Tab 1

Optimization of 3D Printing Biocompatible Plastics for Use in Medical Implants and Devices

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Abstract

Petroleum-based plastics comprise a substantial proportion of goods produced worldwide, yet both their manufacturing processes and degradation byproducts pose significant environmental and biological risks. These concerns are particularly critical in medical applications, where material safety directly affects patient outcomes. While many conventional plastics present biocompatibility challenges, alternative materials such as polylactic acid (PLA) offer safer options for use in implants and medical devices. When combined with modern additive manufacturing technologies, these materials enable the rapid and cost-effective production of customized implants.

However, stereolithography (SLA) and other 3D printing processes are susceptible to dimensional inaccuracies and structural defects caused by thermal and moisture-related distortions. This study investigates the printability of methacrylated PLA oligomers, a biocompatible resin formulation, and seeks to determine optimal SLA printing parameters for manufacturing implant components.

Computer-aided design and slicing software were employed to model, classify, and evaluate simple geometries under varying build orientations and layer heights. Defects were analyzed primarily in terms of island formations and resin traps. Across all models, a 45° build orientation with a 0.05 mm layer height produced the most structurally reliable results. Although resin traps occurred more frequently at 45°, island defects were significantly reduced. Because large islands posed a greater threat to mechanical integrity than small resin pockets, the 45° configuration was determined to be optimal for structural stability and long-term implant performance.

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Introduction

Processes of producing common petroleum-based plastics tend to release greenhouse gases and to propel climate change. Then, the plastics themselves will often lead to further pollution, as the byproducts of their decomposition damage the environment and living organisms in the vicinity, which poses a large problem for manufacturing vital instruments (Yousefi and Wnek, 2024). In the case of medical implants, plastics have been especially challenging to work with due to these major health risks. For instance, silicone implants, used in cosmetic and reconstruction surgeries, joint replacements, etc., may lead to complications such as capsular contracture, rupture, and inflammation or infection (“Risks of Breast Implants”, 2023).

These types of implants could be vastly improved by the use of more biocompatible and properly biodegradable plastics such as PLA (polylactic acid) or PHAs (polyhydroxyalkanoates, a family of biodegradable polymers produced naturally by microbial fermentation). Since these substances are non-toxic and biocompatible, they are by definition less harmful to humans than petroleum-based plastics, especially when inserted into the body as an implant (Mehrpouya et al., 2021). 3D printing is currently possible for these substances and is advantageous for its ability to rapidly produce specialized components. However, the physical qualities of these products can be highly sensitive to the printing parameters and require more advanced technical knowledge than typical 3D printing to print successfully. For example, PHAs are more sensitive to moisture and shearing than most other plastics, leading to increased risk of warping and other physical deformities during or shortly after being printed (“Processing of PHA by 3D-printing”, 2025).

This study’s primary research question is as follows: how can computer software optimize parameters for 3D printing biocompatible plastics for long-term usage and efficient manufacturing?

This investigation’s main goal is to find the significant parameters used for methacrylated PLA oligomers in Stereolithography (SLA) printing. This was accomplished by simulating the 3D printing process with the above parameters as independent variables and the quality of prints as the dependent variable. The quality of a print was characterized by considering physical defects such as degree of warping and printing errors.

The success of the data was considered by the ability of the models to develop accurately during the simulations of the 3D-printing process. Successful models, by this study's definition, have a minimum weighted physical defects from the printing process (resin traps, islands, and overhangs). Each physical defect is weighted based on its size and location, as both are fundamental to visualize the severity of the defect. For example, a resin pocket of size 1 pixel (area of 0.05mm) will be much weighted less than a resin pocket of size 100 pixels (area of 5mm), as the 100 pixel pocket is much more likely to negatively affect longevity and mechanical stability. This project does not involve testing any physical implants on live subjects, so this form of analysis was done by quantitative comparison.

With the results of this project, institutions like biomedical engineering laboratories and similar businesses may be better informed on manufacturing specialized implants both which are more compatible with (and therefore less harmful to) their intended hosts and which durably maintain their form and function comparably to traditional plastic options.

Methodology

3D printing was modeled through the method of Stereolithography (SLA). In contrast to the much more common method of Fused Deposition Modeling (FDM), in which parts are built by repeatedly layering plastic extruded from a heated nozzle, SLA uses UV lasers to solidify photocurable liquid resin into plastic layers, which fuse together to form a predetermined design. Compared to FDM, SLA tends to produce much smoother physical models, which are more accurate to the computer-designed model, oftentimes also with higher per-print speed and long-term cost efficiency ("FDM vs. SLA vs. SLS: 3D Printing Technology Comparison", 2016). Such advantages enable rapid functional prototyping and testing for completed designs.

The particular biodegradable plastic polymer studied in this project is polylactic acid (PLA), specifically in the form of methacrylated PLA oligomers. In this form, PLA exists as a photocurable liquid resin, enabling the use of stereolithography (Figalla et al., 2024; Melchels et al., 2009).

The models were created using Autodesk Fusion (formerly known as Fusion 360), a professional CAD design and simulation software specialized for engineering. Then, the models were sliced using PrusaSlicer, a professional slicing and workflow engine used for 3D printing, including resin printing (SLA, MSLA, or DLP) compatibility. In the PrusaSlicer application, the Prusa SL1S Speed acted as a test machine, chosen because of its default compatibility with the software and because it generated 3D manufacturing files (.sl1s files) designed to be printed quickly with minimal sacrifices to quality, which is a requirement that biomedical engineering facilities and hospitals would likely enforce on their production lines. PrusaSlicer's algorithms determine layer height, lift speeds, and exposure settings to generate supports automatically and convert a .stl file (containing basic information about a model's surface geometry) into a usable 3D manufacturing file for a 3D printer. The only significant, user-controlled 3D-printing parameters for SLA are layer height, build orientation, and exposure time ("FDM vs. SLA vs. SLS: 3D Printing Technology Comparison", 2016). Since exposure time is a constant determined by the material used and the power of the resin printer's lasers, only layer height and build orientation were varied in the following trials. Build orientation was tested as 45° or 90°, and layer height was tested as 0.025 mm or 0.05 mm. UVTools, an open source software used to analyze and repair files for resin printing, was then used to gather data on number, types, sizes, and locations of printing defects for each model at each combination of printing parameters.

Quality of the 3D prints was then assessed using a self-made formula, which is provided in the final analysis with a full explanation.

This project was completely done virtually, so there were no safety risks, including exposure to harmful substances or performing procedures that may inflict physical harm. Therefore, no additional notable safety precautions were taken.

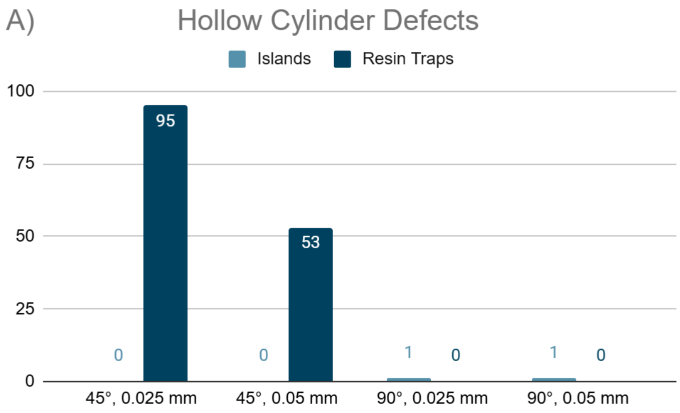
Results

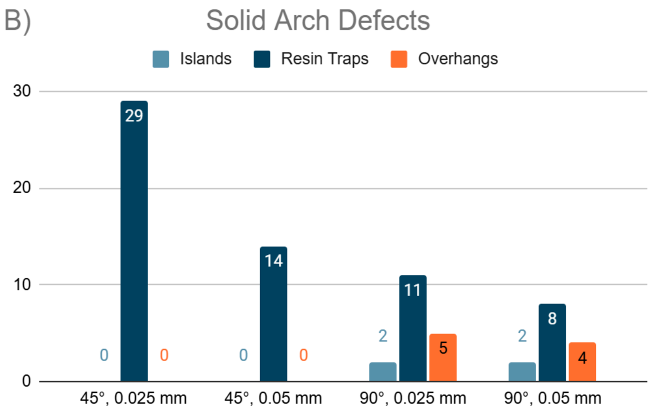
Table 1: Total detected printing defects for hollow cylinder, solid arch, and gyroid lattice models for each pair of printing parameters – build orientation (degrees) and layer height (mm)

Model	45°, 0.025 mm	45°, 0.05 mm	90°, 0.025 mm	90°, 0.05 mm
Cylinder	95	53	1	1
Arch	29	14	18	14
Gyroid Lattice	259	109	85	89

The total number of defects for each model and set of parameters were gathered from UVTools. Out of the three, the gyroid lattice tended to contain the highest number of vulnerable locations for printing defects, likely due to its higher complexity than the other models.

The total number of printing defects for every test model was maximized by a combination of orienting 45° from the build plate and building with a layer height of 0.025 mm. The same number for the hollow cylinder was minimized at a 90° orientation at both 0.025 mm and 0.05 mm layer heights. Two such minimum values were also found for the solid arch, except those occurring at a layer height of 0.05 mm and an orientation of either 45° or 90°. For the gyroid lattice, only one minimum value was found at 90° orientation and 0.025 mm layer height.





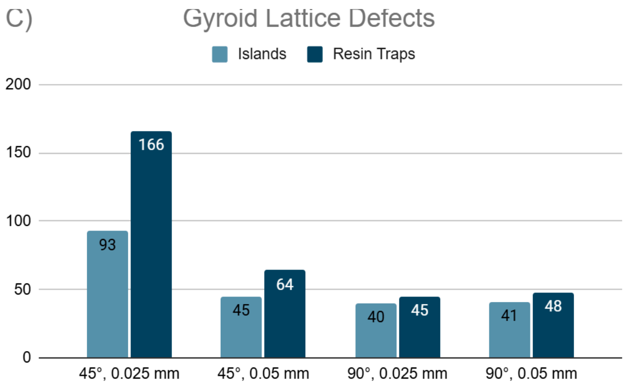


Figure 1: Detected printing defects for A) hollow cylinder, B) solid arch, and C) gyroid lattice divided by type of defect – island, resin trap, and overhang (where applicable)

With the exception of the gyroid lattice and hollow cylinder at 90°, increasing the layer height from 0.025 mm to 0.05 mm, while holding orientation constant, reduced the number of detected resin traps in each model. At 45° orientation, this increase in layer height produced the most pronounced reduction in defects, particularly resin traps, across all geometries. With the exception of the gyroid lattice at 90°, this increase either reduced or did not affect the number of detected islands.

Across all models and layer heights, changing the build orientation from 45° to 90° reduced the number of resin traps (Figure 1). For the hollow cylinder and solid arch, this orientation change slightly increased the number of islands by 1–2 per model. In the solid arch, the 90° orientation also resulted in the appearance of overhangs (Figures 1A,B). This trend was not observed in the gyroid lattice, where the 90° orientation consistently reduced the number of islands (Figure 1C).

Table 2: Maximum sizes (mm^2) of each type of defect detected in each test model for each set of parameters

Model	Layer Height (mm)	Orientation	Largest Island (mm²)	Largest Resin Trap (mm²)
Arch	0.05	90°	60.8	0.025
Arch	0.05	45°	0	0.0625
Arch	0.025	90°	60.8	0.06
Arch	0.025	45°	0	0.045
Cylinder	0.05	90°	62.5	0
Cylinder	0.05	45°	0	0.03
Cylinder	0.025	90°	62.5	0
Cylinder	0.025	45°	0	0.0825
Gyroid Lattice	0.025	90°	0.016	0.06
Gyroid Lattice	0.025	45°	21	0.0825
Gyroid Lattice	0.05	90°	0.016	0.0625
Gyroid Lattice	0.05	45°	22	0.045

With the exception of the gyroid lattice, 45 degrees drastically reduces island size and quantity without a significant increase in maximum resin trap size.

As seen in Table 2, layer height had minimal effects on the size of physical defects.

Discussion and Conclusions

Simple alterations to the basic parameters of Stereolithography printing should significantly affect final print quality. For the cylinder and gyroid lattice, the most significant reduction in the number of printing defects originates at an orientation of 90°. The arch, contrarily, was benefitted most strongly from maintaining a 45° orientation, but increasing the layer height to 0.05 mm.

Alongside these general trends, model-specific characteristics also influenced defect formation. The higher number of island defects observed in the gyroid lattice can be largely attributed to its geometric complexity and the way it was modeled in Autodesk Fusion. Unlike the cylinder and arch, which have relatively simple and continuous surfaces, the gyroid lattice is based on a repeating mathematical pattern with many thin, curved features. When this pattern was generated automatically in the modeling software, the program attempted to preserve the full geometry of the design, even in areas where small segments were difficult to support during printing. As a result, some isolated features did not properly connect to the previous layer during slicing, and were recognized as islands by UVTools. These defects were therefore not caused solely by print orientation or layer height, but also by the challenges of converting a highly complex mathematical design into a layer-by-layer printable model. The findings suggest that geometric complexity and modeling approach should be considered alongside printing parameters when evaluating defect formation in lattice-based implant designs.

While these parameter adjustments influenced the frequency of defects, overall print quality does not depend solely on the raw number of printing defects that occur. Since the various types of defects in each test model were observable, and not just the total number of defects, additional judgments were made on the degree to which the respective errors impact the final structures.

While analyzing data, islands were viewed as having much more impact in the print quality than the resin pockets. This is due to two factors, size and location. While resin pockets were more numerous than islands, a significant portion of resin pockets could be found in the supports. This would mean that these resin pockets would not be included in the final print, as the printing supports are removed before the final product if finished. The size of the pockets were also considered; many pockets were only 1-2 pixels wide (1 pixel = 0.05mm), while islands could be found in the hundreds of pixels.

Because only three models and four parameter configurations were evaluated, the dataset was limited, and broader trends should be interpreted with caution. Although consistent patterns were observed—particularly regarding orientation and layer height—the small sample size restricts the strength of any generalized conclusions. Additional testing across a wider range of geometries, orientations, and processing parameters would be necessary to establish statistically robust relationships between printing conditions and defect formation.

The scope of this investigation was constrained by limited time and restricted access to certain analytical software tools, which reduced the overall volume and depth of data collected. As a result, the findings presented here should be interpreted within the context of an exploratory study. Future research conducted over a longer duration and supported by expanded computational resources would enable more comprehensive modeling, simulation, and experimental validation, thereby strengthening the generalizability of these results.

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Elevator Pitch

Petroleum-based plastics compose a majority of the goods produced and sold worldwide. Both the means of producing them and the plastics themselves tend to damage the environment, harming living organisms in the vicinity. Due to similar health risks, Integrating plastics into medical implants has (and still is) especially challenging. However, while these injurious plastics are very common, more biocompatible plastics, such as PLA, are available alternatives for usage in implants and other medical devices. Adopting such materials for this practice would vastly improve the safety of implants which otherwise would risk infection or other adverse reaction, and modern 3D printing technologies promise quick and cheap means of producing these specialized implants for patients. However, 3D printing processes risk unanticipated inaccuracies as heat and moisture physically warp the products. This project investigates the 3D-printability of methacrylated PLA oligomers (a biocompatible plastic in resin form) and determines the ideal 3D printer configurations for printing implant components out of them using the SLA (Stereolithography) method. Without consistent easy access to such technologies, this project relies on software like Ansys Additive Suite to simulate the 3D printing process, including the final products' physical defects. Despite the reliance on virtual simulation, this project may inform institutions like biomedical engineering laboratories and hospitals on manufacturing specialized, more biocompatible implants.