International Journal of Manufacturing Economics and Management
ISSN 2784-1278 ISSN-L 2784-1278, Vol. IV, No. 1 / 2024
https://doi.org/10.54684/ijmem.2024.4.1.43

WAYS TO REDUCE COMMON IMPERFECTIONS IN 3D PRINTING

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Abstract: 3D printing, or additive manufacturing, has greatly transformed multiple industries by allowing the creation of intricate designs and forms. Nevertheless, despite these advancements, the technology still confronts notable obstacles such as expensive costs, slow printing speeds, restricted part sizes, limited strength and why not imperfections that appear due to equipment, parameter settings or other various reasons. Fused deposition modelling (FDM) is a rapidly expanding technique in the field of additive manufacturing, namely in printing. The performance of the printed parts produced as a result is constrained in comparison to those achieved through alternative manufacturing methods, mostly due to the inherent shortcomings. Therefore, there has been an increased focus on developing strategies to address these limitations in recent years. The primary objective of this study is to identify and examine the primary weaknesses that may arise, as well as to explore the existing techniques for mitigating or reducing them, with the aim of improving the functional characteristics of the printed components.

Key words: 3D printing, FDM, defects, improvements, limitations.

1. INTRODUCTION

Additive manufacturing is one of the best technologies on the market today, enabling the use of a growing variety of greener materials. They fall into three main categories: formative manufacturing (injection molding, molding, molding, stamping and forging), layer removal manufacturing (turning, drilling and CNC) and additive manufacturing. In recent decades, the advantages of traditional manufacturing technologies have outweighed those of additive manufacturing technology. Complex, precise, inexpensive designs and utilization of functional materials based on demand can be quickly realized with 3D modeling [1-4].

Although 3D printing is not an entirely new technology, the benefits of inexpensive and open-source 3D printers have led to a significant proliferation of this technology. As shown in Figure 1.1, 3D processing can be divided into several categories depending on the deposition method used by the printing technology: VAT Photopolymerization - refers to prototyping technologies such as selective laser sintering (SLS), stereolithography (SLA) and digital light exposure (DLP and CDLP), which use plastic materials to produce parts with fine cuts and smooth surfaces. It is used in fields such as dentistry, biology and general medicine. Powder Bed: technologies such as electron beam melting (EBM), direct metal laser sintering (DMLS), multi-jet sputtering (MJF) and other printing methods use metal or plastic powder to create parts with complex geometries. The Thermoplastic Extrusion Molding (FDM) method uses molten plastics to create prototypes in a short time. Material sputtering (including material sputtering and nanoparticle sputtering) is a process that uses wax, plastics, metals and other materials to make prototypes, providing exceptional detail, high accuracy and the ability to print multiple colors in a single object; Binder sputtering - uses gypsum, sand and metal to create architectural designs; Laser Engineered Net Shape (LENS) and Electron Beam Additive Manufacturing (EBAM) are two examples of direct energy deposition that use metallic materials ideal for repairing or adding materials to existing parts [3, 4].

The most widely used additive manufacturing process is thermoplastic extrusion molding (FDM), which is a trade name registered by Stratasys and known in the literature as filament extrusion manufacturing - filament extrusion manufacturing (FFF). To build an FDM landmark, solid thermoplastic wires are deposited layer by layer along a specified path [3-5].

Additive manufacturing, also referred to as 'rapid prototyping' or '3D printing', is a modern manufacturing method in which a layer of material is deposited at one time (sequentially) until a finished product is obtained. A solid marker can be obtained by processes such as material extrusion, VAT photopolymerization, powder bed fusion, material sputtering, binder sputtering and direct energy deposition, depending on the phenomenon and the material used by the 3D printing machine. At this stage, the FDM prototyping technique and the different types of tests that are used to determine the characteristics of plastics are discussed in particular. Many companies, research institutions and consumers are starting to use FDM technology to optimize costs, product quality, functionality and manufacturing time, [5-9].

2. DESIGNING AND PRINTING PART

2.1. Designing the print part

The 3D model, figure 1, FDM method - Fused Deposition Modeling, is converted into STL format (which only describes the surface geometry of the 3D object) and then imported into a prototyping simulation program, which also involves setting the technological process parameters. In this project, an ABS - Acrylonitrile Butadiene Styrene Butadiene Styrene (green color) wire with a diameter of (1.75±0.05)mm was selected as prototyping material.
The software package PrusaSlicer version 2.7.2. used by Original Prusa i3 MK3 printer, simulates the rapid prototyping process, figure 2. The printing simulation software provides precise information on the amount of material (in grams and/or meters) to be used for the landmark prototyping, as well as the time needed to make each type of layer.

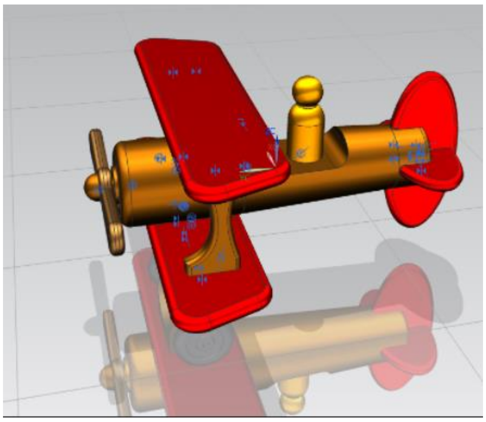


Fig. 1. 3D model of the part to be printed

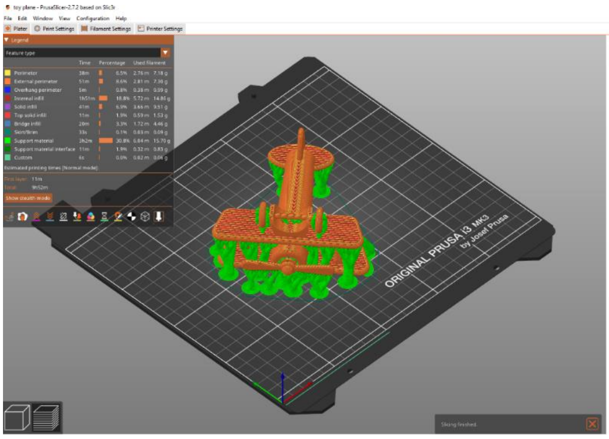


Fig. 2. 3D model of the ABS assembly ready for prototyping

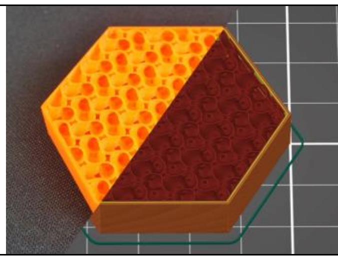
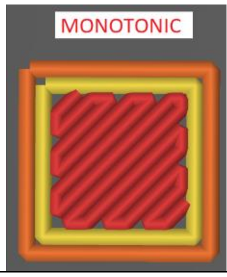
2.2. Setting input parameters

According to specialized literature the technical specifications to be considered when printing with this ABS material are as follows
- Glass transition temperature: 105°C;
- Recommended printing temperature: ~230°C;
- Recommended printing table temperature: ~100°C;
- A closed printing enclosure is required;
- Filament drying is not required, but always recommended.

The printout parameters set before assembly/part execution are given in Table 1:

Table 1. Input parameters

Parameters	Description
Height of deposited layer	0.2mm
Degree of fill	25%
Type of fill	Gyroid

	
Filling type top/ bottom	Monotonic  
Infill angle	+45°/-45°
Orientation of the sample on the printing table	flat
Nozzle temperature	215°C
Speeds for printing movements	
Perimeters	60mm/s
Reduced perimeter	25mm/s
Outer perimeter	35mm/s
Filling	200mm/s
Solid top filling	50mm/s
Support material	50mm/s
Support - part interface	100mm/s
Gap fill	40mm/s
Speeds for non-printing movements	180mm/s
Layer thickness	0.2 mm
Vertical outer layer	2 buc
Start outer horizontal	4 pieces (top) & 4 pieces (bootom)
Outer layer thicknes	0.7 – top, 0,5 -bottom

Due to the fact that the geometry of the model was not a simple one, involving the construction of inclined faces, the construction of a forming support was necessary, Figure 3.

Fig. 3. Print-piece support

2.3. Print the part

The size of the printed part was (115,16x110,41x60,21) mm, the amount of wire used was 62,69g/24,05m, figure 3.5. The equipment used for printing the part was Original Prusa i3 MK3.

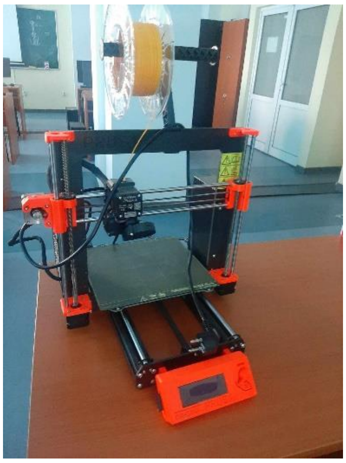


Fig. 4. Printer - Original Prusa i3 MK3

Fig. 5. 3D printed ABS part (airplane)

2.4. FDM 3D printed part post-processing: support removal

Media removal is the first technique used for post-processing 3D FDM printed parts. Removal was done manually, with pliers and cutters. Backing removal usually leaves some marks on the contact points, but these can be further post-processed for a finer finish. Figure 6 shows the removed support structures.

Fig. 6. Material removed after post-processing

3. DEFECTE ÎN PRINTARE PRIN EXTRUDARE DE MATERIAL

3.1. Identify printing defects and make recommendations

Detaching the support

In order to print intricate models, it is necessary to use one or two supports. While removing supports can be challenging, they are sadly a crucial component of the modelling process. The role of the support is straightforward: it provides assistance, but sometimes fails, resulting in the model being left without support (see Figure 7). It should be noted that throughout the extrusion process, the support structure may exhibit an uneven look, develop cracks, or gradually get thinner. The supports not only fail, but the additional filament also undermines the pattern instead of guaranteeing proper printing.

What is the underlying reason of this issue in 3D printing?

Support structures are intricate entities, and the majority of slicer/felter apps provide multiple choices. Adhering to default parameters does not ensure the success of 3D printed superstructures, despite the simplicity it offers. A crucial factor to consider is the type of support that will ensure the model remains solid and well-supported during the printing process.

After the printing process is over, it is often straightforward to remove lines and zigzags. However, these lines and zigzags do not give much rigidity throughout the printing process. Triangles and grids provide enhanced structural reinforcement but can provide challenges when it comes to removal.

We advocate a straightforward bridge design with supporting columns. Choosing lines or zigzags as the pattern may result in the design shifting during printing, which might cause the fragile supports to shatter.

Utilising a rigid framework, such as a grid, would be a more advantageous choice.

Frequently, in tall designs, the supports might be excessively long, and the slender structure is stretched to its maximum capacity. When faced with these situations, it is crucial to select a sturdy foundation, such as a 'block'. Beneath substantial cantilevers, a robust support might be incorporated.

Removing supports can be quite challenging, thus there is a propensity to minimise their density as much as feasible. If the supports are load-bearing, increasing the density of the support is necessary to avoid potential issues.

Outdated or inexpensive filament can pose another issue. If the filament has exceeded its optimal lifespan, you may notice that it does not adhere well enough when extruded, resulting in poor bonding between layers. This can lead to messy and cracked extrusions, ultimately causing the supports to fail.

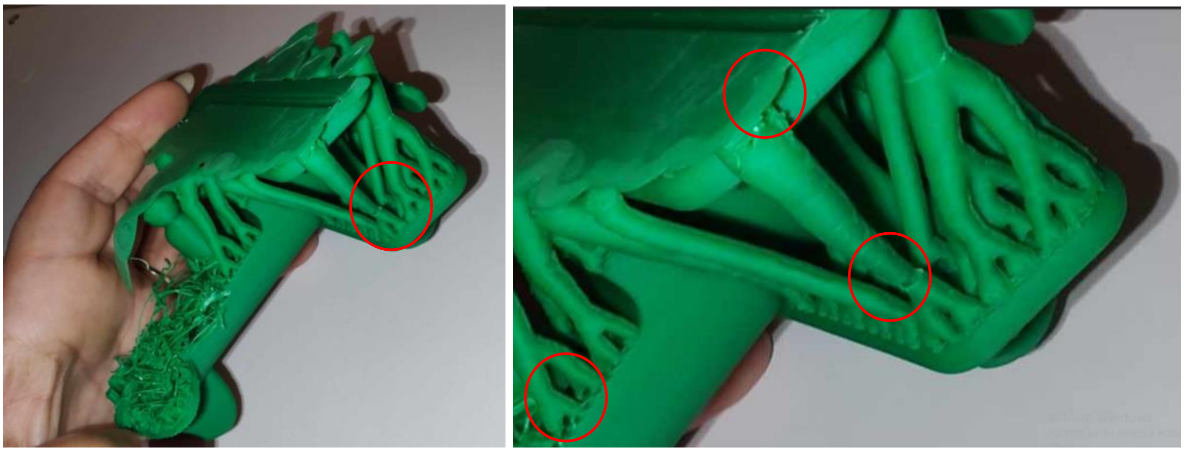


Fig. 7. Detached support

Therefore, if the component necessitates tall supports that connect different areas of the model and have sufficient contact with the platform, consider employing line or zigzag supports.

When the model has minimal touch with the platform or requires more robust support, it is advisable to utilise grid or triangle supports.

Enhancing the density of the support will result in a more compact structure for the model to rely on, making it less susceptible to any motion. However, it will also make the removal process significantly more challenging.

The user did not provide any text. As the filament nears the end of its functional lifespan, it tends to become fragile, resulting in a noticeable decline in the quality of the supports. It is advisable to replace the filament.

Poor surface quality over support

Occasionally, it is effective to decrease the layer height during 3D printing in order to improve the surface quality above the supports. This can be achieved by either increasing the cooling or reducing the printing temperature. Any factor that enhances the performance of the substrate will likewise be beneficial in this scenario, as depicted in Figure 8.

Indications of subpar surface condition across media:

The lower surface of an object that has been printed on a support structure formed by a slicer seems uneven, and may exhibit subtle deformations. Elucidation: The support structure generated by the slicer is unsuitable for the model setup and requires modifications.

Solution: - Fine-tuning the temperatures or layer height can enhance the surface quality of 3D prints. The conventional support structures for single extruder systems are engineered to facilitate easy detachment from the final product. Thus, they deliberately create a slight distance between the supporting framework and the model positioned above it. The vertical dimension of this gap can typically be modified in the slicer configuration. A narrower gap indicates higher quality, but also presents challenges in removal. If the gap is very tight, it may result in the media breaking and causing damage to the surface of the printed object.

- Acquire a twin extrusion system. By utilising water-soluble PVA rigid.ink or the readily removed Break-Away rigid.ink, printing can achieve a seamless transition from the substrate to the model, effectively removing any gap and the associated issues;
- Enhance the media density;
- Adjust the model's position to minimise the need for support structures.

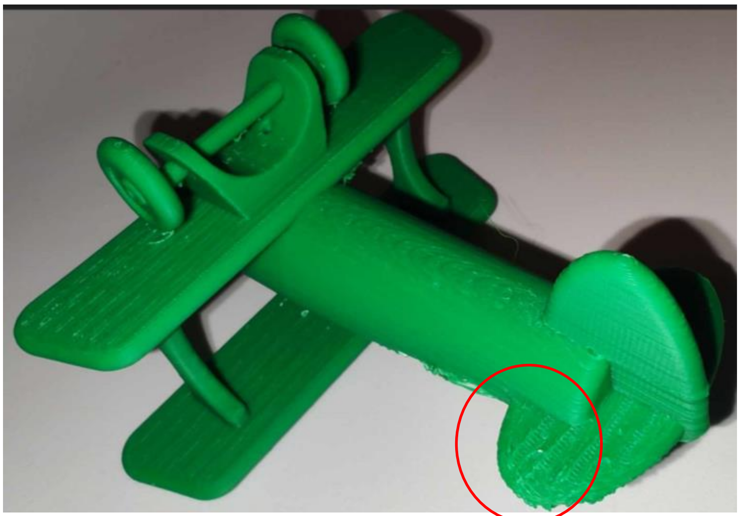


Fig. 8. Poor surface quality above the supports

Supports not functioning

Indicators of media failure include incomplete printing and the absence of Figure 9.

Support struts, especially when arranged with a low support density, lack stability and become more prone to failure as their height increases.

To address the issue, it is important to refrain from using isolated structures and instead opt for broader sets of supports.

- Decrease the printing speed specifically for the supports; - Utilise a greater media density and, if the slicer permits, a distinct media pattern;

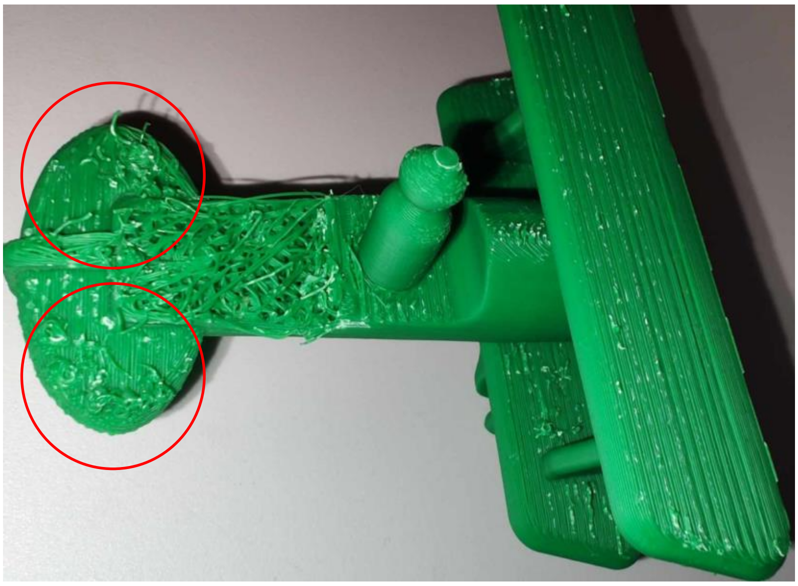


Fig. 9. Supports not functioning

Separating and splitting layers

This flaw, known as delamination, happens when the layers of a printed object separate, resulting in the failure of the print job. Flawless bonding between each consecutive layer is essential during the printing process. Alternatively, if the parts become detached and distorted, a significant amount of excess material may be generated. Cracks arise when the layers of a 3D print split as a result of the differential cooling speeds, which put stresses on the print. The deformation forces surpass the adhesive strength of the layers, resulting in the layers separating from one other, as seen in Figure 10.

Layer separation commonly occurs because to an excessive layer height, which results in the plastic being forced into a volume that is too large. The recommended layer height is approximately 20% less than the nozzle diameter to ensure adequate adhesion between the layers.

Low printing temperatures might hinder the chemical bonding processes of thermoplastics, leading to layer separation.

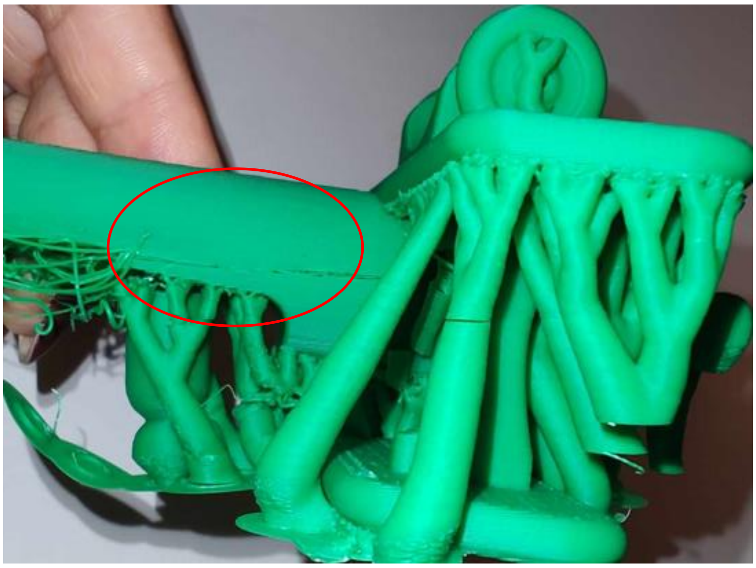


Fig. 10. Layer separation (delamination)

Missing or skipped layers

Probable cause: The layer is likely not absent, but rather, a mechanical issue with the Z-axis resulted in an uneven movement when transitioning to the subsequent layer. Figure 11 can be readily misinterpreted as either under-extrusion or delamination.

Solution: - Decrease the velocity of movement along the Z-axis in the software;

Inspect the Z-axis to ensure that it has unrestricted movement. Occasionally, if the filament does not unwind seamlessly from the spool, it can hinder the movement of the Z-axis. In a direct drive extruder setup, this issue can cause the extruder motor to inadvertently lift the extruder.

- Performing maintenance tasks such as cleaning and lubricating rods, rails, guide screws, and other components. If the mistake consistently appears on the same layer of different parts, it is possible that a bent or misaligned guide screw is causing the problem.

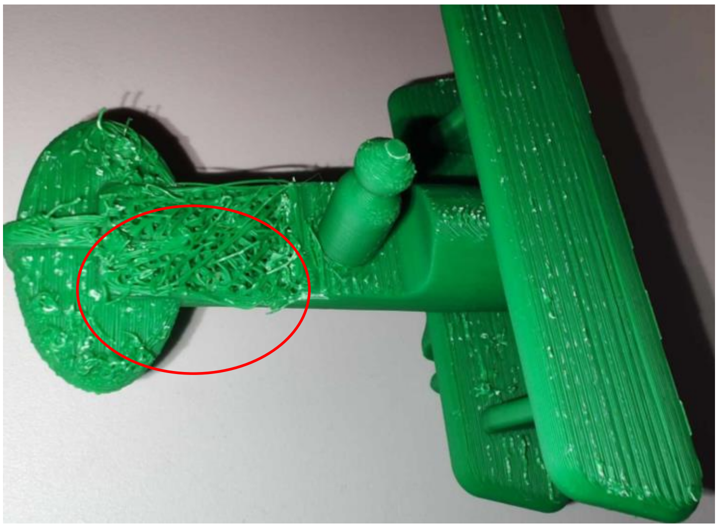


Fig. 11. Missing or skipped layers

4. CONCLUSIONS

The technical variables involved in 3D printing exert a substantial influence on the mechanical qualities, especially the rheological properties, of models created using additive technology. Studying the impact of these elements is crucial for designers involved in the creation of machine components. This article provides comprehensive study on the impact of the number of shells, a technological parameter in 3D printing, on specific mechanical qualities.

An essential requirement for achieving successful 3D printing of intricate models using basic FDM techniques is a well-designed digital model produced in CAD. The model's consistency refers to the degree of compactness exhibited by the boundary surfaces and edges of a solid substance. The alignment of the model with respect to the printer's coordinate system and the use of self-printed supports can be determined during the postprocessing phase by analysing the shape of the model during its construction. The objective is to prevent the need for printing supports by strategically positioning the model. The alignment of the model with respect to the printer's coordinate system influences the internal structure of the product, which in turn impacts the mechanical properties of the printed components in different directions due to the anisotropy of the resulting material structures. To achieve the appropriate accuracy and surface quality while printing small dimensions, it is crucial to properly adapt the model. The form correction relies on the dimensions of the fibres, which is particularly crucial when employing nozzles with greater diameters. The material's structural property is a crucial aspect in printing functioning pieces that meet the requirements for strength and an acceptable level of distortion. The disparity in the composition of the printed volume in relation to the initial material is a crucial determinant.

Funding: This paper has received no external funding.
Conflicts of Interest: There is no conflict of interest.

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Received: March 21, 2024 / Accepted: June 15, 2024 / Paper available online: June 20, 2024 © International Journal of Manufacturing Economics and Management.