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COMPARATIVE ANALYSIS OF DEFECTS OCCURRING IN THE LAYERS OF 3D-PRINTED PLASTIC PARTS USING THE FDM TECHNOLOGY

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Abstract: *The 3D printing process can be significantly improved by understanding the behavior of materials during printing, highlighting the differences in their physical and chemical properties. This understanding allows an analysis of the defects that appear between successively deposited layers, with the aim of reducing them or, in the best case, eliminating them completely. The elimination of these defects naturally leads to an increase in fracture resistance and, consequently, the durability of 3D-printed parts. This article analyzes the common defects that occur between the layers of plastic materials. The plastic materials examined in this study are Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polyethylene Terephthalate Glycol (PETG), Thermoplastic Polyurethane (TPU), and Nylon. Depending on the material used and the optimized printing process parameters, the defects between layers can vary significantly or may have similar causes. The most common defects analyzed in this study are poor adhesion of the first layer, weak adhesion between successive layers, and the occurrence of the warping phenomenon. The main objective of the paper focuses on analyzing these defects, understanding their causes, and proposing solutions for their prevention and correction. The discussions in this analysis will focus on the behavior of these materials in relation with the defects that may occur.*

Key words: *plastic materials, 3D printing, layer deposition, defects, prevention, improvement.*

1. INTRODUCTION

It is well known that additive manufacturing (AM) technology enables the creation of 3D objects through successive layer deposition, which significantly differs from traditional manufacturing technologies primarily based on material removal [1]. Over the past few decades, 3D printers have become highly popular in industries focused on very small series and unique production (rapid prototyping [2, 3], especially for shape and design [4, 5]), in the manufacturing of spare parts [6, 7], and particularly in medicine [8−10, 13]. The quality of parts fabricated through 3D printing is affected significantly by the frequency of defects that occur during the process between layers, influencing both the appearance of the parts and their fracture resistance. The defects and their frequency can vary depending on the material used in the 3D printing process and the optimized parameters specific to each material.

An important factor in achieving high-quality 3D-printed parts is the interaction and response of the material from one layer to the next, which can affect the structural integrity and, ultimately, the functionality of the product [5]. The behavior of one layer in relation to another can be influenced by the porosity of the extruded filament, thermal contraction during and after printing, as well as the internal voids resulting from the printing process. The choice of material plays a significant role in the occurrence of these defects, as the type of plastic used has specific mechanical, chemical, and thermal properties that influence the adhesion between layers or to the platform, ultimately leading to dimensional variations in the final shape of the part. Considering studies in the field, this article comparatively analyzes five commonly used plastic materials in 3D printing, namely: ABS, PLA, TPU, PETG, and Nylon. These plastics have particular characteristics that make them useful for certain applications and lead to defects specific to each material. Following this analysis, users will be able to identify the appropriate material for specific applications while taking into account the occurrence of these defects, thereby improving the quality of printed parts and optimizing the printing process.

2. MATERIALS AND METHODS

The comparative analysis of the five plastic materials ABS, PLA, PETG, TPU, and Nylon used in the 3D printing process is important because these materials have different mechanical, physical, and chemical properties that influence the final shape of the parts.

2.1. Material used in this study

Acrylonitrile Butadiene Styrene (ABS) is frequently used in 3D printing due to its flexibility and resistance to fracture and impact. However, it has a high thermal

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contraction response, making it prone to defects between layers. Polylactic Acid (PLA) is a biodegradable material obtained from natural resources (e.g. corn starch). It is known for its ease of use and excellent interlayer adhesion, but it requires careful adhesion to the build plate. Polyethylene Terephthalate Glycol (PETG) is more flexible than standard Polyethylene Terephthalate (PET) but remains durable and resistant. PETG is similar to the PET used in plastic containers but offers greater flexibility and impact resistance. Its thermal deformation is lower than ABS and PLA. Nylon is a flexible, durable material that is resistant to mechanical stress. However, it absorbs moisture from the atmosphere, which can sometimes lead to defects between layers, such as air gaps or cracks. Thermoplastic Polyurethane (TPU) is an elastic polymeric material frequently used in 3D printing. It is commonly applied to parts that require flexibility, such as gaskets, shock absorbers, and orthoses [11, 12]. However, printing with TPU can be difficult due to printer setup requirements.

2.2. Methods for Analyzing Interlayer Defects

The first method is a visual examination of the parts to identify obvious defects between layers, such as holes, cracks, or disproportionate features. Visual examination is the most accessible and straightforward method for identifying defects. This includes analyzing the physical appearance of the 3D-printed part and identifying defects like delamination, holes, cracks, or surface irregularities. 3D Printing Process: each material was printed under the same baseline conditions (temperature, print speed, nozzle type) to ensure comparability of the observed defects. Specific parameters for each material were adjusted according to the manufacturer's recommendations. The extrusion temperature, printing speed, and build plate temperature were set based on the specifications provided by the filament manufacturers. The final method used in this study was thermographic examination of the additive manufacturing process. This set of tests aimed to determine the thermal field through thermography and identify heat sources in the printing area: the thermal field on the printing platform (during the heating phase), the thermal field on the deposition nozzle, and on the part itself. The experimental tests involved studying the thermal behavior of the above-mentioned elements by exploring the thermal field using infrared thermography. Infrared thermography equipment, specifically the FLIR C3-X Series camera [13], was used. The images presented in the article were captured before and during the heating phase, as well as during printing.

3. Results and Discussion

Table 1 provides an overview of the most common defects observed during the experimental examination for each type of material. From this table, we can also identify the common defects as well as the specific and major defects for each material.

3.1. Poor Adhesion of the First Layer

Comparing the five materials: ABS, PLA, PETG, TPU, and Nylon (Fig. 1), in terms of first-layer adhesion

Table 1

Main defects observed for each type of material

Defect	Material				
	ABS	PLA	PETG	TPU	Nylon
Lack of adhesion between layers	+	+	+/-	+	+
Cracks due to contraction	+	+	-	+	-
Air bubbles and cracks between layers	+	+	+	+	+
Incomplete filling	-	-	+	-	-
Difficult adhesion to the printing bed	+	+	+/-	-	-
Moisture absorption	-	-	-	+	-
Warping or loss of part shape	+	+	+	+	+
Nozzle clogging	-	-	+	+	+

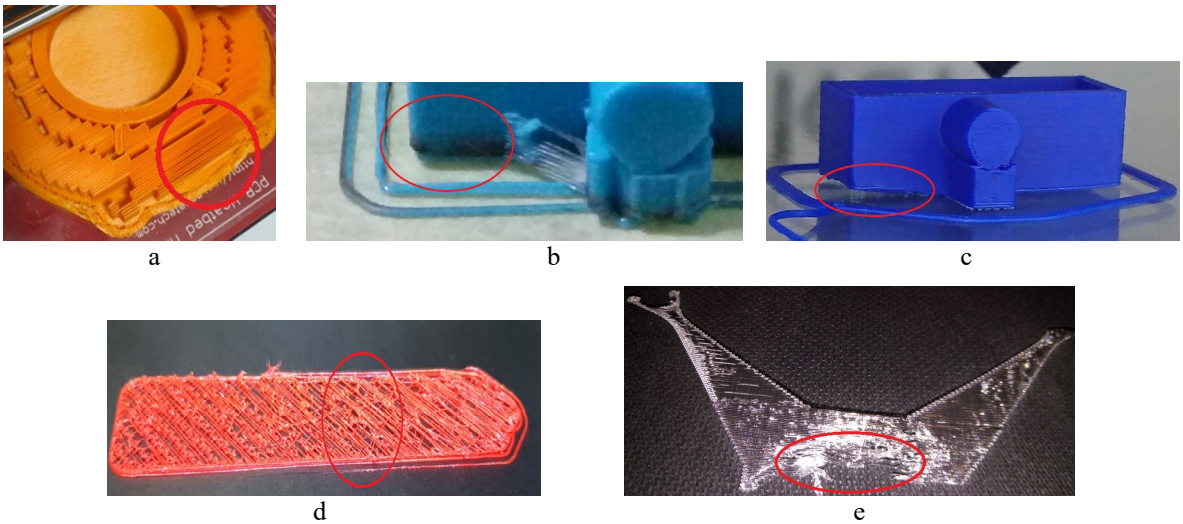


Fig. 1. Poor adhesion of the materials to the build plate: *a* – ABS; *b* – PLA; *c* – PETG; *d* – TPU; *e* – Nylon.

reveals significant differences in the causes of adhesion issues. Below is a detailed analysis of the flaw causes, specifically poor adhesion to the build plate.

When printing with ABS, build plate adhesion can occur due to its tendency to cool rapidly and warp during cooling, leading to detachment between layers or lifting of the first layer edges (Fig. 1, *a*).

Setting the printing bed or extrusion temperature too low exacerbates this issue. For PLA, it generally adheres well to the build plate, but adhesion can be poor if the plate is not properly prepared (e.g. by applying adhesive tape or a special glue for PLA) (Fig. 1, *b*). If the print bed temperature is set optimally based on the filament manufacturer's recommendations (and the filament is not too dry), PLA can be printed directly onto the bed without additional adhesion additives. PETG is less affected by rapid cooling but may experience adhesion problems due to a lower building plate temperature than the recommended range or an incorrectly extrusion temperature set (Fig. 1, *c*). When printing with TPU, a flexible material, adhesion issues on the build plate arise from its tendency to deform or flex easily. A low build plate temperature and high printing speed are factors that affect adhesion negatively (Fig. 1, *d*). For Nylon, low temperatures and moisture lead to poor adhesion of the first layer to the build plate. If the bed temperature is not set correctly, the material may fail to adhere to the plate. Additionally, a high moisture level in the filament can affect both adhesion to the build plate and the overall print quality (Fig. 1, *e*).

Table 2 presents the optimal temperature values, determined through testing, to eliminate such defects (material adhesion to the build plate).

3.2. Layer Separation During 3D Printing (Delamination)

The defects resulting from layer separation during 3D printing can vary significantly depending on the material used, as each material has its own characteristics that influence cooling behavior and adhesion between layers. Table 3 presents a comparison of the delamination causes for materials such as ABS, PLA, PETG, TPU, and Nylon, based on the characteristics and behavior of each material.

Table 2

Temperatures obtained in the process of optimizing printing parameters

Material	Parameter			
	Recommended build plate temperature resulted from experimental tests (°C)	**Recommended extrusion temperature resulted from experimental tests (°C)**	**Main causes of poor adhesion**	**Solutions for improving adhesion to the build plate**
ABS	90	225	Rapid cooling, warping, low bed/extruder temperature.	Build plate at a temperature higher than 80°C depending on the filament manufacturer, correct extrusion temperature setting, use of adhesive or tape, correct plate calibration.
PLA	55	230	Low build plate temperature, incorrect plate calibration.	Build plate at a temperature higher than 55°C, use of adhesive or tape, correct plate calibration.
PETG	75	245	Build plate too cold, incorrect print temperature setting.	Build plate at a temperature higher than 75°C, use of adhesive or tape, correct plate calibration.
TPU	50	230	Material flexibility, build plate too cold, printing speed too high.	Reduced printing speed, correct plate calibration.
Nylon	70	250	Sensitivity to temperature and humidity, build plate too cold.	Properly build plate, drying the filament, correct extrusion temperature setting.

Table 3

Main Causes of Delamination

Material				
ABS	**PLA**	**PETG**	**TPU**	**Nylon**
Rapid contraction during cooling. Solution: Heat the build plate to 100-110(°C).	Rapid cooling. Solution: Heat the build plate to 50-60 (°C).	Too high printing speed. Solution: Print at a moderate speed, avoiding rapid cooling.	Negative response when using a high printing speed. Solution: Heat the build plate to 50-60 (°C).	Rapid cooling. Solution: Heat the build plate to 70-100 (°C).
Low printing bed temperature. Solution: Print in a temperature-controlled chamber.	Low extrusion temperature. Solution: Set the extrusion temperature between 190-220 (°C).	Low extrusion temperature. Solution: Set the extrusion temperature between 230-250 (°C).	Low extrusion temperature. Solution: Set the extrusion temperature between 220-250(°C).	Low extrusion temperature. Solution: Set the extrusion temperature between 240-270(°C).
Thermal instability. Solution: Reduce printing speed and set extrusion temperatures between 210-250(°C).	Too high printing speed. Solution: Print at a moderate speed, avoiding rapid cooling.	Excessive cooling of the material. Solution: Print with controlled ventilation and avoid excessive cooling.	Deficiencies in temperature control. Solution: Print at a slower speed and avoid rapid cooling.	Humidity sensitivity. Solution: Dry the filament before use.

Table 4

General comparison of the warping risk

Material	Parameters		
	Warping tendency	Recommended platform temperature by manufacturers (°C)	Recommended platform temperature based on the experimental tests (°C)
ABS	Very high	90–110	90
PLA	Very low	50–60	55
PETG	Low-moderate	70–90	75
TPU	High	40–60	50
Nylon	Very high	70–100	70

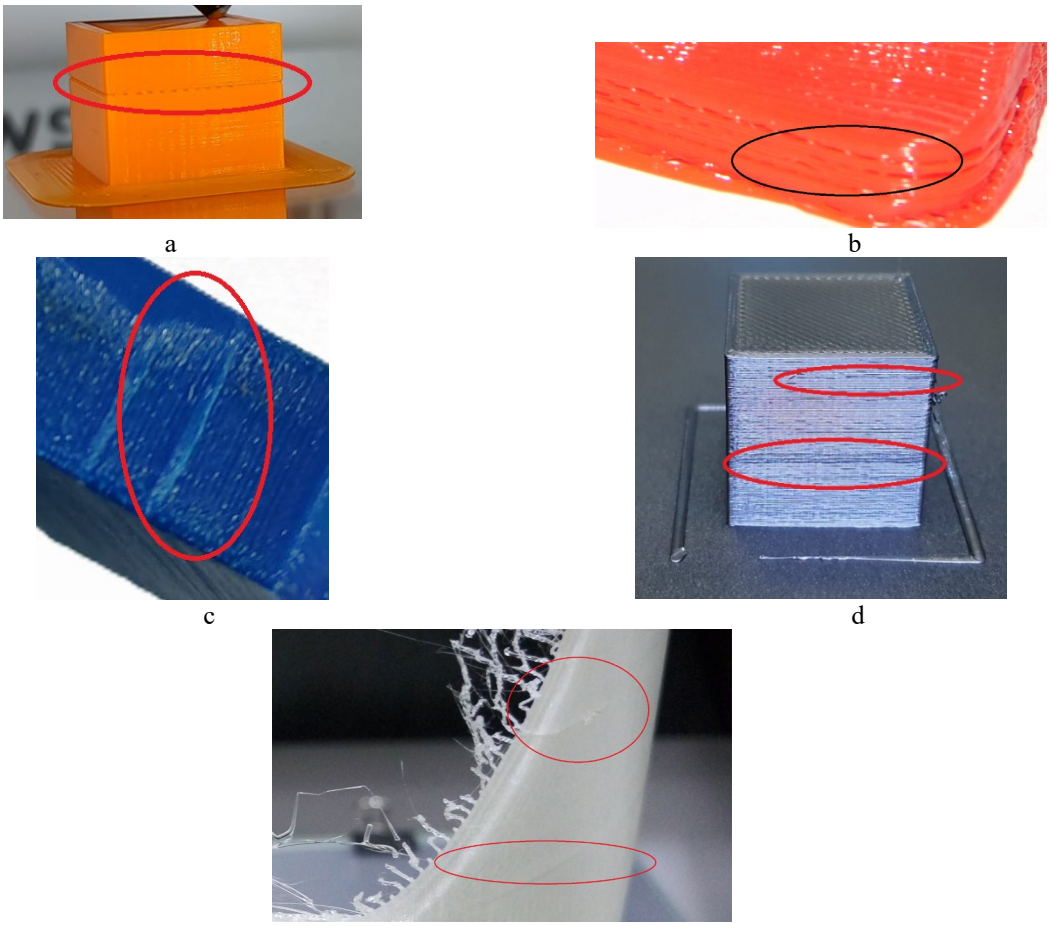


Fig 2. Layer separation during 3D printing (delamination): *a* – ABS; *b* – PLA; *c* – PETG; *d* – TPU; *e* – Nylon.

Figure 2 illustrates five parts made from different materials: ABS in Fig. 2,*a*, PLA in Fig. 2,*b*, PETG in Fig. 2,*c*, TPU in Fig. 2*d*, and Nylon in Fig. 2,*e*. To highlight the defects resulting from layer separation, these defects are marked with a circle on each image. The defects were noticed both during the printing process and after its completion.

3.3. Warping

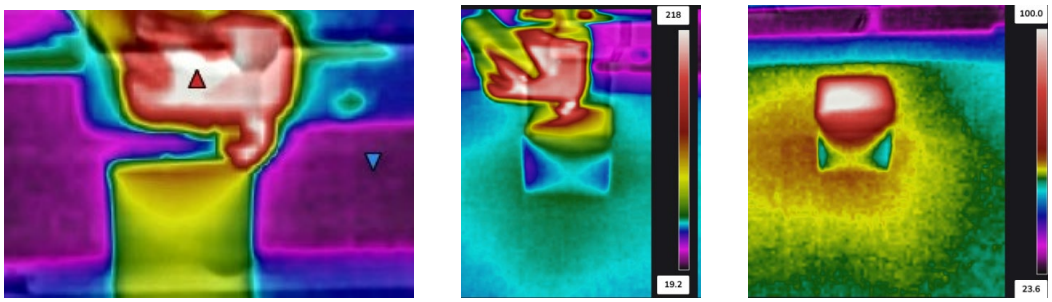
Warping or deformation of parts during 3D printing varies significantly depending on the material used, its thermal properties, and its cooling behavior (Table 4). Based on the analysis of the thermograms obtained in this experimental section, it was concluded that ABS and Nylon materials are more susceptible to this phenomenon, due to high thermal contraction that occurs during solidification. The samples used in the experimental section were cubic shape, with a side length of 20 (mm).

These two types of materials have a higher tendency to deform due to the temperature differences in the printing area, which leads to the stiffening of vertical edges or the deformation of the lower or upper layers (Fig. 3).

After analyzing the thermograms, it was easily observed that the temperature in the print area does not vary significantly during the printing process from one layer to another (see the example in Fig. 4,*a*). The temperature variation is notably observed at the height of the deposited layers, that is, in the vertical build height of the part, which is considered normal because the bed is heated and maintained at a constant temperature. The

a b c d e

Fig. 3. Additive manufactured samples with a side length of 20 mm: *a* – ABS; *b* – PLA; *c* – PETG; *d* – TPU; *e* – Nylon.



a b c

Fig. 4. Thermograms obtained during the 3D printing process with PLA material on a cubic sample with a side length of 20 mm: *b* – top view; *c* – view after printing process is complete.

small parts base contraction does not depend on the temperature variation during the printing process, but rather on the contact area between the deposition and the build plate. The temperature of the build plate is very important for the contact zone, as the part absorbs a significant amount of heat, preventing the base contraction (see the example in Fig. 4,*c*). The nozzle temperature has the greatest influence on the temperature in the print area (see the example in Fig. 4,*a* and *b*)

4. CONCLUSIONS

All five materials have specific characteristics that lead to defects related to poor adhesion of the first layer to the build plate, and the solutions vary depending on the printing temperatures. In general, these solutions depend on adjusting the build plate temperature, extrusion temperature, proper plate calibration, and using a specific adhesive type for the material, which are the most effective measures for improving first-layer adhesion to the build plate. Materials such as TPU and Nylon require more attention during the deposition of the first layers due to their flexibility or moisture response. For materials like PLA and ABS, the main causes of poor first-layer adhesion to the build plate are rapid layers cooling, low bed temperature, or low extrusion temperature.

PLA is the easiest material to work with, compared to the other materials analyzed, from the standpoint of delamination. However, it can experience issues if the print cools too quickly (uncontrolled) or if a high printing speed is used.

ABS and Nylon are more prone to delamination due to contraction during cooling and their behavior in response to temperature fluctuations. Both materials require strict control over the print temperature.

For PETG and TPU, which are less prone to delamination compared to ABS and PLA, proper plate temperature and print speed settings are needed to prevent rapid cooling of the layers.

From a thermal perspective, PLA and TPU behave the most stably, with lower risks of warping. ABS and Nylon require strict measures to control warping, and printing with these materials is best carried out in enclosed chambers with additional adhesion solutions to the build plate.

PETG provides a good compromise between durability and ease of printing, with a moderate risk of warping.

Defects that occur between layers are closely linked to the physical properties of the specific materials. For example, ABS is sensitive to high temperatures and rapid cooling, while PLA is more prone to contraction instability, and Nylon requires special attention to moisture control.

3D printer users should adjust print parameters based on the selected material to avoid the aforementioned defects. These adjustments involve nozzle temperature, print speed, and build plate temperature.

The use of thermally controlled enclosures, careful calibration of the build plate, and drying materials before printing can be important factors in reducing defects between layers.

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