International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06| June 2022 www.irjet.net p-ISSN: 2395-0072

Experimental Studies on Effect of Layer Thickness on Surface Finish using FDM

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Abstract - *Additive Manufacturing (AM) is a discipline in manufacturing technique by which the product or the prototype is developed layer-by-layer. AM uses 3D printing approach majorly, out of other forming methods. It is capable of handling CAD model with varying complexity in terms of designing and incorporates manufacturing. When compared to traditional manufacturing, AM requires fewer tools in regards to the space and physical inventory, it saves a lot of resources financially. It also consists of a digital inventory. The unlimited adaptability of component production is the primary benefit. Now, Layer Thickness is an important aspect in 3D printing. Layer Thickness is a measure of height of each successive layer of material addition in additive manufacturing process. Layer thickness governs the overall surface, and product quality of the component under process. Effect of layer thickness can be seen majorly in terms of surface finish and print time. Increasing layer thickness decreases print time is a known fact. Thus, this paper intends to experimentally establish a logical relation between the surface roughness and layer thickness. This can be achieved by 3D printing components each with different layer thickness, calculating surface roughness of each component and then finding out governing relation between the two. This logical relation can be helpful while trading off between print time and surface finish.*

***Key Words*: Additive Manufacturing, Layer Thickness, FDM, Surface Roughness, 3D Printing**

1. INTRODUCTION

Additive Manufacturing (AM) is a modern name for 3D printing. AM is a layer-by-layer creation procedure that changes the CAD model straightforwardly into completely complex designs. AM requires less tools with regards to space and physical inventory savings. It has a digital inventory. The primary benefit of Additive Manufacturing is that it has an unlimited adaptability to produce a complicated part. The term '3D printing' can allude to an assortment of cycles wherein material is saved, joined or fused under PC control to make three layered objects, with material being added together. [1] Around the 1980s, 3D printing methods were viewed as reasonable just for the development of useful or aesthetic models, and a more fitting term for it at the time was rapid prototyping. Starting in 2019, the accuracy, repeatability, and material scope of 3D printing have expanded to the point that some 3D printing processes are viewed as suitable as a modern creation innovation by which the term Additive Manufacturing can be utilized equivalently with 3D printing. [2]

Additive Manufacturing is basically utilized by specialists, designers, and development administrators, and has supplanted manual drafting. [3] It assists clients with making plans in three aspects to envision development, and empowers the turn of events, change, and streamlining of the plan interaction. This interaction assists engineers with making more exact portrayals and adjusting them all the more effectively to further develop plan quality. Additive designing is advancing at a quick speed. 3D printing presently includes metal laser sintering, powder bed combination, and, surprisingly, crossover strategies including analytical and robotics. It has been embraced by major modern organizations searching for ways of working on their items. The capacity to convey close moment parts creation and completely specially crafts that cannot be recreated with other assembling procedures has sped up venture and examination in added substance designing. [4]

Prior to slicing/cutting, the CAD model is tessellated, for example changed over into a cross section of triangles to shape the external shell of the article and is put away in the STL file format, which is upheld by the RP machines. [5] The way toward changing over the CAD into a cross section of triangles to frame the external surface of the item is called tessellation. This is a significant advance as the process parameter, for example, build-time, part quality and surface roughness rely upon the degree to which the model has been tessellated. The more tessellated a model is, the more is the structure time, and more is the dimensional precision of the actual model in contrast with the CAD model. [6]

Prior to being sliced, the slicing programming permits the end user to settle on a decision of the direction and cut thickness (layer thickness) which enormously sway item fabricating time, material to be utilized and related expense, surface quality and the quantity of extra constructions known as help structures. [11][7]

Following are the requirements that an STL file format must satisfy:

1. Each face of the triangle must share only one edge with the adjacent triangle.[8][9]

2. The vertex of any one triangle cannot lie on the edge of any other triangle [8]. When the part is viewed from external end, the vertices of the triangle should be placed in anti-clockwise direction. The normal vector of each triangle must be pointing outside. [9]

Most of the CAD systems fail to satisfy these necessities and effect in defects such as missing facets, overlapping facets, holes, cracks and inaccurate normal. [8][10]

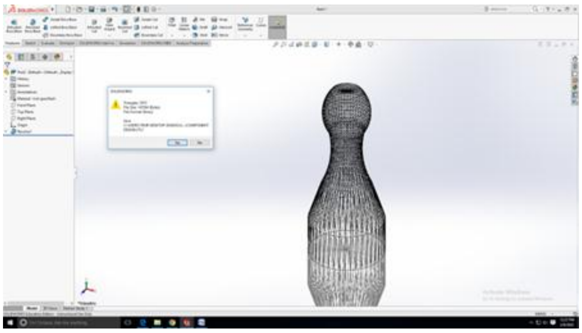

Fig -1: Standard Tessellation Language Format Component in Solid Works

2. PROBLEM STATEMENT/ OBJECTIVES:

- Examine the behavior of the quality of PLA material for FDM process parameters.
- Finding the optimum combination of FDM process parameters like layer thickness for better part quality.
- Analyzing the relationship between the FDM process parameters and comparing it with the mechanical properties. Thereby, examining the results using graphical interpretation.
- FDM Process Parameters: Layer thickness with constant Orientation and Infill density
- Mechanical properties: Surface Roughness

3. LITERATURE REVIEW:

3.1 Printer used:

As we are printing the model using the FDM process, the printer we have chosen in Flashforge Guide IIs as shown in Figure 3.1. Its unique feature is that it has a closed box which allows the efficient control of temperature. Flashforge guider IIs uses software named FlashPrint for slicing the component. The slicing software converts the 3D model into a code that instructs the printer to print it. Many additional features need to be determined during the slicing process. User needs to give parameters as an input during the slicing, for example infill density, layer thickness, printing orientation etc. Some parameters are fixed and need not to be changed, like printing speed, controlling printing speed may lead to bad quality of product.[12]

Fig-2: Flashforge Guider IIs (Manual)

Flashforge Guider IIs is proved as a good choice for small production with its big build volume as well as features such as great compatibility of materials and extruder system, Guider IIs delivers strong functions with industrial-grade accurate parts and quality. With the strong functional features, it allows much freedom to produce accurate work and enhance productivity.

- Video Monitoring printing process with a built-in HD camera
- Durable and industrial-grade extruder for maximum print temperature up to 300°C
- Massive build volume: 280*250*300mm
- Open 1.75mm filament system
- 5-inch touchscreen interface
- Auto bed level system ensures the platform is leveled before printing.

The Flashforge Guider IIs is equipped with HEPA filter, which protects your working environment from potential dust produced in the process of printing industrial filament.

Table -1: Printer Specifications

Nozzle diameter	0.3 to 0.8 mm
Maximum extruder temperature	300^0C
Print speed	30-100 mm/s
Maximum platform temperature	120^0C
Layer Thickness	0.1-0.4 mm
Filament compatibility	PLA, HPS, ABS, PETG, PC, ASA
Screen dimension	5-inch Touch screen
Internal Storage	8 GB
Running Noise	55 dB
Power	500 W
Connectivity	USB, Wi-Fi, Ethernet etc.
Software and file format	FlashPrint (STL, OBJ, BMP, PNG)

3.2 Process parameters:

Fused deposition modelling (FDM) is a fast-growing rapid prototyping (RP) technology due to its ability to build functional parts having a complex geometrical shape in a reasonable time period. Customisation of material properties by route of controlling the process parameters is a landmark ability of the additive manufacturing (AM) processes.[13] FDM is a complex process that exhibits much difficulty in determining optimal parameters due to the presence of a large number of conflicting parameters that will influence the part quality and material properties.[14]. The quality of built parts depends on many process variables.[13]

Hence, it is absolutely necessary to understand the process parameter such as materials used, printing delay, build orientation, print head resolution, geometric features and their topology, post treatment procedures, binder drop volume, binder powder interaction, particle size and layer thickness that will influence the surface quality, part strength, build time, accuracy and repeatability [15].

Build parameters that have an effect on the physical properties of 3D printed samples considered for the present study is given below:

3.2.1 Layer Thickness:

Also known as layer height or vertical resolution is the thickness with which the printer head prints a single sliced layer. Layer height is an important parameter as it governs the surface finish of the final model. Lower the layer height, higher the surface finish. However, build time increases if we reduce the layer height and layer height cannot be reduced below a certain limit.[16]

3.2.2 Printing orientation:

This parameter describes the direction in which the 3D model is to be printed. Once the model is loaded onto the slicing software, the orientation of the model can be changed. The printer then prints the model in the selected orientation. This parameter has a significant impact on the strength of the material and the printing time. By changing print orientation, support requirements can be reduced or sometimes eliminated.

3.2.3 Fill density:

Fill density/ Infill describe the density with which the material is filled within the outer shell of the model. The fill density may vary from a 0% to a 100%. The 100% fill density represents a solid block whereas the 0% of it represents an object with only an outer shell. Mechanical strength increases with increase in fill density, but has longer build times. With increase in fill density, Material requirement and weight of the component also increases. There are various infill patterns available.

3.3 Material Selection:

Additive manufacturing is basically 3D printing. Rather than simply using conventional machining techniques which include wastage of materials by removing unwanted fragments, additive manufacturing deposits layer after layer creating objects. It is comparatively a more flexible technology than subtractive manufacturing. Since technology is advancing day by day, new materials are being created to get desired properties that can be applied to the required functions. This literature review mainly focuses on the properties of polymeric materials that are available and used for 3D printing and their impact in the market of AM. Since various kinds of polymeric materials are available, the manufacturer of the product would prefer the polymer with the optimum conditions for the required objective. For example, optimum strength is required for manufacturing and prototyping. Garment industry requires high elasticity. For a function of insulation high thermal resistivity is desired. High ductility is required for wiring and circuitries. Aerospace industry calls light weight polymers. Higher toughness is required for supporting materials. An optimum melting point is essential for temperature-dependent environmental factors that are experienced by the polymeric substance used. A proper amount of flexibility is required for better portability of the material. [17]

The types of plastic used in this process are usually made from one of the following materials 1) Polyastic acid (PLA) this is eco-friendly material. PLA made up of from sugar cone and corn starch therefore biodegradable. This is available in two forms soft and hard. Plastics are made from polyastic acid so it is used in industries hard polyastic acid are stronger and therefore they used for making ideal products. 2) Acrylonitrile butadiene styrene (ABS) ABS is best option of home-based 3D-printiners. It is valued for strength and safety. ABS is available in various colors. This makes the material suitable for products like stickers and toys. ABS also used to make jewellery and vases. 3) Polyvinyle alcohol plastic (PVA) It is used in low end home printers. It is low cost. This material used for temporary used items. 4) Polycarbonate (PC) PC is only used on this printer which feater nozzle is designed and operates on high temperature. This is less frequently used. [18]

According to the literature survey of 'Synthetic Metals' conducted in order to find a match of polymeric properties with metallic properties in, properties such as metallic conductivity can now be incorporated into polymers such as Polyacetylene (CH) x, which is the least complex natural polymer, can be presently be reversibly doped to the metallic system by incomplete oxidation or reduction either chemically or sometimes electrochemically. Similarly, Polyaniline mentioned can be doped to the metallic system by leading a straightforward acid/ base protonation. There is indeed a long way to go for AM to be able to replace conventional machining processes, and polymers over metals. A study conducted in order to predict the future of metals, a survey was analyzed that in an average US automobile, there was a 12% rise in the utilization of plastics and composites (up to 229 lb), and the net abatement in the utilization of steel was just 1.4% of the complete weight. The examination demonstrated that the utilization of metals in automobile parts of the industry diminished by just '0.4%', as a small amount of the vehicle weight over this equivalent period. There is an inclination towards utilizing a superior polymer because of the requirement of having parts and models that can have exceptional dimensional, mechanical and chemical strength at incredibly high temperature and pressures even after introduction to exceptionally harsh environments for example, as exposed during AM processes.[17]

3.4 Component Design:

To design a product either physical or digital model it is necessary to focus on the end-to-end design parameters of the product. Research showed that the components that were designed were an end product and were not tested for their dimensional accuracy. Therefore, a product is being designed and developed so as to cover all the dimensional aspects of the product like flat, inclined, curved surface having concave and convex structures. Fig 3.2 shows the component design for all the above stated design parameters.

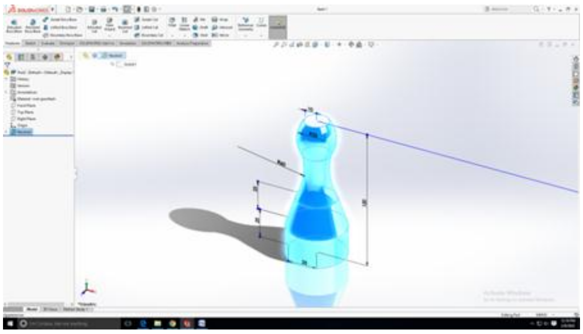

Fig -3: Component Design

3.5 Surface Roughness:

In Additive Manufacturing (AM), surface finish and texture can determine the quality of the end product. Fundamentally, 3D technology under FDM is primarily based on layer manufacturing processes [19]. Surface Roughness can often be defined as the shorter frequency of the surface relative to the troughs [20]. The surface is rough if the present deviations are large; it is smooth if the deviations are small. Roughness also helps in governing how the printed object interacts with the environment. Under certain circumstances, high roughness aids in enhanced adhesion [21]. Often highly rough surfaces are undesirable as they may be hard to control under manufacturing, for instance in the FDM process [22]. Being very vital, the roughness can be calculated using multiple methods based on different processes and varied requirements. Surface roughness can be calculated using the Arithmetical Mean Height system (Ra). Ra considers the average of the absolute values along the roughness sample length [23]. Among many other methods used, this one, in particular, holds merit as it makes use of the ISO standard of measuring the mean line system [24]. Ra is measured in microinch or micrometer.

Amplitude parameters are another class of measurement that classifies various approaches to calculate the roughness of the material. It allows determining the roughness based on vertical deviations present in the profile. This class includes methods like Arithmetic Mean Deviation (Ra), Root Mean Square (Rq, Rms), Skewness (Rsk), Kurtosis (Rku), and Height of Peak, Valley and their ratio (Rv, Rp, Rz) [25,26]. Generally, cross-scale characteristics like surface fractality, instead of scale-specific characteristics, offer more significant predictions of mechanical interactions at surfaces, like contact stiffness and static friction [27]. These methods help greatly in determining the roughness and texture of the surface using various amounts of data available. Various works have been published wherein the different input parameters were used to observe the changes in the final surface output [28]. Also, the printing parameters previously mentioned like infill density, layer thickness have a considerable effect towards the finish and surface quality [29].

Roughness can be measured by manual comparison using a comparator. However, a general method of measurement for sample profile is done by Profilometer [30]. Various measuring instruments are used to determine the roughness of the printed material practically. These are segregated into two parts majorly: Contact-type and non-Contact type. The contact type has instruments like Roughness Tester and Atomic Force Microscope which provide a resolution 1-0.1 nm. Contact type often has a poor angular characteristic and the positioning of the device may be optional. The Non-Contact type consists of instruments like White Light Inferometer and Laser Microscope. They are very strong instruments to measure the roughness, with a resolution scope of less than 0.1 nm. They have built-in camera system along with good angular characteristic. Samples as small as 10 micrometer to a few milimeters in thickness can be analyzed [31].

3.6 FDM part quality:

The study shows that research is done on various additive manufacturing technologies like SLS, SLA etc. but there is a lot of improvement required in the product quality of FDM technology. Generally, FDM is considered to be slower than other RP techniques like SLS which may directly affect the strength of the product. Another drawback of FDM is the staircase-effect. As we know, the FDM technology uses layer by layer manufacturing while building the part; this may create some surface inaccuracies. When a curved geometry is created in 3D CAD modeling software, it loses its geometrical accuracy while printing the part because the part is printed in two and a half dimensional form. This loss of information leads in generation of a stair-like structure on the part. This structure is known as staircase effect. It is negligible in case of perpendicular and horizontal surfaces, but its effect is maximum in inclined or curved surfaces.

Figure 3.4 shows the effect of the staircase in RP processes. The effect can be decreased by decreasing the layer thickness but this might lead to increase in the built time and cost. Therefore, by electing an optimal value of layer thickness one can balance the build time and stair-case effect.

Fig -3: Image of the component showing staircase effect (Layer Thickness = 0.2 mm)

4. EXPERIMENTAL SETUP:

4.1 Component and Machine Specification:

Table -2: Component and Machine Specification

Machine Type	Guider II S Series
Material	PLA
Infill Density	0%
Infill Pattern	Hexagon
Print Speed	60 mm/s
Travel Speed	80 mm/s
Extruder Temperature	210^0C
Platform Temperature	30^0C
Orientation	0^0

4.2 Dimensional Accuracy Measurements

The dimensional accuracy of the components was calculated using a vernier caliper. The Vernier was first tested for no zero error and was found to be calibrated. Further readings of all the components at different instances were measured and noted. The vernier used during the testing was Flat and Knife Edge Vernier Calliper for measurement of external diameter of the circular edge and curved edge. In addition to it, it was used for checking the thickness of raft as well as the overall length of the component. Whereas for testing of the weight, an analytical weight balance was used.

4.3 Surface Roughness Testing

One of the important mechanical parameters is roughness and it is generally carried out to specify for any surface. More the surface rough, more will be the chances of cracks and corrosion, but it can also lead to adhesion as far as additive manufacturing is considered. A surface roughness tester is used to accurately and quickly determine the texture of the surface and/or roughness of the material. A surface roughness tester shows the values of mean roughness values (Ra) as well as measured roughness depth (Rz) depending on the type of component. The values are usually in micrometer (mm) or microns (µm). The surface roughness tester used in this experimentation was Time TR 200.

5. RESULTS:

5.1 Dimensional accuracy measurements

Table -3: Dimensional accuracy measurements

Observation Number	1	2	3	4
Layer Thickness (mm)	0.2	0.25	0.3	0.35
Designed Base Diameter (mm)	50	50	50	50
Actual Base Diameter (mm)	49.8	49.7	49.8	50
Designed Crown Diameter (mm)	31.6	31.6	31.6	31.6
Actual Crown Diameter (mm)	31.5	31.54	31.6	31.6
Designed Length (mm)	121.55	121.55	121.55	121.55
Actual Length (mm)	121.72	121.7	121.7	121.76
Designed Weight(g)	17.95	18.38	18.87	20.05
Actual Weight (g)	16.5	17	17.5	18.5
Time (min)	79	68	69	59
Material Required (m)	79	68	69	59

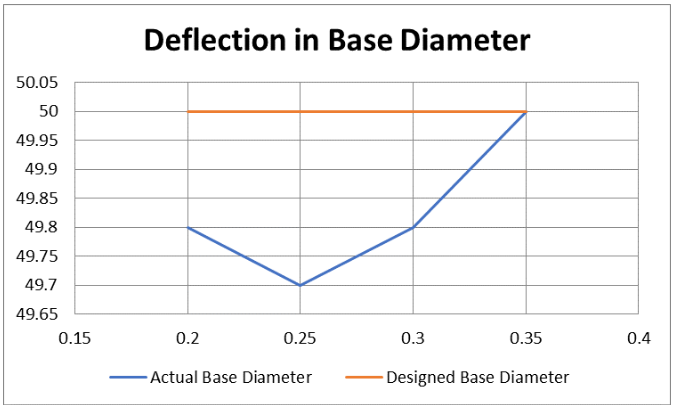

Chart -1: Deflection in Base Diameter

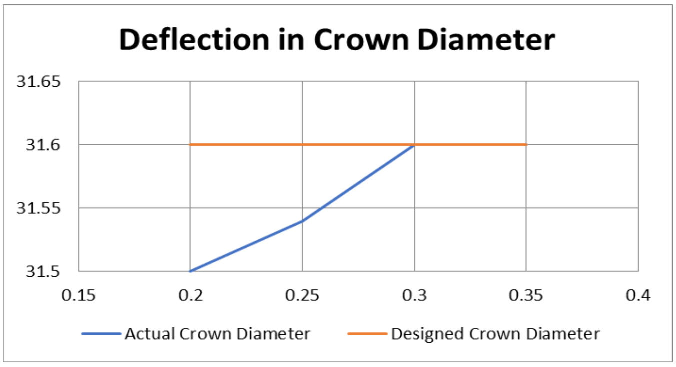

Chart -2: Deflection in Crown Diameter

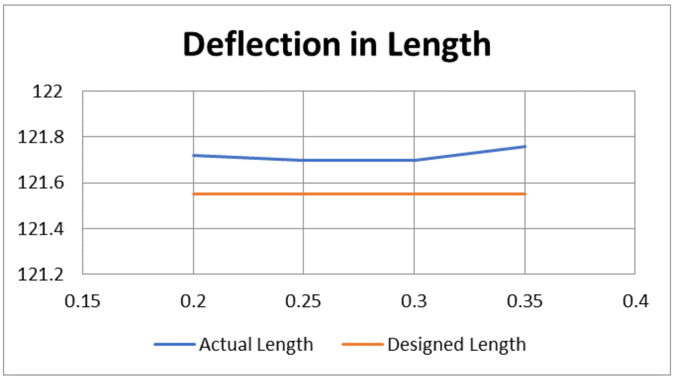

Chart -3: Deflection in Length

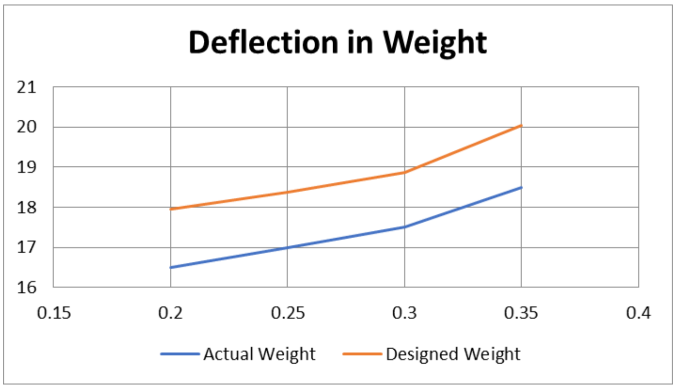

Chart -4: Deflection in Weight

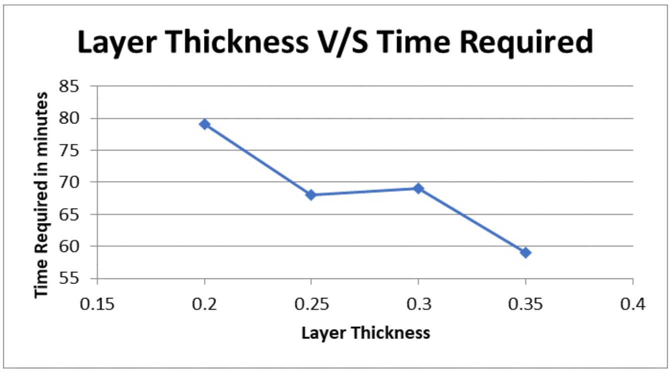

Chart -5: Layer Thickness vs. Time Required

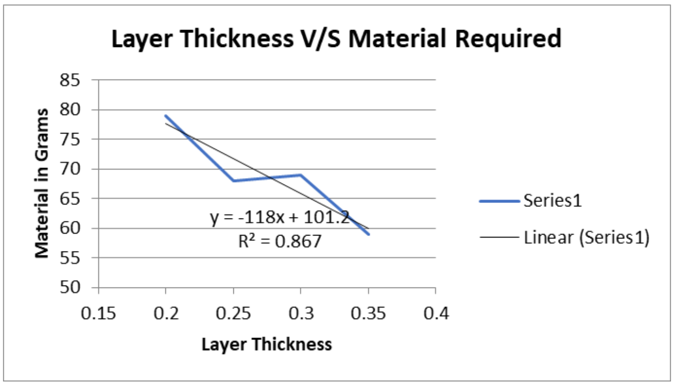

Chart -6: Layer Thickness vs. Material Required

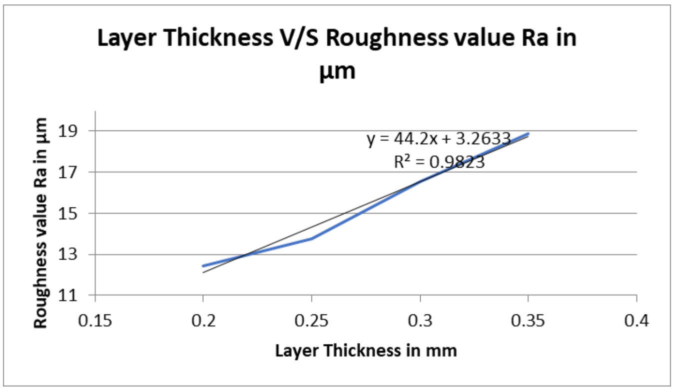

Chart -7: Layer Thickness vs. Roughness value

5.2 Surface Roughness

Table-4: Surface Roughness

Layer Thickness in mm	Roughness Values (Ra) in µm			
	1	2	3	Average
0.2	12.36	12.54	12.45	12.45
0.25	13.71	13.38	14.22	13.77
0.3	16.69	16.53	16.49	16.57
0.35	18.36	19.67	18.62	18.88

6. CONCLUSION

In present work, a specimen with linear angular and curved component was designed developed and fabricated using a flash forge guider IIs 3D printer. The specimen was built with PLA material with varied layer thickness of 0.2 mm, 0.25 mm, 0.3 mm and 0.35mm. The same specimen were tested for its dimensional accuracy as well as for surface roughness testing. The experimentally obtained results were then compared for the deflection in different parameters of the specimen (like the base diameter length etc) with layer thickness and it was found as the layer thickness increases the diameter and the length decreases.

Secondly, the specimen was tested in a surface roughness tester which provided the Ra values, which were calculated and plotted on the graph of layer thickness versus roughness value. This graph showed that the curve is linear in nature that is as the layer thickness increases the roughness value increases. However by decreasing the layer thickness the roughness of the component can be maintained.

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