Experimental Investigation of Surface Finish Enhancement of Fused Deposition Modelled Parts

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ABSTRACT: 3D printing is a promising digital manufacturing technique that produces parts with layer by layer. The influence of process parameters is investigated for PLA material in fused deposition modelling (FDM). This work aimed to determine what are the printing process parameters effect the surface roughness of printing parameters. Major influencing parameters are wall count, top and bottom closing layers effecting the surface roughness when the infill density is less than 100%. Wall count, top and bottom closing layers are need to increased when the wall count decreases. By increasing the wall count, top and bottom closing layers the strength of the component increases. But the material consumption and printing time increases.

Key words: 3DP, PLA, Wall count, layers, Granular material

I.   INTRODUCTION

3D printing or additive manufacturing (AM) is any of various processes for making a three-dimensional object of almost any shape from a 3D model or other electronic data source primarily through additive processes in which successive layers of material are laid down under computer control. A 3D printer is a type of industrial robot. Early AM equipment and materials were developed in the 1980s. In 1984, Chuck Hull of 3D Systems Corp, invented a process known as stereo-lithography employing UV lasers to cure photopolymers. Hull also developed the STL file format widely accepted by 3D printing software, as well as the digital slicing and infill strategies common to many processes today. Also during the 1980s, the metal sintering forms of AM were being developed (such as selective laser sintering and direct metal laser sintering), although they were not yet called 3D printing or AM at the time. In 1990, the plastic extrusion technology most widely associated with the term "3D printing" was commercialized by Stratasys under the name fused deposition modelling (FDM). In 1995, Z Corporation commercialized an MIT-developed additive process under the trademark 3D printing (3DP), referring at that time to a proprietary process inkjet deposition of liquid binder on powder. AM technologies found applications starting in the 1980s in product development, data visualization, rapid prototyping, and specialized manufacturing. Their expansion into production (job production, mass production, and distributed manufacturing) has been under development in

the decades since. Industrial production roles within the metalworking industries achieved significant scale for the first time in the early 2010s. Since the start of the 21st century there has been a large growth in the sales of AM machines, and their price has dropped substantially. According to Wohlers Associates, a consultancy, the market for 3D printers and services was worth $2.2 billion worldwide in 2012, up 29% from 2011. Applications are many, including architecture, construction (AEC), industrial design, automotive, aerospace, military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewellery, eyewear, education, geographic information systems, food, and many other fields.

1. 1 3D Printer

3D-Printer is a machine reminiscent of the Star Trek Replicator, something magical that can create objects out of thin air. It can "print" in plastic, metal, nylon, and over a hundred other materials. It can be used for making nonsensical little models like the over-printed Yoda, yet it can also print manufacturing prototypes, end user products, quasi-legal guns, aircraft engine parts and even human organs using a person's own cells. We live in an age that is witness to what many are calling the Third Industrial Revolution. 3D printing, more professionally called additive manufacturing, moves us away from the Henry Ford era mass production line, and will bring us to a new reality of customizable, one-off production. 3D printers use a variety of very different types of additive

manufacturing technologies, but they all share one core thing in common: they create a three-dimensional object by building it layer by successive layer, until the entire object is complete. It's much like printing in two dimensions on a sheet of paper, but with an added third dimension: UP. The Z-axis. Each of these printed layers is a thinly-sliced, horizontal cross-section of the eventual object. Imagine a multi-layer cake, with the baker laying down each layer one at a time until the entire cake is formed. 3D printing is somewhat similar, but just a bit more precise than 3D baking. In the 2D world, a sheet of printed paper output from a printer was "designed" on the computer in a program such as Microsoft Word. The file - the Word document which contains the instructions that tell the printer what to do. In the 3D world, a 3D printer also needs to have instructions for what to print. It needs a file as well. The file, a Computer Aided Design (CAD) file is created with the use of a 3D modelling program, either from scratch or beginning with a 3D model created by a 3D scanner. Either way, the program creates a file that is sent to the 3D printer. Along the way, software slices the design into hundreds, or more likely thousands, of horizontal layers. These layers will be printed one atop the other until the 3D object is done.
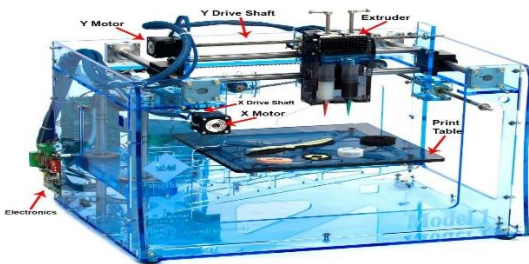

Fig 1.1: Construction of 3D printer

The picture shows the structure of a typical 3D printer. The print table is the platform where the objects for printing has been situated. It provides the basic support for manufacturing objects layer by layer. The extruder is the most important part of a 3D-Printer. As the extruders in the normal paper printers, this extruder is also used to pour ink for printing. The movement of extruder in various dimensions create the 3D print. For printing a 3d object, the extruder has to access X, Y and Z coordinates. For achieving this, many techniques are used according to the printer specification required for various applications. If the 3D-Printer is a desktop printer, the Z axis movement of the extruder can be avoided and that function can be transferred to the print table. This will avoid complexity in 3D printing as well as time consumption. When the STL file is input to the printer, the microcontroller extracts each layer from it and also extracts each line segment from each layer. Then it gives controls to the movement of the extruder at required rate. The X-direction movement of extruder is made possible by the X-motor. When the X motor rotates, the shaft also rotates and the extruder moves

in X direction. The Y-direction movement of extruder is made possible by the Y-motor. When the Y motor rotates, the shaft also rotates and the extruder moves in Y direction. The X direction movement is made by the print table. In the case of desktop printers, the printing ink is usually plastic wire that has been melted by the extruder at the time of printing. While printing, the plastic wire will melt and when it fall down to the printing table. Consider printing larger objects like house using 3D printer. There will not be any X motor or Y motor in that case. An extruder which can pour concrete mix is fixed on the tip of a crane. The crane is programmed for the movement of extruder in X, Y and Z axis. The concept and structure of 3d printer changes according to the type, size, accuracy and material of the object that has to be printed. Generalizing the facts, the extruder need to access all the 3 coordinates in space to print and object. The method used for that doesn't matters much.

1.2 Additive manufacturing

Additive manufacturing is a truly disruptive technology exploding on the manufacturing scene as leading companies are transitioning from "analog" to "digital" manufacturing. Additive manufacturing uses three-dimensional printing to transform engineering design files into fully functional and durable objects created from sand, metal and glass. The technology creates products layer by layer – after a layer's particles are bound by heat or chemicals the next layer is added and the binding process is repeated. It enables geometries not previously possible to be manufactured. Full-form parts are made directly from computer-aided design (CAD) data for a variety of industrial, commercial and art applications. Manufacturers across several industries are using this digital manufacturing process to produce a range of products, including: engine components for automotive applications, impellers and blades for aerospace use, pattern less sand moulds for pumps used in the oil and energy industry, and medical prosthetics which require easily adaptable design modifications. This advanced manufacturing process starts with a CAD file that conveys information about how the finished product is supposed to look. The CAD file is then sent to a specialized printer where the product is created by the repeated laying of finely powdered material (including sand, metal and glass) and binder to gradually build the finished product. Since it works in a similar fashion to an office printer laying ink on paper, this process is often referred to as 3D printing. The 3D printers can create a vast range of products, including parts for use in airplanes and automobiles, to replacing aging or broken industrial equipment, or for precise components for medical needs. There are tremendous cost advantages to using additive manufacturing. There is little to no waste creating objects through additive manufacturing, as they are precisely built by adding material layer by layer. In traditional manufacturing, objects are created in a subtractive manner

as metals are trimmed and shaped to fit together properly. This process creates substantial waste that can be harmful to the environment. Additive manufacturing is a very energy efficient and environmentally friendly manufacturing option. Additive manufacturing swiftly creates product prototypes – an increasingly critical function that significantly reduces the traditional trial-and-error process – so new products can enter the market more quickly. Likewise, it can promptly create unique or specialized metal products that can replace worn or broken industrial parts. That means companies can avoid costly shut downs and drastically compress the time it takes to machine a replacement part. With additive manufacturing, once a CAD drawing is created the replacement part can be printed. Storage of bulky patterns and tooling is virtually eliminated. Major global companies, including Ford, Sikorsky and Caterpillar, have recognized that additive manufacturing can significantly reduce costs while offering design freedoms not previously possible. They have begun to implement the technology into their manufacturing processes. Additive manufacturing has robust market capabilities ranging from aerospace to automotive to energy, and it is not uncommon to find 3D printers in use at metal-working factories and in foundries alongside milling machines, presses and plastic injection moulding equipment. A large number of additive processes are now available. They differ in the way layers are deposited to create parts and in the materials that can be used. Some methods melt or soften material to produce the layers, e.g. selective laser melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modelling (FDM), while others cure liquid materials using different sophisticated technologies, e.g. stereolithography (SLA). With laminated object manufacturing (LOM), thin layers are cut to shape and joined together (e.g. paper, polymer and metal). Each method has its own advantages and drawbacks, and some companies consequently offer a choice between powder and polymer for the material from which the object is built. Some companies use standard, off-the-shelf business paper as the build material to produce a durable prototype.
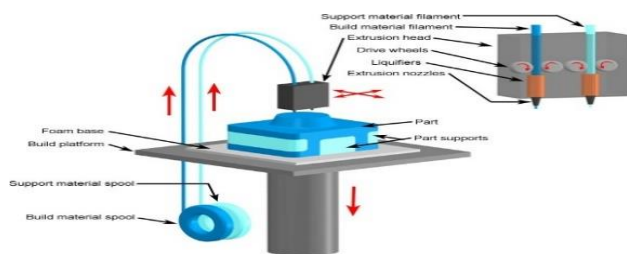

Fig 1.2: Basic Method of FDM Technology

Fig 1.3: Granular material binding
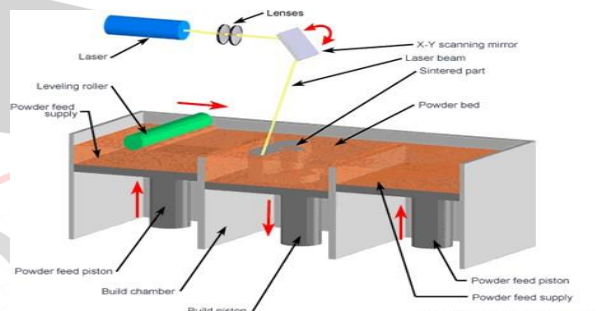

Fig 1.4: Illustration of granular material

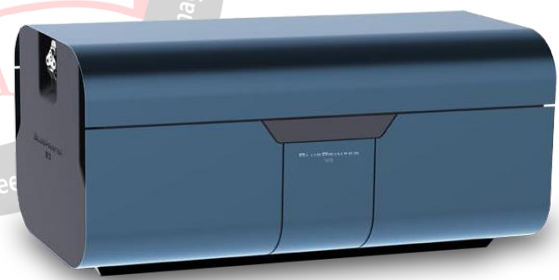Fig 1.5: Selective Laser Sintering Citation Process

Fig 1.6: Illustration of a Blue Printer Citation
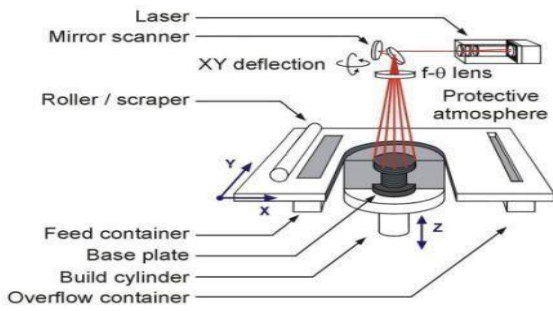

Fig 1.7: A model created by Blue Print Citation

Fig 1.8: Illustration of selective laser melting method

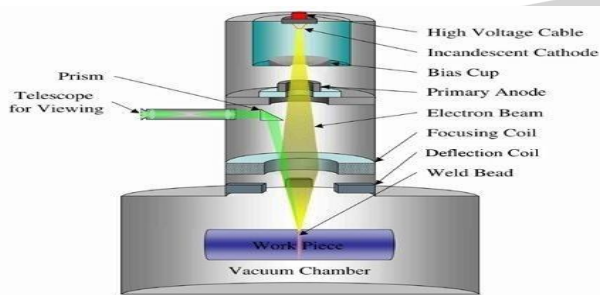Fig 1.9: Selective laser melting in action

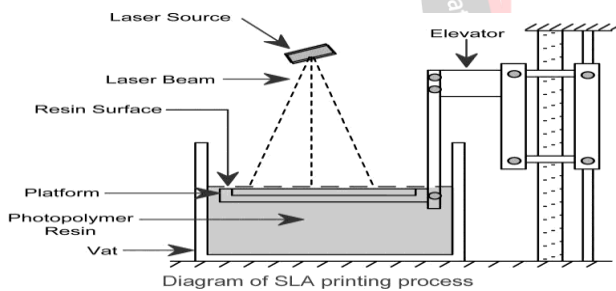Fig 1.10: Illustration of an EBM process citat

Fig 1.11: Illustration of Stereo Lithography process
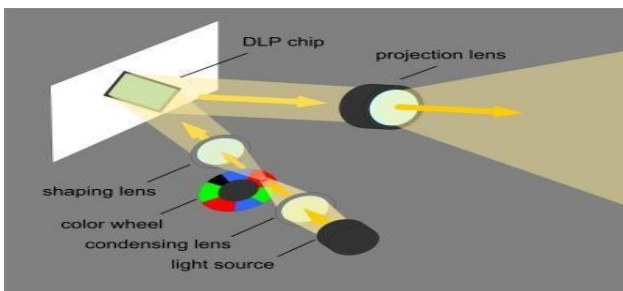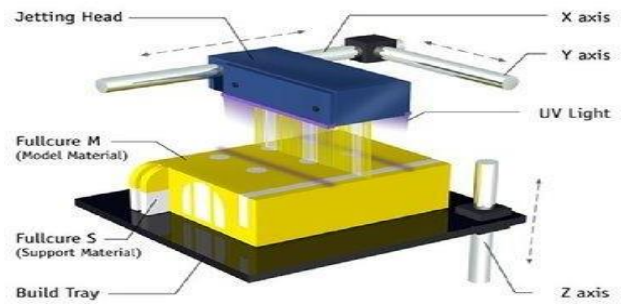

Fig 1.12: Illustration of DLP Projection

Fig 1.13: Illustration of material jetting process citation
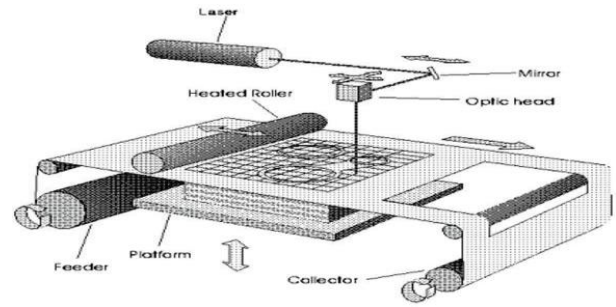

Fig 1.14: Depiction of Laminated Object Manufacturing process

1.3 Materials used in FDM Process:

PLA (Polylactic Acid)

ABS (Acrylonitrile Butadiene Styrene)

Nylon

PETG (Polyethylene terephthalate glycol)

TPU (Thermoplastic polyurethane)

ASA (Acrylonitrile Styrene Acrylate)

PEI (Polyetherimide)

A. Boschetto, V. Giordano, F. Veniali states that the additive manufacturing material extrusion surface finish is periodic in nature, which has been explored by researchers employing either rectangular or elliptical bead models. The shallow inclination angle configurations exhibit the greatest 'staircase impact', but in addition to this, the assumed bead geometry influences physical distribution of undercuts and voids.[1] **T. Wholers, Wohlers report 2006** states that Fused deposition modeling (FDM) is one of the most adaptable additive manufacturing method owing to the cost-effectiveness and environment-friendly nature. It is desirable to explore an efficient technique for FDM parts to enhance the poor surface quality and dimensions precision.[2] **P.M. Pandey, N.V. Reddy, S.G. Dhande** states that the improvement of part surface quality and geometric accuracy in Rapid Prototyping has been a major concern. Reduction in build time and increase of part surface quality are two factors which contradict with each other as decreasing build time detracts part quality because of staircase effect.[3] **R. Anitha, S. Arunachalam, P. Radhakrishnan** states Rapid prototyping (RP) meets the current needs in the industry to

shorten design cycles and improve the design quality. Fused deposition modelling (FDM) is one of the key technologies of RP. Various process parameters used in FDM affect the quality of the prototype[4]. **K.S. Anoop, R.K. Ohdar, S.S. Mahapatra** presents experimental investigations on influence of important process parameters viz., layer thickness, part orientation, raster angle, air gap and raster width along with their interactions on dimensional accuracy of Fused Deposition Modelling (FDM) processed ABSP400 (acrylonitrile-butadine-styrene) part. It is observed that shrinkage is dominant along length and width direction of built part. Optimum parameters setting to minimize percentage change in length, width and thickness of standard test specimen. Experimental results indicate that optimal factor settings for each performance characteristic are different. Therefore, all the three responses are expressed in a single response called grey relational grade. Finally, grey Taguchi method is adopted to obtain optimum level of process parameters to minimize percentage change in length, width and thickness simultaneously. The FDM process is highly complex one and hardly any theoretical model exist for the prediction purpose.[5] **K. Thrimurthulu, P.M. Pandey, N.V. Reddy** states that surface finish and part deposition time are two important concerns in rapid prototyping (RP). These two concerns contradict with each other. Generally, a compromise is made between the two aspects pertaining to model building in RP. A compromise between these two contradicting issues can be achieved by using an adaptive slicing scheme; however, selection of a proper part deposition orientation will further provide an improved solution.[6] **R.L. Zinniel** states that the results of the this highlights the capability of the VSS for improving the surface finish of the FDM based parts to nano-level with negligible dimensional deviations.[7]

II.   FUSED DEPOSITION MODELLING

3.2 Working of FDM machine:

In the FDM process, a gantry-robot which is fitted with the extruder head moves in X & Y directions. The table moves in vertical Z-axis. When a layer gets deposited on the table, it goes down according to the layer thickness and the subsequent layers are built in the same way.
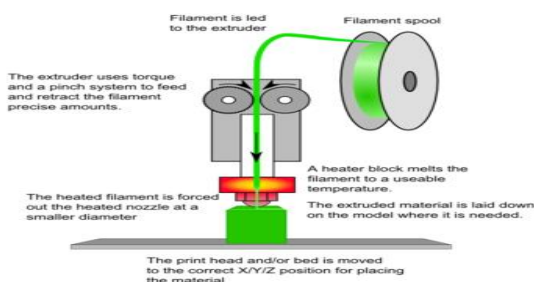

Fig 3.1: FDM Process

3.3 Materials used in making FDM parts:

Most of the existing FDM machines use thermoplastic materials which are in a filament form for the extrusion and deposition purpose. Acrylonitrile Butadiene styrene (ABS) and Polylactide (PLA) thermoplastics are predominantly used in the process.

The above-mentioned materials are used in following forms:

i.   **Build material**: This material is used to obtain actual part.

ii.   **Support material:** This material is used to construct support structures for the actual part. The support material is otherwise called as dissolvable material if it is dissolvable.

Table 1: Properties of materials

S.No.	Name of the material	Normal melting point	Temperature used in FDM
1	ABS	105°C	230°C
2	PLA	65°C	190-210°C

Steps to be carried out to build a model:

Create a CAD model of the product.

1.   Save it in the Stereolithography (STL) file format

2.   Load the .stl file in to the slicing software or the interface platform between the specific machine and the computer.

3.   Upload the sliced file into the FDM machine.

4.   Run the machine with required settings.

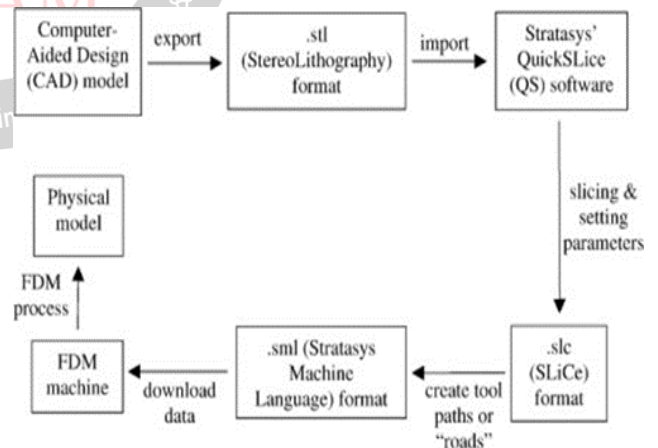5.   Detach the part from the table after completion.

Fig 3.2: Flow chart representing steps to create the CAD model of a product

SLICING THE CAD MODEL WITH ULTIMAKER CURA

Cura is an open source slicing application for 3D printers. It was created by David Braam who was later employed by Ultimaker, a 3D printer manufacturing company, to maintain the software. Cura is available

under LGPLv3 license. Cura was initially released under the open source Affero General Public License version 3, but on 28 September 2017 the license was changed to LGPL This change allowed for more integration with third-party CAD applications. Development is hosted on GitHub. Ultimaker Cura is used by over one million users worldwide and handles 1.4 million print jobs per week. It is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well.

5.1 Slicing features:

At the heart of Ultimaker Cura is its powerful, open-source slicing engine, built through years of expert in-house development and user contributions.

- Intent profiles print specific applications at the click of a button.
- Recommended profiles tested for thousands of hours ensure reliable results.
- 'Custom mode' gives over 400 settings for granular control.
- Regular updates constantly improve features and printing experience.

5.2 Technical specifications:

Ultimaker Cura works by slicing the user's model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

The open source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL, OBJ, X3D, 3MF as well as image file formats such as BMP, GIF, JPG, and PNG.
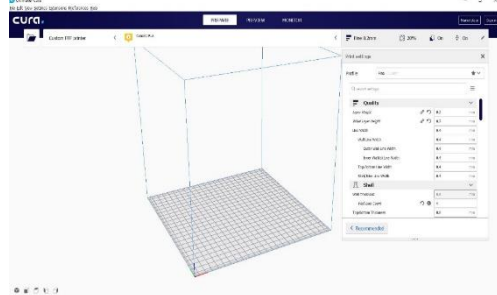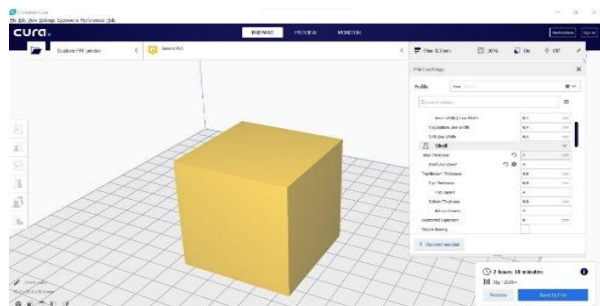

Fig 5.1: Slicing software Interface

Fig 5.2: Loading the model and assigning the process parameters for slicing the model

III.   RESULTS AND DISCUSSION

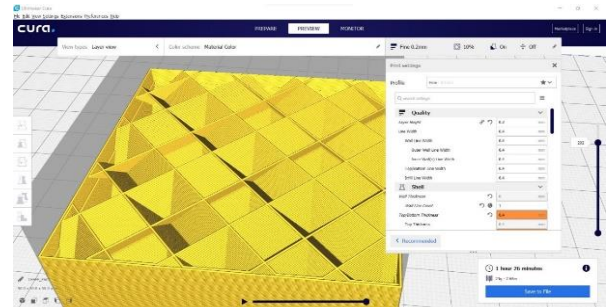### 6.1 Slicing the model with different wall count:

Fig 6.1: Slicing the model with wall count, top and bottom closing layers are 1 at 0.2 mm Layer height and 25% infill.
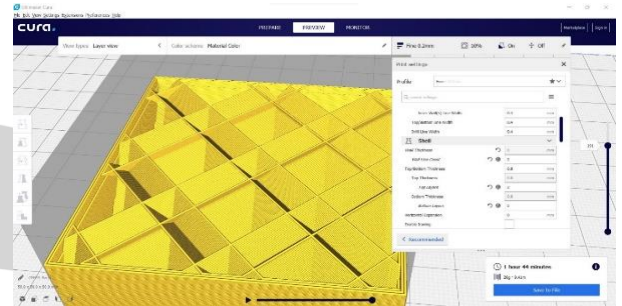

Fig 6.2: Slicing the model with wall count, top and bottom closing layers are 2 at 0.2 mm Layer height and 25% infill.
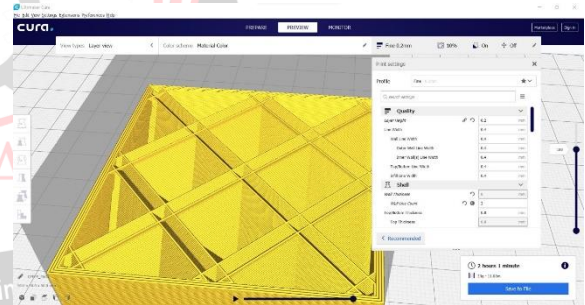

Fig 6.3: Slicing the model with wall count, top and bottom closing layers are 3 at 0.2 mm Layer height and 25% infill.
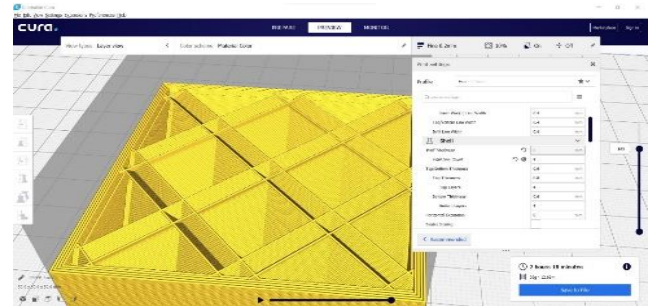

Fig 6.4: Slicing the model with wall count, top and bottom closing layers are 4 at 0.2 mm Layer height and 25% infill.

From reference [8], the results of experiment are shown in table below.

Wall count	Ra$_1$ (µm)	Ra$_2$ (µm)	Ra$_3$ (µm)	Ra$_4$ (µm)	Ra$_5$ (µm)	Ra$_6$ (µm)	Ra (µm)	SD (µm)
1	26.045	20.202	23.188	23.284	19.558	24.358	22.773	2.474
2	20.473	20.497	20.565	17.776	18.318	22.525	20.026	1.728
3	17.937	18.46	21.145	17.205	18.182	21.051	18.997	1.680
4	19.756	17.258	21.908	18.732	19.511	20.347	19.585	1.559

IV.   CONCLUSION

From the above slicing results we can conclude that:

The surface finish of the product increases with the increase of wall count, top and bottom closing layers of the product. Whereas decreases with the increase of printing speed and temperature of printing and vice-versa.

The surface finish of the product increases with decrease of layer height and vice-versa.

The surface finish of the product is increased when its STL file having the high resolution whereas the file having low resolution reduces the surface finish of the product because of its inability to capture the minute surfaces especially at curvatures.

The surface finish of the product increases with the increase of infill density when the wall count, top and bottom closing layers of the product also increases.

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