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

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Introduction

Additive Manufacturing

- Constructs a three-dimensional object from a computer-aided design (CAD) model, usually by successively adding material layer by layer.
- Seven ASTM F42 standard categories of AM: Material Extrusion, Powder Bed Fusion, Material Jetting, Binder Jetting, Directed Energy Deposition, VAT, Photopolymerization, Sheet Lamination.

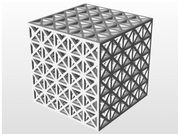

Figure 1. Lattice structure example

Fused Deposition Modelling (FDM)

- The most widely used method
- Economic.
- Most popular (~47% in the world)
- Prone to manufacturability limitations.

Lattice Structures

- Extraordinary geometrical physical characteristic
- Wide applications
- Presents a great challenge for AM and especially FDM

Objectives

- Propose manufacturability measurement metrics for FDM process.
- Identify geometry limitations in FDM process.
- Propose geometrical design guidelines for FDM process.

Methodology

- Two element geometry features identified for lattice structure, walls and islands, as shown in Figure 2a &b
- Manufacturability evaluation metrics are identified as infill area percentage and number of break points
- The geometry feature shape, size and toolpath pattern selection was studied, while other factors are treated constant

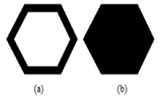

Figure 2. a. The 2D wall feature, and b. The 2D island feature

Experiment Design

- Lattice designs were created with different sizes of square and hexagon shaped walls.
- Using *Prusa Slicer* to slice the design and obtain the toolpaths for Rectilinear, Spiral, Hilbert Curve and contour toolpath. patterns (Figure 3 a).
- Used ImageJ for obtaining the infill area by converting the original image to its binary form (Figure 3b).
- Minitab 19 has been used for plotting graphs.
- Sample data set is shown in Table 1.

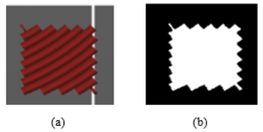

Figure 3. 4mm square island, Fig (a) shows tool path for, Fig (b) binary image of the toolpath

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

Data Analysis

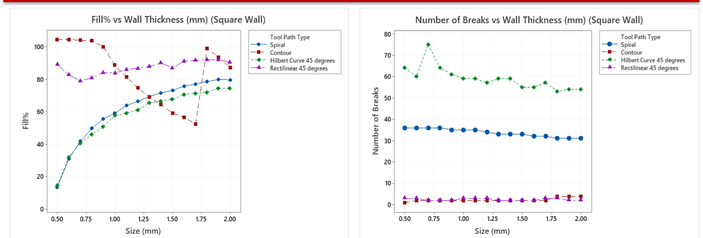

Figure 4. Plots for square wall data

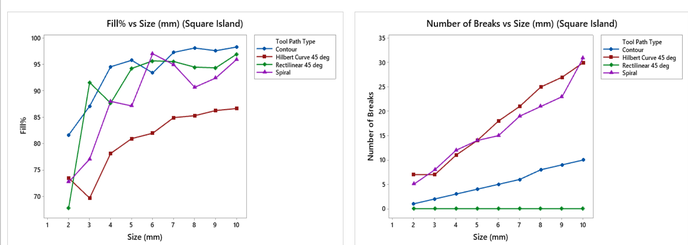

Figure 5. Plots for square island data

Results and Conclusion

Island feature Observations:
Overall, the fill area percentage increases with island size for all different toolpath types. As island size increases, the difference of filling area percentage between infill toolpath types reduces. After 4mm island size, curve starts to flatten. Overfill observed for contour and rectilinear for hexagon islands. Least number of breaks are observed for Rectilinear fill. For every other toolpath type, breaks increase with the feature size.

Wall Feature Observations:
Overall, the fill area percentage increases with wall size for all different toolpath type. An exception to this is contour toolpath in walls, where it alternately increases and decreases. This is due to the algorithm that *Prusa Slicer* uses where a gap develops between the inside and outside of the wall. The rectilinear tool path provides the optimum fill when compared to the other tool paths, it is most consistent. The contour tool path contributes to overfill in square walls with sizes below 0.8 mm. The fill% increases or Hilbert curve and spiral tool paths and starts to flatten at around 1.7 mm (at about 80% fill) for square walls and for hexagon walls it is still increasing at 1.7 mm to 2.0 mm but the fill% achieved is about 60% only. While considering fill% contour tool path is very inconsistent and unreliable.

Guidelines:

- Minimum manufacturable island geometry size is 2-4 mm.
- 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.

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