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Experimental Investigation on Effect of Shell Thickness and Infill Density on Mechanical Properties of Polymer 3D Printing Process (MEX)

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Abstract: A cutting-edge advancement in advanced manufacturing is the use of a revolutionary technique called three-dimensional printing. The primary objective of three-dimensional printing, in comparison to traditional manufacturing methods, is to efficiently create intricate geometries in a shorter timeframe while maintaining the desired characteristics of the object. This task cannot be achieved by conventional production methods. In order to produce any component, it is vital for us to get the necessary material and then secure the power supply. In the process of three-dimensional printing, a diverse range of materials, such as polymers, metal powders, ceramic powder, and others, are used. Several variables contribute to the situation, including the amount of material used. In this specific instance, we are striving to maximize the use of material while maintaining the product's quality prior to printing. The criteria that have the most significant influence on the quantity of material required and the printing time are mostly determined by several key features. This category encompasses several factors, like layer height, infill density, print speed, shell thickness, and more. Furthermore, the line width or layer width is an additional criterion that significantly affects the amount of material used. Expanding the line width will lead to a higher expenditure of material, while reducing the layer width will result in a reduction in material consumption. The breadth of a layer is directly proportional to the amount of material used. The width of this line directly affects the duration of the printing process, the strength of the bond, and the quality of the completed product's surface. Significant changes in the line width could potentially lead to a print failure. Our objective is to enhance the efficiency of material use and printing time by adjusting the line width while maintaining the same layer height and applying various infill densities. This will allow us to maintain a consistent layer height. This research unequivocally proves that a model with 100% infill has no impact on the amount of material required. However, it does result in an increased printing time as the shell thickness decreases, printing time increases. The discoveries made in this study clearly demonstrate this. However, the layer width exhibits varying behavior depending on the kind of infill utilized. Decreasing the degree of infill not only reduces the amount of material used, but also increases the printing time.
Keywords: Shell thickness, Layer width, FDM, Material consumption, Printing time.

I. INTRODUCTION

The increasing number of recommendations indicates that additive manufacturing (AM) has the capability to manufacture components for a wide range of applications. These applications include several fields such as prostheses, automobiles, intelligent buildings, and military materials, among others. This device has the capability to manufacture components using a wide range of materials, such as plastics and metals, as well as other sorts of materials. Available for purchase are many additive manufacturing (AM) systems, including stereolithography equipment (SLA), selective laser sintering (SLS), fused filament fabrication (FFF), and three-dimensional printing (3DP). These systems are specifically designed for intricate applications and include a wide array of different options. Among the several additive manufacturing (AM) methods now accessible, the fused deposition modeling (FDM) process is the most commonly utilized for polymeric materials. The FDM process has several benefits, with the most notable being the wide range of available materials, the versatility in material options, the cost-effectiveness, the small size, and the low operating temperature. Another benefit is the accessibility of resources. Based on the evaluation of the relevant literature, some research has also shown several drawbacks linked to the FDM approach. Surface characteristics, postponed operations, and particular limitations on the measurements are some of the disadvantages that are linked to this substance. Furthermore, the researchers modified the parameters of the technique to overcome the constraints given by the FDM approach.

The cost of a manufacturing process is determined by the amount of energy and materials needed for each individual component. This is true for any production process. Various process factors may lead to differences in the quantity of material utilized for each item. The continuous advancement of the manufacturing technique for 3D printing is the primary source of this improvement. The intricacy of the geometry directly affects the cost of a 3D-printed item, with variations depending on the exact component in question. Simultaneously, with the growing complexity of the geometry, there is a corresponding increase in the cost, leading to an overall rise in expenses. Due to the layered nature of the production process in 3D printing, the amount of material utilized differs for each layer. This is due to the presence of cross-sectional elements of the geometry in each layer, which serves as the underlying explanation for this phenomenon. Furthermore, there is a constant change in the size of each cross section during the process, with variations in energy and material use. This unique form of fabrication significantly streamlines and accelerates the production process compared to conventional manufacturing (CM), which is the traditional approach to production. This is because it eliminates the need for molds, dies, and hand tools. The potential of fast prototyping allows customers to benefit from an efficient production environment characterized by increased resource utilization and reduced time consumption.

II. LITERATURE REVIEW

Additive manufacturing (AM), also known as layer manufacturing (LM), is a modern computer-based approach that has shown to be a valuable alternative for creating components in many applications. Despite the situation, there are still significant constraints associated with the technology. Amplified manufacturing has the capacity to fabricate very intricate things that would be exceedingly challenging or perhaps unfeasible to produce using conventional manufacturing procedures often used in the industry. Due to its reliance on computer-based production technologies, additive manufacturing (AM) offers easily accessible applications in reverse engineering. These applications enable the creation of new components that are almost equivalent to current components, using three-dimensional (3D) scanning instead of starting from scratch with a new design [1–3]. This technology has the capacity to be utilized in various industries, including but not limited to aerospace and military sectors [4], biomedical applications like dental and organ treatments [6], automobiles [7], energy storage devices [8], and numerous other fields. The engineering sector enables the use of several additive manufacturing technologies that are now generally acknowledged. There are several techniques that are included under this category. Examples of additive manufacturing techniques include ink-jet printing, laminated object manufacturing (LOM), three-dimensional printing (3DP), and fused deposition modeling (FDM). Furthermore, this article also discusses the techniques of laminated object manufacturing (LOM), selective laser sintering (SLS), and stereolithography (SL). Fused Deposition Modeling (FDM) has emerged as a very popular method of additive manufacturing and is being used in the fabrication of diverse product range [9]. The widespread adoption of FDM can be attributed to its user-friendly interface, simple manufacturing process, cost efficiency, ability to customize materials extensively, capability to produce complex parts through extrusion, and versatility in processing various thermoplastic polymers including PLA, ABS, PS, PC, nylon, and PET. However, due to the layer-by-layer deposition process of FDM-printed materials, the bonding between the layers is rather weak. Consequently, the mechanical characteristics of these materials are of lower quality compared to materials that have undergone injection molding [10, 11].

The FDM technique has a diverse array of benefits and limitations that are now present in the market. For most applications that use FDM-printed parts, the mechanical qualities, dimensional accuracy, and surface roughness of the finished components are considered crucial attributes [12]. The most advantageous aspects we examine are ease of operations, cost savings, and hastened construction process time [13]. However, we regard complex process characteristics, which significantly impact component manufacture, as a serious limitation. As a result, researchers are unable to conduct comprehensive studies that examine all criteria. Investigators are now focusing on this significant field of research to achieve the objective of determining the best process parameter for standardizing the process, which is necessary to meet individualized criteria [14]. Therefore, the optimization of the process parameters becomes the most crucial area of focus. Because process parameters are interdependent, it is possible that an ideal combination of these parameters might produce a 3D-printed product with greater mechanical strength than the optimal combination of parameters used individually [15, 16]. This is because the process parameters are interdependent.

III. PROBLEM STATEMENT

The production of any component necessitates the use of raw materials, which are an essential element. The component is formed by the process of either subtracting or adding raw components throughout its creation. Similarly, the three-dimensional printing process necessitates the successive addition of raw ingredients to fabricate the component. Control over material use in 3D printing is feasible, unlike in subtractive production.

When it comes to slicing, several factors might influence both the quality and amount of material used for each component. The primary aim of this investigation is to ascertain the amount of material used for each print. This will be achieved by modifying the width of the layer lines. It will be feasible to accomplish this objective without disrupting the geometric properties of the component. The oval form is associated with the cross section and is tied to the layer width. The material extruded from the nozzle will experience compression due to the distance between the nozzle and the preceding layer. The presence of this gap enables the nozzle to generate compressed material. This occurs when the nozzle deposits one layer on top of another during the printing process. When calculating the line width of the layer, one of the elements considered is the nozzle-to-bed distance. There is a clear relationship between the breadth of the layer and the amount of material employed. Previously, it was said that the consumption of material depends on several factors, including the density of the infill and the support structures. This is a previously stated topic. Conversely, the width of the layer line will affect the infill pattern, the thickness of the infill section, and the wall thickness of the resulting object.

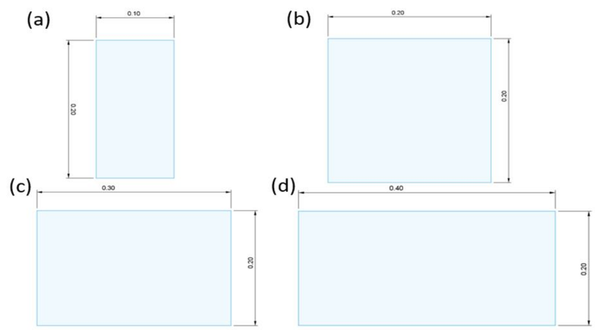

Figure 1: a) shows the layer height 0.2 and layer width 0.1 b) shows the layer height 0.2 and layer width 0.2 c) shows the layer height 0.2 and layer width 0.3 d) shows the layer height 0.2 and layer width 0.4

IV. METHODOLOGY

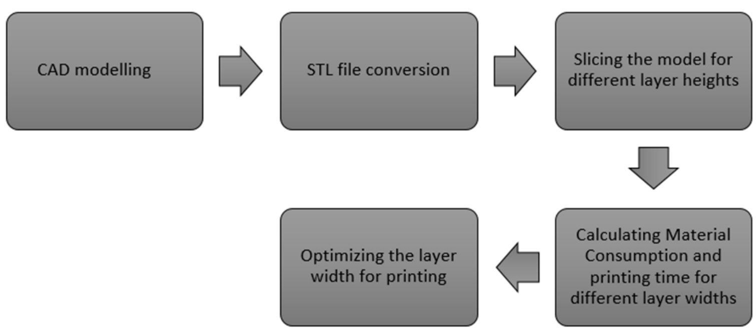

Figure 2: Methodology for optimizing the layer width

V. CAD MODELLING AND SLICING

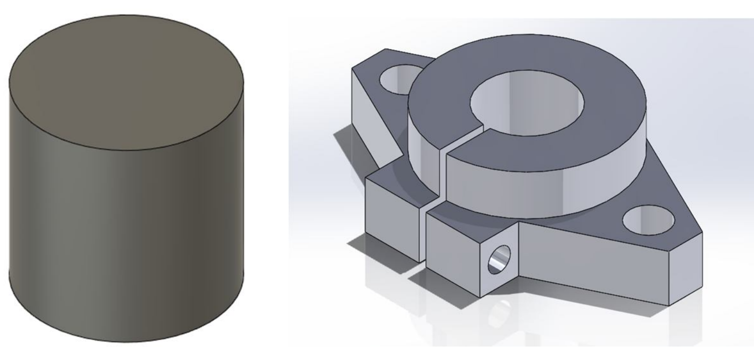

Figure 3: Simple basic model of cylinder and shaft holder for studying the layer width (shell thickness)

To study the effect of layer width here two models were taken to examine the material consumption and printing time. The models can be seen in figure 4.

A. Printing Procedure

Initially, the item intended for production using a three-dimensional printer is designed using computer-aided design (CAD) software and then produced. The CAD model creation procedure has been initiated. Solid modeling software, such as CATIA and Solid Works, is more adept at providing a precise representation of three-dimensional objects compared to wire-frame modeling software, such as AutoCAD. Solid models serve as the foundation for the construction of solid modelers, explaining the current situation. According to [6], this method is similar to most of the tactics used to rapidly produce prototypes.

The procedure for transforming an item into the STL format is: There is a wide range of computer-aided design (CAD) models that can display solid components in different ways. We have chosen the stereolithography format as the industry standard in the field of three-dimensional printing. We made this choice to ensure universal consistency. If you are dealing with an STL file, you need to slice it. Applying the final adjustments to a pre-processing computer program is crucial to ensure the STL format is suitable for construction purposes. The user has access to a diverse array of tools, each of which allows them to modify the model according to their preferences. By using pre-processing software, the stereo lithography model is divided into a larger number of layers. However, the thickness of these layers might vary depending on the building process, ranging from 0.01% to 0.70% of the overall thickness. Moreover, the program generates a supplementary framework to assist the model throughout its production phase. This is done to provide support for the model. In most cases, having access to additional support is critical for complex construction projects.as a port.

B. Machine set up

1) After slicing the model, you must transfer a G-code file to the SD card you are currently using. This is a necessary step to ensure the accuracy of the obtained information.
2) Next, go to the second stage, which involves selecting the appropriate printing file. Following that, insert the SD card into the printer. It is crucial that you do this task.
3) We prepped the bed using a variety of different methods before starting the printing process. The extruder expects the bed to maintain a level position throughout the entire operation.
4) If the printing bed is not level, there is a chance that the printing process may fail. This is because the completed printed object will have an off-cantered bottom, which will lead to a failed printing procedure.
5) The final step entails inserting the material into the extruder, which you can accomplish by choosing the suitable loading option. It is important for you to input the information in accordance with the set standards.
6) The printer will promptly initiate the bed heating procedure to reach the required temperature once you select the file. The temperature of the bed may vary depending on the kind of material being printed.
7) During the subsequent phase, the extruder is subjected to heat, with the specific temperature being determined by the kind of printing material used. If the temperature is below the appropriate level, the layer will not adhere well, while a temperature over the specified level will result in material overflow. Hence, it is essential to avoid setting the extruder temperature above the desired temperature. Hence, it is critical not to exceed the recommended temperature level while adjusting the extruder's temperature.
8) Prior to starting, it is advisable to begin by applying adhesive or printing tape to the bed. This will finalize the procedure. As a result, you will be able to achieve a higher level of adhesion to the bed.
9) Once the printing process has begun, it is critical to examine the first printing layers, and it is equally important to refrain from disturbing the machine in any way.
10) After the component is finished, the bed and the nozzle will be taken out of their designated locations and put in their appropriate placements. Prior to proceeding, it is advisable to wait until the temperature of the bed aligns with the temperature of the room. What is the reason for the increased prominence of the bottom part of the print compared to the rest of the print throughout the printing process? If the removal of the component is not promptly carried out, the bottom of the component will reach a high temperature, resulting in the warping of its proportions. If you fail to promptly remove the component, the proportions will get distorted.

VI. RESULTS AND DISCUSSIONS

During the process of slicing the CAD model, we have observed that the amount of material used and the printing time vary when we slice the model with varying layer line widths while keeping the layer height constant. This is true regardless of whether the layer height is consistent or not. Regardless of whether we use a smaller or larger layer height, this truth remains true.

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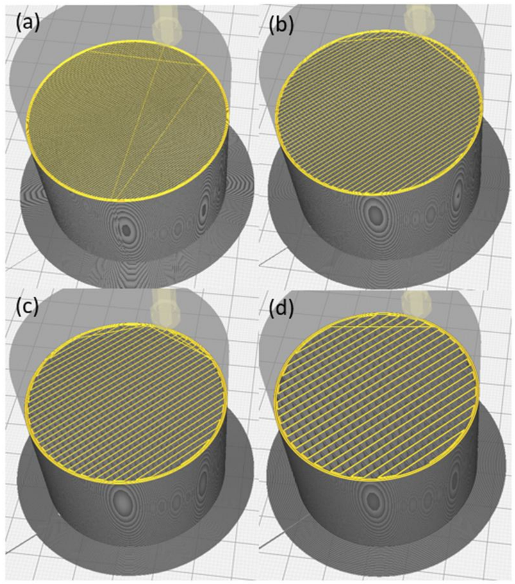

Figure 4: Investigation of layer width (Shell thickness) at (a) LH 0.2 with LW 0.1 (b) LH 0.2 with LW 0.2 (c) LH 0.2 with LW 0.2 (d) LH 0.2 with LW 0.2

Figure 5: Material consumption and printing time of (a) LH 0.2 with LW 0.1 9 (b) LH 0.2 with LW 0.2 (c) LH 0.2 with LW 0.3 (d) LH 0.2 with LW 0.4

Table 1: Material consumption and build time estimation of CYLINDER at 100% infill percentage and 0.2 mm extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	10/3.31	46
0.3	10/3.31	61
0.2	10/3.31	89
0.1	10/3.31	174

Table 2: Material consumption and build time estimation of CYLINDER at 50% infill percentage and 0.2 mm extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	7/2.22	42
0.3	6/2.11	49
0.2	6/1.99	65
0.1	6/1.87	109

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Table 3: Material consumption and build time estimation of CYLINDER at 25% infill percentage and 0.2 mm extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	6/1.67	34
0.3	5/1.49	39
0.2	5/1.4	47
0.1	4/1.13	70

The data shown above illustrates that the thickness of the layer significantly affects both the duration of the printing process and the quantity of material used. Therefore, as shown in the previously stated chart, the thickness of the layer does not affect the complete filling of the object. However, lowering the infill percentage below 100% does lead to a reduction in the amount of material required. In this matter, it is critical to consider this specific piece of information.

Table 4**:** Material consumption and build time estimation of CYLINDER at 100% infill percentage and 0.3 mm extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	10/3.35	41
0.3	10/3.35	51
0.2	10/3.35	71
0.1	10/3.35	120

Table 5: Material consumption and build time estimation of CYLINDER at 50% infill percentage and 0.3 mm extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	8/2.26	31
0.3	7/2.14	37
0.2	7/2.03	47
0.1	7/2	77

Table 6**:** Material consumption and build time estimation of CYLINDER at 25% infill percentage and 0.3 extrusion thickness

Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	6/1.70	17
0.3	6/1.63	20
0.2	5/1.45	26
0.1	4/1.27	42

The duration of the printing process, the volume of material used, and the energy consumption are all closely linked to the modification of the layer width. There is a clear correlation between these three criteria. Irrespective of the different heights of the layers, this truth remains unchanged. The tables in this area are a manifestation of the same concept, which is evident here. The printing time is indirectly influenced by the relationship between the amount of material used and the breadth of each layer. This association is directly proportional to the duration required for printing the material. In this specific case, we managed to establish a direct relationship between the duration of printing and the energy use. Simultaneously, when the duration dedicated to printing rises, there is a corresponding escalation in the overall energy use.

Area of filament = pi /4 $*D^2$

D- Filament diameter which is (1.76 mm)

Volume = Area * L

L- Material length

Weight= Volume * density

Density- PLA material Density

Table 7: Layer width Vs weight at 100% infill for 0.2 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	8	10.1
0.3	8	10.1
0.2	8	10.1
0.1	8	10.1

Table 8: Layer width Vs weight at 50% infill for 0.2 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	5.3	6.5
0.3	5.	6.2
0.2	4.6	5.9
0.1	4.4	5.5

Table 9: Layer width Vs weight at 25% infill for 0.2 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	3.9	4.9
0.3	3.5	4.4
0.2	3.1	3.8
0.1	2.6	3.3

Table 10: Layer width Vs weight at 100% infill for 0.3 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	8	9.9
0.3	8	9.9
0.2	8	9.9
0.1	8	9.9

Table 11: Layer width Vs weight at 50% infill for 0.3 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	5.4	6.7
0.3	5.1	6.3
0.2	4.8	6
0.1	4.5	5.6

Table 12**:** Layer width Vs weight at 25% infill for 0.3 LH

LW (mm)	Filament volume (cm^3)	Weight (grams)
0.4	4	5
0.3	3.6	4.5
0.2	3.2	4
0.1	2.8	3

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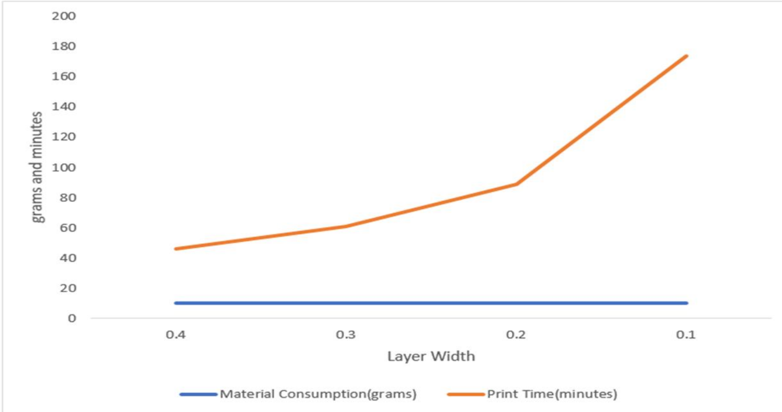

Figure 6: shell thickness Vs printing time and material consumption at 100% infill

When printing with a fill rate of one hundred percent, the quantity of material used does not vary across different layer widths since there is no change. When a component is printed with a 100% infill level, it is considered completely filled, leaving no gaps. This is due to the absence of any remaining gaps. Under these situations, any adjustments made to the layer's width will not affect the quantity of material utilized in any way.

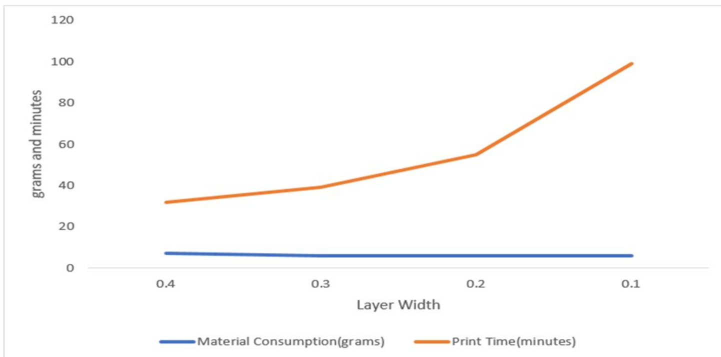

Figure 7: shell thickness Vs printing time and material consumption at 50% infill

An excellent example of this may be seen in the reduction of infill material used when the layer width is halved. Modifying the layer thickness triggers this phenomenon. Conversely, the duration of printing rises, resulting in a corresponding increase in energy consumption throughout the printing process. The graph clearly supports this explanation. When the infill percentage is less than 100%, changing the layer's width will affect the number of infill partitions created. Even after implementing the width reduction, the number of infill partitions will continue to increase.

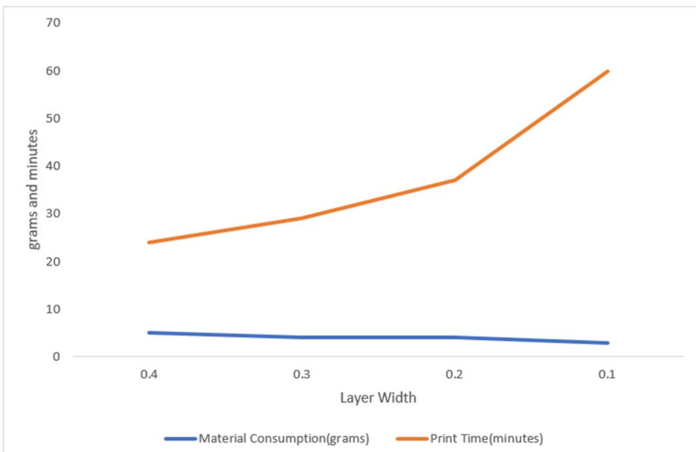

Figure 8: shell thickness Vs printing time and material consumption at 50% infill

A. Investigation of Effect of shell Thickness on Material Consumption

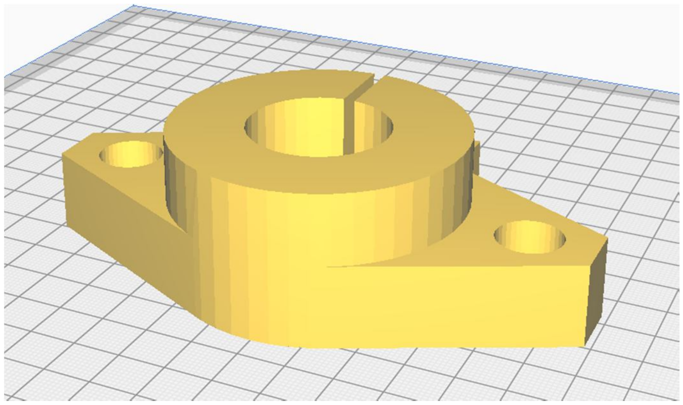

Figure 9: Shaft holder

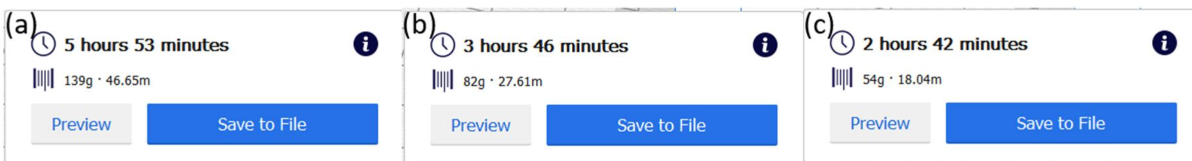

Figure 10: Investigation of shaft holder at (a) 100% infill (b) 50% infill (c) 25% infill

Table 13**:** Material consumption of shaft holder at 100% infill at LH 0.2 mm

Slicing of shaft holder at 100% infill and LH 0.2		
Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	139/46.6	353
0.3	139/46.6	462
0.2	139/46.6	681
0.1	139/46.6	1333

Table 14: Material consumption of shaft holder at 50% infill at LH 0.2 mm

Slicing of shaft holder at 50% infill and LH 0.2		
Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	82/27.61	226
0.3	83/27.52	295
0.2	82/27.36	426
0.1	81/27.22	823

Table 15: Material consumption of shaft holder at 25% infill at LH 0.2 mm

Slicing of shaft holder at 25% infill and LH 0.2		
Layer Width(mm)	Weight (g)/ Pool length (m)	Print Time(minutes)
0.4	54/18.04	162
0.3	54/18.26	210
0.2	53/17.71	298
0.1	52/17.51	566

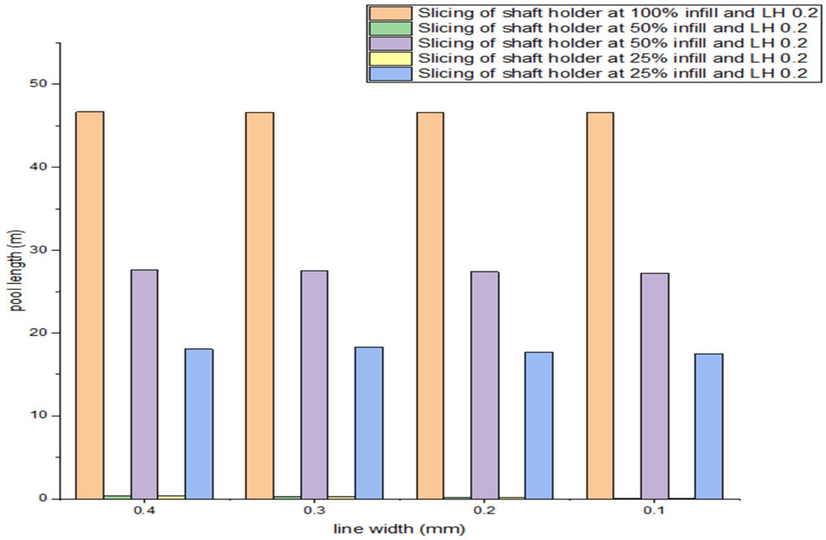

Figure 11: Relation between line width and different infill percentages

VII. CONCLUSIONS

Three-dimensional printing enables the creation of intricate geometries while maintaining precise dimensional accuracy in the final outcome. This is because the printing process operates in three dimensions. Conversely, the amount of material and energy lost during the production process is the primary limitation of every manufacturing process. However, additive manufacturing uses more energy compared to conventional machining, even if it uses less material than traditional cutting methods. Compared to conventional machining, there is a significant reduction in the quantity of material needed. We are giving more focus to the printing parameters in order to maximize material efficiency. When the layer thickness remains constant, the line width has a significant impact on the amount of material used. While the amount of material used decreases with the line width, power consumption increases. Expanding the line width similarly leads to an increase in material use, but it also causes a reduction in energy consumption. However, the printed product's quality is much worse when using a narrower layer width. Reducing the line width results in increased dimensional accuracy and improved surface polish, whereas the inverse is also true.

1) In this specific instance, it is crucial to note that the only parameter that is modified is the layer width parameter, while all other values stay the same. Table 3 displays the amount of material used and the duration of printing for various layer widths of a cylinder with 25% infill and a layer height of 0.2. Let us examine this table. Conversely, the proportion of infill remains constant regardless of any changes that occur throughout the process. Although it was expected that the weight of the last section would remain the same in that situation, the weight of the last component is actually dropping in this specific case.
2) Reducing the amount of infill at various layer widths leads to an expansion in the range of weights found in the final section. If you look at Tables 1, 2, and 3, you will see an increase in the variation in the final weight of the component as you go through the different infill percentages for the various layer widths. These tables have a distinctive feature.
3) During this investigation, we created a basic cylinder with equal dimensions of dia 30 and length of 60 on all sides. The tiny size of the block means that printing any important component will require a significant amount of material. This is because the block is quite small. Similarly, the time required for printing will increase, as will the amount of energy used.
4) The amount of material utilized stays constant while the fill level is set to 100%; nevertheless, the printing level will increase when the layer width is decreased. Upon examining tables 1 and 4, it becomes evident that the material usage is consistent for layer widths of 0.2 and 0.3. Conversely, reducing the layer width results in a longer printing time. Every reduction in layer width leads to an increase in extruder travel time, which is the primary factor that prolongs the printing process. Consequently, this prolongs the printing process.

Our findings are based on the fact that the width of the line directly affects the printing parameters. We want to do more testing to evaluate multiple layer heights and line widths, as well as to analyze the dimensional accuracy of the final printed component across varying layer heights. Both of these items are highly sought-after. Our objective is to do experiments on different line widths and layer heights in order to assess the influence of layer width on the surface roughness and mechanical properties of the material.

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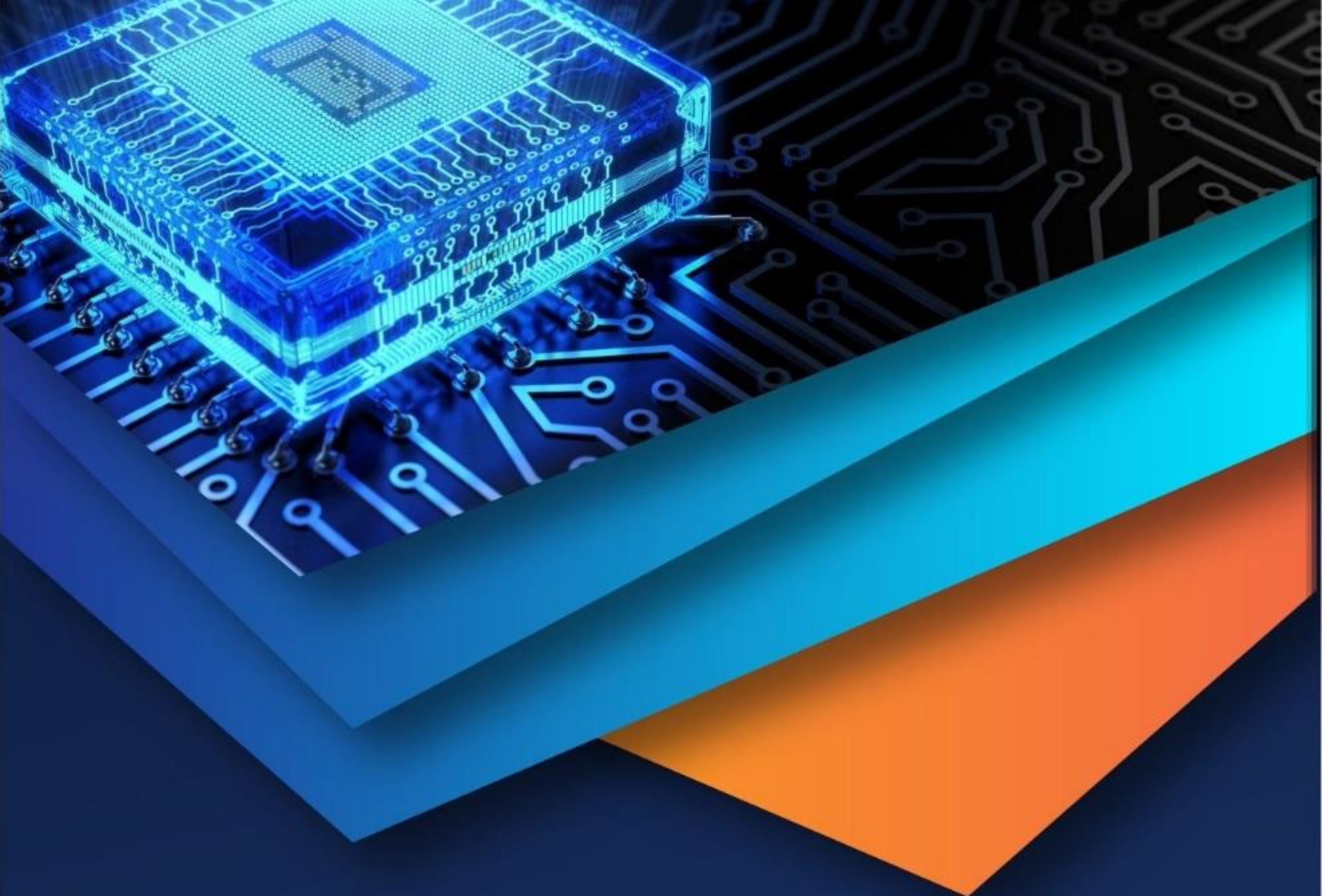

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