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TYPES AND APPLICATION OF INFILL IN FDM PRINTING: REVIEW

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Abstract: 3D printing encompasses many forms of technologies and materials as 3D printing is being used in almost all industries you could think of. It’s important to see it as a cluster of diverse industries with a myriad of different applications. 3D printing is technology that today has various application in production, through mechanical industry, medicine, civil engineering, food production, etc. Through 3D printing the fabrication of complex geometrical parts using various materials had been made possible. Fused deposition modeling (FDM) is widely used 3D printing technology. It has found its place from manufacturing consumers products through industrial parts. FDM also has been popular because of low price of commercially used printers and plastic materials such as PLA or ABS. In 3D printing process there are many elements that have great influence on finished product, such as part orientation, used material, support, infill, etc. Part infill have impact on overall part functionality, printing process and material consumption. In this paper it will be discussed the infill types, printing parameters of infill and their functional role in part production for FDM 3D printing.

Keywords: 3D printing, FDM, infill

INTRODUCTION

3D printing is, relatively, new technology used for production of parts (with various purpose, from decorative like ornaments, figurines etc. to mechanical elements) from various materials. There are several parameters that influence on 3D printing production and quality. Some of these parameters are part orientation, printing speed, layer size, type and percentage of infill, thickness of printing part exterior wall etc. that can be defined in slicer software (with regards of printer capabilities), and also the characteristics and material of 3D printer (temperature of nozzle and bed, movement speed, type of materials, etc.). For example, the part orientation has influence on printing time and material consumption [1].

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the object is created [9]. Each of these layers can be seen as a thinly sliced cross-section of the object [9].

3D printing is the opposite of subtractive manufacturing which is cutting out / hollowing out a piece of metal or plastic with for instance a milling machine [9]. Adoption of 3D printing has reached critical mass as those who have yet to integrate additive manufacturing somewhere in their supply chain are now part of an ever-shrinking minority. Where 3D printing was only suitable for prototyping and one-off manufacturing in the early stages, it is now rapidly transforming into a production technology [9].

Infill is a measure of how dense the object is, i.e. how much material has been used to print its internal structure. We can also determine the shape or pattern of the internal structure in the slicer (infill pattern), and selecting the right infill settings at the time of slicing can optimize the strength, rigidity, weight, feel, appearance, cost and print time of the model.

Infill in 3D printing is “filling” that allows printed parts to be solid, hollow or in between [2]. In comparison to conventional production, infill is unique for 3D printing. In conventional production like injection molding or subtractive manufacturing the interior of part is solid without the control or possibility to change that [3]. Based on that, with appropriate infill parameters, a desired part can be printed with reduced material consumption, or with lesser weight (where weight plays significant role).

Fused deposition modeling (FDM) is one of the most widely used additive manufacturing techniques [10,11]. It has been utilized in the automobile industry, ranging from testing models, lightweight tools to final functional components. However, FDM technique faces two main obstacles to be developed as an effective processing method in the automobile industry: weak and anisotropic mechanical properties and limited variety of printing materials [10,11]. The weak interlayer bond formed in the layer-by-layer process contributes to the mechanical characteristics of FDM parts [10,11].

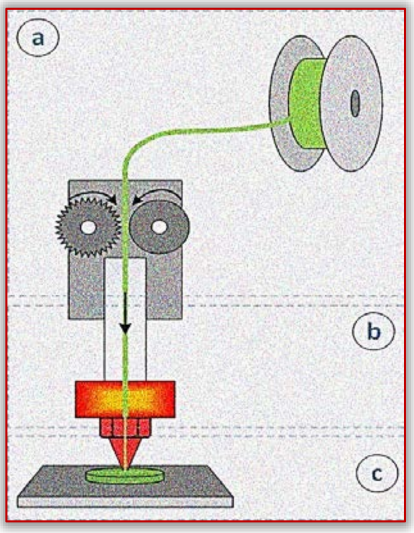

Figure 1. FDM additive manufacturing process [10,11]

Figure 1 shows schematically the FDM additive manufacturing process [10,11]:

- A thermoplastic filament with constant diameter is feed into a heated extrusion head by motor driven feeding rollers (a).
- The polymer melts inside the heated 3D printing head and is extruded through a thin nozzle (b).
- During the deposition process the material cools and solidifies. In this way the head makes one layer with the desired shape and pattern of the deposited material. After the completion of the first layer the head is lifted in z-direction, and a new layer is deposited fused with the previous (c).
- Finally, a complete part is constructed layer by layer.

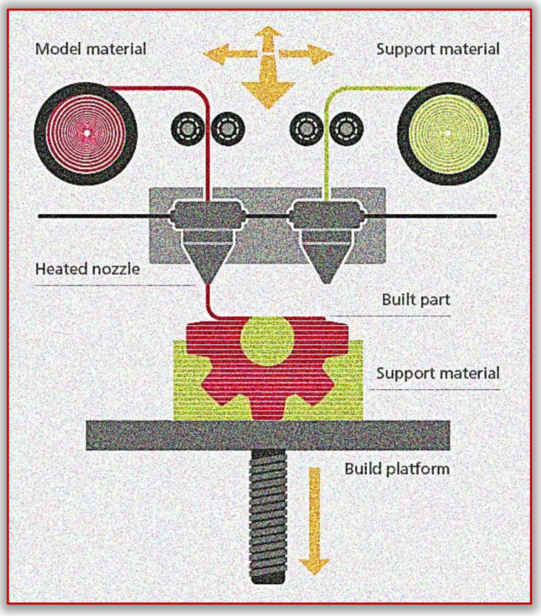

Figure 2. Fused Deposition Modelling (FDM) [10,11]

Fused Deposition Modelling (FDM) is the most accessible 3D printing process, from home hobbyists through to full production systems, with rapid turnaround times and a wide range of materials and colours aimed at functional applications and design verification [10,11].

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Fused deposition modeling parts used in the automobile industry requiring desired mechanical properties and good dimensional accuracy can be attained by either optimizing printing process or improving material properties [10,11].

Fused Deposition Modeling (FDM) is one of the widely used additive manufacturing processes due to its capability to create complex parts. One of the major research issues related to FDM process has been its ability to create components with esthetically appealing geometry. The optimum selection of FDM process parameters is playing an important role for improving the quality and the surface roughness of the manufactured components [10,11].

INFILL PATERNS AND INFILL DENSITY

The density of the infill defines how much material is going to be used on the inner structure of the print, which can go from 0% all the way up to 100% [10]. At 100%, the object will be completely solid from the inside and at 0% it will be completely hollow [10].

The amount of filament to be used during printing is highly determined by the infill density (also called infill percentage). The printed object's strength, rigidity, weight, buoyancy, cost and printing duration are all highly affected by the Infill density [10]. The weight, strength and print time of a part depend on the amount of material it has inside [10].

Different infill patterns and infill density are defined through slicing software. CURA [6], as well as most other slicers, allows you to have different infill densities, as well as patterns, within the same part [10]. This technique is also known as variable infill density. In CURA, the default infill percentage is usually 20% [6,10].

— Infill patterns

Infill patterns can be divided in 4 (or 5) different groups, based of part usage [4]:

1. Low strength (prints that are decorative, in most cases without any functional use)
2. Medium strength (functional parts, with low durability)
3. High strength (functional parts)
4. Flexibility (patterns to use with flexible materials)
5. Vanity (patterns that look good but without application in specific cases. For example, printing the flexible pattern but with nonflexible materials)

Why 4 or 5 groups? Basically in the fifth group are the infill types that look good, but have their application in other four groups. By Ultimaker (based only on Cura software) there are 4 groups [5]:

1. Strong 2D infills are used for everyday prints
2. Quick 2D infills are used for quick, but weak models
3. 3D infills are used to make the object equally strong in all directions
4. 3D concentric infills are used for flexible materials

Different infill patterns from different softwares are shown on Figures 3–5, and printed example of different infill patterns is shown on Figure 6.

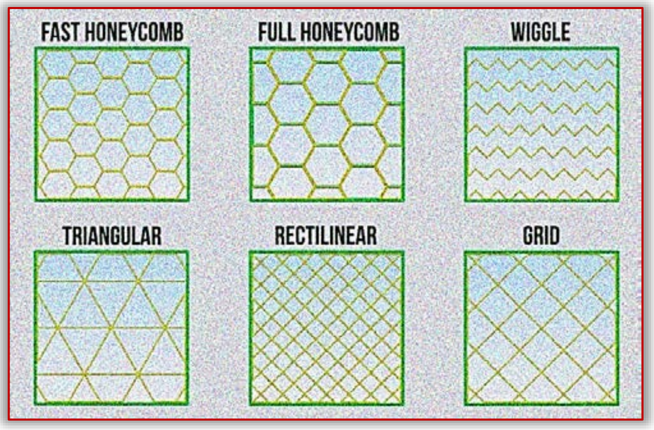

Figure 3. Infill patterns from Simplify3D software [4]

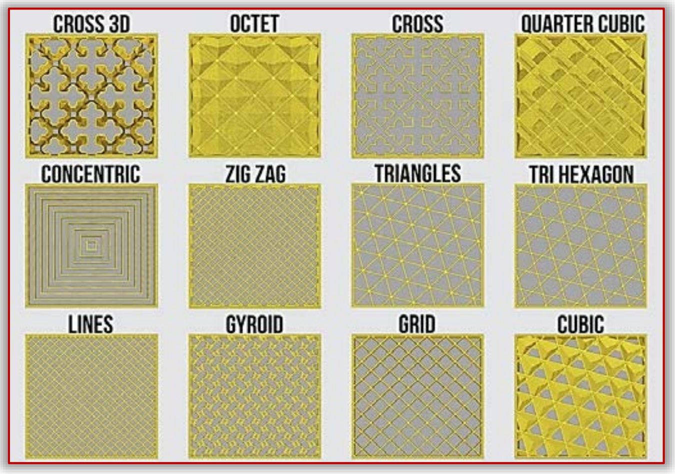

Figure 4. Infill patterns from Cura software [4]

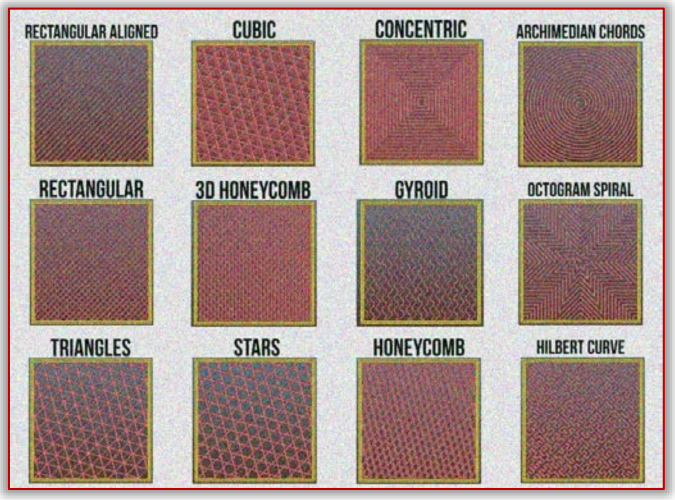

Figure 5. Infill patterns from Slic3r software [4]

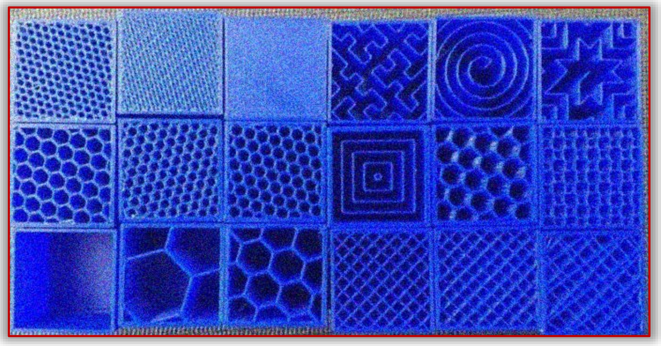

Figure 6. Different infill patterns printed [6]

In 3D printing, infill plays an important role in a part's strength, structure, and weight. Infill in 3D printing is different from other, more traditional manufacturing methods [10,13]. Infill pattern is the structure and shape of the material inside of a part [10,13]. Ranging from simple lines to more complex geometric shapes, infill patterns can affect a part's strength, weight, print time, and even flexibility [2,10,13].

3D printing involves selective extrusion of material in almost any pattern. Let's take a closer look at different options for infill density and pattern [2,10,13]. Based on groups mentioned before, Table 1 shows infill pattern by groups.

Table 1. Infill types from different softwares [4]

	Simplify3D	Cura	Slic3r
Low strength	Wiggle	Lines	Rectangular Aligned
Medium strength	Rectilinear Fast honeycomb Full honeycomb	Octet Quarter Cubic Gyroid	Honeycomb 3D Honeycomb Gyroid Grid (not included in patterns image) Archimedian Chords Octogram Spiral
High strength	Grid Triangular	Cubic Cubic Subdivision Triangles Tri-Hexagon Grid	Cubic Rectangular Triangles Stars
Flexibility	Wiggle	Concentric Cross 3D Cross Lines	Concentric Cross 3D Cross
Vanity	Wiggle	Concentric Cross 3D Gyroid Cubic Subdivision Cubic Octet	Concentric Cross 3D Gyroid Archimedian Chords Hilbert Chords Octogram Spiral

— Infill density

Infill density have impact on weight and durability of printed parts. It also can be defined through printed part application, or mentioned pattern groups. Basically [5]:

- for low strength parts typical infill density ranges from 0 – 15%,
- for medium strength parts typical infill density ranges from 15 – 50%,
- for high strength parts typical infill density ranges from 50 – 100%,
- for flexible parts typical infill density ranges from 0 – 100%,

Percentage of infill density depends on part application and used patterns. Also in some softwares the multiple infill density can be defined and printed. Different infill density percentage is shown on Figure 7.

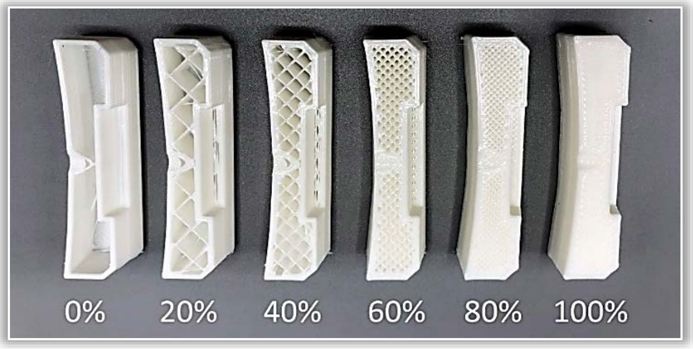

Figure 7. Different infill density percentage [7]

INFILL PATTERNS AND INFILL DENSITY APPLICATION

Infill patterns and infill density are entwined in 3D printing. As mentioned before, there are some guides to apply in 3D printing in order to obtain desired printed part (what pattern to use and what density corresponds). But there are also several other parameters to consider: printing speed, visuals, support for top layer, flexibility, filling (if used for creatin mold). For example, printing speed. If low strength infill pattern is used with higher infill density, printing time is reduced yet part durability is increased.

Also there are many papers on infill influence on mechanical strength. In paper [8] the authors give review of mechanical properties of 3D printed PLA products for various infill design. Based on that research it can be seen that infill patterns and infill density have great impact on different mechanical properties (tensile strength, flexural strength, compression strength, yield strength, stiffness etc.)

CONCLUSION

3D printing is highly used technology today. Low price of commercial FDM printers make this technology suitable for creation of unique parts (visual and functional) even in homemade conditions. When 3D printing, it is necessary to adjust printing parameters in order to obtain desired printed part, to decrease material consumption, to reduce printing time, and overall to reduce printing cost.

As shown in this paper, there are various infill patterns that can be used in 3D printing to fullfill desired goals. There are multiple guidelines that can be used to determine what is the suitable infill pattern for part to be printed based on part application. Most important, the guidelines are, in many cases, based on experience. It varies because of different printer's configurations and also because of different material characteristics.

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