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Printing and Adhesion of 3D Objects on Textile Substrates
Tisk in adhezija 3-D struktur na tekstilne podlage

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Abstract
3D printing onto textile substrates was performed to create 3D objects in connection with textile materials. The adhesion force between the realised 3D-printed objects and the textile surface was determined. The aim of the research was to evaluate the best application parameters to realise high adhesion of the printed object, and to gain a stable product which can withstand washing and abrasive processes. Two different types of testing arrangements were performed. Several parameters were evaluated. These parameters can be categorised into three types, i.e. textile substrate related, printing process related and according to the type of polymer filament used for printing. Apart from other parameters, the temperature of the printing head, which can be set as the temperature of the applied polymer filament, is especially important.
Keywords: 3D printing, textile, functionalisation, cotton, adhesion, additive manufacturing

Izvleček
3-D tisk se uporablja za izdelavo 3-D struktur na tekstilnih materialih. Določena je bila adhezijska sila med izvedenimi 3-D natisnjenimi strukturami in tekstilno površino. Cilj je bil ovrednotiti najpomembnejše uporabne parametre za doseganje visokega oprijema natisnjene 3-D strukture, da se doseže končna stabilna 3-D oblika, ki lahko prenese pranje in drgnjenje. Uporabljena sta bila dva različna postopka preizkušanja za oceno parametrov. Ti so bili opredeljeni glede na povezavo s tekstilnim substratom, povezavo s postopkom tiskanja oziroma glede na vrsto polimernega filamenta, uporabljenega za tisk. Med preostalimi parametri je še zlasti pomembna nastavitev temperature tiskalne glave, ki določa temperaturo polimernega filamenta na mestu tiskanja.
Ključne besede: 3-D tisk, tekstil, funkcionalizacija, bombaž, adhezija, aditivna proizvodnja

1 Introduction

3D-printing technology offers a great chance to functionalise textiles in the third dimension and opens new dimensions in textile and fashion design [1, 2]. Possible applications can be printed buttons, locking systems and protective textile materials [3]. Furthermore, items for identification and branding can be realised with 3D printing [2]. This could also be called 3D branding. Finally, the elements for decoration and design can be produced by 3D printing onto textile fabrics. An interesting application in this field also includes optical elements from 3D-printed polymer objects [4]. Additionally to the aimed properties, usually for textile applications, high fastness properties are demanded. Therefore, it is necessary to reach good abrasion and washing fastness of the printed material [2, 5, 6]. In certain cases, lightfastness should play an important role as well. To reach high fastness properties, the printed 3D object has to be permanently fixed onto the textile fabric. The actual presentation describes several investigations on a variation of parameters which are able to optimise the fixation of 3D printed objects on textiles. To determine the adhesion of 3D prints onto textiles, several testing procedures were used and optimised. The presented data are based on two master theses and two bachelor theses, which have been performed on this topic. The investigated parameters can be categorised into textile substrate related, printing process related and according to the used type of 3D filament. The investigated textile parameters were the type of textile substrate (e.g. cotton, nylon or polyester), chemical pretreatment of the substrate (e.g. washing or precursor), textile roughness and plasma treatment. The parameters related to the printing process were printing speed, temperature and z-distance. Figure 1 supports a schematic overview of categories and subcategories of parameters influencing the 3D-printing result. Additionally to the shown categories, other influencing parameters are possible as well, especially the chemical and thermal aftertreatment procedures can be used to adjust the adhesion of the 3D-printed object on the textile substrate [7]. This can be summarised by the term final fixation of the 3D print. Finally, it can be concluded that the presented technique has the potential to lead to new functional materials.

2 3D printing processes and textiles

2.1 General statement on 3D-printing processes

3D printing is one type of additive manufacturing. It is proposed that 3D-printing processes belong to the most important techniques, which will influence the future of humankind [8]. It should be considered that 3D-printing devices are available in industrial scale but also in scales that are achievable for single consumers at a low-cost level [9]. Through this high availability, a democratic aspect as a kind of individual production process could be possible in future, which would be completely different from traditional industrial mass production, which is related to the ownership of large production plants.

2.2 3D printing on textile substrates

3D printing is mostly used to create new and individual three-dimensional objects. However, it is also possible to combine these new objects with a substrate on which the printing process is performed. If the substrate and the 3D object are not separated after the printing process, a combined object is realised. This combined object can be understood as

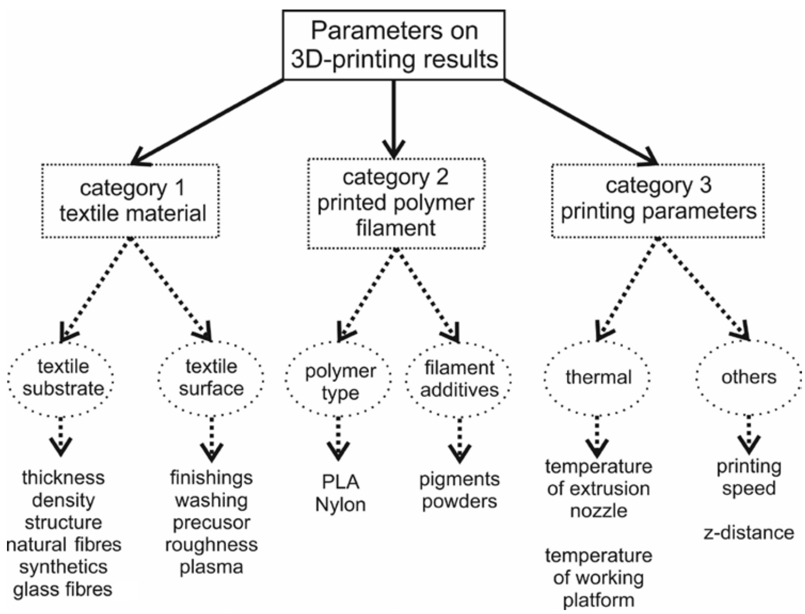


Figure 1: Schematic overview of categories and subcategories for parameters influencing result of 3D printing on textile substrates

a substrate which is functionalised by the attached 3D object. The modification and functionalisation of textile substrates with printing processes is a well-known technique. However, the functionalisation of textiles with 3D printing has been a topic of research in recent years [2, 10, 11]. 3D-printing technology also offers the chance to functionalise textiles in the third dimension. A schematic image of a printing process is presented in Figure 2. Possible applications can be printed buttons and locking systems, which are related to traditional items. Moreover, items for mechanical protection can be printed on textiles, e.g. for realisation of protective sport clothing. Finally, elements for decorative and design purposes can be realised with 3D printing on textiles, which is especially attractive due to the possible high personalisation of this method [2, 12–15]. Hence, customers' demands can be covered with a unique personalised textile product.

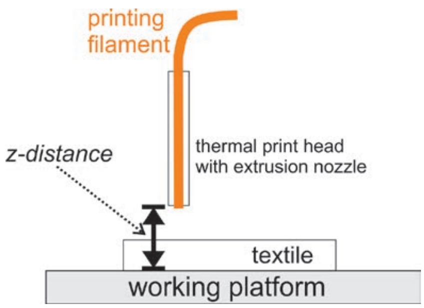


Figure 2: Schematic image of 3D-printing process on textile substrate, z-distance between thermal print head with extrusion nozzle and working platform being specially indicated

2.3 Demands for textile functionalisation with 3D printing

The functionalisation of textile materials with printing and also with 3D printing is possible. Apart from the application of the new function to textiles, there is a main demand for such an application. For textile applications, it is absolutely necessary that the added functional objects are stable on textile substrates and cannot be removed by rubbing or washing procedures. In fact, the washing fastness is one of the main properties that needs to be fulfilled by textile materials. The fastness against rubbing and washing is mainly related to the adhesion of the 3D-printed object on the textile substrate. Strong adhesion supports good fastness against washing and rubbing [13–16]. With this background, the aim of the actual presentation was an overview of adhesion of 3D-printed objects on textile surfaces. Focus was put on two aspects. Firstly, that possible testing arrangements are presented and secondly, that the material and process parameters influencing adhesion are presented and discussed.

3 Testing arrangements

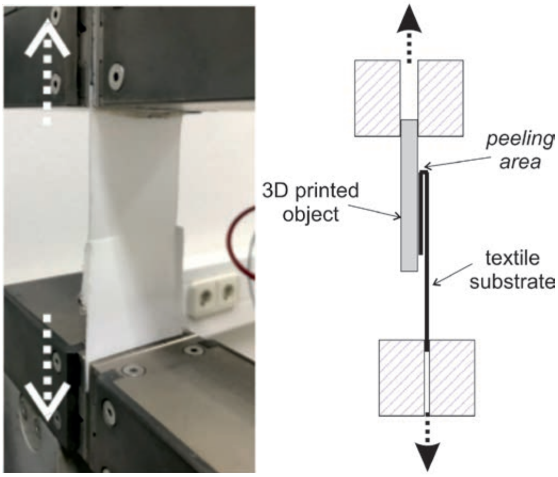
The evaluation of adhesion of a 3D-printed object to a textile substrate can be conducted in different arrangements. The principle of all arrangements is the application of a 3D print on a textile and the following removing of this printed object while measuring the force which is necessary to remove the 3D print. This idea of measurement is possible in different geometries, depending on the type of applied 3D-printed object and the set-up which is used for its removing.

3.1 Plane geometry

The simplest arrangement for testing is the "plane geometry". Here, the 3D-printed object is simply applied in several layers up to the height of several millimetres. The removing of these printed layers is done in an arrangement which is quite similar to the testing of adhesion of coatings on textile substrates in artificial leather. The testing in this plane geometry can be also called "peel test". This simple plane testing geometry has been mainly used in the first testing of 3D objects on textiles reported in recent years [13–16]. The set-up of this testing arrangement is depicted in Figure 3 with a photograph and schematic illustration. This type of testing arrangement is relatively simple and the sample preparation is quite fast due to the simple printed 3D object used for this test. Nevertheless, problems with reproducibility of testing results have to mentioned; thus, several measurements with similar samples need to be performed to receive valid results. An additional challenge during these measurements is the possible damaging of the textile substrate during the mechanical test (cf. Figure 4). In this case, the measured force is determined by the mechanical stability of the textile and not by the adhesion between the printed 3D object and the textile substrate.

3.2 Dolly geometry

The testing of 3D-printed objects has the advantage that the tested object can be printed in a shape which is suitable for different testing arrangements [17,



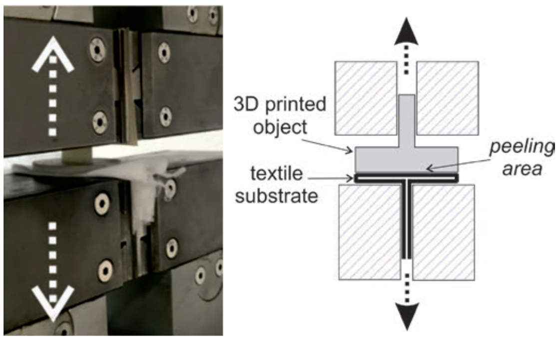
(a) (b)

Figure 3: Images describing adhesion tests in plane geometry: a) sample arranged in testing device, b) schematic drawing of testing arrangement

(a) (b)

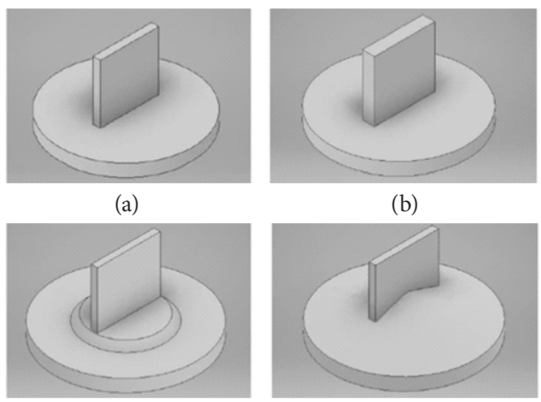
Figure 4: Photographs of damaged textile samples after adhesion test in plane geometry – such sample destruction leads to misinterpretation of gained measurement results

18]. Such a 3D-printed object, prepared and constructed for testing purposes, is called "dolly" and the arrangement is analogously called "dolly geometry". The set-up of this testing arrangement is depicted in Figure 5 with a photograph and schematic illustration. Compared to the test in plane geometry, the testing with dolly geometry is more time consuming due to longer printing duration of the used 3D-testing object. Furthermore, it should be kept in mind that the construction of dolly is not a simple issue, as it has to be stable in the afterwards performed mechanical test. Some different geometries are depicted schematically in Figure 6. Dolly has to be constructed in a form that it does not break during the mechanical test. To test adhesion, it is necessary that the break occurs at the interface between the 3D print and the textile surface. If the 3D-printed object is not stable enough and breaks before the delamination occurs, the strength necessary to destroy the 3D object is measured but not the adhesion between the 3D print and substrate. Examples of some failures during mechanical tests are presented in Figure 7. Finally, it can be stated that certain thickness of the handle and certain foundation is needed to gain the necessary stability of dolly for the mechanical test. The finally used optimised dolly geometry for an object made from PLA is presented in Figure 8. The duration of printing such an object is approximately 15 minutes.



(a) (b)

Figure 5: Images describing adhesion tests in dolly geometry: a) sample arranged in testing device, b) schematic drawing of testing arrangement



(a) (b)

(c) (d)

Figure 6: Different geometries of 3D-printed objects intended for mechanical tests: a) original, b) thicker handle, c) handle with foundation, d) handle with slope

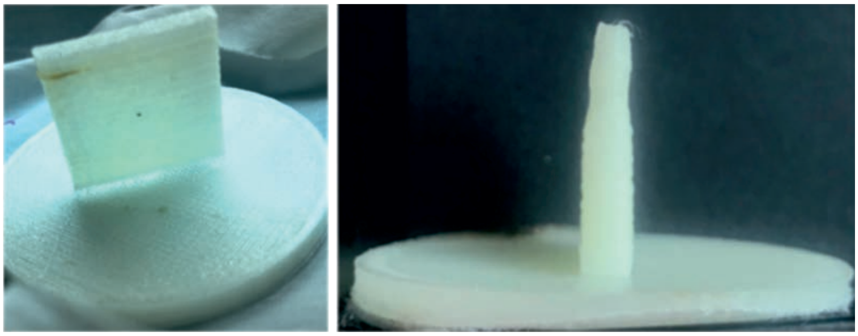


Figure 7: Examples of broken 3D-printed object (left) and deformed 3D-printed object (right) after mechanical testing

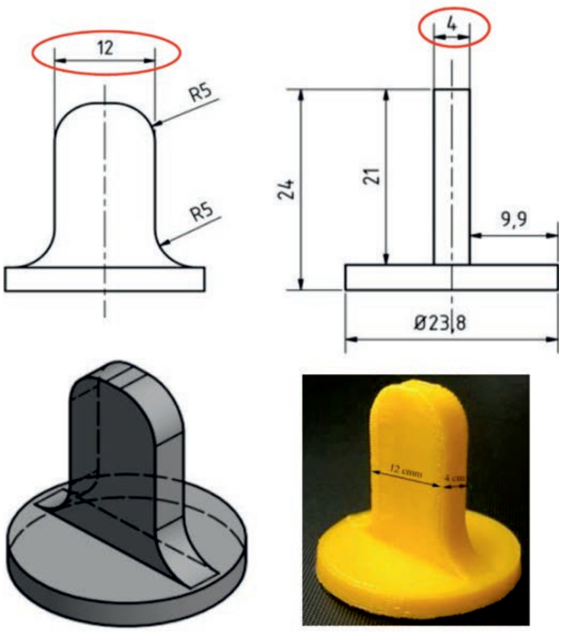


Figure 8: Finally used optimised dolly geometry for 3D object made from PLA

4 Experimental

For the actual preparation of 3D printed objects, a PLA filament (polylactide acid) and a nylon filament (polyamide) were used. The PLA filament was supplied by the company Filamentworld and the nylon filament by taulman3D. For the construction of the 3D object, 3D-CAD-Software "Autodesk Inventor Professional 2016-Studentenversion" was used. The 3D printing was performed with the device "Orcabot XXL Pro". Mechanical tests were conducted by using the device Zwick 1455 (Zwick/Roell GmbH). The mechanical tests were repeated three times, and the average was calculated and used for further discussion.

5 Results and discussion – parameters influencing adhesion

The adhesion between the 3D-printed object and the textile substrate is influenced by many different parameters. Roughly, these parameters can be categorised into two group, related to material and processes. Process parameters are related to the process and conditions under which 3D printing is performed.

5.1 Process parameters

Process parameters are all parameters that can influence the printing results – without material dependent parameters, e.g. type of used filament or textile substrate. Such process parameters are for example the printing speed, process temperature and process geometry. It is supposed that the process temperature higher than the glass temperature of the textile substrate can support the interdiffusion of polymer chains from the printed object and textile substrate. With this, an increase in adhesion is introduced. A part of the process geometry is for example the z-distance, which is the distance between the printing head and the textile substrate. Even a small change in this parameter can have a significant influence on the adhesion of the 3D-printed object on a textile substrate. Compared to other parameters, such a geometry-related effect is often underestimated and difficult to predict. Some examples of process related parameters and their influence on the adhesion of a 3D-printed object to a textile substrate are presented in Figures 9–12. Figure 9 presents the influence of the printing speed on adhesion. Here, especially the printing speed for the first applied layer has a significant influence on adhesion. The printing speed for the following layer onto the first applied one mainly has no influence on adhesion properties. The first layer makes the adhesion and the interdiffusion into the textile structure; therefore, particularly here, a slow application rate is effective to improve the adhesion. Figure 10 presents the influence of z-distance on adhesion. The z-distance describes the distance between the extrusion nozzle and working platform. The optimal z-distance is also determined by the thickness of the used textile substrate. However, there is a minimum value for a small z-distance to realise good adhesive properties. By increasing the z-distance, the adhesion of the 3D-printed object to the textile substrate decreases. A sufficiently small z-distance is required to support the penetration of the printed polymer into the structure of the textile substrate.

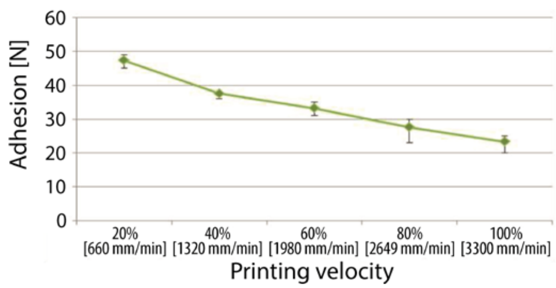


Figure 9: Adhesion as function of velocity of printing first layer of 3D-printed object – object from PLA

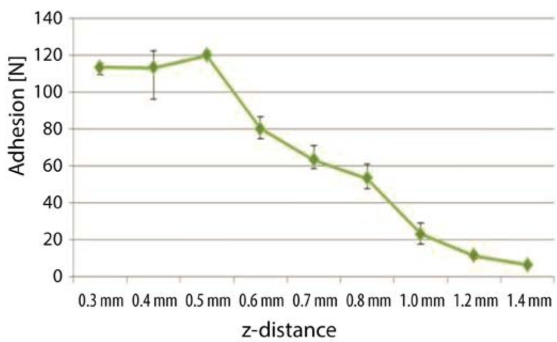


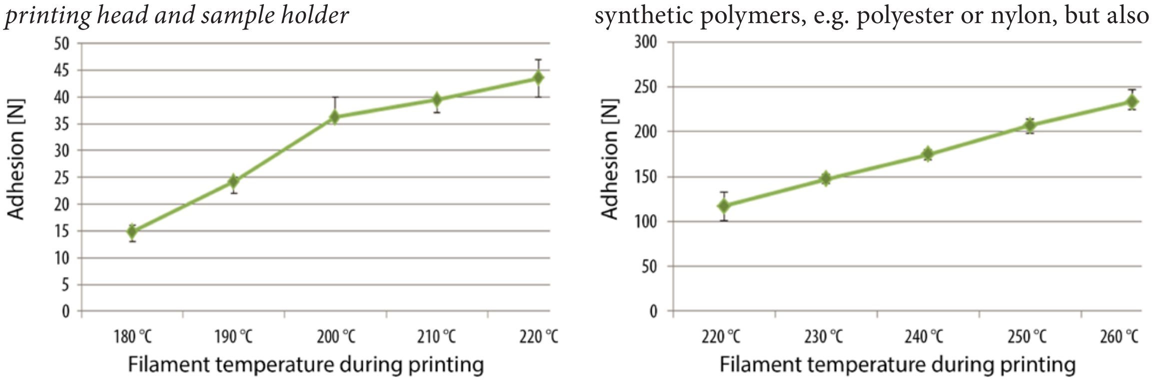
Figure 10: Adhesion as function of z-distance between printing head and sample holder

The influence of the temperature of the extrusion nozzle on the adhesion of 3D-printed objects is presented in Figure 11. Here, also a comparison of printed PLA and nylon filament is given. This temperature is the temperature of the applied polymer filament and can be set in general in the temperature range of the melting temperature and the decomposition temperature of the applied polymer. In the following discussion, the temperature of the extrusion nozzle is also referred to as filament temperature. Due to the higher decomposition temperature of nylon, by using nylon filaments for printing, higher process temperatures are possible. In general, it can be stated that by increasing the printing temperature, adhesion increases as well. A polymer melt with higher temperature exhibits lower viscosity; thus, it can penetrate deeper into the textile structure. The use of a polymer with a higher decomposition temperature is with this background advantageous.

During 3D printing, the temperature adjustment is not possible only with the temperature of the extrusion nozzle. Also the temperature of the working platform can be adjusted, influencing the temperature of the treated textile substrate. Moreover, a clear increase in adhesion by increasing temperature of the working platform is determined (cf. Figure 12).

5.2 Material parameters

Material parameters are related to the materials which are finally combined. In a first simple view, there are two different objects which are combined; hence, two types of materials should be considered. These are the textile substrate and the 3D object. The 3D object is deposited from a thermoplastic filament and could be for example from PLA, polyamide or other polymers. The textile substrate can be from synthetic polymers, e.g. polyester or nylon, but also



(a) (b)

Figure 11: Adhesion as function of filament temperature during printing – examples for using two different types of printing filaments: a) PLA, b) nylon

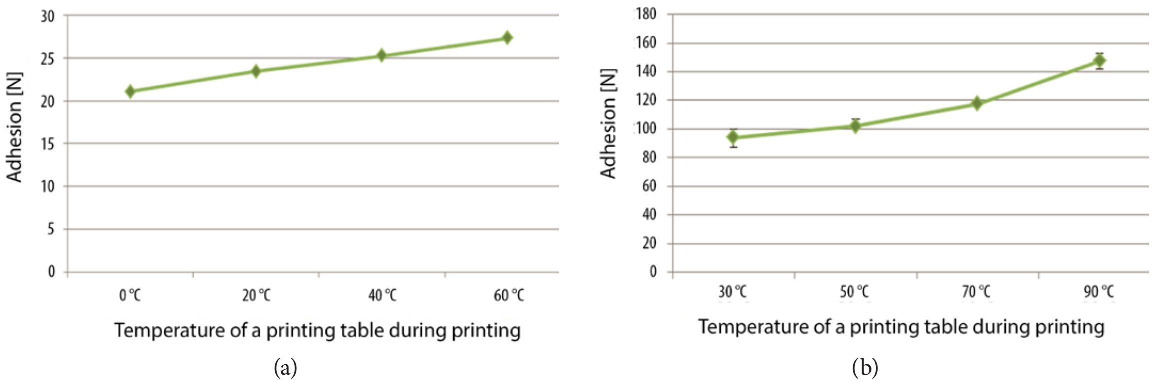


Figure 12: Adhesion as function of temperature of working platform during printing – examples for using two different types of printing filaments: a) PLA, b) nylon

from natural fibres, e.g. cotton, or inorganic fibres, e.g. glass fibre fabrics. However, the textile substrate is not only described by the type of the fibre. The structure of the fabric, its hairiness and roughness are important material parameters as well. Furthermore, the surface of the textile fibre and its modification can have an important influence on the adhesion to an applied 3D-printed object. It might also matter if the textile is washed before the 3D-printing process is performed, and what washing procedure and washing agent is used. Additionally, the textile surface can be modified with a plasma treatment using different process gases. Regarding the material properties, some main trends can be described. Textile surfaces with higher roughness and hairiness often result in stronger adhesion to the 3D-printed object. In some cases, better adhesion is achieved if a hydrophobic thermoplastic object is deposited on a hydrophobic textile. However, a hydrophobic and oleophobic finishing with a fluorocarbon treatment can significantly decrease the adhesion of the 3D-printed object [19]. The treatments of textile surfaces with washing procedures and plasma processes can strongly influence the finally reached adhesion. However, for these surface treatments, the effect and its intensity is difficult to predict [15]. A plasma pretreatment can improve but also decrease the adhesion of the 3D-printed object onto the textile substrate, depending on the type of plasma, the treated textile and the applied polymer filament [15].

5.3 Washing behaviour

Most washing processes include a combination of mechanical treatment, temperature impact and liquid washing agents. The washing process could damage the 3D-printed object or remove it from the textile substrate. However, especially washing procedures using elevated washing temperatures can cause in some cases increased adhesion of the 3D-printed object to the textile substrate, as reported and analysed by Störmer et al. [20]. Such an increased adhesion could be explained by the interdiffusion of polymer chains from the thermoplastic 3D object and the textile substrate occurring at elevated washing temperature.

6 Conclusion

3D printing has the potential to be a powerful tool for the textile functionalisation and individualisation of textile-based products. One main condition for a broad use in this field is a suitable adhesion between the 3D-printed object and the textile substrate, leading to a sufficient washing and abrasion stability. Many different parameters can influence this adhesion; therefore, a product-based and individual optimisation is necessary for most types of applications, especially if strong stability properties are demanded, e.g. for the application in sports textiles or for technical textile applications.

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Gorlachova (bachelor thesis in 2020). Boris Mahltig is responsible for data evaluation and writing of the actual paper contribution.
Conflict of interest: The authors declare no conflict of interest.

References

1. XIAO, Y.-Q., KAN, C.-W. Review on development and application of 3D-printing technology in textile and fashion design. *Coatings*, 2022, **12**(2), 267–279, doi: 10.3390/coatings12020267.
2. SITOTAW, D.B., AHRENDT, D., KYOSEV, Y., KABISH, A.K. Additive manufacturing and textiles – state-of-the-art. *Applied Sciences*, 2020, **10**(15), 5033–5045, doi: 10.3390/app10155033.
3. KORGER, M., GLOGOWSKY, A., SANDULOFF, S., STEINEM, C., HUYSMAN, S., HORN, B., ERNST, M., RABE, M. Testing thermoplastic elastomers selected as flexible three-dimensional printing materials for functional garment and technical textile applications. *Journal of Engineered Fibers and Fabrics*, 2020, **15**, 1–10, doi: 10.1177/1558925020924599.
4. BLACHOWICZ, T., EHRMANN, G., EHRMANN, A. Optical elements from 3D printed polymers. *e-Polymers*, 2021, **21**(1), 549–565, doi: 10.1515/epoly-2021-0061.
5. GRIMMELSMANN, N., KREUZIGER, M., KORGER, M., MEISSNER, H., EHRMANN, A. Adhesion of 3D printed material on textile substrates. *Rapid Prototyping Journal*, 2018, **24**(1), 166–170, doi: 10.1108/RPJ-05-2016-0086.
6. MEYER, P., DÖPKE, C., EHRMANN, A. Improving adhesion of three-dimensional printed objects on textile fabrics by polymer coating. *Journal of Engineered Fibers and Fabrics*, 2019, **14**, 1–7, doi: 10.1177/1558925019895257.
7. GÖRMER, D., STÖRMER, J., EHRMANN, A. The influence of thermal after-treatment on the adhesion of 3D prints on textile fabrics. *Communications in Development and Assembling of Textile Products* – CDATP, 2020, **1**(2), 104–110, doi: 10.25367/cdatp.2020.1.p104-110.
8. GORE, A. *The future*. London : WH Allen, 2014.
9. SOMMER, W., SCHLENKER, A., LANGE-SCHÖNBECK, C.D. *Faszination 3D-Druck: Alles zum Drucken, Scannen, Modellieren*. Munich : Markt+Technik Verlag, 2016.
10. DELEERSNYDER, K., RUYS, L. 3D-Druck auf Textilien. *Textilplus*, 2015, **3**(7/8), 23–25.
11. KORGER, M., LUTZ, M., RABE, M. 3D-Druck kombiniert mit Textil. *Textilplus*, 2015, **3**(11/12), 25–28.
12. YAP, Y.L., YEONG, W.Y. Additive manufacture of fashion and jewellery products. *Virtual and Physical Prototyping*, 2014, **9**(3), 195–201, doi: 10.1080/17452759.2014.938993.
13. KORGER, M., BERGSCHNEIDER, J., LUTZ, M., MAHLTIG, B., FINSTERBUSCH, K., RABE, M. Possible appllications of 3D-printing technology on textile substrates. *IOP Conference Series: Materials Science and Engineering*, 2016, **141**(1), 1–5, doi: 10.1088/1757-899X/141/1/012011.
14. KORGER, M., BERGSCHNEIDER, J., NEUSS, J., LUTZ, M., MAHLTIG, B., RABE, M. Functionalization of textiles using 3D printing – add-on technology for textile applications testing new material combinations. *Fibres and Textiles*, 2016, **23**, 106–111.
15. BERGSCHNEIDER, J., KORGER, M., KYOSEV, Y., LUTZ, M., RABE, M., MAHLTIG, B. 3D printing for functionalization of textiles – aspects of durability and coating adhesion. *Melliand International*, 2017, **22**(1), 45–47.
16. GORLACHOVA, M., MAHLTIG, B. 3D-printing on textiles – an investigation on adhesion properties of the produced composite materials. *Journal of Polymer Research*, 2021, **28**(6), 207–216, doi: 10.1007/s10965-021-02567-1.
17. SANATGAR, R.H., CAMPAGNE, C., NIERSTRASZ, V. Investigation of the adhesion properties of direct 3D printing of polymers and nanocomposites on textiles. *Applied Surface Science*, 2017, **403**, 551–563, doi: 10.1016/j.apsusc.2017.01.112.
18. MALENGIER, B., HERTLEER, C., VAN LANGENHOVE, L., CARDON, L. 3D printing on textiles: testing of adhesion. In *International Conference on Intelligent Textiles and Mass Customisation*, 2017, http://hdl.handle.net/1854/LU-8535084.
19. SITOTAW, D.B., MUENKS, D., KYOSEV, Y., KABISH, A.K. Influence of fluorocarbon treatment on the adhesion of material extrusion 3D prints on textile. *Journal of Industrial Textiles*, 2022, **52**, doi: 10.1177/152808372211370.
20. STÖRMER, J., GÖRMER, D., EHRMANN, A. Influence of washing and thermal post-treatment on the adhesion between 3D-printed TPU and woven fabrics. *Communications in Development and Assembling of Textile Products – CDATP*, 2021, **2**(1), 34–39, doi: 10.25367/cdatp.2021.2.p34-39.