Design for Additive Manufacturing: A Case Study on Lattice Structure FDM Printing

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***Abstract*—Additive Manufacturing (AM) is an advanced manufacturing process in which units of material is added in a predefined sequence to build an object. Although deemed to be a highly autonomous manufacturing process, building failures in AM are not uncommon due to improper designing factors such as intricate geometric features and small dimensions. To address this issue, a case study has been conducted with lattice structure as it presents the most challenges, especially for the FDM process. Experimental lattice designs were created at different geometry patterns and dimensional sizes. The designs were sliced with commercially available software to obtain each individual layer for analysis. The area infill percentage and number of breaks for various feature type and dimension are measured and recorded. Data analysis on the recorded information is performed to observe patterns and trends. Based on the results, a set of design for additive manufacturing guidelines for the FDM process are proposed.**

Keywords- Additive Manufacturing(AM); lattice structure; tool path, manufacturability

I. INTRODUCTION

The most widely used AM process is Fused Deposition Modelling (FDM). FDM has a significant advantage over other methods because it is low equipment and material cost. FDM uses a spool of thermoplastic filament, which is melted and extruded through a nozzle on a surface in a predefined sequence. However, it does not achieve the highest geometric accuracy among all AM processes. FDM is also prone to a lot of manufacturing geometrical limitations. This project focuses on exploring the geometrical manufacturability of the FDM process, and further proposes Design for Additive Manufacturing (DfAM) guidelines.

This project chooses the lattice structure design for the case study. Lattice structures are a type of geometry that is made of repetitive element cells. Programmable mechanical and physical properties made lattice structures find various application in different fields. An example for lattice structure design is shown in Figure 1. The introduction of AM has allowed easier production of lattice structures compared to the traditional manufacturing methods [1].

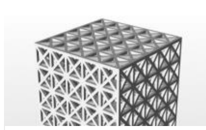

FIGURE 1. LATTICE STRUCTURE EXAMPLE

II. LITERATURE REVIEW

In 3D printing, there are different toolpath patterns to fill the area of the 2D layers. The most commonly used tool path patterns are: Hilbert Curve [2], Rectilinear [3], Contour [4], and Spiral [5].

Understanding impact of toolpath pattern on the manufacturability of different shapes of geometry at different dimensional sizes is the main goal of this case study. Similar challenges have been addressed for bars and overhangs by Fernandez et.al (2015). This study was focused on three characteristic geometric features: overhangs, angles, and bridges, which are 3D features [6]. In this work, we focus on studying 2D geometry features from the slices of the 3D part design.

III. PROJECT DESCRIPTION AND SCOPE

This project aims to address the manufacturability limitations of the FDM process and to formulate DfAM guidelines. Based on these guidelines one can determine the probability of the design being manufactured without any failures. Example of such error is shown in Figure 2.

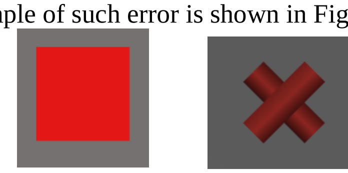

FIGURE 2. EXPECTED FEATURE CROSS SECTION FOR A SQUARE OF 1MM(LEFT) COMPARED TO THE OBTAINED TOOL PASS(RIGHT)

Although there are many different types of AM processes, within the scope of this project the FDM process is studied. In this project, all the process parameters and material selection are kept constant. The filament material chosen for printing is the commonly used Acrylonitrile Butadiene Styrene (ABS). The filament diameter used is 1.75mm and the nozzle diameter is 0.4mm. Overlap is set to 0mm, bead width is 0.45mm and layer height is 0.05mm. The project is also limited to the study lattice structure geometries. The guidelines created are based on the model geometry, dimension, and toolpath pattern selection.

IV. PROJECT OBJECTIVES

The objective of this research is to propose DfAM guidelines of the FDM process through identifying the manufacturability limitations in lattice structures printing. By the end of the research, the following sub-objectives will be achieved:

- Propose manufacturability evaluation metrics
- Identify geometry limitations
- Propose geometrical design guidelines

V. METHODOLOGY

A. *Element geometries identification*

A lattice structure can be a combination of different features of different shapes. By observing 2D layers of those lattice structures, it could be concluded that there are generally two element 2D geometries in the layers, walls and islands as Figure 3 shows.

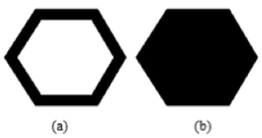

FIGURE 3. A. THE 2D WALL FEATURE, AND B. THE 2D ISLAND FEATURE

B. *Data Collection*

With the identified the major toolpath types and element geometries of 2D layers, to formulate the design guidelines, the connection between the two will need to be identified. The infill area percentage and number of breaks in the toolpath is proposed to be the manufacturability evaluation metrics. The larger the infill area percentage, and lower the number of breaks, the better the manufacturability. By collecting data related to different toolpath types, for the two element features, we can observe trends in the collected data, from which we can formulate guidelines. The layer height, layer number and bead width information are collected. The toolpath images were taken from *Slic3r PE*. Infill area was determined by converting the tool path image to a binary image and finding the respective area using ImageJ. Infill area percentage, feature size, and number of breaks data was collected and later analyzed using *Minitab 19*. An example respective to data set (Table 1) is shown below.

Table 1. Example data set

Size	4
Infill Type	Spiral
Fill Area(mm^2)	14.076
Area of Island	16
Fill Area %	87.975
Bead Width(mm)	0.45
Breaks	12
Layer Height(mm)	0.05
Layer No.	255

VI. RESULTS AND ANALYSIS

The data obtained from the previous sections are analyzed and plotted as Figure 4 shows. From analyzing the

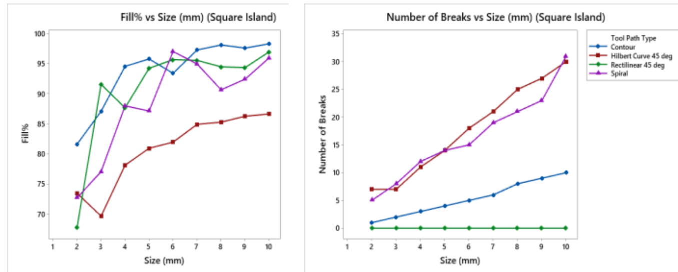

FIGURE 4. SQUARE ISLAND DATA PLOTS, INFILL PERCENTAGE VERSUS FEATURE SIZE (LEFT), NUMBER OF BREAKS VERSUS SIZE

plot the following DfAM guidelines for FDM process are formulated:

- The minimum manufacturable island geometry size is 2-4 mm.
- The minimum manufacturable wall geometry sizes are 1.7mm and 2mm for square and hexagon shapes respectively.
- Rectilinear presents the best manufacturability over other toolpath patterns.

ACKNOWLEDGMENT

The authors would like to thank Dr. Niechen Chen with the Department of Industrial and Systems Engineering at Northern Illinois University. We would also like to thank Dr. Purushothaman Damodaran for giving us this opportunity to work at NIU.

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