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Developing Design Rules for Fused Deposition Modeling Technology

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Abstract

3D printing is an advance technology that have changed many industries and the way of producing the products, and in the foreseeable future 3D printing will be a major contributor in most of advance industries such as medical and aerospace industries. In the future, 3D printing will play a significant role in most industries and will advance many fields. However, 3D printing technologies are considered by many designers as good and valid technology in which most of geometries can be produced without considering the limitation of the technology which makes it a problem in the final stages of the process. FDM is one of the most popular 3D printing technologies, however the designers are unaware of the process limitations and design rules the process. This research aims to address the absence of awareness in such designs, by developing a set of design rules so the design can be more reliable, predictable and gives the required results when making parts.

Keywords
3D printing, Fused Deposition Modeling Technology, Design for 3D printing, Design rules, Support structures, Small features.

1. Introduction
The manufacturing wheel was pushed to develop new technologies to satisfy the world's requirements by the industrial revolution that occurred over the last century, as well as increased use of natural resources and expanding consumption. One of the most critical difficulties in manufacturing is the time it takes to produce a prototype. Previously, a prototype would be created using a lathe, injection molding, casting, and other ways. Traditional procedures take time to create and have a high cost to manufacture a model, but modern technology like as 3D printing can help to reduce manufacturing time and costs. In the 1980s, pioneered 3D printing. 3D printing technologies are being used in a variety of industries, including medicine, aerospace, automotive, architecture, industrial equipment, education, and consumer goods (Shahrubudin, 2019, Ramya, A). The advancement of 3D printing over the last decade has resulted in lower machine costs, improved precision, and the development of a wide range of materials for use. One of the most appealing features of 3D printing is its simplicity; only requires a CAD model to produce the product, and it can print any complex shape or geometry. 3D printing allows you to create a part from scratch in only a few

hours. It allows designers and developers to go straight from design to manufacturing without having to plan ahead of time. Steps in a typical 3D printing process are shown in Figure 1.

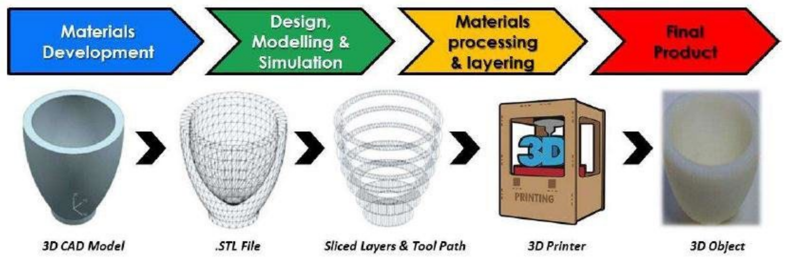


Figure 1. 3D printing process flow [Jun, W 2013-Ameen,W 2022]

Fused Deposition Modeling (FDM) is a sort of 3D printing technology that uses a computer-aided or driven manufacturing process to create three-dimensional objects, products and prototypes,. In a layered or additive technique, it is employed in 3-D printing or the design of solid models and prototypes (Siemiński, Przemysław,2021, AMEEN, Wadea, 2019).

2. Literature Review

Serval researchers gave attention to the features manufacturability and the quality of the objects produced via FDM. Design for three dimensional (3D) printing have attracted much attention from the researchers for example, Gregory A. Teitelbaum and Linda C. Schmidt et al, 2009, presented a preliminary set of design guidelines for use in Fused Deposition Modeling (FDM). Ala'aldin Alafaghani et al, 2017, discusses the design considerations that lead to optimize the quality of FDM par. Nicoleta Elisabeta Pascu et.al 2015 established a set of rules to be followed in FDM - Fused Deposition Modeling 3D printing process using ABS (Acrilonitril-Butadien-Styren) type plastic materials. The objects have been printed on a 3D "Ultimaker –2" printer. The results showed the printing constraints generated by the machine. Mahesh Mani et al, 2017, developed a design rules in AM technologies. The review's ultimate goal is to offer insights into extracting and classifying the fundamental principles of derived rules for various asset management activities. Syed Hammad Mian et.al 2020, examine the numerous causes of errors in FDM. A benchmark part, which is involved of various shapes, features, and geometries, was used for the evaluation of the FDM process. The literature review showed the importance of developed design rules in utilization the unique capabilities of 3D printing techniques.

3. Methods

3.1 Design the Benchmark Parts

Benchmark components are designed using SolidWorks CAD software to assess the capabilities and limitations of the FDM process for manufacturing microscopic features such as wall thicknesses, pins and square channels. The features were designed in a variety of sizes and were ready for fabrication.

3.1.1.The minimum diameter pin

A test item consisting of pins with varied diameters ranging from 0.1 mm to 1.2 mm with increments of 0.1 mm is d esigned to evaluate the manufacturability and quality of the smalls minimum diameter pin via FDM, as shown in Fi gure 2.

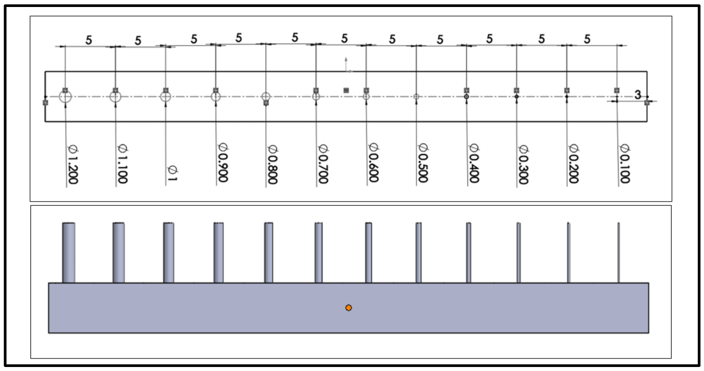


Figure 2. Model of small pins

3.1.2 Minimum wall thickness

A test part consisting of plates with thicknesses ranging from 0.1 mm to 1.2 mm with increments of 0.1 mm are designed and prepared for printing in multiple directions to determine the minimum wall thickness that can be manufactured using FDM as shown in Figure 3.

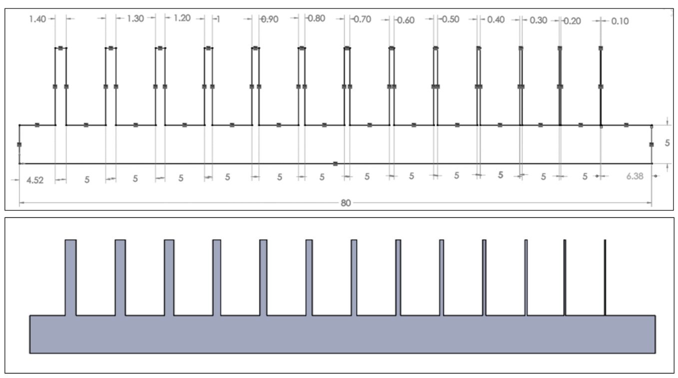


Figure 3. Model of small wall thickness

3.1.3. Minimum square channels

To assess the manufacturability and quality of the fabricated small square channels, channels with a width sizes ranging from 0.1 mm to 1.2 mm and increments of 0.1 mm and 1mm depth are developed, as shown in Figure 4.

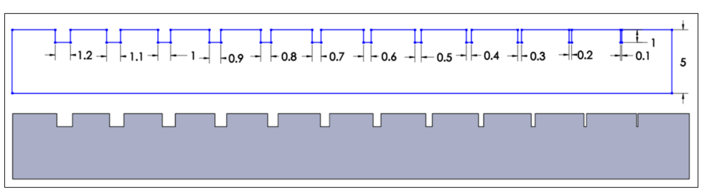


Figure 4. Model of square channels

3.2. Fabrication the Benchmark Parts

RAISE3D E2 printers are used to fabricate the design specimens (parts). Raise3D E2 printer is a dual extrusion FDM printer. In this printer the process begins by feeding the thermoplastic material from a spool of thin plastic filament. This thermoplastic is melted in a liquefier head by a resistance heater. Afterwards, the molten thermoplastic is extruded to form a thin layer which is solidified to form one layer of the part, starts from the lower level of the shape, layers are deposited on previous layers, laminating and fusing together in a layer by layer fashion. Figure 5 shows the used RAISE 3D E2 printers.

Figure 5. RAISE3D E2 printer

4.Measurement

In order to evaluate the manufacturability and the quality of the small features, a Mitutoyo 500-196-30 digital scale caliper with advanced onsite sensor (AOS), a measuring range from 0 to 150 mm, and resolution 0.01 mm is used in this study. Also USB-Digital-Microscope-attached with Camera (Model B011) is used to evaluate the micro features.

5.Results Analysis

5.1 The minimum diameter pin

The visual inspection shows that the minimum diameter pin that can be printed by the used 3D printer is 1mm as show in Figure 6, Table 1.

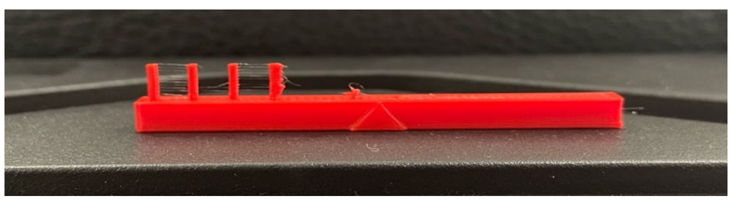


Figure 6. minimum diameter pin fabricated sample

Table1. Pins diameters measurement results

#	Designed diameter (mm)	Measured diameter (mm)	Error (mm)
1	0.1	None	N/A
2	0.2	None	N/A
3	0.3	None	N/A
4	0.4	None	N/A
5	0.5	None	N/A
6	0.6	None	N/A
7	0.7	None	N/A
8	0.8	None	N/A
9	0.9	0.9	0
10	1.0	0.91	0.09
11	1.1	1.11	0.01
12	1.2	1.13	0.07

5.2.Minimum wall thickness

The visual inspection shows that it's possible to fabricate 0.1mm wall thickness by used 3D printer show in the Figure 7.

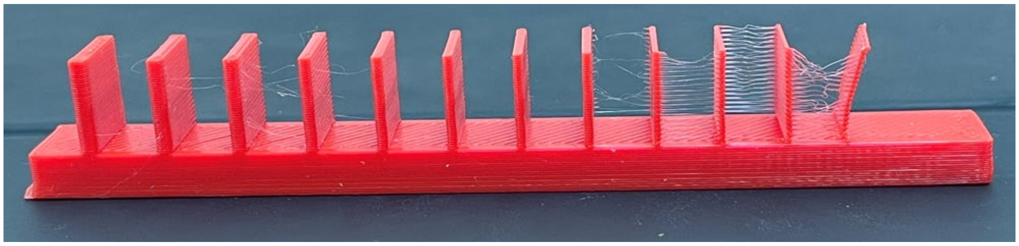


Figure 7. minimum wall thickness

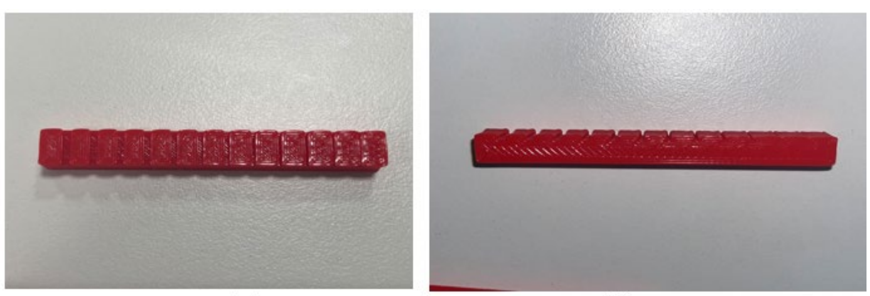
The fabricated wall thickness are measured by digital scale caliper and the results shown in Table 2.

Table 2. Wall thickness measurement results

#	Designed wall (mm)	Measured wall (mm)	Error (mm)
1	0.1	None	
2	0.2	0.29	0.09
3	0.3	0.35	0.05
4	0.4	0.45	0.05
5	0.5	0.55	0.05
6	0.6	0.81	0.21
7	0.7	0.83	0.13
8	0.8	0.84	0.04
9	0.9	0.94	0.04
10	1.0	1.04	0.04
11	1.1	1.22	0.12
12	1.2	1.30	0.1
13	1.3	1.61	0.31

5.3.Minimum square channels

Fabricated square channels in both build directions are shown in Figure 8.



(a) (b)

Figure. 8 minimum square channels sample

According to the results the minimum channel appeared in the horizontal build detraction is 0.3mm whereas the minimum channel in the vertical build detraction is 0.5mm. It's also observed that the channels of vertical build detraction has more quality compared by the other detraction (see Tables 3 and Table 4).

Table 3. Minimum samples of square channels measurement by microscope

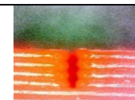
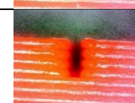
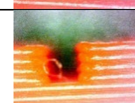
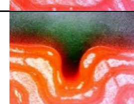
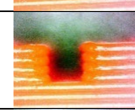
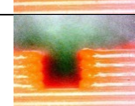
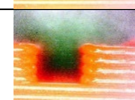
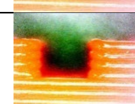
#	Designed width (mm)	Horizontal detraction	vertical detraction
		Measured width (mm)	Measured width (mm)
1	0.1	NA	NA
2	0.2	NA	NA
3	0.3		NA
4	0.4		NA
5	0.5		
6	0.6		
7	0.7		
8	0.8		
9	0.9		
10	1.0		
11	1.1		
12	1.2		

Table 4. Minimum square channels measurement results

#	Designed width (mm)	Horizontal detraction		vertical detraction	
		Measured width (mm)	Error (mm)	Measured width (mm)	Error (mm)
1	0.1	NA	NA	NA	NA
2	0.2	NA	NA	NA	NA
3	0.3	0.1114	0.1886	NA	NA
4	0.4	0.243	0.157	NA	NA
5	0.5	0.2784	0.2216	0.8575	0.3575
6	0.6	0.4026	0.1974	0.9924	0.3924
7	0.7	0.5557	0.1443	1.096	0.396
8	0.8	0.6886	0.1114	1.197	0.397
9	0.9	0.7997	0.1003	1.395	0.495
10	1.0	0.947	0.053	1.582	0.582
11	1.1	1.16	0.06	1.65	0.55
12	1.2	1.225	0.025	1.815	0.615

6. Conclusion
The objective of this research is to evaluate the capabilities and limitations of FDM 3D printing technology and develop a first draft of design rules for the technology. The following conclusions are drawn from the results:

- The minimum printable diameter pin is 0.9mm and any diameter less than 0.9mm didn't appear in the fabricated part.
- The minimum printable wall thickness the minimum is 0.2 mm, and any thickness less than 0.2 mm didn't appear in the fabricated part.
- The minimum printable square channels in the horizontal direction is 0.3 width mm and 0.5mm in vertical detraction.

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