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# 3D PRINTING OF POLYMERS: METHODS AND CURRENT PROGRESS

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**Abstract**
*In this paper some methods for 3D printing of polymeric components were investigated, along with some typical representative of polymers used in practice. The paper presents a basic understanding of the current status of the 3D printing technology and hopes to give new insight on future tasks and problems regarding this topic.*

**Keywords:** 3D printing, additive manufacturing, polymers, thermoplastics.

## INTRODUCTION

Production of components and systems of components with well-established methods and processes has a significant value in all industrial fields as it sets the base for quality control of manufacturers. However, dictated from the everlasting need and desire for technological and scientific growth, new ideas and designs constantly arise. Traditional manufacturing and testing of new materials and components is a process related to high costs and high losses for every company in terms of time, resources, and expenses.

In order to resolve this issue a new method for efficient and rapid prototyping was developed in the 1980s based on manufacturing products following a layer-by-layer infrastructure. Compared to traditional methods for manufacturing such as milling the addition of material in the form of layers seems to be the complete opposite process. Some of the benefits of manufacturing components this way are as follows:

- less waste of material;
- lower costs;
- lower production time;
- low energy consumption;
- high accuracy of production;
- highly customizable products;
- excellent process control;
- automatization possibility and more.

Based on the excellent advantages of rapid prototyping in the late 1990s and early 2000s the term additive manufacturing was introduced. This was necessitated due to the beginning of the fourth industrial revolution, namely Industry 4.0 (I40). The last enforces the full production automation paradigm. It encompasses the possibility of using automated, man-maintained, machines capable of self-regulation and self-learning (machine learning). These are typically either robots or cobots, however, other specially designed machines have been proposed before.



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The production of components using additive manufacturing can and typically is fully automated, which is in agreement with the I40 paradigm. 3D computer designs are converted into a program code that is injected into the control unit of the robots or cobots. Along with the design initial technological conditions are introduced in order to begin the process. The output products are monitored using specialized sensors and if any inconsistencies with the given design are detected the machine learning algorithm is capable of automatic variation of the technological conditions until minimal error between the input/output is detected.

Although 3D printing has proven as a viable method for modeling and producing components for practical applications, since the methods for printing are relatively new and less explored compared to traditional ones there are still some unknown specifics of the process related to the structure-technological conditions ratio.

This short review aims to introduce the current status of 3D printing of polymers and discuss future improvements and relationships between the structure and technological conditions.

## EXPOSITION

Rapid prototyping (3D printing) as we know it today was introduced in 1980s. Two specific techniques used for manufacturing components stood out, namely the fused filament fabrication (FFF) technique as shown in figure 1 (a), and the stereolithography (SLA) technique as shown in figure 1 (b). Fused filament fabrication was developed by the company Stratasys. In this processes a tubular filament (typically with a diameter of 1.75 mm) is fed into a heated head. The filament turns into a semi-liquid substance at which point it is extruded through a nozzle with a diameter of 0.4 mm. Due to the semi-liquidus state of the extruded material it solidifies rapidly forming a solid layer. Due to the specifics of this manufacturing process some of the main factors determining the output characteristics of the layers are nozzle temperature, bed temperature, purity of the filament, deposition speed, thickness of the layer, flow rate of the filament, material viscosity, and more.

The advantages of this method are the low cost, the low preparation process, minimal waste, ease of production, minimal (if any) post processing needed. Some of the disadvantages are related to the low accuracy, high printing time, and uncontrollable shrinkage of the material [1].

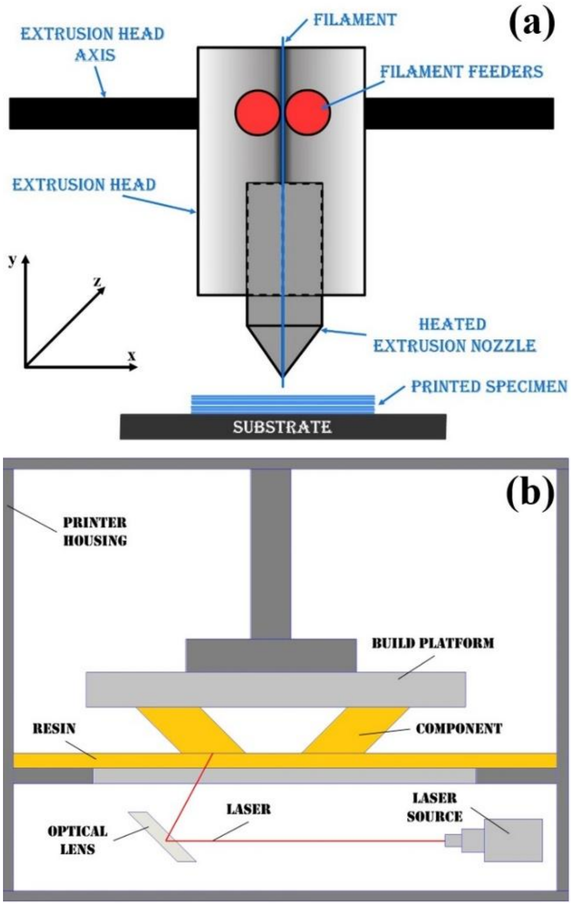


***Fig. 1.*** *Fused filament fabrication technique (a); stereolithography technique (b).*

Comparatively stereolithography was also developed as a 3D printing technique in the 1980s by Hideo Kodama. This process is based on using a UV sensitive resin in a liquidus state. The build platform is dipped in the resin and the desired layer geometry is irradiated by a laser with a wavelength in the ultraviolet range (200-300 nm). The resin hardens in the irradiated zone and the layer is formed. This process is performed a number of times until the component is finally formed. In this case the output characteristics of the layers is not so much a function of the material properties or deposition speed, but a function of the irradiation time [2].

The advantages of this technique are: high deposition accuracy, easy building of components with complex external and internal geometries, fast manufacturing speed, and more. The disadvantages, as compared to FFF, are the higher price and the necessity for post-processing of the components, which need to be carefully washed and hardened further in a special UV curing machine.

Typically, the most common materials used for 3D printing are different types of polymers such as polylactic acid (PLA), polyethylene terephthalate glycol (PETG), acrylonitrile butadiene styrene (ABS), acrylonitrile styrene acrylate (ASA), polyamide (PA), and others, due to their excellent processing and forming potential at low temperatures (usually in the range between 200-300 °C).

Polylactic acid (PLA) (H-[$OCHCH_3CO]_n$-OH) is one of the most commonly used materials for 3D printing. This polymer's primary ingredient is lactic acid, which is produced by fermenting corn starch or sugarcane. The lactic acid is used to form lactide, which undergoes a ring-opening polymerization process [3]. Since PLA is produced of natural substances, as opposed to petroleum based ones, it has a very high degree of biocompatibility and can easily be used in the medical field for drug containers, tissue engineering, medical sutures, and others [4]. Of course the properties and applications of any 3D printed material are a direct function of the technological conditions used during the manufacturing stage. Although every filament's manufacturer tests their products and suggests some optimal parameters of printing some are still left for the component designer to figure out such as the correct infill density, and infill patterns. Previous research has been conducted in that regard and the authors [5,6] have found that increasing the infill density increases the strength of the component, and applying either grid or triangular infill patterns results in obtaining the highest possible component strength. Despite the excellent results new methods have been proposed to further increase the strength of PLA made components by reinforcing its matrix with carbon fibers. Research supports this hypothesis and suggests that adding carbon fibers to the polymer increases its tensile strength nearly threefold from 28 MPa to 80 MPa [7].

Another common material used for 3D printing is polyethylene terephthalate glycol (PETG), which is an amorphous copolymer manufactured by combining polyethylene terephthalate with a glycol modifier such as 1.4-cyclohexanedimethanol (CHDM). As a result, a high-strength polymer is formed with excellent mechanical and thermal properties, perfect for implementation in the 3D printing technology [8]. PETG is typically known to have higher strength and chemical resistance compared to PLA, and replaces it where emphasis is paid to these factors. Again, as with PLA, the manufacturing of PETG requires a deep understanding of the relationship between structure and technological conditions. Due to this a number of researchers have been investigating the possibilities of increasing component strength by selecting optimal conditions such as: infill patterns, infill densities, post-thermal treatments, and more [9–11] Even though PETG is not as ecologically friendly as compared to PLA, it can very easily be reprocessed as confirmed by Dohan et al. [12] who proposed a method for turning waste PETG material into a reusable filament with no evident loss of mechanical strength.

Acrylonitrile butadiene styrene (ABS) is a polymer consisted of the following monomers: acrylonitrile; butadiene, styrene. They build up the matrix of the polymer and depending on their proportion it changes its functional properties and thus application [13]. Higher concentrations of butadiene increase the strength and impact resistance of the polymer, and higher concentrations of acrylonitrile result in better thermal and chemical properties. Owning to its incredible properties ABS has found a large number of applications such as in the automotive industry, in electrical engineering, for production of consumer items, production of pipes, in construction, and more. Due to the high practical interest in this material, 3D printable filaments have been developed and successfully integrated in the 3D printing industry. A number of research has been conducted so far in order to establish basic technological conditions related to good structure of the components, high mechanical strength, and low cost. Previous research, such as [14], claims that the best functional properties during FFF 3D printing of ABS can be achieved using a 65 mm/s printing speed, 100 % infill density, and a tri-hexagon infill geometry. In an attempt to expand the applications of 3D printed ABS components a recent research has investigated their application in cryogenic environments [15]. During the research such components were successfully made and incorporated in liquid nitrogen containers, however, high brittleness of the components was reported. Different additives have reportedly been used in ABS filament fabrication in order to produce components with improved strength such as carbon fibers [16]. Despite the excellent potential and characteristics of ABS it poses a known weakness in the form of poor UV resistance. To accommodate this issue butadiene can be replaced with acrylate to form a new type of a polymer, namely acrylonitrile styrene acrylate (ASA), which has similar mechanical properties compared to ABS, however, with the addition of a very high UV resistance [17, 18].

Of course the abovementioned polymers are just some of the many types of polymers that are used for 3D printing of components. Others also include polyamide (PA), polypropylene (PP), polyether ether ketone (PEEK), and many more. The correct choice of polymeric material is of course a function of desired cost of print, time of print, structure, mechanical properties, chemical properties, weather resistance, and other functional properties. In order to improve the functionality of already well-known polymeric materials, as mentioned above, the infusion of such with different additives such as carbon fibers was proposed. Additional substances used for this purpose are iron, antioxidants, zinc ferrite fibers, and much more. The post-processing of the build components is also another possible perspective that has currently been investigated such as the irradiation of polytetrafluoroethylene (PTFE) with a pulsed electron beam [19]. This was proven to positively affect the surface properties of the formed polymeric components and alter their functional properties as well [19].

In summary it can be concluded that the 3D printing technology is more than desirable due its attractive advantages and future possibilities. Due to the never-ending desire for perfection of both scientists and manufacturers new and improved materials for 3D printing are designed regularly with the sole purpose to improve or even just alter the functional properties of materials to either suit large scale manufacturing processes or a specific nièce application in unique designs.

## CONCLUSION

In this paper some methods for 3D printing of polymeric components were investigated, along with some typical representative of polymers used in practice. The paper presents a basic understanding of the current status of the 3D printing technology and hopes to give new insight on future tasks and problems regarding this topic.

## REFERENCE

[1] Kai, C; Fai, L; Sing, L (2003). Rapid Prototyping: Principles and Applications. Singapore: World Scientific. p. 124. ISBN 978-981-238-117-0.

[2] Jiang, T; Yan, B; Jiang, M; Xu, B; Gao, S; Xu, Y; Yu, Y; Ma, T; Qin, T. Study of

Forming Performance and Characterization of DLP 3D Printed Parts. Materials 16 (2023) 3847.
[3] Eynde, M; Puyvelde, P. (2017) Advanced Polymer Science. Springer Nature Link. p. 139-158. ISSN 1436-5030.
[4] Liu, Z; Wang, Y; Wu, B; Cui, C; Guo, Y; Yan, C. A critical review of fused deposition modeling 3D printing technology in manufacturing polylactic acid parts. The International Journal of Advanced Manufacturing Technology 102 (2019) 2877-2889.
[5] Aloyaydi, B; Sivasankaran, S; Mustafa A. Investigation of infill-patterns on mechanical response of 3D printed poly-lactic-acid. Polymer Testing 87 (2020) 106557.
[6] Wang, X; Huang, L; Li, Y; Wang, Y; Lu, X; Wei, Z; Mo, Q; Zhang, S; Sheng, Y; Huang, C; Zhao, H; Liu, Y. Research progress in polylactic acid processing for 3D printing. Journal of Manufacturing Processes 112 (2024) 161-178.
[7] Li, N; Li, Y; Liu, S. Rapid prototyping of continuous carbon fiber reinforced polylactic acid composites by 3D printing. Journal of Materials Processing Technology 238 (2016) 218-225.
[8] Valvez, S.; Silva, A.; Reis, P. Optimization of Printing to Maximize the Mechanical Properties of 3D-Printed PETG-Based Parts. Polymers 14 (2022) 2564.
[9] Baltic, M.; Vasic, M.; Vorkapic, M.; Bajic, D.; Pitel, J.; Svoboda, P.; Vencl, A. PETG as an Alternative Material for the Production of Drone Spare Parts. Polymers 16 (2024) 2976.
[10] Kadhum, A.; Al-Zubaidi, S.; Abdulkareem, S. Effect of the Infill Patterns on the Mechanical and Surface Characteristics of 3D Printing of PLA, PLA+ and PETG Materials. ChemEngineering 7 (2023) 46.
[11] Srinivasan, R.; Ruban, W.; Deepanraj, A.; Bhuvanesh, R.; Bhuvanesh, T. Effect on infill density on mechanical properties of PETG part fabricated by fused deposition modelling. Materials Today: Proceedings 27 (2020) 1838-1842.
[12] Dohan, V.; Galatanu, S.; Marsavina, L. Mechanical evaluation of recycled PETG filament for 3D printing. Fracture and Structural Integrity 70 (2024) 310-321.
[13] Vishwakarma, S; Pandey, P; Gupta, N. Characterization of ABS Material: A Review. Journal of Research in Mechanical Engineering 3 (2017) 13-16.
[14] Yankin, A; Alipov, Y; Temirgali, A; Serik, G; Danenova, S; Talamona, D; Perveen, A. Optimization of Printing Parameters to Enhance Tensile Properties of ABS and Nylon Produced by Fused Filament Fabrication. Polymers 15 (2023) 3043.
[15] Bartolome, E; Bozzo, B; Sevilla, P; Martinez-Pasarell, O; Puig, T; Granados, X. ABS 3D printed solutions for cryogenic applications. Cryogenics 82 (2017) 30-37.
[16] Dul, S; Fambri, L; Pegoretti, A. Filaments Production and Fused Deposition Modelling of ABS/Carbon Nanotubes Composites. Nanomaterials 8 (2018) 49.
[17] Hameed, A; Raj, S; Kandasamy, J; Shahzad, M; Badhdadi, M. 3D Printing Parameter Optimization Using Tagauchi Approach to Examine Acrylonitrile Styrene Acrylate (ASA) Mechanical Properties. Polymers 14 (2022) 3256.
[18] Zhang, Y; Xu, Y; Zheng, Q. Study of poly(vinyl chloride)/acrylonitrile-styrene-acrylate blends for compatibility, toughness, thermal stability and UV irradiation resistance. Journal of Applied Polymer Science 130 (2013) 2143-2151.
[19] Korzhova, A; Laput, O; Kazakov, A; Lazareva, N; Vasiliev, A; Tarasova, P; Kapitonova, N; Okhlopkova, A; Kurzina, I. Effect of surface treatment with pulsed electron beam on structural and functional properties of polytetrafluoroethylene. Basic Problems of Material Science 22 (2025) 272-281.