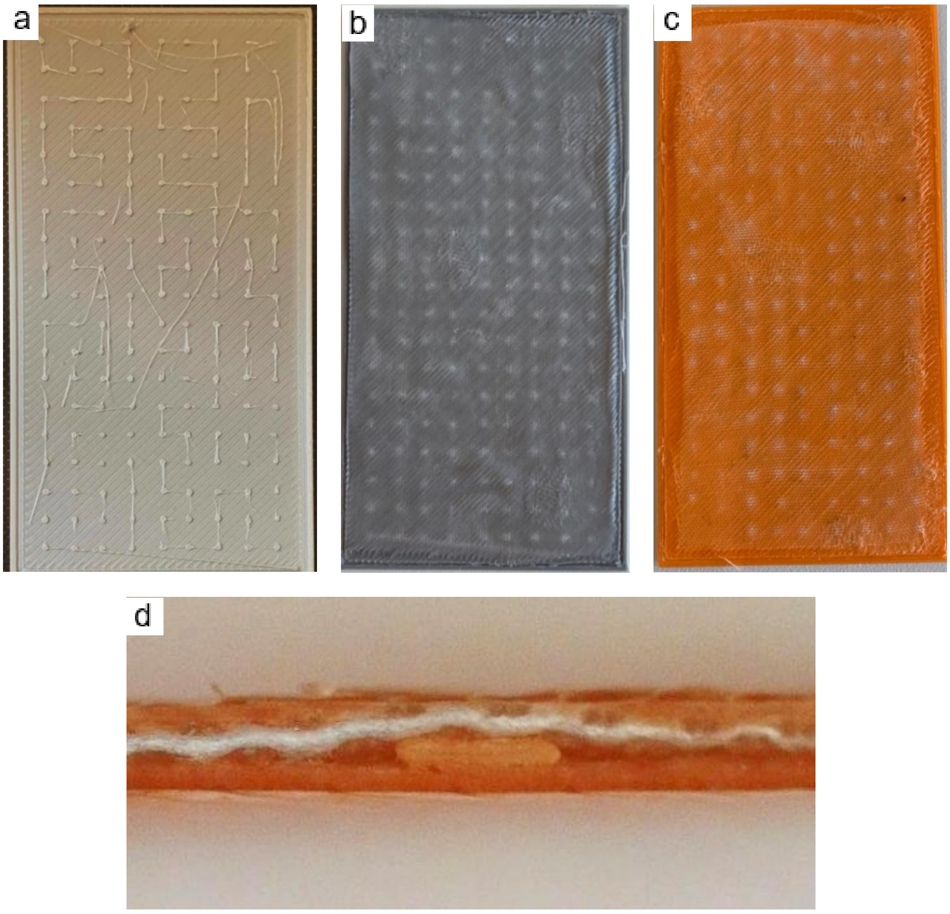

Figure 4. Samples with nubs: (a) first two layers; (b) PLA/cotton; (c) TPU/cotton; (d) TPU/cotton cross section.

Figure 5 shows the results of a sample with an aramid fabric. Due to the thickness and unevenness of the fabric, printing is more difficult than on the cotton textile. Even if the textile is cut out precisely, the aramid fabric causes the two print layers to not be joined properly, as can be seen in Fig. 5c. Fig. 5d shows the print with steps at the edge. Here it can be also seen that the upper layer, as in the previous test, is not connected to the intended edge due to the deformations of the textile. However, the upper layer is connected to the first step and thus ensures that the sandwich construction is stable.

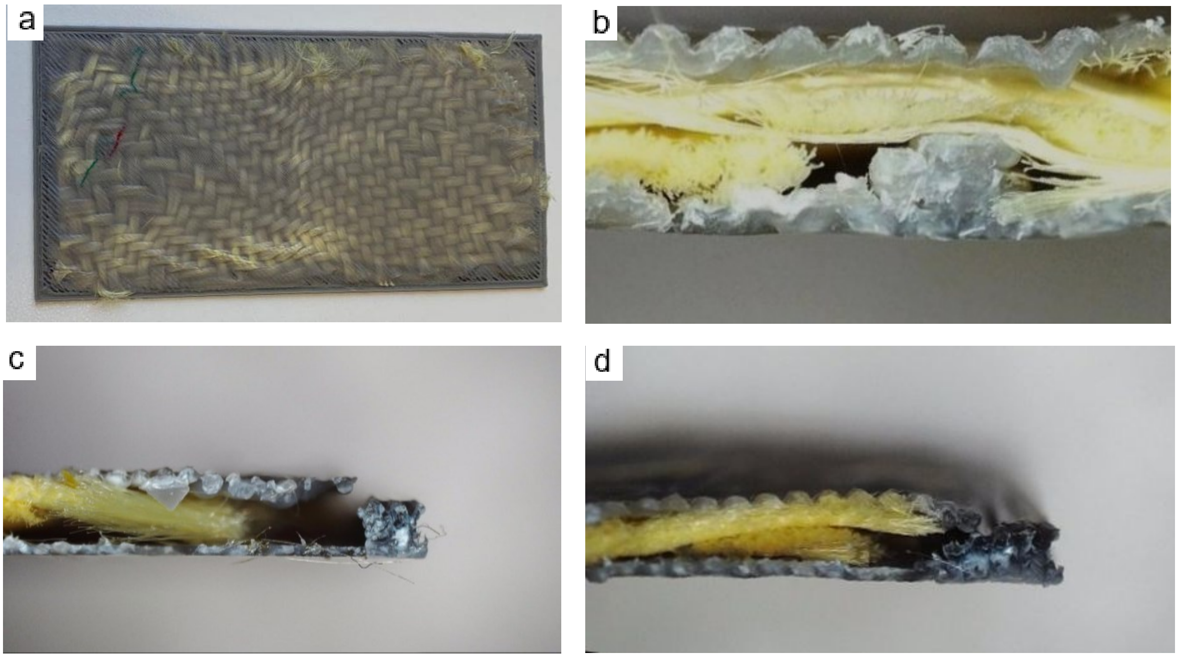

Figure 5. Samples with aramid/PLA: (a) entire sample; (b) cross-section with nub; (c) cross-section with straight edge; (d) cross-section with steps at the edge.

4 Conclusions and outlook

Different textiles, filaments and methods for sandwiching textiles within 3D printing were tested. It turned out that especially thin and even textiles are very well suited for this process. Surprisingly, TPU provides better results than PLA, although it is usually less easily printable. The nubs that were implemented ensured that the textile was very firmly fixed within the print and showed no movement during repeated bending tests. Even though it is more difficult to print with aramid fabrics due to their unevenness and thickness, this can also be achieved with suitable adjustments.

As a next step, we plan to develop more sophisticated maze-like structures for the lower as well as the upper layer to increase the friction between different sandwiched textile fabrics and the outer FDM-printed layers. In this way, reliable sandwich structures could be produced, which can be used, e.g., to add higher rigidity or even stab-resistant properties to defined areas of textile fabrics or garments.

With regard to measurement, it is necessary to define a method to quantify the adhesion of the textile fabric inside the sandwich structure, e.g. by leaving one edge open and measuring the necessary force to pull the fabric out of the sandwich, as it was previously done for tests of the adhesion of carbon yarns in 3D-printed sandwiches [21].

Author Contributions

S.-M. Özev: conceptualization, methodology, investigation, visualization, writing – original draft preparation; A. Ehrmann: supervision, writing – original draft preparation.

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Conflicts of Interest

The authors declare no conflict of interest.

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