Monitoring the Surface Treatment Effect on the Polyvinyl Butyral Samples in the Context of Industry 4.0

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Abstract. The introduced paper is focused on monitoring the surface treatment of the Polyvinyl Butyral (PVB) samples. Surface treatment is an inseparable part of postprocessing techniques. Additive manufacturing technology has countless definitions, but it can be concluded that this technology is revolutionary and conventional and is a fundamental part of Industry 4.0. Since technology has rapidly evolved and spread in almost every industry the requirement for its quality is getting to be more meaningful and relevant. The basic evaluation of quality needs is challenging and unquestionably will be in the future. Postprocessing techniques are becoming an integral part of additive manufacturing and the resulting quality of manufactured products. Consequently, several peculiar techniques are applied to boost and upgrade the final surface quality or mechanical properties of printed samples. The fundamental target of the given paper is to enhance the resulting quality of fabricated specimens using Fused Deposition Modeling (FDM) technology. The chosen filament for the 3D printing process is Polyvinyl Butyral, which has remarkable mechanical properties. From various postprocessing techniques, which are usually used we had chosen chemical smoothing, which is a part of surface treatment postprocessing techniques. For the proposed research were fabricated four specimens for chemical smoothing in an electrical device designed for this specific surface treatment Polysher. The results were obtained from the measurement of each specimen and its layer height from a digital microscope Keyence VHX7000. According to measurement, it can be concluded that chemical smoothing can affect the overall surface quality.

Keywords: FDM Fabricated Specimens · Polyvinyl Butyral · Surface Treatment · Chemical Smoothing · Additive Manufacturing

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1 Introduction

There is no doubt, that additive manufacturing is nowadays ongoing technology and definitely will be in the future, but some processes, that are closely related to the technology itself are often pushed to the background despite their importance. Based on the topic of the proposed paper it is possible to predict, which process in connection with the mentioned technology will be discussed in a more detailed way. Postprocessing of 3D printed samples is an attractive area of research. Since the requirements for the quality of samples are becoming increasingly important. Utilization of various types of postprocessing methods can improve the overall quality. Visual quality is a subjective term, which can be described in so many ways, but one thing is clear, visual quality is one of the up-to-date challenges for applications in Industry 4.0. Naturally, the resulting quality is affected not only because of some post-processing methods but also because of the quality of the chosen filament and many other parameters during the additive manufacturing process. [1, 2].

However, the main goal of the proposed paper is to understand how specific surface treatment can affect the visual quality of 3D printed samples from Polyvinyl Butyral filament.

Previous research has shown that there is no reliable method for the quality evaluation of 3D-printed samples. Lech et al. in their study have focused on the overall quality evaluation of the scanned surfaces of the 3D prints. To investigate the quality of samples they have used a new approach based on Histogram of Oriented Gradients (HOG). [1] Peng et al. in their article have documented the four most used post-processing technologies such as thermal post-processing, laser peening, laser polishing and machining, and abrasive finishing. [2] Kuo et al. have experimented to improve the surface quality of wax injection tools. They have found that aluminum-filled epoxy resin used as filler can improve the surface quality of specific samples [3]. In the following study where authors Cunico et al. have done experiments based on solvent vapor attack, also known as the smoothing process, and evaluated the main benefits of mechanical properties of

Table 1. Related Works [1–5]

Author	Year of publications	Title
Lech et al.	2018	Quality evaluation of 3D printed surfaces based on HOG features
Peng et al.	2021	A review of post-processing technologies in additive manufacturing
Kuo et al.	2013	A simple method for improving the surface quality of the rapid prototype
Cunico et al.	2017	Investigation of additive manufacturing surface smoothing process
Mu et al.	2020	Surface modification of prototypes in fused filament fabrication using chemical vapor smoothing

specific objects [4]. Another research has been done by Mu et al. to investigate the effect of chemical vapor smoothing for specimens fabricated in fused filament fabrication [5].

Although the mentioned literature addresses post-processing and its effect on 3D printed samples, no specific research focuses on the chemical smoothing of fabricated specimens. The following table represents the literature review of research, that has been done in the chosen field of research. Table 1 conducts related works, which are closely connected to the proposed paper.

2 Work Methodology

Referring to the introduction section of the paper, the technology of additive manufacturing is popular and obviously will be prevalent in the future, but the technology globally comes with various complementary processes. The goal of the presented paper is to analyze the effect of one chosen complementary process, which is chemical smoothing. According to analyzed data from the Web of Science database, it seems to be reasonable to anticipate, that this area of research can come up with interesting ideas for future research.

Work methodology has started with analyzing the input data from the Web of Science database. The following figure represents the most popular categories related to the chosen area of research (Fig. 1).

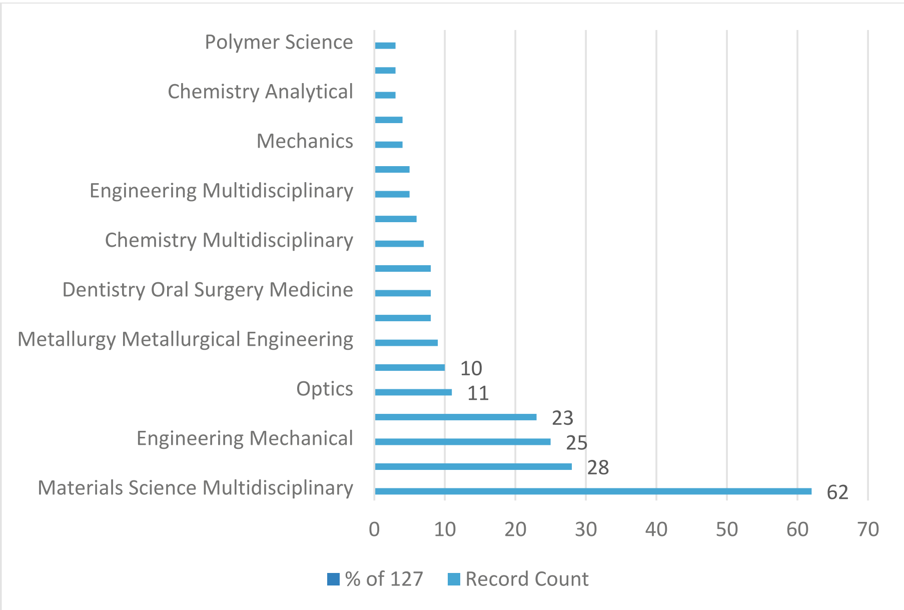

Fig. 1. Most popular web of science categories closely related to the specific area of research.

The entered keyword was "post-processing method, additive manufacturing, chemical smoothing, and solvent vapor attack". The total number of articles given on specific keywords was 127 publications. In 2021, the most articles related to the given issue were published. It was followed by the year 2022 with a total number of published articles of 22. And only 15 articles were published in 2023 on the given issue. The following figure represents the most popular Web of Science categories, where publications, which are closely related to our area of research were found.

Among all Web of Science categories, the most popular category for publication was Material Science Multidisciplinary with a total of 62 articles, which were closely related to proposed research. The second most popular category of specific databases was Engineering Mechanical with a total of 28 articles.

The overall methodological framework has begun with analyzing the input data searched from various scientific papers, which are all mentioned in the introduction section and references. Peculiar steps of work methodology are outlined in the figure below. The introduction section is applied to the overall aim and problem definitions. Moreover, the related work connected to the specific area of research is presented in this section. The further part of the paper is focused on detailed specifications of selected materials, electrical devices, and methods, that are used for the practical part of the paper. The experimental part consists of chemical smoothing in the chosen electrical device and evaluating of attained results (Fig. 2).

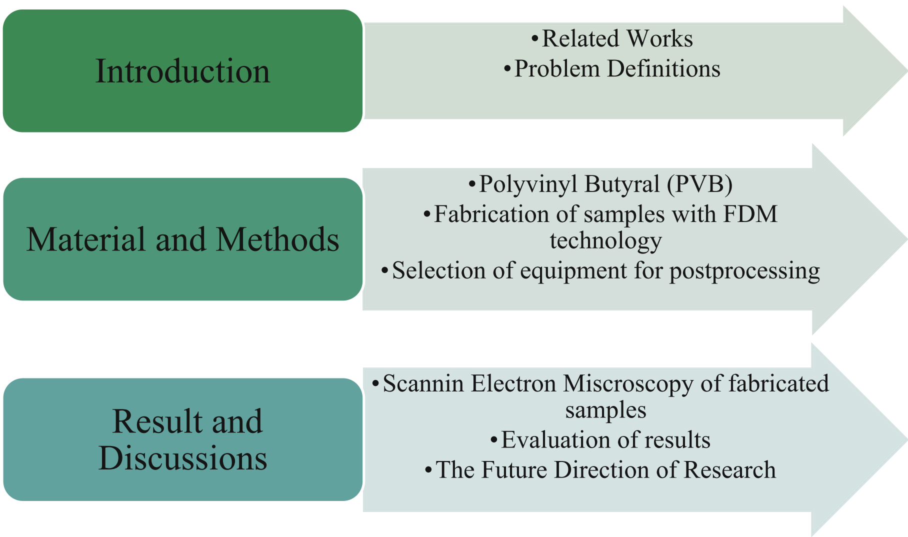

Fig. 2. Methodological Framework

3 Materials and Methods

Polyvinyl Butyral has been chosen as input material for the experimental part of chemical smoothing in order to study the effects of specific methods on surface quality. Polyvinyl Butyral (PVB) is a polymer material with outstanding mechanical properties for instance high tensile strength, transparency, and high adhesion. Nowadays PVB has various applications as laminated safety glass, paint, adhesive, primers binder, and other applications. The most common application of PVB is in the automotive industry, where PVB is used as an interlayer of car windshields and safety glass in the building industry. The advantage of PVB is its outstanding adhesive properties with many materials such as glass, metal, plastics, and wood. Another benefit of PVB is the possibility of recycling and it´s repeated usability.

In recent years PVB has found another area of its pertinence – additive manufacturing. This material is used in this technology as input material for producing 3D physical objects from digital models. The filament is the key component for the whole printing process and the choice of this component can generally affect the quality of the resulting sample. What is impressive and the reason, why this specific material has been chosen is the reaction of PVB filament and alcohol. The goal of this paper is to study how chemical smoothing can affect the surface of samples produced from PVB filament. The following figure shows PVB filament and samples fabricated by FDM technology [10–13] (Fig. 3).

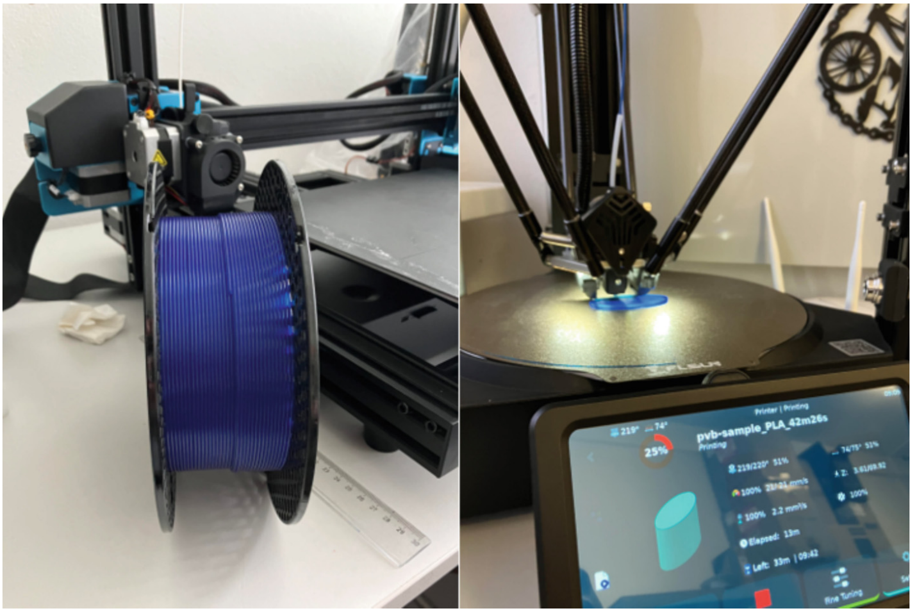

Fig. 3. PVB filament and process of fabricating on 3D printer FLSUN QQ-S

Samples were fabricated with the utilization of Fused Deposition Modeling technology, which is the most popular technology for 3D printing. The mentioned technology is popular because of its simple manipulation, which fits beginners also. The whole process itself starts with the movement of filament from the large spool, and then the filament is captured by an extruder and pushed down through the hot end. Subsequently, the melted filament is layered onto the printing pad. Based on the 3D model the layers are layered on top of each other until the final sample is printed [9, 14].

The following table represents the basic technical parameters of a specific electrical device 3D printer on which the specimens were fabricated and its printing parameters such as printing speed, layer height, or temperature needed for the printing process.

Table 2. Printer Parameter of 3D printer [7]

3D printer parameters - FLSUN QQ-S			Printing parameter
Technology	FDM/FFF	Hot Bed Temperature: ≤270 °C	Printing speed: 50 mm/s
Frame	DELTA	Nozzle Temperature: ≤270 °C	Layer height: 0,2 mm
Printer size	260 × 260 × 320 mm	Nozzle Diameter: 0,4mm	Bed Temperature: 75 °C
Power input	110–220 v	Layer Thickness: 0,1 mm-0,4 mm	Hot end Temperature: 215 °C
Printable materials	PLA, ABS, PVB, HIPS, PVA, Wood	Leveling Method: One-click Auto-leveling	

3.1 Selection of Equipment for Postprocessing of Printed Samples from PVB

There are many methods for postprocessing in additive manufacturing.

In general, we know five basic techniques:

- Cleaning
- Repairing
- Hardening
- Surface treatment – Finishing
- Painting

Among all the mentioned techniques, the one that has been chosen for our experiment was surface treatment. Surface treatment can be divided into two sections: grinding and chemical smoothing. Individual layers of some supporting material can be removed with gentle grinding and with abrasive paper with different granularity. Cleaning is a postprocessing method used to remove the supporting material. We distinguish two types of supporting material: soluble and insoluble. Insoluble material is relatively strong and can be removed only with some auxiliary tools, for instance, pliers. Soluble material is safer because there is minimal risk of destroying the sample. These materials are mostly dissolved in water or in a chemical, which is designed for specific material. An example of a soluble material is HIPP (this soluble material is used when printed samples are made from ABS filament or PVA when samples are printed from PLA filament. Chemical smoothing works on the principle of isopropanol reaction together with a sample, which is placed in the chamber, where the specific liquid is evaporating. The final result of the reaction is the linking of individual layers into a smooth surface. To carry out this experiment, the specific electrical device Polysher from Polymaker. This device can be seen in the following figure [23–26] (Fig. 4).

Fig. 4. Equipment for postprocessing the samples from PVB

4 Results and Discussion

For the experimental part of the study were prepared four specimens, which were fabricated with the utilization of FDM technology on a 3D printer mentioned in the section Materials and Methods. The parameters for the printing process itself are depicted in Table 2. The first specimen had no surface treatment, the second one was inserted into the chamber for twenty minutes, the third one for forty minutes, and the fourth specimen was inserted into the chamber for chemical smoothing for sixty minutes. According to the length of time of vapor attacks inside of chamber, it can be seen visual differences between specimens. Of course, the best visual contrast is between the specimen, which was not inserted into the chamber and the last specimen, which was inserted for the longest time.

Fabricated specimens, which were intended for surface analysis were extracted from printed samples. Specimens were printed at size 30 × 10 mm. For optimal stability and manipulations during the observation, the samples were cold-hardened into the resin Stuers DuroCit-3. It is fast-setting acrylic resin with a filler. This type of resin has a low degree of shrinkage and is ideal for samples, where layer protection and great adhesion to the surface are crucial.

Just for precision, the experimental part of the study specimen was labeled according to the duration of postprocessing chemical smoothing in the chamber of Polysher 0, 20, 40, and 60 min. After the specimens were embedded into Durocit, another step consisted of sanding under water with sandpapers P320 and P4000. Afterwards, they were polished on polishing cloth with suspension, that consisted of abrasive particles. The following figure shows the specimens embedded into DuroCit [6, 8].

Fig. 5. Specimens embedded into DuroCit3.

Prepared specimens in form as it can be seen in Fig. 5, were subsequently observed under microscope Keyence VHX7000 and zoomed in 100x a 300x. Sample labelled as 0 represents a material, which was not exposed to chemical smoothing. The following figure represents the results of taken measurements in each sample specifically. In Fig. 6 can be seen the roughness of the sample surface. The measured layer height of the sample is in this case 114,08 μm.

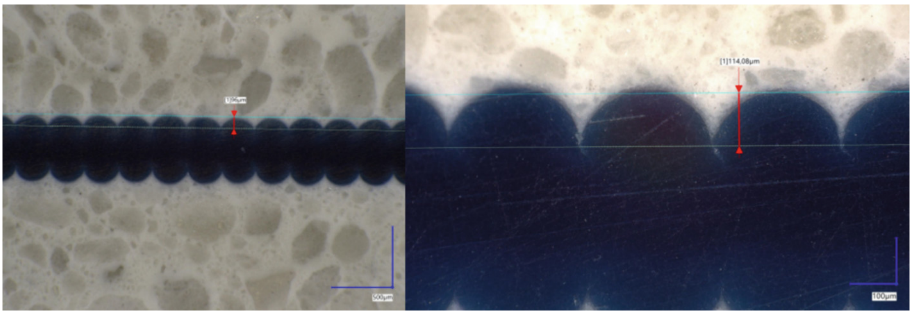

Fig. 6. Sample n. 0 (no chemical smoothing)

The second sample, which can be seen in Fig. 7 is getting smoother surface. The total time spent in the chamber of Polysher was twenty minutes. In this case, the measured layer height is 84,35 μm.

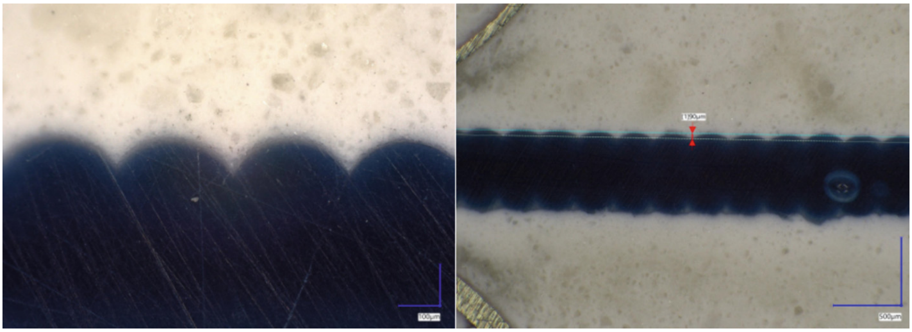

Fig. 7. Sample n. 20 (length of chemical smoothing 20 min)

The third sample had the total time of chemical smoothing in the chamber of Polysher forty minutes. The visual surface difference between sample n.0 and sample n.40 is significant. The measured layer height for sample n.40 is 19,86 μm (Fig. 8).

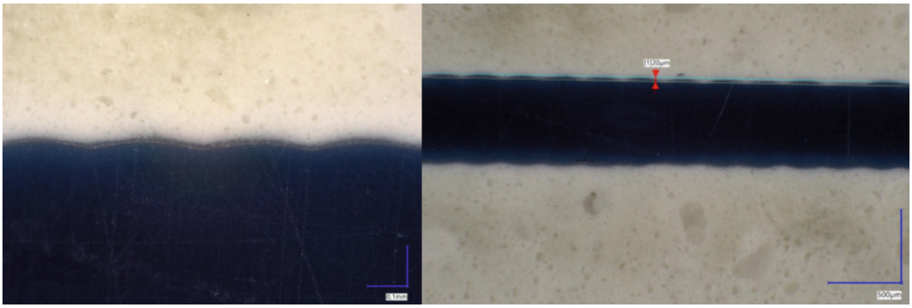

Fig. 8. Sample n.40 (Length of chemical smoothing 40 min)

The last one was inserted into the chamber for the longest time and the smoothness of the surface is completely obliterated as we can see in Fig. 9. In this sample (n.60) it was impossible to measure the layer height, which points to the successful surface treatments on the presented sample.

Based on the taken measurements of layer height in each sample can be concluded that chemical smoothing significantly affects the layer height of samples and therefore the smoothness of the surface.

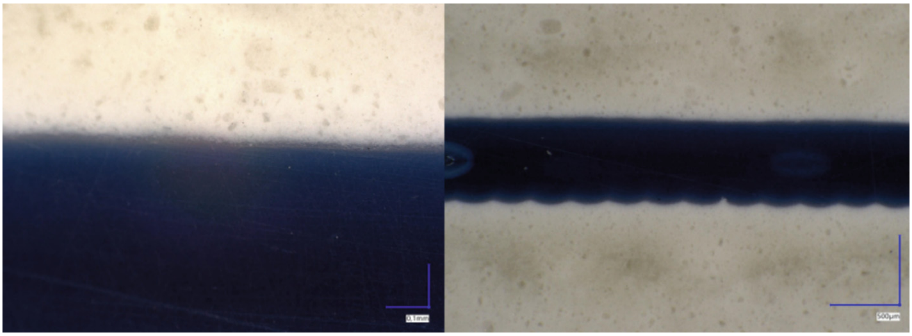

Fig. 9. Sample n.60 (Length of chemical smoothing 60 min)

5 Conclusion

The intention of submitted paper was to analyze the effect of specific chosen postprocessing techniques on fabricated specimens using FDM technology. The experimental part of the research consisted of chemical smoothing in a closed chamber, where liquid containing isopropanol gradually evaporated. The specimens placed in a closed chamber reacted with the released steam, which led to the gradual joining of the specimen layer. Each of fabricated specimen was placed into the chamber for chemical smoothing at different times, to see the differences. The first specimen had no surface treatment, the second one was placed into a chamber for twenty minutes, the third one for forty minutes, and the last one for one hour. According to taken measurements using digital microscopy, it is possible to measure the layer height of each specimen. The effect of chemical smoothing had the greatest impact on the visual quality of the last specimen.

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References

1. Lech, P., Fastowicz, J., Okarma, K.: Quality evaluation of 3D printed surfaces based on HOG features. In: Chmielewski, L.J., Kozera, R., Orłowski, A., Wojciechowski, K., Bruckstein, A.M., Petkov, N. (eds.) ICCVG 2018. LNCS, vol. 11114, pp. 199–208. Springer, Cham (2018). https://doi.org/10.1007/978-3-030-00692-1_18
2. Peng, X., Kong, L., Fuh, J.Y.H., Wang, H.: A review of post-processing technologies in additive manufacturing. J. Manufac. Mater. Process. **5**(2), 38 (2021)
3. Kuo, C.C., Su, S.J.: A simple method for improving surface quality of rapid prototype (2013)
4. Cunico, M.W.M., Cunico, M.M., Cavalheiro, P.M., de Carvalho, J.: Investigation of additive manufacturing surface smoothing process. Rapid Prototyp. J. **23**(1), 201–208 (2017)
5. Mu, M., Ou, C.Y., Wang, J., Liu, Y.: Surface modification of prototypes in fused filament fabrication using chemical vapour smoothing. Addit. Manuf. **31**, 100972 (2020)
6. Keyence VH-ZST Data sheet
7. FLSUN QQ-S Data sheet

8. https://www.3djake.sk/polymaker/polysher-1. Accessed 24 Jan 2024
9. Kogut, P., Kalinowski, K., Grabowik, C., Ćwikła, G., Paprocka, I.: Algorithms of control parameters selection for automation of FDM 3D printing process. In: MATEC Web of Conferences, vol. 112, p. 05011. EDP Sciences (2017)
10. Xu, D., et al.: Comparative analysis on strength properties of fabric using intra-layer Polyvinyl Butyral-paste spinning. Fibers Polym. **22**, 2027–2035 (2021)
11. Le, V.S., Buczkowska, K.E., Ercoli, R., Pławecka, K., Marian, N.M., Louda, P.: Influence of incorporating recycled windshield glass, PVB-foil, and rubber granulates on the properties of geopolymer composites and concretes. Polymers **15**(9), 2122 (2023)
12. Knapcikova, L., Radchenko, S., Dupláková, D., Hatala, M.: Advanced materials based on the recycled Polyvinyl Butyral (PVB). In: 2nd EAI International Conference on Management of Manufacturing Systems, pp. 239–247
13. Salam, L.A., Matthews, R.D., Robertson, H.: Pyrolysis of polyvinyl butyral (PVB) binder in thermoelectric green tapes. J. Eur. Ceram. Soc. **20**(9), 1375–1383 (2000)
14. Gibson, I., et al.: Additive manufacturing technologies, vol. 17, pp. 160–186). Springer, Cham, Switzerland (2021)
15. Khouri, S., Behun, M., Knapcikova, L., Behunova, A., Sofranko, M., Rosova, A.: Characterization of Customized Encapsulant Polyvinyl Butyral used in the solar industry and its impact on the environment. Energies **13**(20), 5391 (2020)
16. Pérez, M., Medina-Sánchez, G., García-Collado, A., Gupta, M., Carou, D.: Surface quality enhancement of fused deposition modeling (FDM) printed samples based on the selection of critical printing parameters. Materials **11**(8), 1382 (2018)
17. Okarma, K., Fastowicz, J.: Improved quality assessment of colour surfaces for additive manufacturing based on image entropy. Pattern Anal. Appl. **23**(3), 1035–1047 (2020)
18. Carrot, C., Bendaoud, A., Pillon, C., Olabisi, O., Adewale, K.: Polyvinyl butyral. Handbook of thermoplastics, vol. 2, pp. 89–137 (2016)
19. Kristiawan, R.B., Imaduddin, F., Ariawan, D., Arifin, Z.: A review on the fused deposition modeling (FDM) 3D printing: filament processing, materials, and printing parameters. Open Eng. **11**(1), 639–649 (2021)
20. Ngo, T.D., Kashani, A., Imbalzano, G., Nguyen, K.T., Hui, D.: Additive manufacturing (3D printing): a review of materials, methods, applications, and challenges. Compos. B Eng. **143**, 172–196 (2018)
21. Guinovart, T., Crespo, G.A., Rius, F.X., Andrade, F.J.: A reference electrode based on polyvinyl butyral (PVB) polymer for decentralized chemical measurements. Anal. Chim. Acta **821**, 72–80 (2014)
22. Hackel, L., Rankin, J.R., Rubenchik, A., King, W.E., Matthews, M.: Laser peening: a tool for additive manufacturing post-processing. Addit. Manuf. **24**, 67–75 (2018)
23. Piedra-Cascón, W., Krishnamurthy, V.R., Att, W., Revilla-León, M.: 3D printing parameters, supporting structures, slicing, and post-processing procedures of vat-polymerization additive manufacturing technologies: a narrative review. J. Dent. **109**, 103630 (2021)
24. Nelaturi, S., Behandish, M., Mirzendehdel, A.M., de Kleer, J.: Automatic support removal for additive manufacturing post processing. Comput. Aided Des. **115**, 135–146 (2019)
25. Salonitis, K., D'Alvise, L., Schoinochoritis, B., Chantzis, D.: Additive manufacturing and post-processing simulation: laser cladding followed by high speed machining. Int. J. Adv. Manufac. Technol. **85**, 2401–2411 (2016)
26. Jin, B., et al.: A review of additive manufacturing techniques and post-processing for high-temperature titanium alloys. Metals **13**(8), 1327 (2023)