Experimentally investigate influence of 3d printing parameters on rigidity of PLA parts

Étude expérimentale: l'influence des paramètres d'impression 3d sur la rigidité des pièces en PLA

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ABSTRACT. The aim of this paper is to analyze the impact of 3D printing parameters on the strength of polylactic acid (PLA) parts. We will look at how the mechanical characteristics of printed objects are influenced by material properties, extruder temperature, printing speed and layer thickness. We will emphasize the importance of monitoring print parameters to ensure optimal quality and reproducibility of parts using traction tests on samples. To develop empirical models that will establish a correlation between print parameters and mechanical properties, we will use the Taguchi method. Our goal is to find the optimal parameters, such as layer thickness, extrusion temperature and print speed, in order to maximum rigidity of 3D printed parts.

RÉSUMÉ. L'objectif de ce document est d'analyser l'impact des paramètres d'impression 3D sur la résistance des pièces d'acide polylactique (PLA). Nous examinerons comment les caractéristiques mécaniques des objets imprimés sont influencées par les propriétés du matériau, la température de l'extrudeuse, la vitesse d'impression et l'épaisseur de la couche. Nous mettons l'accent sur l'importance de la surveillance des paramètres d'impression pour assurer la qualité et la reproductibilité optimales des pièces en utilisant des tests de traction sur les échantillons. Pour élaborer des modèles empiriques qui établiront une corrélation entre les paramètres d'impression et les propriétés mécaniques, nous utiliserons la méthode Taguchi.Notre objectif est de trouver les paramètres optimaux, tels que l'épaisseur de la couche, la température d'extrusion et la vitesse d'impression, afin de maximiser la rigidité des pièces imprimées en 3D.

KEYWORDS. Additive manufacturing, Mechanical properties, Taguchi method.

MOTS-CLÉS. La Fabrication additive, les Propriétés mécaniques, la Méthode Taguchi.

1. Introduction

3D printing, also called additive manufacturing (AM), is an innovative technology that allows you to design three-dimensional objects. The material is incorporated line by line, layer by layer or piece by piece to create the final product. The fields of energy, sports cars, automotive, aerospace and medicine are heavily influenced by this technology. The implementation of this innovation has profoundly changed the ideas and production methods of companies [ELJ 23]. Additive manufacturing offers infinite conceptual flexibility by enabling the creation and modification of complex product shapes [OUC 23a]. Additive manufacturing aims to optimize the intrinsic functional characteristics of manufactured objects, as well as to reduce costs and production times, in order to enhance productivity [ZHO 24].The layers are deposited at extremely high temperatures using metals, ceramics and artificial polymers. Each built layer is supervised by a computer-assisted design modeler (CAO), which measures features such as tool trajectory and orientation for each product medium. The 3D printer generates thin layers using a thermal or chemical source, such as an ultraviolet laser beam or a solvent jet, both controlled by an electronic device [LIU 21] [ALN 23]. Polylactic acid (PLA) is a very popular biodegradable polymer and widely used in FDM technology. PLA is a monomer derived from renewable resources such as potato starch [OUH 18], cane sugar and corn sugar. The PLA has acceptable mechanical and thermal characteristics. It is used in various industries, such as tissue engineering and medicine, as well as in the manufacture of everyday consumer products such as food packaging, bottles and lids [SWE 23].The mechanical characteristics of PLA were evaluated using the Taguchi method. The Young modulus was evaluated using tensile tests. This paper presents the main characterization and analysis methods for evaluating the quality of PLA. This document has the following structure. Section 2 describes the procedures and techniques for the analysis of proposed experimental designs with polylactic acid (PLA) materials. The results of the production and compression processes, as well as an examination of the mechanical characteristics of the sample, are presented and discussed in section 3. The final section gives the conclusion.

2. Materials and methods

The additive manufacturing technique of three-dimensional printing by fused deposition modelling (FDM) is commonly used to design and test parts and objects of different shapes and geometries. During the last two decades, many studies have been conducted on the materials and applications of FDM, but few articles have revealed the characteristics of the machine related to this technique [ALA 17]. This article presents an analysis of the materials and characteristics of the machine associated with FDM printing, highlighting the influence of the material's mechanical and thermal characteristics on the longevity and strength of the printed objects. The characteristics of the machine, such as layer resolution, construction orientation, we address also the aspects of frame angle, flow and print speed, hose and plate temperature, as well as air space formation in samples of various materials. This paper provides researchers with a comprehensive view of the various process parameters, applications of 3D printed parts by FDM in different sectors, and future perspectives of this technology.

2.1. *3D Printer (RAISE 3D Pro2)*

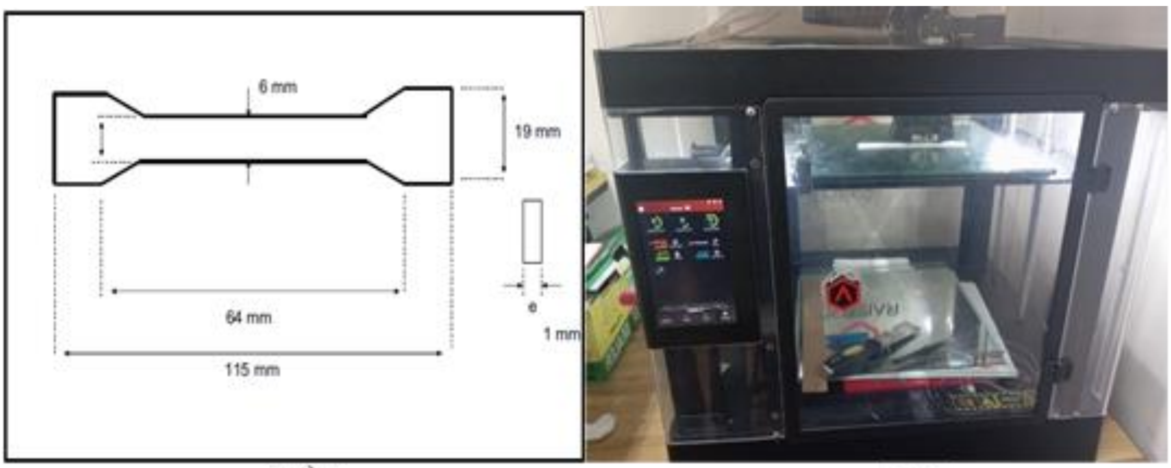
The samples were manufactured from the Poly-Lactic acid (PLA) wire supplied with the 3D printer RAISE 3D Pro2. The diameter of this PLA filament is 1.75 mm and its density is 1.25 g/cm3. The melting temperature of PLA varies from 180°C to 230°C, while the glass transition temperature varies between 60°C and 66°C [OUH 18]. The main physical and mechanical characteristics of different biopolymers were presented (PLA, PC, PETG...). The mechanical and physical characteristics that have an impact on the stability, deterioration, aging and recyclability of PLA have been examined. In addition, the ability of the PLA to meet specific implementation requirements has been studied.The technical characteristics of the RAISE 3D printer include its construction capacity, layer thickness and the different filaments it can borrow. Other key elements include maximum print head speed, maximum extruder temperature and connectivity options (USB, Ethernet and Wi-Fi).The usage, reliability and support provided by the manufacturer are also criteria to be considered when choosing a 3D printer.

Designation	Value
Printing Size	300×300×300 mm
Layer thickness	0.01–0.35mm
First layer printing speed	30 mm/s
Print speed of other layers	150 mm/s
Filament	1.75mm (PLA/ABS/HIPS/ PC/TPU/TPE/PETG/ASA/PP/ PVA/ Nylon)
File Format	STL/ OBJ/ 3MF/ OLTP
Number of perimeters	2
Power Supply	100-240VAC, 50/60 Hz 3.3A
Output	24V DC, 600W
Temperature	230 °C

Table 1. *details of the machine* [PRO2 GUI]

Tensile specimens were prepared in accordance with ASTM D638. This is an ASTM D638 sample (figure 4). The machine is capable of reading. STL files and converting them into G code. Each sample was then printed by modifying various parameters such as layer thickness, extruder temperature and printing speed [OUH 18]. Other variables, such as fill level (80%), nozzle diameter (0.4 mm) and orientation angle (45°), were kept constant. The three layer thicknesses studied were 0.15, 0.25 and 0.35, as shown in figure 3. Printing speeds were set at 40 mm/s, 50 mm/s and 60 mm/s. Three extrusion temperatures were considered: 205°C, 215°C and 225°C [MANI 22].

The printing time for each printed sample is determined by the parameters used during printing. This means that various parameters such as temperature, print speed and other elements have an impact on The time required to print each sample.



a) b)

Figure 1. *(a)Standard tensile testing specimen (ASTM D638), (b)The 3D printer machine RAISE 3D.*

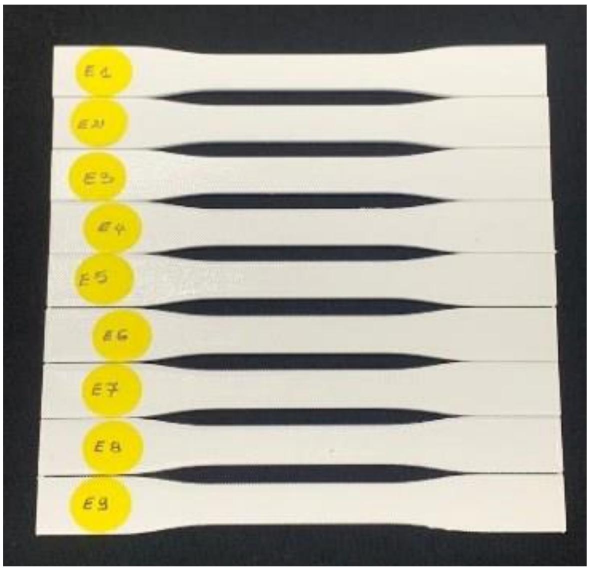
2.2. Experimental Plan

The aim of this study is to examine the tensile characteristics of PLA parts produced by FDM in compliance with the ASTM standard. Table 2 presents the printing parameters of the filaments used to prepare the FDM samples, as well as the consequences of these parameters on the mechanical characteristics.

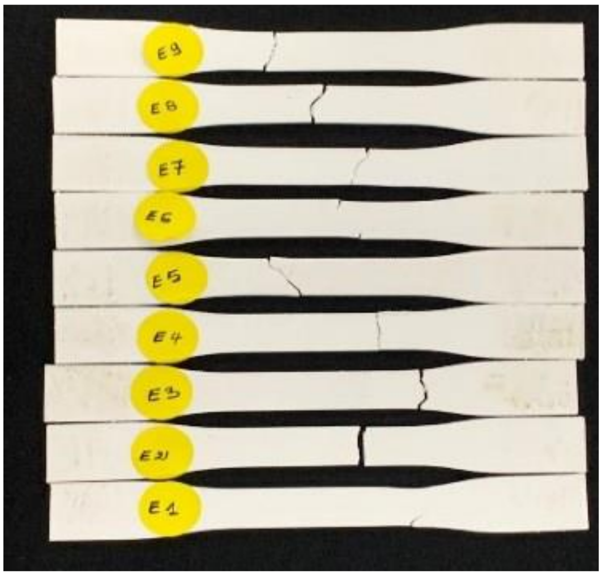
Levels	Layer thickness	Temperature	Deposition velocity
1	0,15	205	40
2	0,15	215	50
3	0,15	225	60
4	0,25	205	50
5	0,25	215	60
6	0,25	225	40
7	0,35	205	60
8	0,35	215	40
9	0,35	225	50

Table 2. *Orthogonal Array of Taguchi Design*

Initially, SolidWorks software was used to design a virtual 3D geometry of the test specimens. As most cutting programs support files in formats.obj and .stl, the SolidWorks file has been converted to format .stl and imported into the Ideamaker cutting software [LKA 24]. It offers a larger variety of customizable settings, allowing for more precise samples to be printed.Object deformation and stripping or slipping of wires from the print platform are more likely if layer thickness, print speed and print temperature are not optimized. Thus, these parameters have been thoroughly modified, as indicated in Table 2. The printing parameters can be seen in Figure 3.a. The quality of a 3D object is influenced by the quality of the original 3D model and the print parameters used [OUC 23b]. There are three distinct criteria for print quality: smooth surface, good mechanical characteristics and short print time. In this work, the implications of print parameters on mechanical characteristics are studied.



a)



b)

Figure 2. *(a) The appearance of the printed tensile test specimens, (b) Images of PLA specimens after tensile test.*

These numbered specimens are used for tensile testing to study variations in mechanical properties as a function of the various 3D printing parameters employed. Thanks to labeling, each specimen can be easily tracked and associated with its particular manufacturing conditions, facilitating comparative analysis of test results.

3. Results and discussion

In this document, we look at how print parameters and conditions affect the rigidity of PLA parts. Mechanical characteristics are influenced by the material, extruder temperature, print speed and layer thickness. The print quality is also influenced by differences in filament composition and environmental conditions. Monitoring these elements is critical in order to obtain optimal parts and ensure the reproducibility of the results, as illustrated in Figure 3 below:

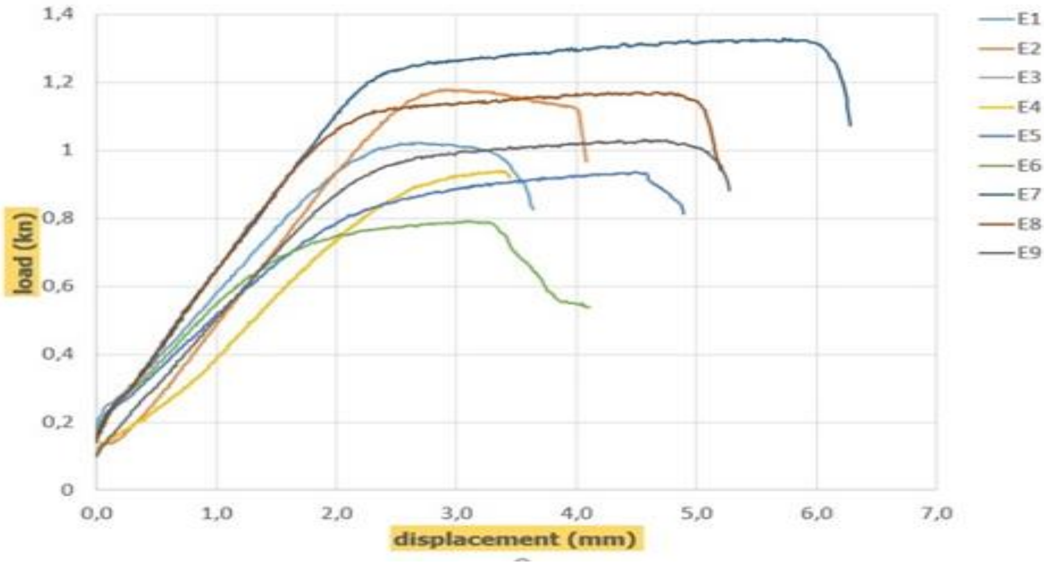


Figure 3. *Load / displacement Graph for the 9 specimens*

The rigidity of parts is greatly influenced by the material used for 3D printing, such as PLA, due to its stiffness and ease of use. A traction examination with a series RP25ATF machine, as shown in Figure 3,obtained accurate information on the strength and elasticity of the objects. The chemical composition, manufacturing quality and storage conditions of filaments influence the mechanical properties of the parts, which is why each PLA coil behaves differently, even with constant print parameters. The microstructure of the parts and their rigidity can be modified by essential print parameters, such as extruder temperature, print speed and layer thickness [HAN 19].

The Taguchi method was used to analyze samples and evaluate experimental results, creating an empirical model that establishes a clear correlation between the different print parameters and the printed models [LOK 22]. According to the following figure:

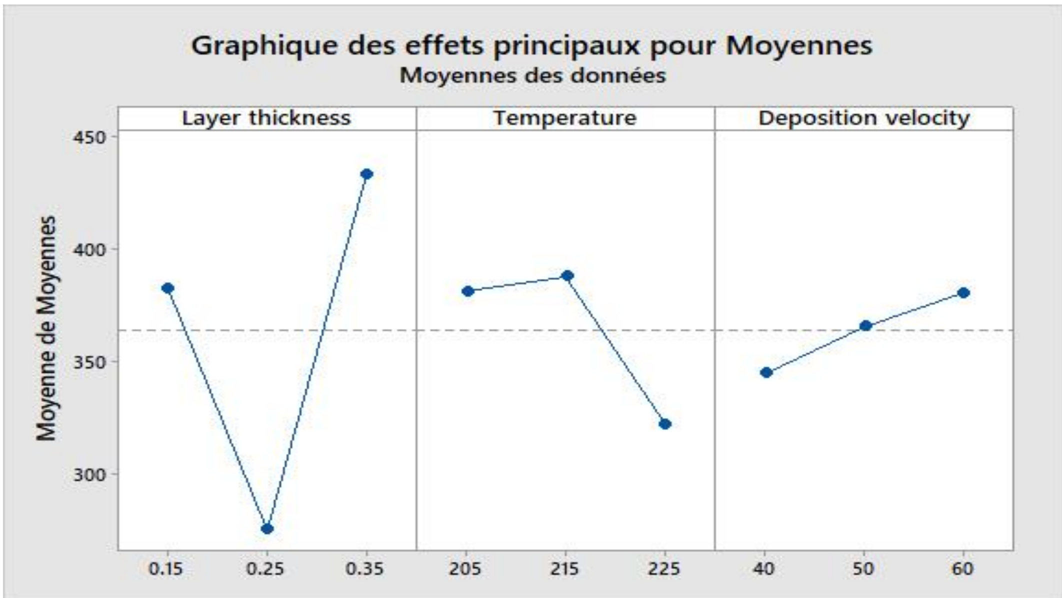


Figure 4. *Optimal parameters for rigidity*

Finally, the optimal parameters for high rigidity are defined as follows: According to Figure 4, it is necessary to have a layer thickness of 0.35 mm, an extruder temperature of 215°C and a print speed of 60 mm/s.

4. Conclusions

In this study, we look at how different print parameters and environmental conditions influence the mechanical characteristics of PLA parts manufactured using FDM technology. Factors such as extruder temperature, print speed and layer thickness have a significant influence on material rigidity and the quality of printed parts, as well as on filament composition and storage conditions. For experimental design, the Taguchi method is used to show the correlation between these parameters and the resulting mechanical properties. Based on the results, optimum rigidity can be achieved using a layer thickness of 0.35 mm, an extrusion temperature of 215°C and a print speed of 60 mm/s. It is essential to have this information in order to improve the reproducibility and performance of 3D printed PLA parts.

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