Effects of Infill Patterns on Time, Surface Roughness and Tensile Strength in 3D Printing

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Abstract **- The effects of three different infill patterns on printing time, surface roughness and tensile strength in 3D printing is investigated. 3D printing is an additive manufacturing technology to rapidly create prototypes by laying down a broad range of material onto successive layers of surfaces. Standard 3D printers use infill patterns known as grid, lines, cubic, triangles, tetrahedral, concentric and zigzag. We tested infill patterns of lines, grid and concentric at a density of 40% and 60% using a 0.6 mm nozzle. The prints were timed to allow comparison of print speeds. After printing, the printing time was checked, and the surface roughness and tensile strength was measured. The results showed that the concentric infill pattern had the fastest printing time as compared to lines and grid infill patterns. The tensile strength of the lines infill pattern was higher than the grid pattern followed by the concentric infill pattern. (**Abstract)

***Keywords* – 3D Printer, Infill Pattern, Printing time, Surface Roughness, Tensile Strength.**

I. INTRODUCTION

3D printing is a rapid manufacturing technique where a variety of materials can be printed using an additive process, where successive layers of materials are laid down in different shapes. A wide range of 3D printers are available commercially, such as stereo lithography, fused deposition modelling (FDM) and laser type 3D printer. In fused deposition modelling generally 0.25mm, 0.4 mm, 0.6 mm, and 0.8mm nozzles are available as standard. In rapid prototyping, materials are available in the form of solid rods of different diameters (generally 0.75mm and 3mm diameters are used). Materials are melted at higher temperatures according to their properties in the range of 210 ℃ to 260 ℃ and laid down in layers according to the size of the nozzle in different shapes, as per the CAD design and dimensions.

The basic process of 3D printing constitutes the following steps [3]:

1. Creating the 3D CAD model of the design.
2. Converting the 3D model to STL or OBJ format.
3. Slicing the OBJ or STL file into a step file. The step file is also known as G-code file.
4. Prototyping the object using a 3D printer.
5. Removing and finishing the object.

Infill pattern in 3D printing refers to the structure that is printed inside the model. By using slicing software, an infill pattern for an object can be defined in various percentage and shapes. Infill patterns influence the print time, weight, print quality, object strength and its mechanical properties. For printing solid patterns, an infill route must be defined that completely fills the desired area, while giving a uniform print quality over the area, with as little material usage as possible. Standard infill patterns are available on slicing software such as lines, grids, cubic, triangles, tetrahedral, concentric and zigzag.

In practice, the grid pattern is in most common use for printing as grid is the default set in most slicing software. However, according to the quality and strength required, there are a number of infill patterns available as mentioned above. Generally, the higher the infill percentage, the stronger the object, but the longer the printing time. In most cases, a 40% to 60% infill is sufficient, while a 100% infill is very rarely used.

II. REASONS FOR USING DIFFERENT INFILL PATTERNS

1. It can create any complex geometry in any form of shape and structure.
2. It reduces the printing time by changing the infill pattern according to the use of the model in real face.
3. It increases the strength of the model by changing the infill pattern in slicing software.
4. Less use of material by changing settings. If a model is not for use in real life cycle (only used for checking dimensions or an assembly design), printing on lower density gives saving of material.
5. It is most suitable for production of customized or single objects.
6. All the components in assembly are fabricated simultaneously, layer-by-layer. A support material is used to fill-up the cavities.

III. METHOD AND DIFFERENT INFILL PATTERNS

The system at the IGNITE – The Silver Oak Incubation Centre utilises a program known as 'Cura 2.3.1' to convert the design into a step file know as G-code. Cura 2.3.1 [2] is designed for three-dimensional (3D) printing, but it is open source, meaning it can easily be adapted from 3D to dispenser printing. The software offers the infill pattern algorithms by calculating a 'Rectangle box' fine pixels to clearly indicate the print route. [1]

A rectangle box pattern was chosen to test the infill patterns as it has a simple geometry for the software to process, requiring the extruder (printer head) to be raised and lowered during the printing. The infill route is affected by the selected infill pattern, the nozzle diameter as well as the selected density.

A rectangle box was printed by using the 'Ultimaker 2 Extended Plus' type 3D printer, which is a part of the maker lab at the IGNITE – The Silver Oak Incubation Centre. The box was printed using a 0.6 mm nozzle with 40% and 60% infill densities. Infill patterns used for making a rectangle box were line, grid and concentric on both the 40% and 60% densities with parameters as shown in Table 1.

Table 1

Parameters	**Units**	**Value**
Bed Temperature	°C	60
Nozzle Temperature	°C	230
Layer Thickness	Mm	0.3
Solid top layers	Mm	3
Solid bottom layers	Mm	3
Wall Thickness	Mm	2

The following figure shows the pattern for the lines infill pattern process using the Rapid Prototyping 3D printer. The figure 1 shows the line infill pattern at 40% density and figure 2 shows same type of infill pattern at 60% density.

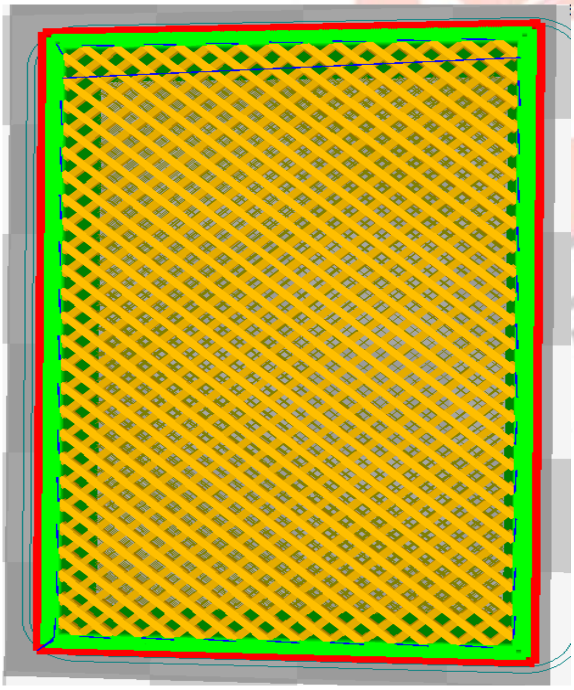

Figure 1: Line Infill Pattern at 40% density

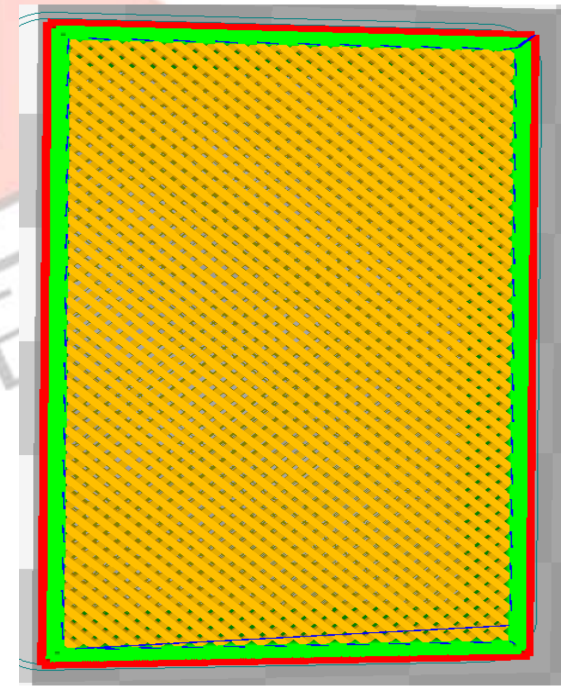

Figure 2: Line Infill Pattern at 60% density

A grid infill pattern is the same as a line pattern, but the area covered by the filling material in the case of the grid is low as compared to the line infill as shown in the figure. Figure 3 shows the grid infill pattern at 40% density and figure 4 shows the grid pattern at 60% density. The concentric infill pattern has a unique style as compared the line and grid patterns. Figures 5 and 6 show concentric infill patterns at 40% and 60% density respectively. After making six different objects, the time for printing each model was recorded and the surface roughness checked by testing each object. The results are shown in Table 2.

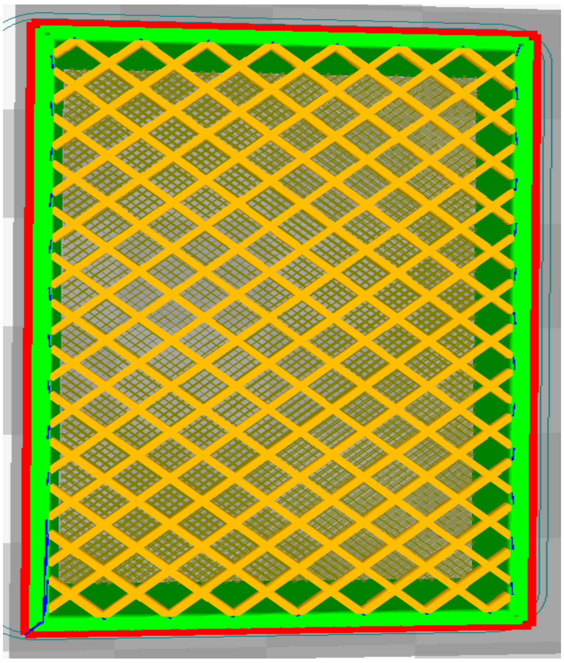

Figure 3: Grid Infill Pattern at 40% density

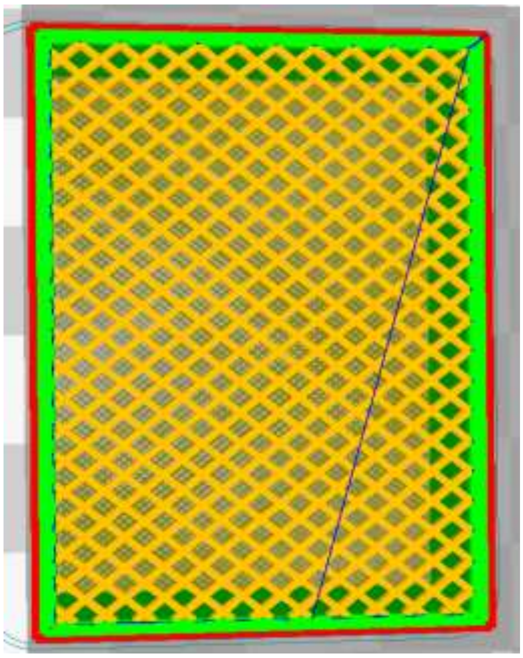

Figure 4: Grid Infill Pattern at 60% density

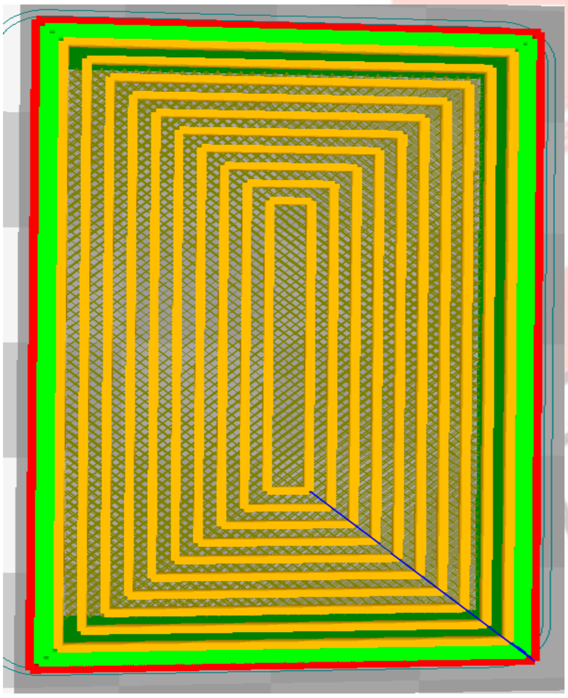

Figure 5: Concentric Infill Pattern at 40% density

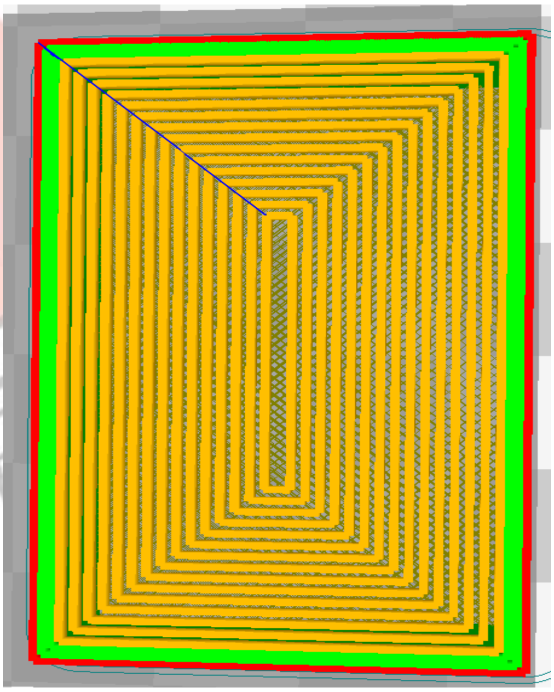

Figure 6: Concentric Infill Pattern at 60% density

IV. RESULTS

The results obtained from the test show differences between the different pairs of parameters of infill density and pattern. As can be seen, a higher level of density resulted in a lower amount of voids in the infill, and subsequently, higher tensile strength. This situation is similar for the three types of infill patterns, especially in the lines infill pattern. Observing the change in the surface roughness in the objects, this value decreases as the density increases. To evaluate these changes, Table 2 shows a comparison between the changes in the tensile strength and surface roughness with respect to change in density and infill patterns.

Table 2

Density	**Infill Pattern**	**Printing time (Minutes)**	**Surface Roughness (Ra-µm)**	**Tensile Strength (MPa)**
40%	Lines	72	15.8	20.60
40%	Grid	71	16.15	19.10
40%	Concentric	71	21.85	18.80
60%	Lines	82	5.25	26.10
60%	Grid	82	7.1	24.60
60%	Concentric	80	16.7	24.00

V. CONCLUSION

In this work, the effect of infill pattern and density on mechanical properties and printing time have been studied. The results in the 3D printing process show that,

- The lines infill pattern with 60% density shows the highest tensile strength, with the value of 26.10 MPa, and finest surface roughness with the value of 5.25 Ra-µm but it takes a longer time to print the object.
- Under the same density, the concentric infill pattern shows the lowest tensile strength, and with a higher surface roughness.
- In 40% density the lines infill pattern shows a higher tensile strength in comparison to the grid and concentric patterns.
- We find very little difference in printing time between infill patterns in both 40% and 60% density, but a large difference in surface roughness.
- Printing time for grid and concentric infill patterns are nearly the same. When increasing density, the concentric pattern takes a lesser time for printing the object.

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VII. REFERENCES

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