Advance Research in Textile Engineering

Open Access
Austin Publishing Group

Special Article: Textile Printing

3D Dispensing of Waterborne Polyurethane on Textile

Maximilian Scherf[1]; Agnes Psikuta[2]; Julia Hemetzberger[1]; Daniel Wittwer[1]; Michael Wieser[3]; Viktor Weichselbaumer[3]; Thomas Schmidt[4*]; Leo Schranzhofer[1]; Julia Kastner[1]

[1]Functional Surfaces and Nanostructures, Profactor GmbH, 4407 Steyr-Gleink, Austria

[2]Empa Swiss Federal Laboratories for Material Technology and Science, 9014 St. Gallen, Switzerland

[3]yokai-studios GmbH, 4040 Linz, Austria

[4]Key Lab for Sport Shoes Upper Materials of Fujian Province, Fujian Huafeng New Matierals Co., Ltd., Putian, Fuijian, China

***Corresponding author:** **Thomas Schmidt**

Key Lab for Sport Shoes Upper Materials of Fujian Province, Fujian Huafeng New Matierals Co., Ltd., Putian, Fuijian, China.

Tel: +86 136 1593 4792

Email: thomas.schmidt@huafeng-cn.com

Received: October 16, 2023

Accepted: November 15, 2023

Published: November 22, 2023

Abstract

The paper presents an investigation into the digital printing of waterborne Thermoplastic Polyurethane (TPU) ink using advanced dispensing technology. The study focuses on assessing the ink's adhesion properties on four distinct textile substrates and explores the challenges and possibilities of applying this ink to curved textile geometries.

The research employed cutting-edge digital printing equipment to precisely dispense waterborne HAPTIC® ink onto polyester, cotton, and viscose textile. Adhesion testing was conducted to evaluate the ink's performance on each substrate, considering factors such as elongation at maximal force. The results provide valuable insights into the suitability of waterborne TPU ink for various textile types, offering guidance for potential applications in the textile industry.

Furthermore, this study delves into the intricate process of digitally dispensing waterborne TPU ink onto curved textile surfaces. The investigation examines the challenges posed by irregular textile geometries, including curvature, elasticity, and stretchability, and explores innovative solutions for achieving consistent and high-quality printing results on such surfaces.

The findings of this research contribute to the advancement of digital printing technology in the textile industry, offering a deeper understanding of ink-substrate interactions and paving the way for new possibilities in textile design, customization, and manufacturing.

Keywords: Waterborne polyurethane dispersion; Dispensing; Additive manufacturing; Textiles

Introduction

Printing on textiles for decorative purposes was already used in ancient times. Several techniques have been used, changed and evolved with times. Nowadays screen printing is the most used technology in the textile printing industry. More than 90% of all printed textiles around the world are printed by screen printing processes including flat-bad, rotary and table screen printing where a flat or cylindrical screen is used to apply ink or paste on the fabric [1]. However, screen printing is a non-ecological way of using resources and is limited to flat substrates. Additionally, in the textile industry digital deposition techniques receive more and more attention due to reduction of waste, flexible production and freedom of design [2]. Methods for digital deposition include dispensing [3,4], valve-based inkjet [5], piezoelectric-based inkjet [6-8] and extrusion [9-11] or polyjet [11,12] based 3D printing. While 3D printing is very often connected to extrusion-based 3D printing (also known as fused filament fabrication, FFF), there are several methods to create to create structures onto textiles or even stand alone garments [13-15].

Polyurethane (PU) is one of the most common materials in the textile industry used for creation of protective and haptic structures [16-18]. Huafeng developed the HAPTIC® ink for screen printing for modifying textile surfaces in visual appearance, functional reinforcement and any haptic effects. HAPTIC® is a fully water-based PUD 2K system with isocyanate hardener. To be able to use this material in a digital process, in this work, the dispensing technology was used to deposit this material [4]. Additionally, the dispensing technique can combine mixing and material transport in a single process in a two-component (2K) dispensing device.

Adhesion of the printed or dispensed HAPTIC® material to the textiles is very important for most applications. Standard tests are bending or bally-flex tests [4]. The adhesion or bonding of the ink to the specific textile substrate is usually tested by gluing a strip of plastic material strongly onto the surface of the ink and then pulling the plastic stripe and the textile materials apart by a tensile testing machine. In most cases the ink will

Citation: Scherf M, Psikuta A, Hemetzberger J, Wittwer D, Wieser M, et al. 3D Dispensing of Waterborne Polyurethane on Textile. Adv Res Text Eng. 2023; 8(3): 1089.

separate from the textile at certain pulling strength usually in a range of 25–50 N/cm. However, in some cases cohesion breakage or breakage of the textile can also be observed showing that the bonding of the ink is not the limiting factor for these products. The material properties of the pure HAPTIC® ink also play a key role and elongation of the PU resins is another important performance factor of the overall system. In most applications the HAPTIC® coatings are applied for decorative appearance and for improving abrasion resistance in certain areas as shown in Figure 1. Printing around half cylindrical sock-like 3D knitted textiles can provide an opportunity to reinforce the textile sock in the heel area of a shoe upper and providing better support to the fit of the shoe in the heel area.

For manufacturing those haptic structures not only on flat, but on already assembled or 3D knitted textile objects, robot-assisted printing plays a key role. In this work, a collaborative robot was used for the dispensing process on 3D objects. Collaborative robots are industrial robots but have the advantage that they work together with humans and don't have to be separated from them in the production process by protective arrangements. Hence, a significant increase in design freedom can be achieved, which lays the pathway for an individual tailored and on-demand textile manufacturing process.

This work investigates a new way of testing the tensile strength of dispensed, highly thixotropic high solid waterborne PU-based inks material on natural- and synthetic fiber-based textiles. Furthermore, the transfer from flat dispensing to robot-assisted digital printing on curved surfaces such as a half-cylinder was developed.

Experimental Section

Materials and Preparation of Dispensing Paste

The four tested fabrics were a black gabardine textile (100% viscose, 152 g/m²), a black Softshell (100% polyester, 315 g/m²), knitted fleece (100% polyester, 260 g/m²) in blue and knitted jacquard (100% cotton, 200 g/m²) in grey-white.

The two-component (2K) HAPTIC® ink from Fujian Huafeng New Materials Co., Ltd was used for dispening onto textiles. It contains a waterborne thermoplastic PUpolyurethan dispersion (component 1), which is mixed with 4% of the corresponding hardener Desmodur 3900 (Hexamethylene-1,6-diisocyanate homopolymer from Covestro) (component 2). The viscosity of the HAPTIC® ink is 62.12 mPas, which was determined at a constant angular frequency of 7.5 RPM with an Anton Paar MCR 302 Rheometer [4].

Figure 1: HAPTC® coating on shoes applied via screen printing.

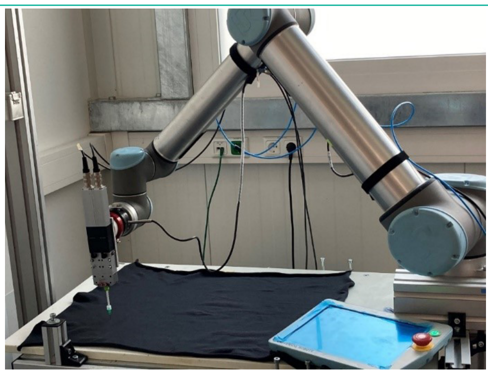


Figure 2: Robot-assisted dispensing setup for dispensing the waterborne HAPTIC© ink formulation on a flat gabardine textile.

Dispensing Process

The 2K Vipro-Head 3/3 dispensing unit from ViscoTec Pumpen- u. Dosiertechnik GmbH (Toeging am Inn, Germany) was used to dispense the high viscose waterborne HAPTIC® ink formulation onto four different textile substrates. The head was mounted on a robot (UniversalRobot-UR10). Figure 2 shows the UR-10 robot with the integrated 2K Vipro-Head 3/3 for dispensing 3-dimensional structures on the textile. This allowed mixing the ink with the corresponding hardener right before the deposition. By operating the 2K dispensing system with a pressurized cartridge a continuous dispensing of the high viscose HAPTIC® ink is ensured. Both materials are stored in two separate cartridges and conveyed towards the mixing tube, in which the two materials are homogeneously mixed with a predefined mixing ratio of 25:1.

Characterization and Measurements

The tensile tests of the fabric junction with dispensed connection was carried out according to ISO13935:2014 to determine the maximum force to textile or ink rapture using the strip method using Zwick tensile tester (Zwick Roell, Germany) (Figure 3a). The samples were prepared based on four selected fabrics in form of stripes 40mm x 170mm (longer edge along fabric grain or warp direction) with the dispensed material gluing together cut fabric stripe (Figure 3b). Five samples per fabric and dispensed designs were tested and the mean ±Standard deviation reported. Each sample was clamped in the sample holder with the initial distance of 70mm without excreting any tension on the samples as well as avoiding any loose sample hanging. The samples were pulled apart at the speed of 100mm/min until maximum force was reached and the dispensed ink or fabric ruptured. In addition to the maximal force causing sample rupture the additional parameters describing elongation at maximum force. All experiments were done in ambient conditions of 23°C and relative humidity of 50% with samples being acclimatized in the same conditions for at least 24h.

For height measurements of the dispensed lines on the textile, a Veeco Dektak 150 profilometer was used. The detailed images of the dispensed HAPTIC® on the on 3D printed objects spanned gabardine textile were taken with a Keyence VHX-5000 light microscop.

Results and Discussion

Dispensing Experiments for Tensile Testing

For testing the adhesion and strength of the dispensed HAPTIC® ink on different textiles, two pieces of the same fabric were slightly overlapped and dispensed across the interface. A tensile test pulling the two pieces apart was then carried out to determine the tensile strength of the dispensed ink on the fabric.

Two different designs were tested: a straight line along the interface and grain direction and a zig-zag line across the cut with a 45° angle between the dispensing propagation and the straight of grain as shown in Figure 4a).

Table 1: Dispensing parameters on the textiles with a 6mm/s extrusion speed.

Sample type	Softshell	Gabardine	Knitted fleece	Knitted Jaquard
PU-Line	400 mm/min CNC speed in x direction 0,25 mm nozzle diameter 0,5 bar	400 mm/min CNC speed in X direction 0,41 mm 0,5 bar	400 mm/min CNC speed in X direction 0,25 mm 0,5 bar	400 mm/min CNC speed in X direction 0,25 mm 0,5 bar
PU-Zig-zag	1000 mm/min CNC speed in x direction 0,41 mm nozzle diameter 0,5 bar	1000 mm/min CNC speed in x direction 0,41 mm 0,5 bar	1000 mm/min CNC speed in x direction 0,41 mm 0,5 bar	2000 mm/min CNC speed in x direction 0,41 mm 0,5 bar

Table 1 shows the used parameters for the dispensing.

The resulting surface profile possesses a layer thickness of an average layer thickness of 165 µm with a penetration depth of 197.2 µm. Due to the rather thin layer thickness of the deposited line, the surface roughness is still visible on the surface of the coating.

Tensile Testing of dispensed PU on Textiles

Adhesion to the textile and flexibility of the dispensed HAPTIC® material itself is very important. For the validation, tensile testing was done. The goal was not only to observe adhesion, which was already proofed on polyester mesh [4].

Figure 5 shows the maximum applied force, elongation, and relative elongation at the point of sample rupture for all four investigated textile samples.

Generally, the maximum applied force until rapture is much higher of the uncut plain textiles, however, it can be seen, that the dispensed line reacts elastic to the force applied on softshell, gabardine and knit fleece. Especially on softshell the HAPTIC® line can be elongated when pulled along the line and the final rapture is a mixture of material and adhesion to textile.

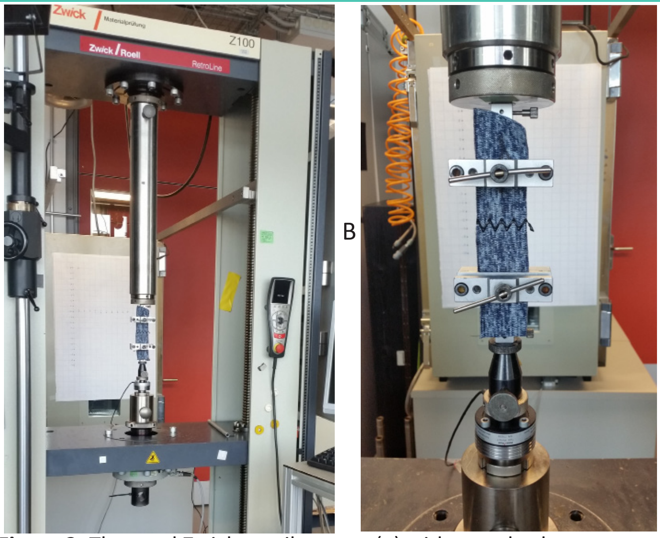
It is observed that, the non-elastic fabrics (gabardine and softshell) elongate less until the point of tearing, hence they required a larger force to tear than elastic fabrics (knitted jacquard and fleece). It seems that elastic fabrics were pulled out from the cut area yarn by yarn during elongation for knit jacquard. Therefore, the force needed to finally delaminate the dispended PU is much smaller compared to elastic fabrics. For application of reinforcement on garment or shoes, this material failure seems to be very small, the required elongation could possibly protect the PU coating from destruction since it is often larger than the elongation exerted by the body during posture change (provided that the garment or sock is not already tightly fitting with negative ease allowance).

As the HAPTIC® was designed for adhesion on polyester fabric, the tensile showed good results especially to the knitted fleece, where the dispensed ink also can penetrate into the textile. On these polyester textiles, the break point for the zig-zag lines is caused by a fracture of the HAPTIC® ink itself (22.92 N for softshell fabric and 48.99 N for knit fleece). And the dispensed line is stretched along the line with 100% (Figure 4b).

The gabardine fabric started to fray at the cut edge and disintegrated very fast due to its relatively loosely woven structure, therefore no result could be derived for adhesion to viscose. The jacquard fabric showed a high degree of elongation with a poorer adhesion compared to the other tested fabrics, and with the interface adhesion limit of 7.12 N and 12.11 N for the zig-zag and continuous dispensed line, respectively.

In summary, when it comes to adhesive properties, polyester and cotton exhibit good adhesion, while viscose tends to perform poorly. Additionally, adhesion is generally better on knit fabrics, as exemplified by materials like Softshell and knitted Fleece.

A



B

Figure 3: The used Zwick tensile tester (a) with sample clamp holder (b).

a

b

c

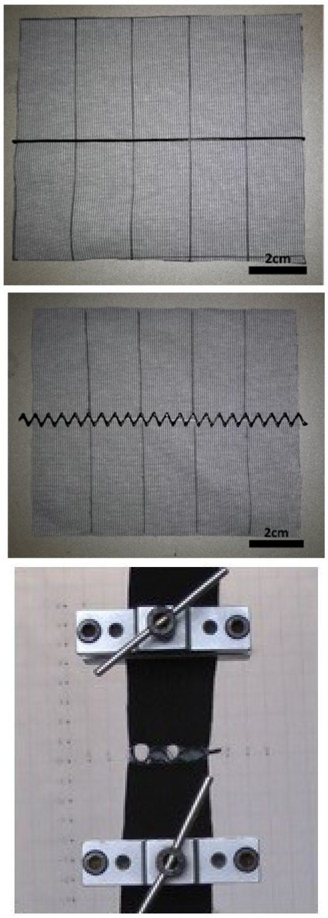


Figure 4: a) Dispensed lines on knitted jacquard, straight and zig-zag; b) Tensile test of the garbadine textile with dispensing PU line at the moment of material failure.

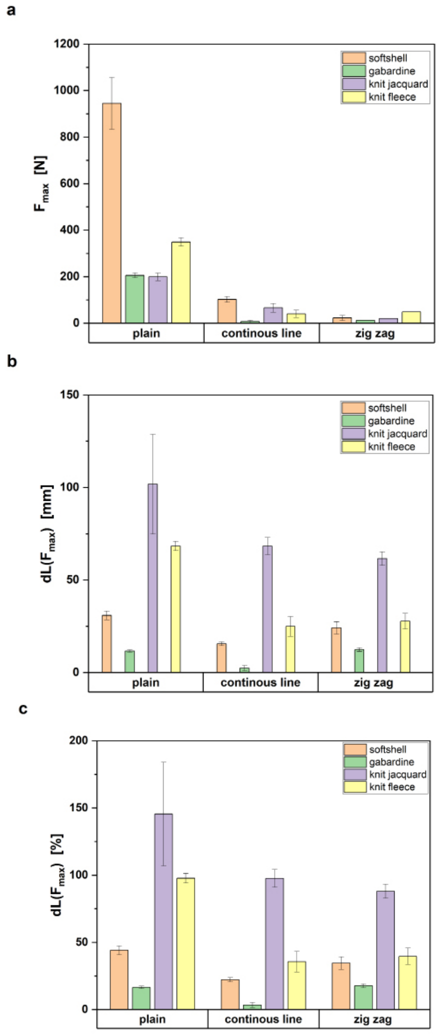


Figure 5: a) Maximum force, b) elongation, and c) relative elongation at the point of sample rupture for softshell, gabardine, knit jacquard, and knit fleece fabric.

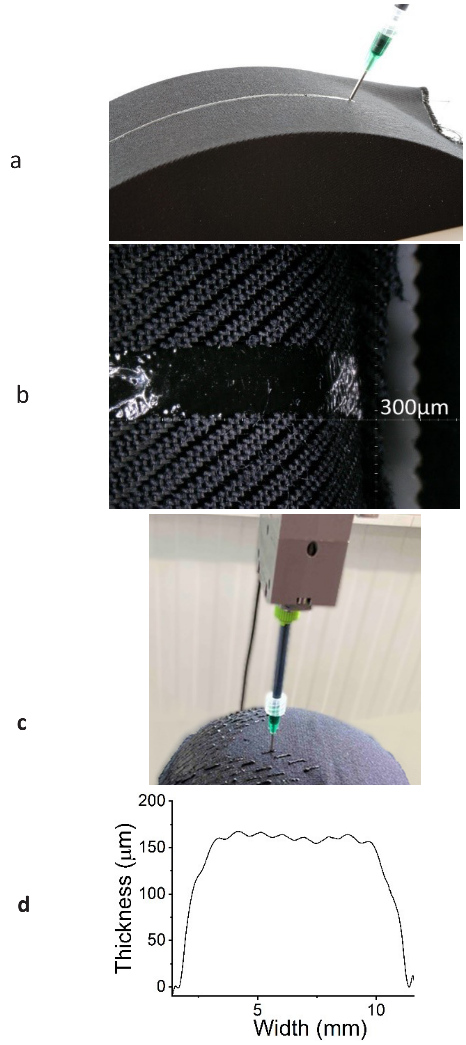


Figure 6: a) Robot-assisted dispensing process of a line on a elliptic curved gabardine textile using the Vipro head dispensing unit integrated on a UR 10 robot; b) microscopic view of the dispensed HAPTIC® ink on curved surfaces. c) Robot-assisted dispensing of TPU test structures on spherical knitted fleece fabric with its shape retaining behavior profilometry measurement of dispensed HAPTIC® onto gabardine textile with an average layer thickness of 165 µm (d).

Robot-Assisted Dispensing on Textile

The following section presents the developed process, which was required to dispense the HAPTIC® PU ink onto curved textiles geometries.

For 3D dispensing a universal robot (UR10) was used to dispense on the gabardine textile assembled on an FDM 3D printed half cylinder and ellipsoids. The robot-assisted dispensing was performed by integration of the 2K Vipro-Head 3/3 dispensing unit onto a UR10 robot. For achieving both, a fine enough resolution (sharp pattern edge) and guarantying enough material flow (continuously dispensing line) process parameters such as printing speed, extrusion rate, height off-set between textile and dispensing tip were tailored for 0.41 mm dispensing tips.

Especially, ensuring a constant offset between textile and dispensing is of utmost important in terms of printing quality. The offset was monitored and adapted by placing a thin PET foil on top of the fabric and performing a test run. After finding the suitable dispensing parameters the dispensing tip offset was reduced by the thickness of the foil.

In order to avoid unwanted excess material deposition at the end and at the beginning of the dispensing process, the retraction parameter and applied pressure were tailored to -0.2 mm/s and 4 mm/s, respectively. The textile was attached to the UR10 printing table via double-sided scotch tape, which ensures a wrinkle-free flat fabric for subsequent dispensing. Figure 6a shows the dispensed path of a single line on the FDM printed half cylinder. After the promising results from the adhesion and outstanding printing quality the high viscous waterborne HAPTIC® ink on was dispensed onto a half cylinder and ellipsoid, due to its high viscous nature the HAPTIC® ink possesses a shape retaining behavior on an incline plane up to 60° depending on the layer thickness.

Robotic path planning plays a pivotal role in ensuring precise and efficient dispensing of waterborne polyurethane ink onto textiles. Because of the diverse nature of each textile surface, with variations in texture, tension, and thickness, robotic path planning must account for these variations to ensure consistent ink deposition. The path planning process was adapted from Schmidt et al [4]. Figure 6b shows the detailed microscopic image of the single layer dispensed HAPTIC® ink on gabardine textile. Because of its thin layer thickness of 143.3 microns (see Figure 6d) the textile structure is imprinted onto the dispensed line. This imprint can be overcome by dispensing sub sequential layers on top of the first sealing layer, depending on the final application and specifications requested. It is further observed that the dispensed single layer doesn't compromise the flexibility and its wear comfort of the nature gabardine textile. Further it becomes evident that dispensing of sharp defined lines on curved geometry such as the half a half can be achieved using robot-assisted dispensing technique. Figure 6c shows a 3 layers thick TPU test structure on ellipsoidal surface arranged knitted fleece. Due to multiple layer printing, the height thickness can be tuned to 165 µm to retain its shape for heel protection as discussed in the introduction.

Conclusion

A digital dispensing process for applying the polyurethane HAPTIC® material on textile was developed and the adhesion and strength of the dispensed material was tested by tensile tests. Adhesion on knitted polyester (knit fleece) was stronger than the HAPTIC® ink material itself and therefore a maximal force of 48.99 N with an maximal elongation of 27.72 mm was measured for the ink material.

Then 3D printing was established by using a collaborative robot to move the dispensing head over an ellipsoidal assembled textile. One of the biggest challenges when dispensing high-viscose materials, such as the waterborne HAPTIC® ink formulation, is to ensure a constant height offset between dispensing tip and the textile substrate. Although the used method to counter the height offset yielded quite satisfactory printing results in terms of homogeneity, layer thickness and sharp edges, it would be highly beneficial to standardize the monitoring process. Especially the possibility of scanning the surface profile prior to printing with in integrated camera on the robot would be very interesting and should be further investigated.

The integration of robotics in textile printing not only enhances production efficiency but also reduces material waste and environmental impact, making it a sustainable and economically viable choice for modern manufacturing.

Robotic path planning is a critical component of dispensing waterborne polyurethane ink onto textiles. It enables precise and efficient printing, reduces material waste, and supports sustainable textile manufacturing. Advances in path planning algorithms and the integration of machine learning will continue to drive innovation in this field, making it an indispensable part of modern textile production.

Author Statements

Acknowledgment

The research leading to these results has received funding from the Österreichische Forschungsförderungsgesellschaft (FFG, Beyond Europe program) for the project d-PU 874150 and European Commission under Grant number 825647 (ReFREAM).

References

1. Ujiie H. Fabric finishing. [Verfügbar unter]. In: Elsevier; 2015. Textiles and Fashion [zitiert Feb 26 2017]. Available from: http://linkinghub.elsevier.com/retrieve/pii/B9781845699314000209. S 507–29.

2. Tyler DJ. Textile digital printing technologies. Text Prog. Verfügbar unter. 2020; 8.

3. Li B, Li D, Wang J. Copper deposition on textiles via an automated dispensing process for flexible microstrip antennas. Text Res J. November 2014; 84: 2026-35.

4. Schmidt TW, Scherf M, Wittwer D, Schumann P, Guillén E, Kastner J. HAPTIC digital 3D printing on textile surfaces for high-volume footwear manufacturing. Mater Today Proc. 2023; 8.

5. ZIMMER AUSTRIA [internet]. Zimmer Austria. Verfügbar unter; 2016 [zitiert Mai 8 2023]. Available from: https://www.zimmer-austria.com/en/home.

6. Kastner J, Faury T, Außerhuber HM, Obermüller T, Leichtfried H, Haslinger MJ, et al. Silver-based reactive ink for inkjet-printing of conductive lines on textiles. Microelectron Eng. 2017; 176: 84-8.

7. Wang X, Zhang M, Zhang L, Xu J, Xiao X, Zhang X. Inkjet-printed flexible sensors: from function materials, manufacture process, and applications perspective. Mater Today Commun. 2022; 31: 103263.

8. Yeo Y, Shin Y. Inkjet printing of textiles using biodegradable natural dyes. Fibers Polym. 2023; 3: 1695-705.

9. Hashemi Sanatgar R, Campagne C, Nierstrasz V. Investigation of the adhesion properties of direct 3D printing of polymers and nanocomposites on textiles: effect of FDM printing process parameters. Appl Surf Sci. 2017; 403: 551-63.

10. Eutionnat-Diffo PA, Chen Y, Guan J, Cayla A, Campagne C, Zeng X. a. Stress, strain and deformation of poly-lactic acid filament deposited onto polyethylene terephthalate woven fabric through 3D printing process. Sci Rep. 2019; 9: 14333.

11. Xiao YQ, Kan CW. Review on development and application of 3D-printing technology in textile and fashion design. Coatings. 2022; 12: 267.

12. Polyjet. Technology. 2016. StrataSys. PolyJet technology. [Verfügbar unter]. Available from: http://www.stratasys.com/3d-printers/technologies/polyjet-technology.

13. Sabantina L, Kinzel F, Ehrmann A, Finsterbusch K. Combining 3D printed forms with textile structures - mechanical and geometrical properties of multi-material systems. IOP Conf Ser Mater Sci Eng. 2015; 87: 012005.

14. Sitotaw DB, Ahrendt D, Kyosev Y, Kabish AK. Additive manufacturing and textiles—state-of-the-art. Appl Sci. 2020; 10: 5033.

15. Keefe EM, Thomas JA, Buller GA, Banks CE. Textile additive manufacturing: an overview. Dinh Duc N, Herausgeber. Cogent Eng. 2022; 9: 2048439.

16. Engels HW, Pirkl HG, Albers R, Albach RW, Krause J, Hoffmann A, et al. Polyurethanes: versatile materials and sustainable problem solvers for today’s challenges. Angew Chem Int Ed Engl 2. 2013; 52: 9422-41.

17. Patti A, Costa F, Perrotti M, Barbarino D, Acierno D. Polyurethane impregnation for improving the mechanical and the water resistance of polypropylene-based textiles. Materials (Basel). Januar 2021; 14: 1951.

18. Nugroho WT, Dong Y, Pramanik A, Leng J, Ramakrishna S. Smart polyurethane composites for 3D or 4D printing: general-purpose use, sustainability and shape memory effect. Compos B Eng. 2021; 223: 109104.