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Research Article

Preliminary Study Analysis of 3D Printing Process Of Artificial Vascular Models Using Additive Manufacturing

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A B T R A C T

Manufacturing technology is developing very rapidly, especially in the production process production process. One of them is the emergence of additive manufacturing technology. One type of additive manufacturing is stereolithography (SLA) which is applied in the world of health. Many factors in the success of the print process of additive manufacturing technology. One of the important factors is the process parameter, namely build orientation. In addition, post processing is also an influential factor in production success. This research analyses the best production process by looking at the effect of print position at 0°, 45° and 90°. This research is applied to This research uses experiments by printing the product. printing the product. The material used is a flexible material, Anycubic Though Resin, with the help of a 3D printer, Anycubic Photon Monon. printer Anycubic Photon Mono X. The printing process uses the same parameters in the 0°, 45° and 90° positions. The three positions produce defective results that are not significantly different, with the most optimal results obtained at the 0° position. However, support settings must be considered because they affect the success of the product as well as the amount of resin used. The study also found that the best post processing is resin cleaning without the use of rotating machine and without the use of curing. This is because it will damage the the product and change the mechanical properties.

INTRODUCTION

Technological advancements play a crucial role in influencing progress in the manufacturing sector, with additive manufacturing (AM) technology, commonly known as 3D printing, being a noteworthy development. AM involves the sequential addition of material layer by layer (Wang et al., 2017), offering advantages such as cost and time savings, as well as the capability of single-process production (Asif et al., 2018; Bekas et al., 2019). Fused Deposition Modeling (FDM) and Stereolithography (SLA) are prominent types of 3D printers, with SLA standing out for its superior dimensional accuracy and surface roughness (Dai et al., 2019; Jeong et al., 2018). The evolution of AM technology extends beyond manufacturing, finding applications in diverse fields such as aerospace, food, and healthcare (Shahrubudin et al., 2019). Notably, within the healthcare domain, a specific focus is on creating medical training tools. Given that cardiovascular diseases (CVDs) are identified by the World Health Organization (WHO) as a leading cause of mortality, AM technology is employed to develop innovative tools for medical training in this critical health sector.

In 2019, approximately 17.9 million individuals succumbed to cardiovascular disease, constituting 32 percent of the global mortality rate. Addressing coronary heart disease involves the use of technologies such as coronary stents(Borhani et al., 2018). The advancement in this field allows for stent installation training through the replication of anatomical structures, specifically blood vessels. Additive manufacturing research has delved into creating materials for training tools, including those designed for cannulation simulation training (Etami et al., 2022). Various studies have explored the duplication of human organs, encompassing the liver (Fitski et al., 2022), brain arteries (Stefano et al., 2022), pelvis (Burgade et al., 2021), and teeth (Jeong et al., 2018). However, certain investigations have relied on solid models, neglecting comprehensive process analysis and focusing solely on 3D printer parameter settings. Moreover, previous research has only compared two positions without assessing the necessity of post-curing for the final print result. It is imperative to consider the entire process, including post-processing stages, as they can significantly impact the ultimate quality of the printed product.

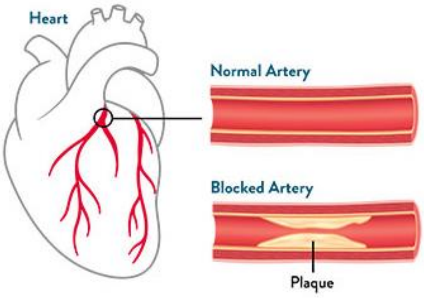

Fig. 1. Normal and plaque-affected artery cross-sections

Despite the numerous benefits and advantages offered by AM technology, there are several challenges in achieving optimal production, and one key challenge is the careful selection of appropriate parameters (Ren et al., 2017). Build orientation, in addition to the established parameters, plays a crucial role in influencing the printing process, particularly impacting the material properties of the final product (Canellidis et al., 2009). Beyond material characteristics, the build orientation also affects process duration, material consumption, and the required post-processing procedures. Each 3D printing method involves distinct post-processing steps, and when using resin materials like stereolithography and digital light processing, post-processing entails cleaning remaining resin with alcohol liquid. Removal of support structures attached to the main product is also a vital aspect of post-processing. In the specific context of this research, the printed products exhibits a cylindrical shape with minimal thickness, underscoring the importance of recognizing that parameters alone may not suffice for achieving optimal results; a thorough analysis of the post-printing process is essential.

The artificial vascular models being produced mimic the branching cylindrical shape of blood vessels, with the smallest diameter measuring 2.5 mm and a product layer thickness of 0.2 mm. However, this study focuses on the smallest section initially to identify a suitable and cost-effective process while reducing experimentation time. Given the small cylindrical shape, careful consideration of parameters and other factors is essential in the production process. Key parameters, including layer thickness, exposure time, lift speed, and lift height, must be taken into account (Piedra-Cascón et al., 2021). The study conducted printing with three different orientations: 0°, 45°, and 90°. The analysis will determine which orientation yields the best overall results, considering both the quality of the output, the time required, and minimizing defects throughout the entire product printing process.

METHOD

This research uses an experimental study by printing whole product parts and analyzing quantitatively and quality. There are several stages carried out in this research according to the research flow in Figure 2. The research flow covers from the beginning to data analysis.

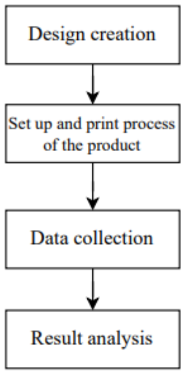

Fig. 2. Research flow

The designs are created using Autodesk Inventor 2021 software for this research. The printed product represents a specific part or segment of the entire product, deliberately chosen due to its complexity compared to the other sections. The selection is based on the fact that this particular part presents the greatest challenge, primarily due to its smaller diameter compared to the remaining components. Figure 3 provides a visual representation of this selected section, highlighting its dimensions, with a consistent thickness of 0.2 mm throughout.

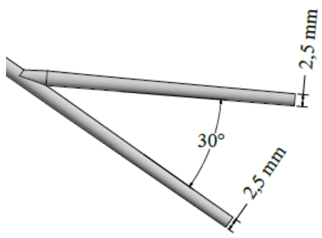

Fig. 3. Product Section

Utilizing Autodesk Inventor 2021 software, the designed products are saved in .stl format to facilitate their input into the slicing software. The slicing process is executed with the assistance of Anycubic Photon Workshop software. Uniform parameters are applied across all orientations—0°, 45°, and 90°—as well as consistent treatment for support provision and post-processing. The printing process employs specific parameters, including a layer thickness of 0.05 mm, exposure time of 7 s, z lift speed of 1.5 mm/s, z retract speed of 2 mm/s, and a bottom exposure time of 28 s. Figure 3 illustrates the input of the product into the slicing software and the corresponding print positions.

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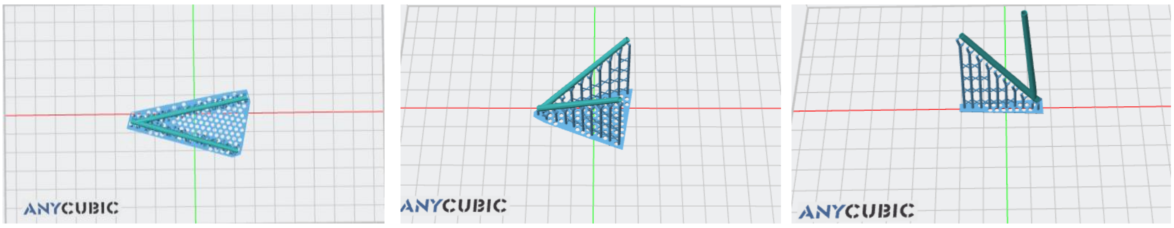

Fig. 4. Position setting of slicing software

The SLA type 3D printer employed for printing the product is the Anycubic Photon Mono X, known for its high precision of 0.01 mm, ensuring optimal outcomes. SLA printers, like this one, utilize resin as the primary material. In this research, Anycubic UV Though Resin from the Anycubic company was chosen due to its suitable level of flexibility, with a hardness value of 76 Shore D. The selection of this resin is influenced by its transparent color, providing both flexibility and transparency, aligning with consumer preferences for ease of use. The flexible characteristic is particularly relevant in simulating blood vessels. Post-processing activities are conducted after printing, involving tasks such as removing the product from the printing platform and cleaning residual resin with 96% alcohol liquid. Data collection encompasses the amount of resin used, processing time, print dimensions, and qualitative observations. Given the small size, dimensional measurements are facilitated by a Dino-Lite digital microscope. Slicing software is employed for obtaining data on resin consumption and the duration of the print process.

RESULT AND DISCUSSION

Applying the same parameters of layer thickness of 0.05 mm, exposure time of 7 seconds, z-lift speed of 1.5 mm/s, z-withdrawal speed of 2 mm/s, and bottom exposure time of 28 seconds, the products were successfully printed in all three orientations without any failures. Figure 5 provides a visual representation of the product printout before the removal of the support structures. The relevant data obtained post-printing is presented in Table 1.

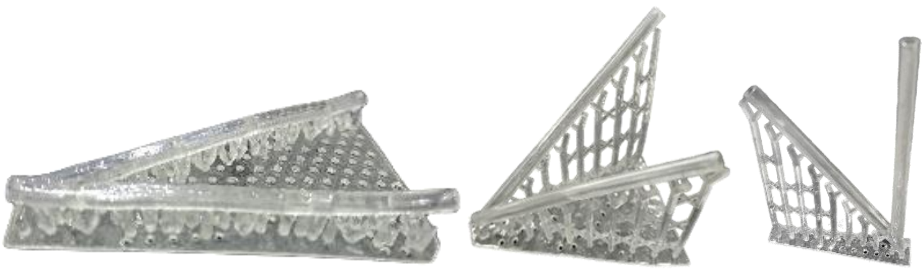

Fig. 5. Product printouts (a) 0° (b) 45° (c) 90°

Table. 1. Comparison of 0°, 45° and 90° printout data

Orientation	Amount of resin	Process time	Dimensional size		
			Diameter	Angles	Thickness
0°	1.485 ml	49 m 45 s	2.893 mm	31.5°	0.357 mm
45°	1.331 ml	4 h 42 m 9 s	2.769 mm	30.5°	0.359 mm
90°	0.787 ml	6 h 18 m 34 s	2.862 mm	31.25°	0.404 mm

The product results, especially in dimensional measurements, provide inaccurate sizes where there are several factors such as the accuracy of the 3D printer machine and the environment. Environmental factors are included because after the printing process, there is a post-processing action, namely cleaning the remaining resin using 96% alcohol. From the data in Table 1, the print position at an angle of 0° gives the most optimal results in terms of processing time and dimensional size. However, in terms of the amount of resin, the printing position consumes the most resin in contrast to the 90° position which consumes the least resin but takes the longest time. In the printing process, the 0° position requires more support than the 45° and 90° positions. This is the reason that the amount of resin used in the 0° position is the most compared to the other two positions. A lot of resin is wasted and the addition of support in that position costs more in the production process (Das et al., 2018; Shen et al., 2020). The 90° printing position consumes the least amount of resin but takes the longest time. This longest time occurs because the additive manufacturing concept uses layer by layer horizontally, so the higher the product, the longer the time used (Huang et al., 2020).

With a small difference in defects, there must be other factors to consider. Both in how to place the support and post-processing such as removing the support. Providing too much support will cause marks and damage to the product, but providing too little support will make the product not stick well. Figure 6 shows that when too little support is applied, the product does not stick well. The product will print well but will also detach itself without human assistance. The product falling into the resin tank can result from the printing still being on the platform, which can be fatal. The SLA method requires the use of a support structure attached to the platform to prevent deflection due to gravity, resisting the pressure of the newly formed layer during printing from bottom to top (Huang et al., 2020).

Fig. 6. Defects due to support

Another caution also applies to post-printing treatment, especially at the 0° print position. With many supports placed on the product, care must be taken in removing the supports. Less careful treatment will result in product damage or leftover supports, as shown in Figures 7a and 7b. The process of removing supports can use tools to facilitate the process. Basically, the defects formed are due to removing the support too quickly and using too much force. With a product that has a thin thickness, the product is easily damaged. Another difficulty that must be considered is how high the support lifts the product from the printing platform. If the support height is too low, it will be more difficult to remove in post processing. In this research, the height used is 5 mm for the 0° position and 3 mm for the 45° and 90° positions. This is also to maximize the printing time, because the higher the support lifts the product from the platform, the longer the printing process.

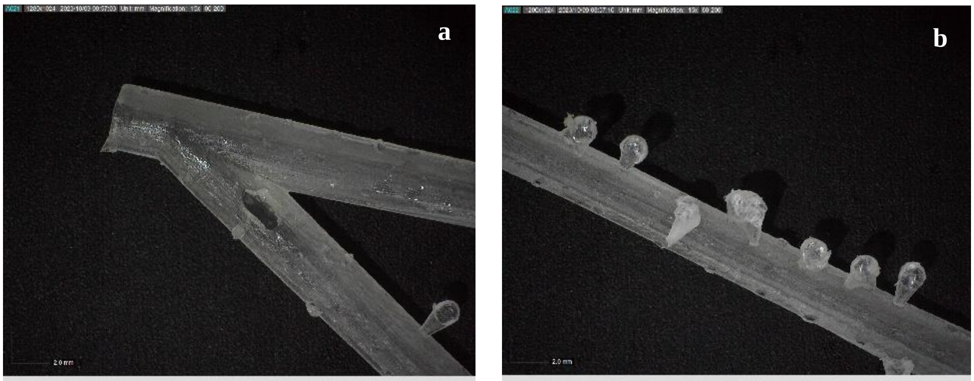

Fig. 7. a) Failures during post-processing, (b) Residual support

Another factor in post-processing is the removal of excess resin using alcohol. Manual or machine-assisted methods can be used for this purpose. An ultrasonic cleaner is recommended to avoid damaging the product, as opposed to using other machines such as the Anycubic wash and curing machine. The use of this machine in the resin removal process can cause damage to the product, as shown in Figure 8b. The damage is caused by the product's thin thickness and high-speed rotation from the machine. Therefore, using an ultrasonic cleaner provides better results, as shown in figure 8a. For small-sized, thin, and soft material products, curing is not necessary. Curing process can cause product deformation, as shown in figure 9b. The product will be better off without undergoing the curing process, as shown in figure 9a.

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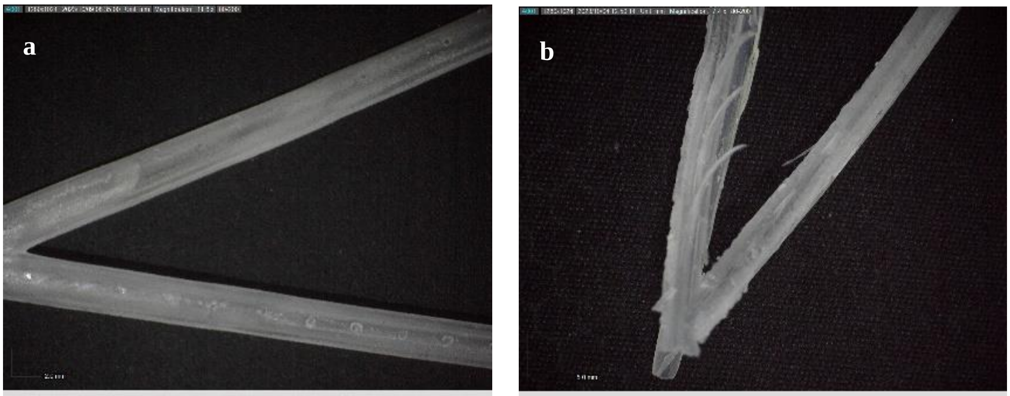

Fig. 8. (a) Using an ultrasonic cleaner, (b) using a wash spin.

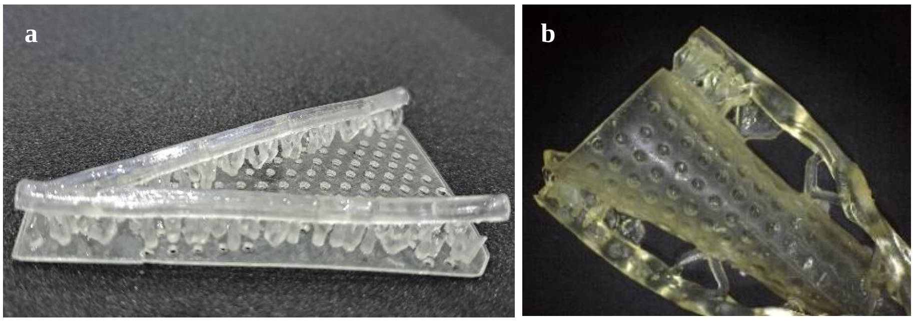

Fig. 9. (a) Without curing, (b) curing

If the product is printed in a single unit type, then the 0° position will provide the most optimal result. The same applies when we print by maximizing the available platform area on the 3D printer. Using the simulation software Photon Workshop, the 0° position resulted in the least production quantity, which was 12 products per print. Although it produces the fewest number of products per print run, it has the fastest per-product time. This is advantageous when considering print time per product, despite having a similar defect rate. If the product is printed to maximize the platform, position 0° takes 248.75 seconds per product, position 45° takes 846.45 seconds per product, and position 90° takes 344.15 seconds per product.

CONCLUSION

The results of the 3D printing process reveal differences in the advantages of the three positions. The 0° position excels in processing time and contributes to product thickness. The 45° position offers dimensional advantages in diameter and angle size, while the 90° position minimizes resin usage. Considering the obtained data and considerations, the 0° position proves to yield the best results, both in terms of time efficiency and defect reduction. It is crucial, however, to factor in the support amount during the printing process to minimize resin usage, especially since the 0° print position consumes more resin compared to others. Due to the small cylindrical shape of the printed product, various factors, such as the number of supports and post-processing, must be considered. The quantity of supports directly influences resin usage and the final product outcome. Additionally, the post-processing method employed doesn't necessitate curing assistance.

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