RESEARCHING AND TRENDS IN ADDITIVE MANUFACTURING POST-PROCESSING

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Rezumat. *În ultimul deceniu, fabricarea aditivă a devenit din ce în ce mai populară în diverse industrii, de la producția de piese aerospațiale și medicale până la bijuterii și design artistic. Cu toate acestea, chiar și cu tehnologiile de ultimă generație, piesele fabricate cu aditivi pot necesita o post-procesare pentru a îndeplini standardele necesare de calitate, finisaj și durabilitate. Acesta este motivul pentru care cercetările și tendințele în post-procesarea producției aditive devin din ce în ce mai importante în industrie. Această lucrare își propune să exploreze diverse tehnici și metode de post-procesare, precum și tendințele actuale în acest domeniu în continuă evoluție. Sunt evidențiate avantajele și dezavantajele fiecărei tehnologii, precum și principalele tehnici de post-procesare pentru tehnologiile de imprimare SLA, SLS și FDM, prezentându-se câteva exemple de piese și rezultatele obținute în funcție de tehnologia utilizată și de materialul din care piesele au fost realizate.*

Abstract. *In the last decade, additive manufacturing has become increasingly popular in various industries, ranging from the production of aerospace and medical parts to jewelry and art design. However, even with state-of-the-art technologies, additive manufactured parts may require post-processing to meet the necessary quality, finish, and durability standards. This is why research and trends in post-processing of additive manufacturing are becoming increasingly important in the industry. This paper aims to explore various techniques and methods of post-processing, as well as current trends in this continuously evolving field. There are exposing the advantages and disadvantages of each technology, as well as the main post-processing techniques for SLA, SLS, and FDM printing technologies, providing some examples and the results obtained depending on the technology used and the material from which the objects were printed.*

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1. Introduction

Manufacturing through additive technologies represents an important component in industrial engineering, allowing the generation of three-dimensional objects by adding successive layers of material until the final product is built. Typically, a part is classified as additive manufactured when is produced using one of the known technologies, such as stereolithography (SLA), selective laser sintering (SLS), laser powder bed fusion (SLM), multi-jet fusion (MJF), fused deposition modeling (FDM), and direct ink writing (DIW) [1].

All additive manufacturing (AM) technologies have advantages and disadvantages, being suitable for specific applications, such as prototypes generation, parts with complex geometry, or custom objects. This article will point the advantages and disadvantages of each technology, starting with SLA, which is one of the first 3D printing technologies that can produce objects with fine details and smooth surfaces. However, is also highlighting the technologies associated with high production costs, limited dimensional capabilities, and the use of potentially toxic raw materials, which can pose health and safety risks for users.

Post-processing methods in additive manufacturing instead refer to techniques and procedures applied to 3D-printed objects to improve their properties, such as aesthetic appearance, surface quality, hardness, or strength. These techniques include mechanical finishing, painting, polishing, bonding or welding, thermal and chemical treatments, etc., but all of these treatments are applied depending on the printing technology and materials from which the objects were generated. Subsequently, we will explore some post-processing techniques for 3D printing technologies such as SLA, SLS, and FDM, providing some examples and results following the application of some of these finishing or post-processing procedures.

2. The main additive manufacturing technologies

Today, additive manufacturing represents an important component in industrial engineering, allowing the generation of three-dimensional objects by adding successive layers of material until the object is built. We generally classify a part as additive manufactured when it has been produced by using one of the following known technologies:

- Stereolithography or SLA is an additive manufacturing technology that uses a UV laser to solidify a photosensitive printable material, in the form of a liquid that solidifies layer by layer, until creates a three-dimensional model [2];

- Selective Laser Sintering or SLS is an AM technology that uses a laser to selectively melt material powder, thus building a three-dimensional part by adding successive layers of melted powder [3];
- Selective Laser Melting or SLM is a technology that involves using a laser to melt metal powders and solidify them into a three-dimensional model, thus used to generate objects from metals [4];
- Fused Deposition Modeling or FDM is the classic and perhaps the most used AM technology that involves using a filament made of various thermoplastic materials that can be heated to different temperatures and then extruded layer by layer into a part [5];
- Multi Jet Fusion or MJF is an AM technology that uses a thermal inkjet to melt a material in the form of a powder and then fuse it together to generate a three-dimensional part or object [6];
- Digital Printing Machine or DPM is an AM technology that uses a material jet to deposit material onto a substrate layer by layer to generate three-dimensional objects [7].

These are the main AM technologies used today in various industries or among amateur users passionate about designing and creating objects or technical parts, including artists. In the following, we will present the advantages and disadvantages of each technology.

2.1. The advantages and disadvantages of SLA printing technology

SLA parts manufacturing is a relatively accessible technology both in the industry and to general users due to the availability of lower-cost printing equipment on the market. Obviously, depending on the printing equipment, parts with different characteristics can be obtained, depending on the performance of each 3D printer.

One of the most notable advantages of this technology is its high precision, as stereolithography allows the production of objects with very fine details and extremely smooth surfaces, making it ideal for generating prototypes and parts with complex shapes. Compared to other 3D printing technologies, SLA can produce parts relatively quickly, and the diversity of materials accessible to this technology allows for the generation of parts in a wide range of materials such as acrylic resins, epoxies, photopolymers, and even other photosensitive materials. Finally, as in most AM technologies, customization is one of the most important advantages as it allows parts to be customized according to the needs and specifications imposed by clients or users [8].

Regarding the disadvantages of SLA technology, we can mention the high production costs, as this is one of the most expensive additive manufacturing technologies, especially when the use of specialized equipment and expensive materials is required. The materials used in stereolithography can be very toxic, and because they are in a liquid state, they can emit dangerous vapors that can cause health and safety problems for those who directly use this technology [8].

SLA technology imposes dimensional limitations on parts because the solidification process using laser light is limited to a certain depth, and finally, the fragility of the parts is a notable disadvantage because objects generated using this technology are sensitive to scratches or other types of physical damage (Fig. 1).

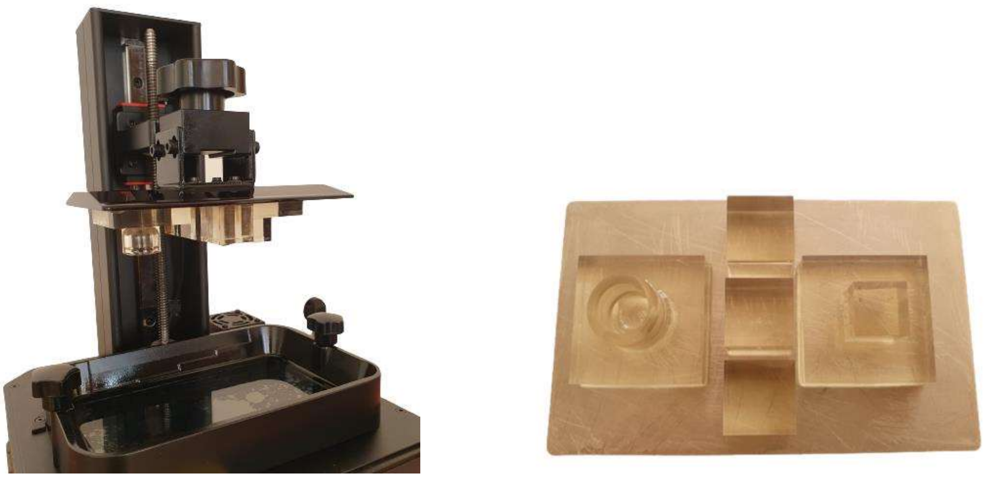


Fig. 1. Parts printed with SLA technology using colorless resin.
a. Parts after completing the SLA printing process; **b.** Parts attached to the printing bed.

2.2. The advantages and disadvantages of SLS/SLM technology

The advantages of SLS/SLM 3D printing technology include the ability to use a wide variety of materials such as plastics, metals, ceramics, etc., making it suitable for various applications, and the durability of the parts produced by SLS/SLM has shown resistance to stress and wear, making them suitable for industrial applications. The printing process of parts does not require the generation of raft structures as objects are generated by selectively melting a powder, and no support structures are needed even for models with complex geometries or inclined surfaces. Furthermore, this technology can produce very fine details and smooth surfaces, as well as complete functional assemblies [9].

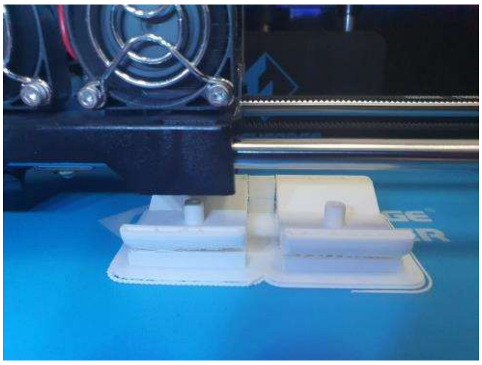
As for the disadvantages, SLS/SLM technology involves high costs and is, along with SLA, one of the most expensive additive manufacturing technologies, as the equipment used is expensive, depending on the materials that can be used with it, and the production time is relatively long compared to other technologies, because involves selectively melting each layer of powder. The size of parts produced by SLS/SLM is limited to the size of the machine's working chamber and its temperature limitations (Fig. 2). The production process of parts using SLS/SLM involves powder residues that must be properly removed after each use, which is a laborious process that can affect the health and safety of direct users of this technology [9, 10].

Fig. 2. Additive manufacturing using SLS technology.
a. LISA Pro 3D printing equipment; **b.** Assembly from Sinterit sample box.

The advantages and disadvantages of FDM technology

The FDM printing technology presents relatively low equipment costs, making it one of the most accessible technologies, especially for amateur users or small businesses. Also, the wide availability of materials that can be used within this technology, including thermoplastic materials such as ABS or PLA, is a plus. The parts manufactured with FDM present good details and finishes and offer flexibility in producing parts of different sizes, from small objects to very large ones, depending on the printing bed of the equipment (Fig. 3). Lastly, is a relatively simple and intuitive technology to use, making it very popular, especially in educational purposes [11].

As for the disadvantages of this technology, we can start by mentioning the relatively low precision compared to other 3D printing technologies, due to the large dimensions of the deposited layers and the risk of deformation of parts during the printing process. We can also include limitations of materials and layer structures that can limit the performance of parts for specific industrial applications, the relatively long time to generate parts compared to other printing technologies, especially if we want high quality or if we work with materials that are more difficult to print with FDM technology (TPU materials), and the difficulty of reproducing fine details due to the thickness of the layers [11].



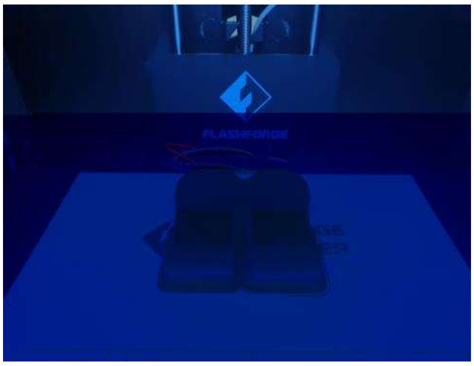


Fig. 3. Additive manufacturing using FDM technology.
a. Part printing with Creator Flash Forge; **b.** 3D finish part printed.

3. Additive manufacturing post-processing techniques

The post-processing methods in additive manufacturing are techniques and procedures applied to 3D printed objects to improve their properties, such as aesthetic appearance, surface quality, hardness, or strength. These methods include mechanical finishing, painting, polishing, bonding, or welding, thermal and chemical treatments, etc. However, all these treatments are applied depending on the printing technology and materials from which the objects were generated. In the following, we will explore some post-processing techniques for 3D printing technologies such as SLA, SLS, and FDM, providing some examples and results after applying some of these finishing or post-processing procedures.

3.1 Post-processing techniques of SLA technology 3D printed parts

Some of the most used post-processing methods for SLA printed parts include:

- cleaning and raft removal from the printed structure involves removing of any excess material from the part, or simply removing the part from the build platform using manual tools (Fig.4) or finishing equipment;

Fig. 4. Removing the parts from the building platform with the help of a putty knife.

- painting the parts by applying acrylic paint to improve the aesthetic appearance of the part, or to fill in any gaps or imperfections in the part surface;
- polishing with abrasive materials such as polishing paste or a variable speed polisher to achieve a smoother and glossier surface [12];
- heat treatments are used to improve the mechanical properties of the part such as hardness, dimensional stability, or heat resistance, and can be done by heating the parts to high temperatures or treating the parts with UV radiation (UV curing - Fig. 5) [12];

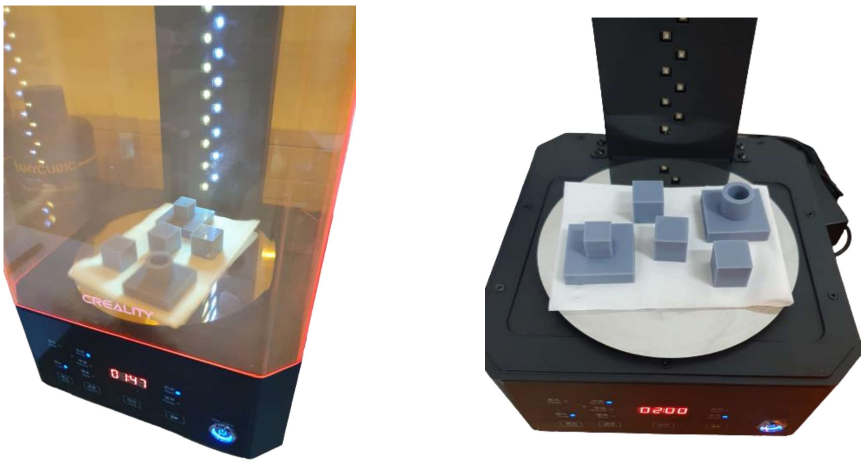


Fig. 5. UV curing of parts printed by using SLA technology.
a. Parts during UV curing; **b.** 3D parts after the UV treatment.

- painting with photopolymers is a method that involves applying additional layers of photopolymerizable material to a part, which is then exposed to UV light.

For all the parts represented in Fig. 4 and Fig. 5, a prior cleaning was performed by immersing them in an isopropyl alcohol bath to remove uncured resin residue before being subjected to the UV treatment.

These mentioned techniques represent some of the main methods of post-processing for parts fabricated using SLA, with the techniques being adapted according to the specific needs of each part and the printing technology used.

3.2 Post-processing techniques of SLS technology 3D printed parts

Although this technology has many advantages, especially the ability to 3D print complex objects directly assembled, post-processing the parts represents a quite laborious method. The first post-processing stage is simply removing the cake from the printing equipment as shown in Fig. 6, placing it inside a clean and dry container, where the unsintered powder is separated from the 3D printed objects. After the objects are removed from the powder, brushes of different sizes can be used to remove the powder stuck on the part's surface [13].

Fig. 6. Post-processing parts printed with SLS technology.
a. Cake removing from the printing equipment; **b.** Separating parts from the powder.

This is the simplest post-processing stage of the parts, it should be noted that the unsintered powder can be reused to a certain percentage with new powder, only after it has been sieved (Fig. 7, a), this can be done manually or using special powder separation equipment, and the printing equipment is carefully cleaned using brushes and specially designed vacuum cleaners because conventional vacuum cleaners deteriorate quickly due to the fact that the powder is very fine and can even reach the vacuum cleaner electrical engine. Additionally, the SLS powder is very demanding in terms of storage conditions, this process of cleaning and separating the powder must be done as quickly as possible because the powder absorbs humidity from the environment quickly and this aspect should be avoided, besides that it must be stored in special containers with hermetic closure, even the cap must be sealed with another layer of duct tape for example, if the powder will not be used for a longer period of time [13].

After completing this entire cleaning process, the parts can be further post-processed depending on the materials they are made of using one of the methods below:

- sanding involves using abrasive paper to finish the surface of the objects and can be useful in eliminating roughness or various imperfections that may appear on the part's surface after the printing process;
- painting is usually used in SLS to give the object a color and a possible shine of its surface; it can also be useful in eliminating fine scratches or minor imperfections;

Fig. 7. SLS post processing techniques.
a. Passing the used powder through the Sinterit sieve; **b.** Sandblasting preparing process.

- steam polishing is a process that involves using steam jets to smooth the surface of the objects;
- lacquer coating is used for SLS printed objects to protect the part from water, dust or other destructive elements, while also representing a method of improving the appearance and durability of the 3D printed objects;
- sandblasting is a method that involves using a sand jet to smooth the surface of the object in a controlled environment and helps to remove residue from the surface of the SLS printed objects and improve their appearance (Fig. 7, b);
- wax finishing involves applying a layer of wax on the object surface, so that it creates a smoother surface and can also improve its appearance and increase its durability.

Usually, is recommended to choose the appropriate finishing method based on the specific needs and preferences of the SLS manufactured object, the application to which the object is intended and the special requirements of the user (Fig. 8).

Fig. 8. Articulated finger prosthesis printed by using SLS technology [14].

3.3 Post-processing techniques of FDM technology 3D printed parts

In the following we will present the most common methods for finishing FDM printed objects such as:

- sanding by using abrasive paper, which can be done manually or with special electrical equipment; this process involves sanding the outer layer of the object, usually starting with a coarse grit and gradually moving to a finer grit depending on the quality of the printed object and its intended application, with the goal of achieving a smoother surface (Fig. 9) [15];

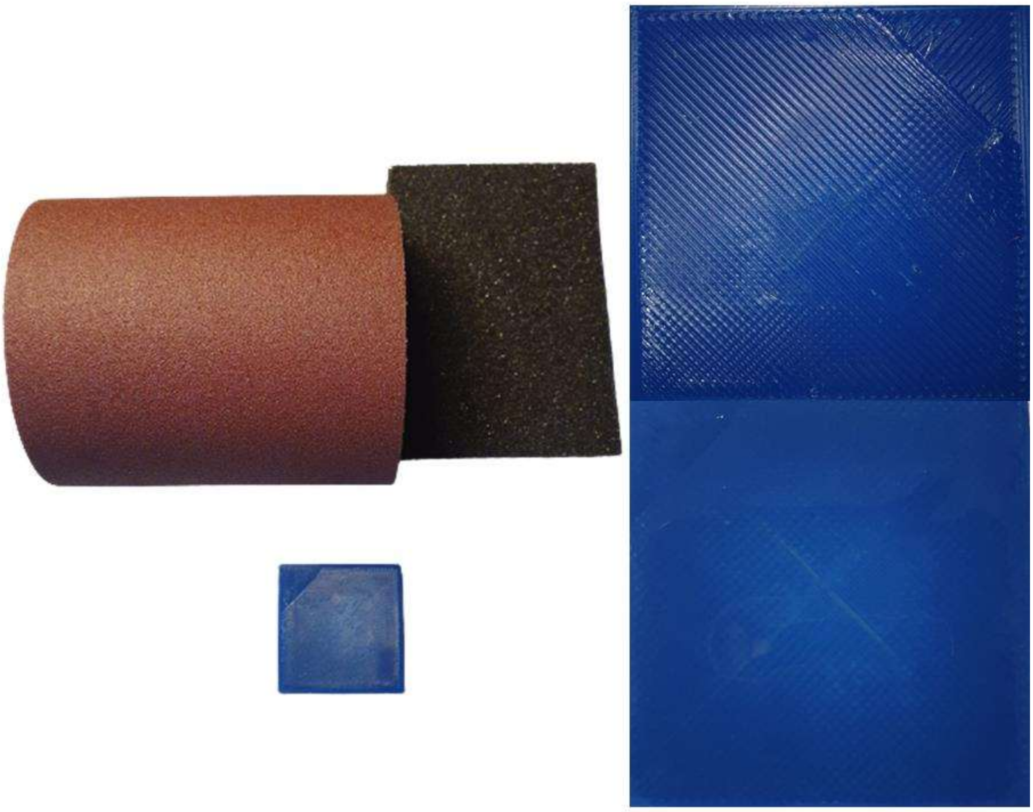


Fig. 9. 3D printed PETG part before and after post-processing with different grit sandpapers.

- chemical finishing treatments with chemical substances such as MEK (Methyl Ethyl Ketone), which can melt the external surface of FDM printed parts with plastic materials to generate a smooth surface (Fig. 10);
- heat treatment, which can be used to transform the surface of printed parts into a smoother and glossy surface for materials such as TPU (Fig. 11);
- filling gaps with special materials such as Bondo, which is sprayed on the object's surface to fill in gaps resulting from printing errors and make the surface much smoother (Fig. 12) [18, 19];
- coating FDM printed surfaces with epoxy resin to add a protective layer and make the surface much glossier [18];

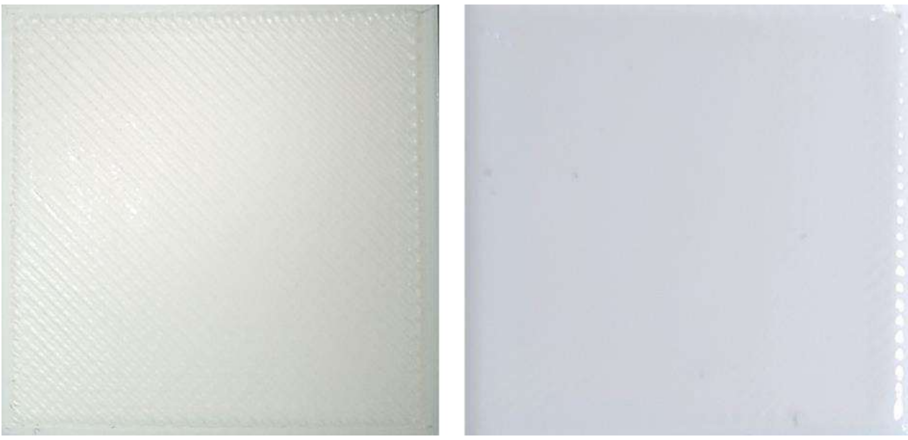


Fig. 10. 3D printed ABS-white color surface part before and after post-processing with industrial Acetone [16].

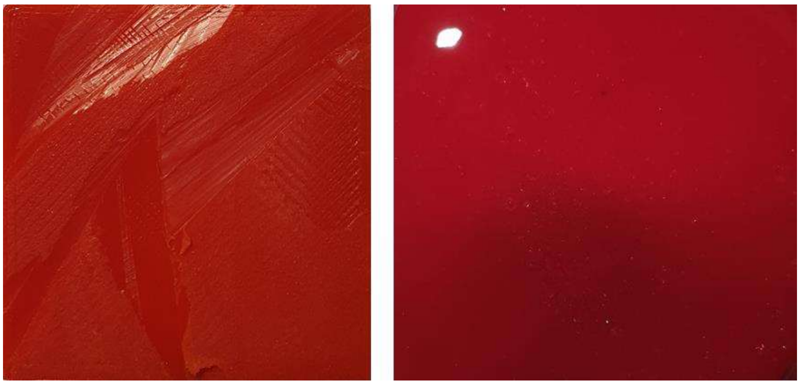


Fig. 11. 3D printed TPU 83A part before and after thermal post-process [17].

Fig. 12. 3D printed ABS white color part before and after painting process with chrome spray.

- painting the external surface of the parts to make them more aesthetically pleasing [19, 20];
- applying protective coatings to increase the durability of the parts or to make them shinier [18, 20];

- applying self-adhesive film to the parts to protect them and give them a more attractive appearance;
- polishing with polishers to remove any marks or imperfections that may have resulted from the 3D printing process [20];
- sandblasting with compressed air to remove any dust or impurities from the surface of the parts [21].

Conclusions

This article presented various post-processing techniques and methods applied to 3D printed objects to improve their properties such as aesthetic appearance, surface quality, hardness, or strength. The mentioned methods are adapted according to the printing technology used and include mechanical finishing, painting, polishing, heat, and chemical treatments, etc. Post-processing parts can be a laborious method that requires careful part cleaning and its separation from the raft in the case of some technologies.

As the industry continues to evolve, new finishing techniques and trends will emerge, further improving the overall quality and capabilities of 3D printing technology.

Abbreviations

AM – Additive Manufacturing

SLA – Stereolithography

SLS – Selective Laser Sintering

SLM – Selective Laser Melting

FDM – Fused Deposition Modeling

MJF – Multi Jet Fusion

DPM – Digital Printing Machine

DIW – Direct Ink Writing

UV – Ultraviolet radiation

ABS – Acrylonitrile Butadiene Styrene

PLA – Polylactic Acid

TPU - Thermoplastic Polyurethane

MEK – Methyl Ethyl Ketone

R E F E R E N C E S

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