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# Investigating the effect of Fused Deposition Modeling processing parameters using Taguchi design of experiment method

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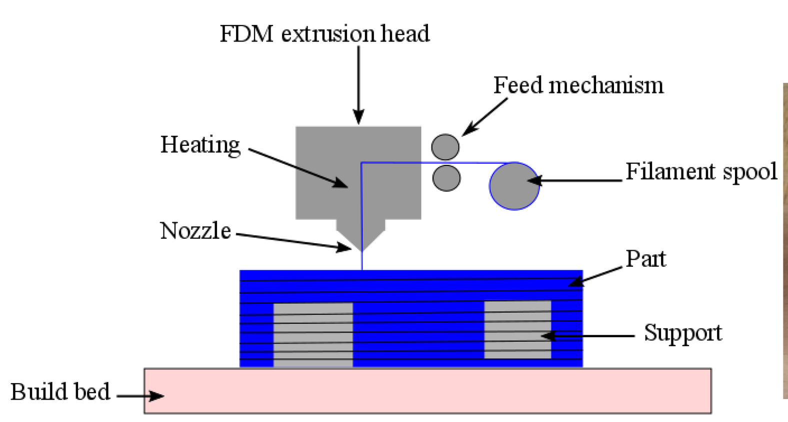
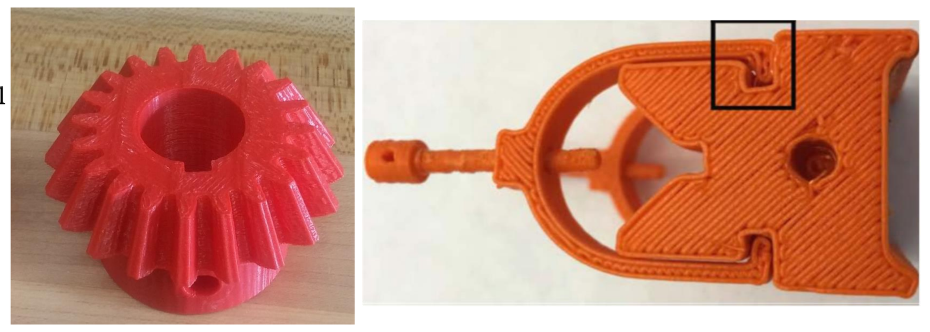
## Background

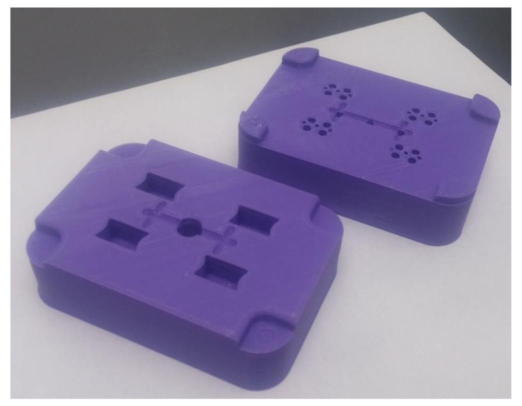
- FDM is an Additive Manufacturing technology that fabricate parts layer by layer by heating a filament to a semi-liquid phase and extruding it through a small nozzle, that rasters across the layers along computer controlled paths.

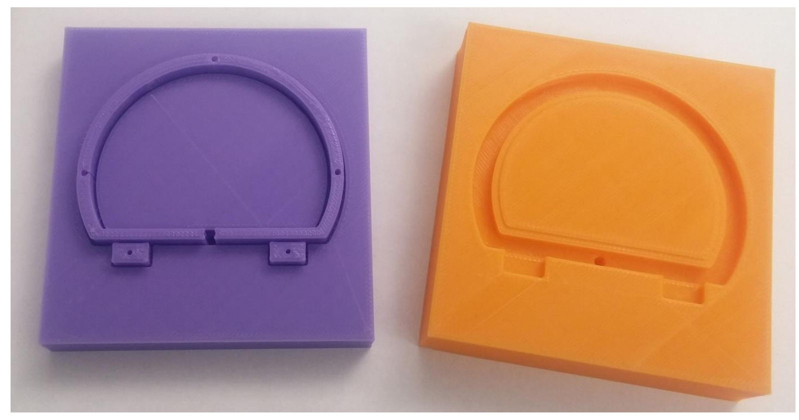


Schematic of FDM


Mechanical prototypes printed using FDM

- FDM has started as a rapid prototyping technology, due to the inferior mechanical properties, high anisotropy and poor surface finish of FDM parts compared to injection molding parts. However, due to the recent improvement during the last few years, FDM can produce parts with comparable mechanical properties for a wider range of materials.
- With the rapid improvement of FDM and the increasing range of materials compatible with it, it is essential to look for new applications for this novel technology and investigate its limitations.


Injection molding prototype


FDM printed mold

## Why Fused Deposition Modeling?

Due to the nature of FDM as an Additive Manufacturing (AM) technology, FDM has many advantages over traditional manufacturing methods such as molding, extrusion and machining.

- Complex geometries
- Printing assemblies as a single part
- Mass customization
- Feasible for small production volumes
- Creating parts with different materials
- Cheaper raw material compared to other AM technologies

## Objective

Because FDM is a relatively novel technology, optimizing its processing parameters for a set of desired properties is essential. This research aims to find the best FDM processing parameters that increase the tensile test mechanical properties, such as the tensile strength, Young's modulus and ductility. At the same time, find the best processing parameters for good dimensional accuracy, which will enable good part fit and better assemblies.


FDM printed working hinge

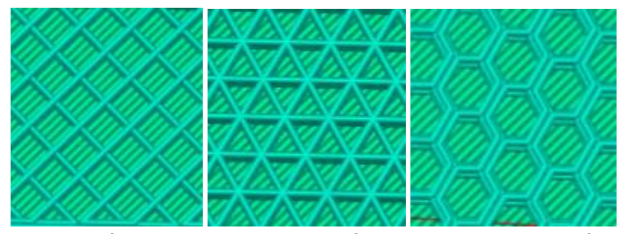

Assembled FDM printed mechanism

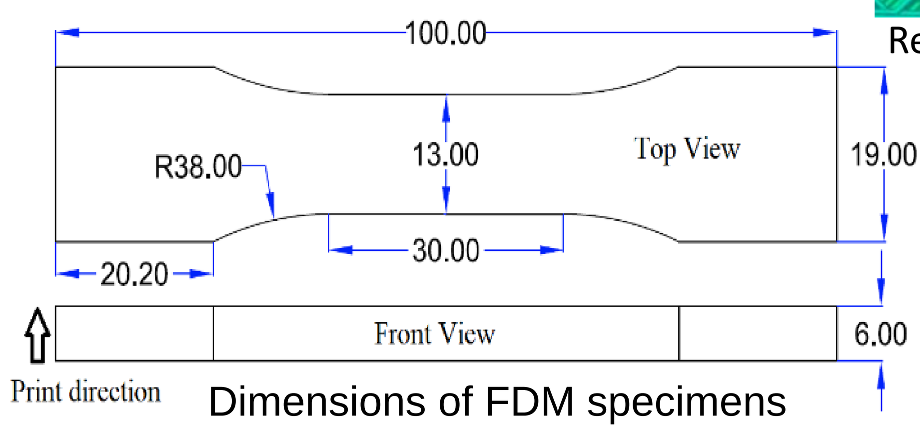
## Abstract

Fused Deposition Modeling (FDM) is additive manufacturing technology that builds parts layer by layer. There are various processing parameters that determine the construction of these layers. Therefore, the quality of the parts produced by FDM heavily depend on these parameters. Due to the huge number of processing parameters involved, it is not practical to study all of the processing parameters and their interactions using full factorial analysis. In this research, Taguchi's Design of Experiments (DOE) is used to investigate the main effects of four processing parameters in the FDM process, those are the infill percentage, infill pattern, layer thickness and extrusion temperature. The influenced properties investigated, are the tensile test mechanical properties and the dimensional accuracy of the FDM specimens. Using L9 array a total of 27 specimens were printed, measured and compared with the CAD based on ASTM D638 and then tensile tested for their mechanical properties.

## Experiment Procedure

- To investigate the influence of the extrusion temperature, the layer thickness, the infill patter and the infill percentage, we used the Taguchi's L9 DOE.
- All specimens dimensions were adapted from ASTM D638-15
- Material PLA Pro Series 3.00 mm
- For each run, 3 repeated specimens were printed and tested.
- All specimens were printed horizontally.
- Specimens were measured and dimensions were compared with CAD.
- Tensile testing speed was conducted at 50 mm/s as per ASTM D638.

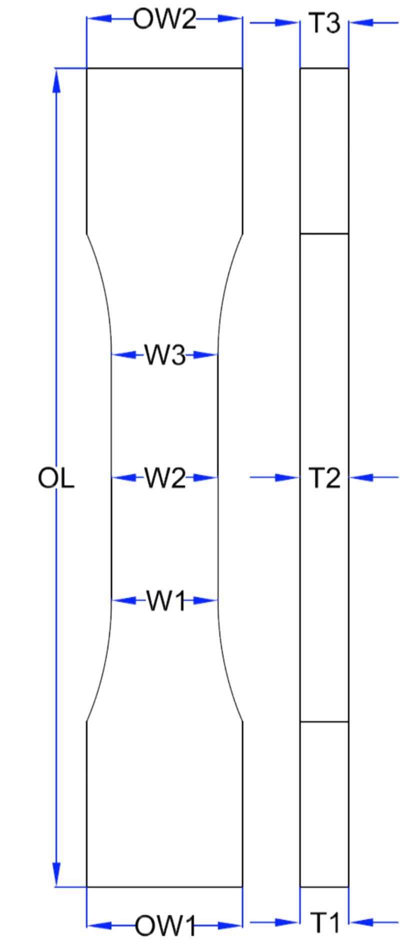

Rectilinear Triangular Hexagonal



Dimensions of FDM specimens

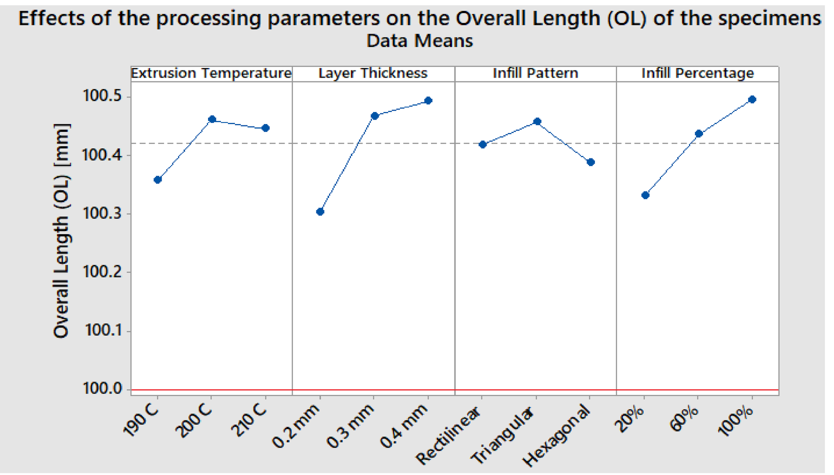
Taguchi L9 runs

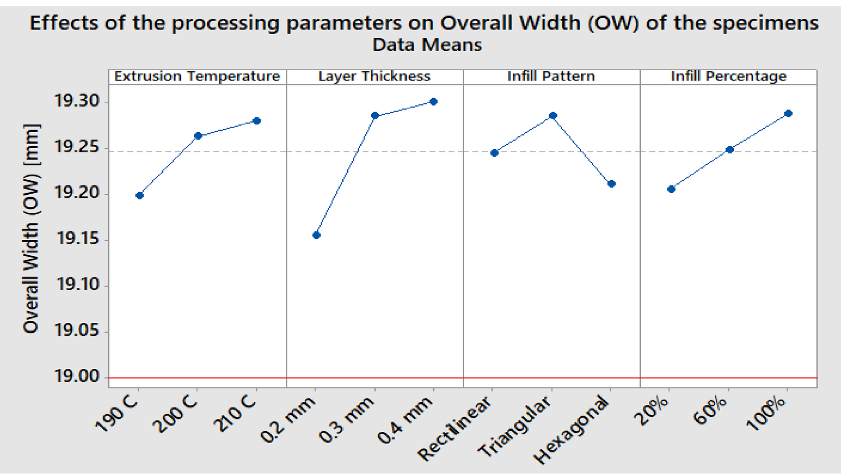
| Run | Nozzle Temp. [C°] | Layer Thickness [mm] | Infill Patterns | Infill % |
|---|---|---|---|---|
| 1 | 190 | 0.20000 | Rectilinear | 20 |
| 2 | 190 | 0.30000 | Triangular | 60 |
| 3 | 190 | 0.40000 | Hexagonal | 100 |
| 4 | 200 | 0.20000 | Triangular | 100 |
| 5 | 200 | 0.30000 | Hexagonal | 20 |
| 6 | 200 | 0.40000 | Rectilinear | 60 |
| 7 | 210 | 0.20000 | Hexagonal | 60 |
| 8 | 210 | 0.30000 | Rectilinear | 100 |
| 9 | 210 | 0.40000 | Triangular | 20 |

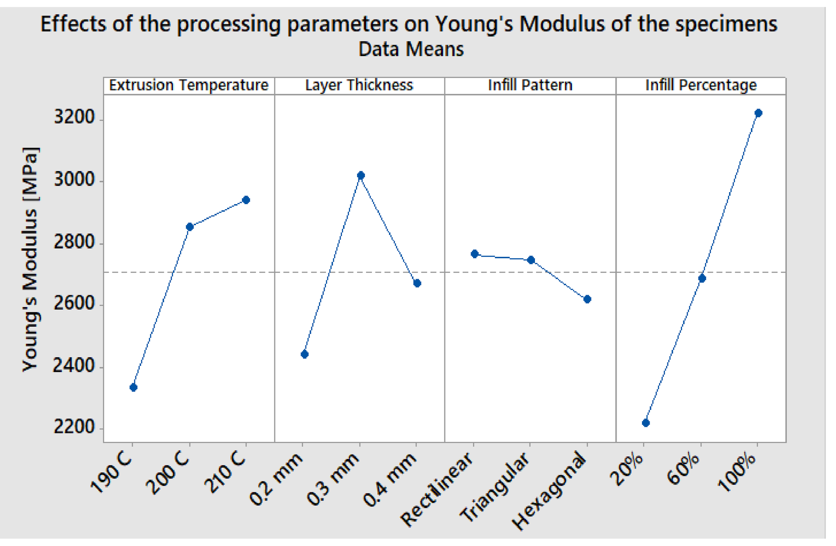


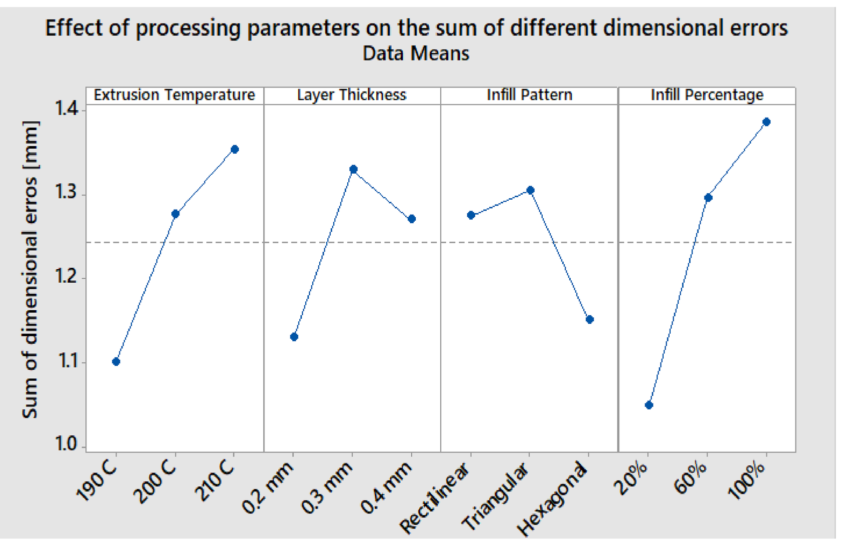
Measurement locations

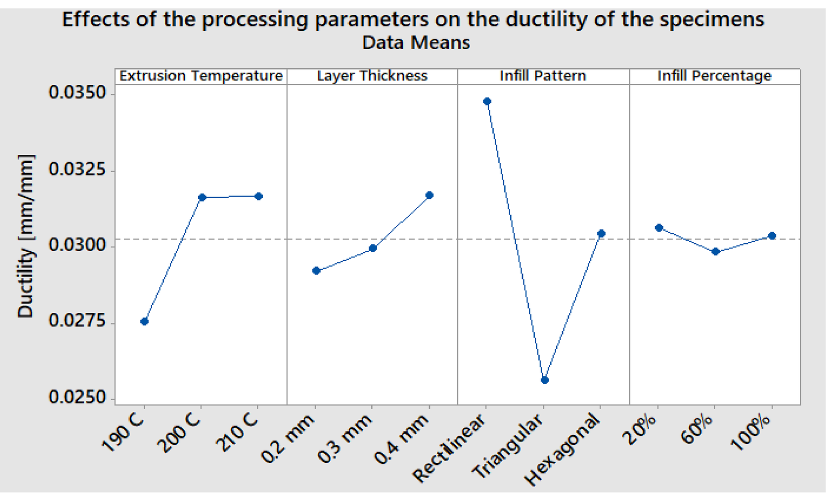
## Test Result

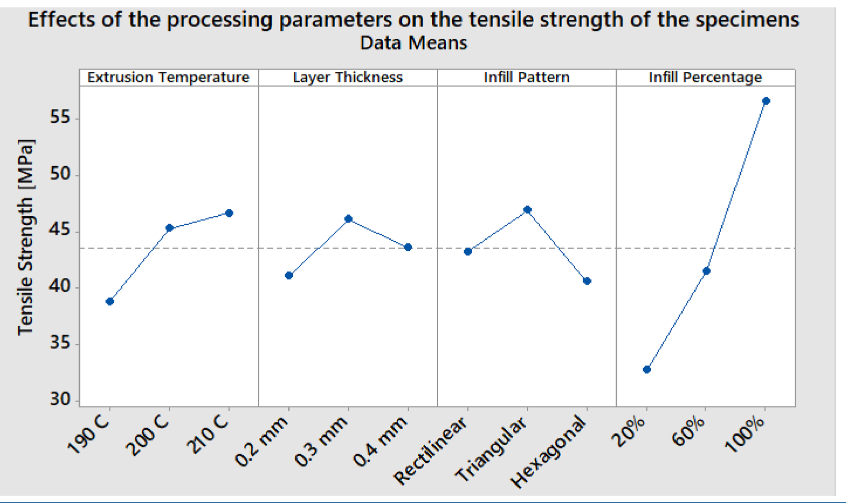



## Discussion and Conclusion

- It was found that for better dimensional accuracy lower extrusion temperature i.e. 190 C0, smaller layer thickness, lower infill percentage and hexagonal infill pattern were required to improve most dimensions accuracy.
- No common processing parameters were found for improving the S/N ratio of all the dimensions simultaneously
- However, it was found that extrusion temperature 190 C0, layer thickness 0.20 mm, hexagonal infill pattern and 20% infill percentage will yield lowest error sum and highest S/N ratio for most dimensions.
- it was found that FDM usually generates parts with larger dimensions.
- it was found that higher extrusion temperature produces parts with higher stiffness, strength and ductility, however, not much improvement is yielded by increasing the temperature from 200 C0 to 210 C0
- Generally, 0.30 mm layer thickness, optimizes the stiffness and tensile strength, while for higher ductility, larger layer thicknesses are required.
- Hexagonal infill pattern produces parts with the highest stiffness and strength but with the lowest ductility
- Rectilinear infill patterns gave the largest ductility.
- The stiffness and strength of the specimens increased almost linearly with the infill percentage, however, the ductility was almost not affected by the infill percentage.

## Reference

1. Dhande SG. Slicing procedures in layered manufacturing : a review. Rapid Prototyp J 2003;9:274–88. doi:10.1108/13552540310502185.
2. ASTM D638-14, Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, 2014, www.astm.org.