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Analysis of Additive Manufacturing Processes: FFF versus SLA on Shopping Bag Holder

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Abstract

Additive manufacturing (AM), particularly Fused Filament Fabrication (FFF) and Stereolithography (SLA), plays a critical role in modern manufacturing. This paper offers a comparative analysis of FFF and SLA, focusing on their processes, advantages, limitations, and applications. FFF, which extrudes thermoplastic filaments to create objects layer by layer, is known for its simplicity, cost-effectiveness, and material versatility but has drawbacks like limited resolution and surface finish quality. Conversely, SLA uses a laser to cure liquid photopolymer resin, producing highly precise and detailed objects with smooth surfaces, albeit at higher costs and slower speeds. By examining these techniques using a 3D printed part, the study provides valuable insights for manufacturers, designers, and researchers to choose the optimal technology for specific needs, ultimately enhancing the understanding and application of these AM processes in various fields.

Keywords: AM, CAD, FFF, SLA, 3D Printing

Introduction

Additive manufacturing (AM), also known as 3D printing, has revolutionized the field of manufacturing by enabling the creation of complex geometries and reducing material waste. Among the various AM technologies, Fused Filament Fabrication (FFF) and Stereolithography (SLA) are two of the most widely used methods. This paper aims to compare these two prominent techniques, examining their processes, advantages, limitations, and applications.

FFF, also known as Fused Deposition Modeling (FDM), involves the extrusion of thermoplastic filaments through a heated nozzle, layer by layer, to build up the desired object. This method is widely appreciated for its simplicity, cost-effectiveness, and compatibility with a broad range of materials. It is particularly favored in rapid prototyping, educational settings, and the production of functional end-use parts. However, FFF faces challenges such as limited resolution, surface finish quality, and anisotropic mechanical properties.

In contrast, SLA employs a different approach, using a laser to cure liquid photopolymer resin in a layer-by-layer fashion. This technique is renowned for its high precision, fine detail, and smooth surface finishes. SLA is extensively used in applications requiring intricate designs, such as jewelry, dental models, and engineering prototypes. Nevertheless, the process is often more expensive and slower than FFF, with limitations in material choices and mechanical strength.

By analyzing and comparing the characteristics of FFF and SLA, this paper will provide insights into their respective strengths and weaknesses, guiding manufacturers, designers, and researchers in selecting the most appropriate technology for their specific needs. Through this comparative study, a comprehensive understanding of these additive manufacturing processes will be established, highlighting their contributions to the advancement of modern manufacturing practices.

Part Design

The component chosen for the comparison of two additive manufacturing (AM) processes is a shopping bag holder (depicted in Figure 1). This part is engineered to help users carry at least three shopping bags simultaneously. Its design is simple, elegant, and user-friendly, providing relief by freeing up one hand, especially when managing multiple bags. The holder comprises three J-shaped hooks for hanging the bags and a handle for single-handed use. The CAD model for this shopping bag holder was sourced from an online library, Thingiverse [1].

Figure 1: Shopping bag holder [1]

Additive Manufacturing (AM) Processes

Two distinct additive manufacturing (AM) processes were employed to fabricate the shopping bag holder: (a) Fused Filament Fabrication (FFF) and (b) Stereolithography (SLA) as shown in figure 2 below.

Figure 2: Finished FFF part (left) and SLA part (right)

The reasons for choosing these AM processes are as follows:

(1) Low production volume: The small-scale production of just two parts justified the use of AM processes.

(2) Geometric complexity: AM processes allowed the creation of the intricate geometry of the shopping bag holder without increasing production costs.

(3) Tooling cost: AM processes eliminated the high tooling costs associated with traditional manufacturing methods such as machining or injection molding, leading to a near-flat cost-per-part relationship regardless of volume.

(4) Customization and rapid prototyping: The ability to customize designs extensively and fabricate parts quickly made AM processes highly suitable.

(5) Benchmarking: AM processes were utilized to compare the two different methods.

Key Dimensions

The five critical dimensions essential to the overall form and function of the part, as illustrated in Figure 3, are:

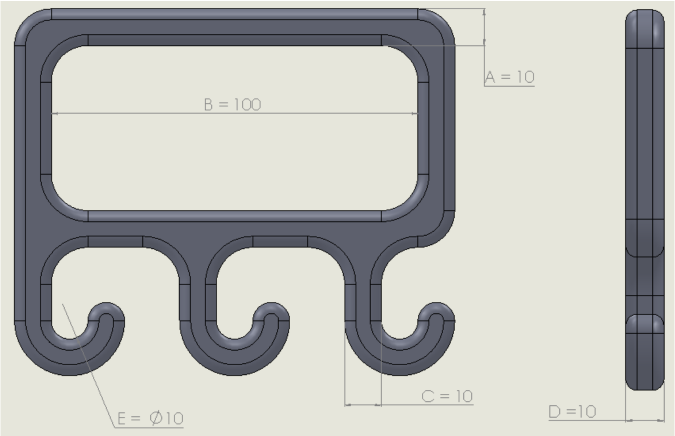

Figure 3: 2D part drawing

A - Width of the handle

B - Length of the handle

C - Width of the hooks

D - Overall thickness of the part

E - Inner diameter of the hooks

Dimensions A, B, and C are crucial to the handle's design, determining its cross-sectional area and volume, which ensures users can comfortably grasp the shopping bag holder with minimal stress on their fingers. If this cross-sectional area and volume are too small, the part design fails, causing users to experience equal or greater stress on their fingers compared to holding individual shopping bags.

Dimensions C and D define the cross-sectional area of the hooks, which is perpendicular to the direction of the load from multiple shopping bags. Stress is defined as force acting over a specific cross-sectional area and is inversely proportional to the cross-sectional area. Therefore, it is vital to maintain the cross-sectional area as per the design to prevent failure or permanent deformation of the hooks due to high localized stress concentration.

Dimension E refers to the inner diameter of the hooks. It is essential to have a minimum inner diameter to accommodate various types and quantities of shopping bags on a single hook. If the inner diameter is too small, only limited types and quantities of shopping bags can be hung using the hook.

AM Printers

Two types of AM printers were used for this experiment – one for FFF process and other for SLA process

(1) Ultimaker 3

The Ultimaker 3 is a desktop 3D printer (shown below in figure 4) that utilizes fused deposition modeling (FDM) technology, also known as Fused Filament Fabrication (FFF), to produce parts. It features a dual extrusion printhead capable of extruding both support and print materials. The Ultimaker 3 can achieve a minimum print layer thickness of 0.06 mm and can fabricate parts from a variety of polymers. It offers a maximum build volume of 571 in^3 (9245 cm^3) with single nozzle extrusion. The printer requires the use of Ultimaker Cura, a print preparation software, for design and topology optimization. This software ultimately converts the CAD model into a G-code file, which is then fed to the printer [2].

Figure 4: Ultimaker 3 [2]

The settings used to print the shopping bag holder with the Ultimaker 3 are outlined as in table 1 below:

Type of Parameters	**Settings**
Print and Support Material	PLA – Silver metallic color, 2.85 mm Filament
Layer Thickness	0.06 mm (minimum)
Infill Percentage	100%
Build Plate Adhesion	Yes
Print time	24 hours

Table 1: Ultimaker 3 Print Settings

These print settings were selected to meet the desired form and function of the shopping bag holder.

Infill Percentage: The strength of an FFF 3D printed part is directly proportional to the infill percentage, or density, of the part. A higher infill percentage results in greater part strength. The shopping bag holder needed to have high strength to withstand the load exerted by multiple shopping bags, thus the highest possible infill percentage or density was set for the part.

Layer Thickness: Layer thickness determines the resolution and surface finish of the FFF printed part. It is important to consider the part geometry and its application before selecting the layer thickness. The design of the shopping bag holder included fillet edges and required an attractive appearance and smooth surface finish. Therefore, the lowest possible layer thickness of 0.06 mm was chosen to minimize the impact on the fillet edges and achieve a smooth surface finish, enhancing the part's visual appearance.

With the print settings outlined in Table 1, the printing process for the part was completed in 24 hours.

(2) Form 2

The Form 2 is a desktop 3D printer (shown in figure 5 below) that employs stereolithography (SLA) additive manufacturing technology to create parts. It uses a 140 µm UV laser to cure liquid photopolymer (resin), constructing the part layer by layer. The Form 2 can achieve a maximum resolution or minimum layer thickness of 0.025 mm and has a maximum build volume of 224 in^3 (3674 cm^3). It can utilize various resins to achieve the desired properties for the SLA 3D printed part. PreForm, a print preparation software, is required for design and topology optimization, and it is ultimately used to send the print command to the printer [4].

Figure 5: Form 2 [4]

The settings employed to print the shopping bag holder using the Form 2 printer are outlined below:

Type of Parameters	Settings
Print and Support Material	Formlabs V4 clear standard resin
Layer Thickness	0.025 mm (minimum)
Support Structures	Yes, auto-generated
Print time	14 hours 30 minutes

Table 2: Form 2 Print Settings

These print settings were chosen to meet the desired form and function of the shopping bag holder.

Layer Thickness: Layer thickness is a key parameter that influences the part quality in terms of surface finish and visual appearance. The design requirements of the shopping bag holder necessitated smooth fillet edges and a good visual appearance. Therefore, to minimize visible layer ridges and achieve a smooth surface finish, the layer thickness was set to 0.025 mm.

Using these settings, the Form 2's SLA printer completed the printing process in 14.5 hours.

Qualitative Analysis

(1) FFF Print

Part Defects

Overhang quality issues are among the most significant challenges faced in the FFF AM process. Overhang defects occur when the printed layer is inadequately supported by the layer beneath it. Overhangs of up to 45° can be printed without compromising part quality, as at a 45° overhang angle, the previous layer provides 50% support to the next printed layer. For overhang angles greater than 45°, additional support is required to maintain part quality. Curling is a subsequent defect associated with excessive overhang angles, causing the part to deform upwards due to differential cooling rates, as newly printed layers become increasingly thinner at the overhang's edge [5].

Two primary defects were identified in the FFF printed shopping bag holder:

(a) Loss of part quality: As shown in Figure 6, the base layer and subsequent layers of the part failed to achieve the desired corner and edge fillets, resulting in undesired contour ridges around the part. This defect occurred because the part had an overhang angle greater than 45° for the fillets and was printed without overhang support structures.

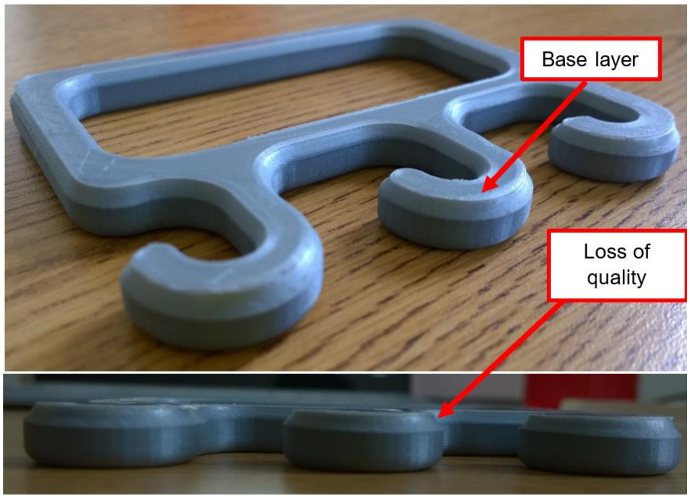

Figure 6: FFF part defect (base side facing up)

(b) Curling: The consequence of printing excessive overhang features without support structures caused the part to deform upwards due to differences in the cooling rates of subsequent layers (Figure 7).

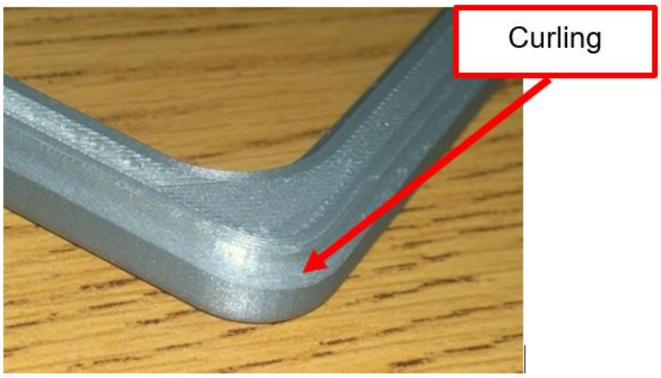

Figure 7: Curling defect at the corner of the FFF part

Support and Build Orientation

The absence of support structures for overhang angles greater than 45° contributed to the poor quality of the part, resulting in undesirable contour ridges on the base side. The FFF AM process is inherently anisotropic, as the bond strength between the layers is lower than the material's base strength. This means that the strength of FFF printed parts is always lower in the Z-axis than in the X&Y plane.

Given the highly anisotropic nature of the FFF process and the part's design application, the part was printed in a horizontal orientation, as depicted in Figure 8. This orientation ensured higher strength in the vertical plane, as the load on the hooks would be parallel to the layers [6]. Additionally, the horizontal build orientation eliminated the need for support and bridging structures that would have been necessary if the part were built in other orientations.

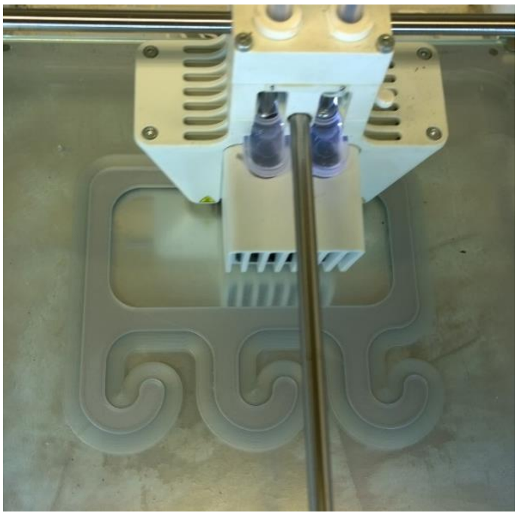

Figure 8: Horizontal build orientation of the FFF part

Post-Processing

The standard post-processing steps for an FFF printed part include the removal of support structures and the build plate adhesion layer. Needle-nose pliers were used to remove the build plate adhesion layer. The post-processing did not introduce any additional defects in the printed part. Additionally, the well-considered build orientation and the absence of support structures significantly reduced the post-processing requirements, thereby maintaining higher aesthetic standards.

(2) SLA Print

Part Defects

Figure 9: Bad surface finish defect on the SLA part

A single significant defect was identified in the SLA-printed part: (a) Poor surface finish: The transparent visual appearance of the middle hook indicates an inferior surface finish compared to the rest of the part (illustrated in figure 9 above). This defect arose after the part was successfully printed but before it underwent post-processing. The transparent appearance developed while the part was out of the printer and waiting to be washed and post-cured. Residual photo initiators in the part continued to react due to exposure to environmental heat and light after printing, resulting in a transparent finish, slight stiffening, and embrittlement of the part.

Support and Build Orientation

Support structures are always necessary in the SLA AM process. In SLA, the requirement for support structures is heavily dependent on the build direction of the printer. For printers with a bottom-up build direction (such as the Form 2), the priority is to minimize the cross-sectional area of each layer to limit the forces acting on the part during the peeling step, preventing it from detaching from the build platform. These forces during the peeling step are directly proportional to the cross-sectional area of the layer. Consequently, parts are oriented at an angle to minimize the cross-sectional area, and reduction of support structures is not prioritized. The support structure is made from the same resin used to print the part [7].

The SLA AM process is isotropic because the photo-resin forms a 3D crosslinked network of polymer chains, resulting in near-identical properties in the X, Y, and Z directions. Unlike FFF printed parts, the final mechanical properties of SLA printed parts are independent of their build orientation [8].

In summary, minimizing the cross-sectional area of each layer to reduce the likelihood of print failure is the optimal orientation strategy for SLA printing. Thus, the SLA version of the shopping bag holder was optimized to minimize failure likelihood by orienting it at an angle to reduce the cross-sectional area of each layer (as depicted in figure 10 below).

Figure 10: Build orientation of the SLA part

SLA printed parts require extensive post-processing compared to FFF printed parts. After printing, the part was transferred to a Form Wash machine, an automated device that agitated the part in isopropyl alcohol (IPA) for 30 minutes, ensuring thorough cleaning of every nook and cranny. Next, the part was transferred to the Form Cure machine, which precisely controlled temperature and light to further cure the 3D printed part, optimizing its mechanical properties [9]. The part was cured for approximately 60 minutes before proceeding to the support structure removal step.

The support structure was removed using needle-nose pliers, which left small nibs on the surfaces in contact with the support structures. The removal of the support structures did indeed introduce significant surface defects due to these residual nibs (as show in figure 11 below). To further enhance the surface finish, these small support nibs were scraped off using a hand scraper. Nonetheless, the SLA printed part exhibited an uneven surface finish on the areas that were in contact with the support structures.

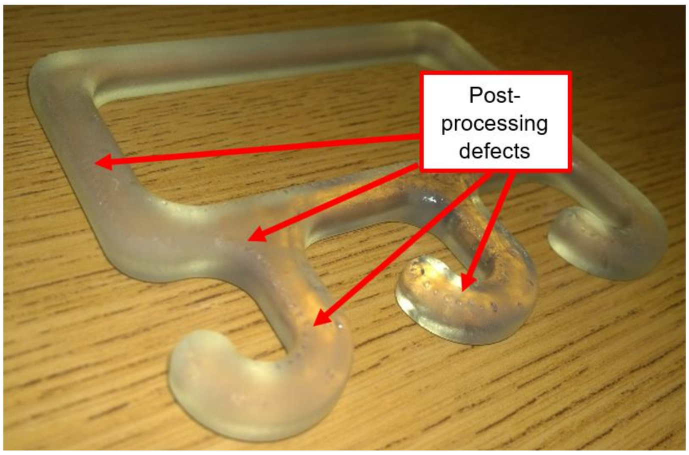

Figure 11: Defects induced by post-processing

Quantitative Analysis

The ideal dimensions of the part were measured using the CAD model and are shown in table 3 below.

Ideal Dimensions	
Dimensions	**Measurements (in mm)**
Width of the handle, A	10
Length of the handle, B	100
Width of the hook, C	10
Thickness of the hook, D	10
Inner Diameter of the hook, E	10

Table 3: Ideal dimensions based on CAD model

When selecting the appropriate measurement tool, the following factors should be considered [10]: (1) Accuracy and Repeatability: The measuring tool should offer a certain degree of accuracy and reliability in terms of measurement. (2) Size of the Part: The choice of measurement tool depends on the size of the feature and the part to be measured. The maximum dimension or feature of the part should be considered, ensuring the measurement scale of the tool is large enough to measure the maximum dimension or feature. (3) Rule of Ten (Gage Maker's Rule): A measuring instrument should be at least ten times more accurate than the dimensional tolerances of the part being measured. (4) Resolution: The resolution of a measuring instrument is the smallest dimension that can be read on the instrument. (5) Versatility: The measuring tool must be versatile enough to measure different types of basic part features, such as linear and circular features. It should also be capable of measuring hard-to-reach features or dimensions, considering all constraints.

Taking all these factors into account, a digital caliper was used to measure the key dimensions of the FFF and SLA parts. The digital caliper had a rated accuracy of 0.02 mm, a resolution of 0.01 mm, and could measure dimensions up to 150 mm. Furthermore, the digital caliper satisfied the Rule of Ten, as the general dimensional tolerance limits for FFF and SLA AM processes are ±0.5 mm and ±0.01 mm, respectively [11]. Digital calipers were also successfully used to measure circular features of the part, such as the inner diameter of the hook.

FFF Part Analysis

The measurements of key dimensions of the FFF printed part are shown in table 4 below.

FFF Process							
Dimensions	**Measurements (in mm)**						
	1	**2**	**3**	**4**	**5**	**Mean**	**Standard Deviation**
Width of the handle, A	10.05	10.06	10.06	10.05	10.04	10.05	0.008
Length of the handle, B	99.88	99.9	99.89	99.87	99.83	99.87	0.027
Width of the hook, C	10.11	10.12	10.13	10.12	10.14	10.12	0.011
Thickness of the hook, D	10.07	10.05	10.05	10.08	10.06	10.06	0.013
Inner Diameter of the hook, E	9.91	9.92	9.93	9.92	9.91	9.92	0.008

Table 4: Dimensions measured on the FFF part

Upon comparing the dimensions listed in Tables 4 and 5, it is evident that all five measured dimensions deviate from the ideal specifications. Further analysis of the dimensions of the FFF parts reveals that the internal dimensions are consistently smaller, while the external dimensions are larger when compared to the ideal values. These discrepancies between the actual and ideal dimensions of the FFF parts can be attributed to several factors.

(1) Extrusion profile: ideally, the extrusion profile of the FFF material exiting the nozzle should be perfectly spherical. However, to enhance adhesion between adjacent layers, a certain amount of force is applied by the nozzle, resulting in an oblate-shaped profile (as depicted in figure 12 below).

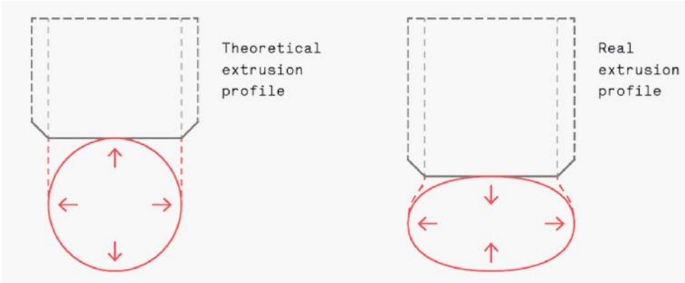

Figure 12: FFF material extrusion profiles [12]

The compressive effect on the extruded layer is the primary cause of discrepancies between the ideal and actual dimensions of the part. The oblate-shaped profile leads to a reduction in all internal dimensions and an increase in all external dimensions. Figure 13 illustrates the variation between the dimensions of the sliced model and the actual printed part. Consequently, the actual dimensions A, B, C, and E of the part deviate from the ideal dimensions due to the oblate-shaped profile of the extruded material.

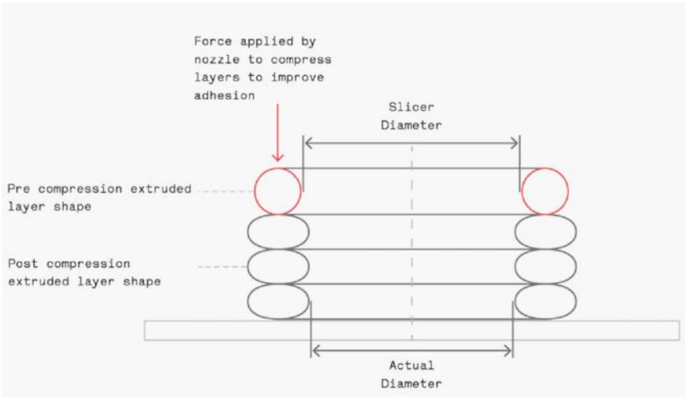

Figure 13: Variation in slicer vs. actual dimension [12]

(2) Support Structure and Build Plate Adhesion Layer: The presence of remnant support structures and the build plate adhesion layer often results in a bumpy surface finish after post-processing, significantly impacting the final dimensions of the FFF part. Specifically, dimension D deviates due to variations in the actual thickness of the part, as it was printed horizontally.

(3) Measurement Error: Errors in measuring the key dimensions of the part could also contribute to the discrepancies observed between the ideal and actual dimensions of the FFF part.

SLA Part Analysis

The measurements of key dimensions of the SLA printed part are shown in table5 below.

SLA Process							
Dimensions	**Measurements (in mm)**						
	1	**2**	**3**	**4**	**5**	**Mean**	**Standard Deviation**
Width of the handle, A	10.09	10.08	10.1	10.09	10.11	10.09	0.011
Length of the handle, B	99.88	99.85	99.92	99.91	99.9	99.89	0.028
Width of the hook, C	10.27	10.3	10.23	10.29	10.27	10.27	0.027
Thickness of the hook, D	10.22	10.25	10.28	10.25	10.28	10.26	0.025
Inner Diameter of the hook, E	9.85	9.82	9.87	9.84	9.89	9.85	0.027

Table 5: Dimensions measured on the SLA part

Upon comparing the results in Tables 3 and 5, it is evident that all five measured dimensions deviate from the ideal specifications.

The discrepancies between the actual and ideal dimensions of the SLA part can be attributed to several factors:

1. Sagging of Unsupported Spans: During the SLA AM process, the part being built does not reach its full strength until it is post-processed with UV light. Due to the relatively low strength and angular build orientation, sagging can occur at unsupported spans. This effect accumulates layer by layer, eventually leading to dimensional discrepancies in the SLA part [11].
2. Peeling Forces: The peeling forces experienced by the SLA part during the printing process can be strong enough to bend the soft print. This bending effect accumulates over subsequent layers, contributing to dimensional discrepancies [11].
3. Support Structures: In the SLA AM process, the surface finish of support structure surfaces is inferior compared to other AM processes. Post-processing steps such as support structure removal and sanding result in an uneven surface, contributing to the dimensional discrepancies.
4. Measurement Error: Errors in measuring the key part dimensions could also contribute to the discrepancies observed between the ideal and actual dimensions of the SLA part.

The combination of these factors results in deviations between the ideal and actual part dimensions of the SLA part.

Print Times

Tables 6 and 7 below showsoftware estimated print time for different layer resolution for the FFF and SLA processes.

FFF	
Layer thickness (in mm)	**Print time**
0.2	6 hours 17 minutes
0.15	9 hours 20 minutes
0.1	14 hours 34 minutes
0.06	24 hours

Table 6: FFF print times

SLA	
Layer thickness (in mm)	**Print time**
0.1	6 hours 42 minutes
0.05	10 hours 53 minutes
0.025	14 hours 30 minutes

Table 7: SLA print times

From the data above, it can be observed that as the layer thickness decreases (or resolution increases) the estimated print time increases.

To verify this data, print time for FFF process was calculated using mathematical formula and assumptions below.

Assumptions and Considerations for Calculations:

1. Build speed, extruder temperature, feed rate, infill percentage, support structure, filament diameter, print material, and print orientation are assumed to be constant.
2. Part geometry is approximated as a hollow rectangle with maximum dimensions of 120 mm x 100 mm x 10 mm, and a border width of 10 mm.
3. The part has a constant cross-sectional area, with the extruder following a rectangular toolpath at 100% infill percentage.
4. The number of passes per layer is maintained at 40.
5. The time to print the build plate adhesion layer and support structure is ignored.
6. The nozzle diameter is set at 0.25 mm, as specified in Ultimaker 3's technical data.

7. The extruder must make 40 passes to print the cross-sectional area of the hollow rectangle in each layer.
8. The average cross-sectional area printed by the extruder in 40 passes is 4006 mm^2.
9. The average volume printed in each layer of the part is calculated as 4006 mm^2 multiplied by the layer thickness.
10. The build speed of the extruder is 23 mm/s, as mentioned in Ultimaker 3's technical data.
11. The build rate of the extruder is calculated as 23 mm/s multiplied by 0.25 mm and the layer thickness.
12. The print time of one layer is determined by dividing the average volume printed in each layer by the build rate of the extruder.
13. The total number of layers required to print the part is calculated as 10 mm divided by the layer thickness.
14. The total print time is the product of the print time of one layer and the total number of layers required to print the part.

Based on the above assumptions and considerations, calculated print times are shown in table 8 below.

FFF Process	
Layer thickness	**Print time**
0.2	9 hours 41 minutes
0.15	12 hours 54 minutes
0.1	19 hours 21 minutes
0.06	32 hours 15 minutes

Table 8: Calculated FFF print times

Rearranging the formulas from (13) and (14) we get,

$$Total\ print\ time = Print\ time\ of\ one\ layer * \frac{Part\ thickness}{Layer\ thickness}$$

or

$$Total\ print\ time = Print\ time\ of\ one\ layer * Total\ number\ of\ layer\ required\ to\ print\ the\ part$$

Print time is inversely proportional to the layer thickness of the part (or directly proportional to the total number of layers required to print the part). As the layer thickness decreases, the volume of material printed in each layer decreases, and the number of layers to be printed increases. Consequently, it takes more time to print the same total volume of the part.

However, the regression model (Figure 14) of the software estimated print times indicates that the relationship between layer thickness and print time is not linear. Instead, it appears to be a second-order polynomial, suggesting the presence of another variable, apart from the number of layers, that influences the print time.

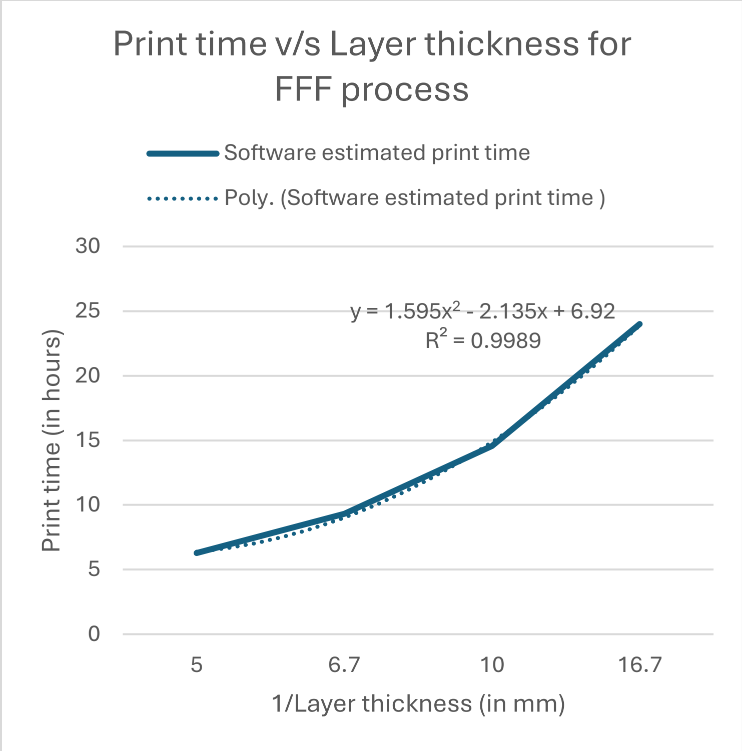

Figure 14: Regression model of FFF process

To make a more precise estimate of the print time, it is essential to identify the second variable that affects the print time of the part. Once this second variable is incorporated, a much more accurate relationship can be derived.

From the process physics, it can be deduced that as the layer thickness decreases, the number of passes per layer also decreases because the extrusion profile becomes more oblate due to the higher compressive force from the nozzle. Consequently, the number of passes per layer required decreases with decreasing layer thickness, reducing the time required to print one layer. This implies that print time also depends on the number of passes per layer.

Therefore, the relationship between print time and layer thickness is a combination of:

1. The number of passes per layer (directly proportional to the layer thickness of the part)
2. The total number of layers (inversely proportional to the layer thickness of the part)

Conclusion

(1) Improvement in FFF Process

Print Design: To enhance the print quality of the FFF printed shopping bag holder, it is recommended to split the model into two halves along the centerline of the part. Printing these halves with flat faces as the base layer for each will eliminate the need for overhang support structures, preventing defects such as curling and insufficient support. The two halves can then be cold welded during the post-processing step using an appropriate adhesive for the PLA material.

Material: To further improve the surface finish of the FFF printed part, the support structure and build plate adhesion layer can be printed with a dissolvable material like PVA. This material can be fed through the second nozzle of the Ultimaker 3, while the first nozzle prints the part using PLA. An additional advantage of PVA is that it is water-soluble, eliminating the need for expensive solvents. Consequently, the printed part can simply be placed in a bath of plain water to dissolve the support structure and build plate adhesion layer.

(2) Improvement in SLA Process

Material: The two main disadvantages of the SLA AM process are: (a) the use of the same material for printing both the part and the support structure, and (b) the post-processing step of support structure removal, which involves cutting off support structures and leaving behind small nibs and bumpy surfaces that hinder the final quality of the part. To address this issue, it is recommended to orient the part at a steeper angle to minimize the amount of support structure required, and/or to orient the part such that the support structures are attached to surfaces that are not critical to the form and function of the part.

Additionally, it is essential to develop a multi-resin SLA AM process capable of printing the part and support structure using two different materials. With a multi-resin SLA AM process, the support structure material could be printed using an IPA-dissolvable material. Consequently, the support structures would be easily removed when the part is placed in a bath of IPA for cleaning. This approach would simplify the post-processing of SLA printed parts and enhance the overall process quality.

AM Process

If cost is not a concern for producing the shopping bag holder part using the AM process, the FFF process would be the ideal choice. Parts produced using the FFF process, with the recommended improvements, will have the following advantages:

(a) **Free of Defects:** After implementing the recommended improvements to the FFF print design, the FFF process will produce parts without any defects.

(b) **Smoother Surface Finish:** Utilizing water-dissolvable material for the support structure and build adhesion layer will result in a much better surface finish compared to the SLA process.

(c) **No Post-Processing Induced Defects:** Unlike the SLA process, the FFF post-processing steps will not introduce any defects in the part.

(d) **Dimensional Accuracy:** As demonstrated in Tables 3, 4, and 5, the FFF printed part exhibits better dimensional accuracy and less dimensional variance compared to the SLA printed part.

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