Experimental Investigation of Mechanical Behavior in 3D Printed PLA Triply Periodic Minimal Surface Structure for Orthopedics

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Abstract : This project is related to the design, fabrication and characterization of scaffold structures of different structure Using Polylactic Acid (PLA) filament, the micro bone structures are manufactured by Fused Deposition Modeling (FDM). Such morphology is chosen for its good strength, high porosity leading to good nutrient and waste diffusion, and favorable mechanical properties. Load vs Displacement values are obtained by taking compression tests for each as an overall outcome of the research, microstructure with better mechanical properties to replace the damaged bone tissues is identified.

Introduction

Additive manufacturing (AM), or 3D printing, builds objects layer by layer using 3D modeling data. AM has been explored from rapid prototyping to tooling that leads to direct production. More importantly, AM can be used to integrate with CAM (computer-aided manufacturing), CNC (computer numerical control) and CAD (computer-aided design) for 3D printing objects. AM is applied everywhere from biomedical applications to aircraft design and is being slowly explored for applications in the oil and gas industry. The materials used in AM include polymers, metals, ceramics and composites however, the materials for AM are still limited. AM is potentially capable of enabling design of products with complex structures with reduced cost and waste and could also reduce the overheads associated with documentation and production planning. AM technology produces parts with fewer materials compared to conventional technologies and provides a quick response to demand for spare parts. Additive manufacturing, unlike the traditional manufacturing, involves manufacturing of parts by adding the raw material layer by layer. Different AM technologies have been invented, the most popular of which is Stereo Lithography (STL), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Three Dimensional Printing (3-DP).Irrespective of the type of AM technology, in general, any AM technology involves the same basic steps, from the virtual CAD description to the physical part. These steps are followed for the product that is realized during the early stages of the product development process as during this stage the part may require the only rough estimate. At later stages of the process, parts may require post-processing (like sand blasting, surface preparationand painting etc.)

Fused Deposition Modeling

Fuse deposition modeling (FDM) is a common material extrusion process. The material is drawn through a nozzle, where it is heated and then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited. It is a commonly used technique used on many inexpensive, domestic and hobby 3D printers.

Build parameters

1. Speed

Print Speed

The print speed depends on at what speed the print head is moving while it's printing, based on the speed, feed is calculated. Increasing the speed directly affects otherparameters.

Travel Speed

The travel speed defines the speed at which the print head is moving from one point to another when it's notprinting.

Infill Speed

Its speed at which the infill is printed. Using higher speed for the infill affects the strength of the speed.

2. Quality

layer thickness

one of the most often changed parameter is layer thickness. thinner layer increases the quality of the print, leading to a smoother surface and better strength. thicker layer decreases the print time substantially.

Initial layer width

The initial layer width should be thicker than the layer height to create a stronger adhesion with the build plate. the disadvantage of using a thicker initial layer results in poor adhesion and wrapping. it is even more important to ensure the build plate is leveled correctly.

Line width

The line width defines the width of a single printed line, which should be almost equal to the nozzle size. Based on the line width and speed, the extrusion rate is adjusted, which means that it will automatically calculate how much material must be extruded.

3. Infill

Infill Density

Infill density relate to the strength of print, as define the internal structure of the print. Infill density defines the amount of mass inside the print. A higher fill density means that more plastic on the print, leading to a stronger object. In general, a fill density varies between 10% and 20% will be strong enough for most objects. It is also possible to print the object complete hollow, which is desired in some cases. This can be done by simply setting the infill density to 0% Most FDM slicer programs set default option within 18% - 20% infill which is perfectly adequate for the majority of 3D printing applications. This also allows for faster and more affordable prints. The strength of a design is directly related to infill percentage.

Design

The scaffolds were designed and translated into a wider structure for a fixed x, y, z voxel length. This creates a preliminary structure comprising multiple individual shells, each equal to the voxel size and which are effectively seen as individual sub models within the overall structure These shells, therefore, need to be

digitally joined together to form the scaffold as a single model. This is achieved using a wrapping procedure, which comprised a uniform surface averaging and extrusion and effectively bridges any perceived digital boundaries thereby creating one seamless assembly.

Material selection

Material selection is a step in the process of designing any physical object. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals Systematic selection of the best material for a given application begins with properties and costs of candidate materials The intricate branching and surface configurations of such unit cells provide a challenging geometry to accurately reproduce by additive manufacturing.

Polylactic Acid (PLA)

Poly lactic Acid (PLA) is a biocompatible and bioactive thermoplastic aliphatic polyester derived from renewable resources, such as corn starch, cassava roots, chips or starch or sugarcane. It is often used in medical implants that biodegrade within the body over time   **.**

Additive Manufacturing (AM)

In this project, Fused Deposition Modelling system was used as the principal means of additive manufacturing. This printer uses 1.75mm diameter filament and is open source allowing for complete control of the operational parameters. All scaffolds were printed in POLYLATIC ACID (PLA) material using a layer thickness of 0.1 mm, nozzle temperature of 210 degrees Celsius, and it has adhesive based.

Unit cell design

Once a unit cell configuration had been generated as a surface, the first procedure was to convert it into a three-dimensional form. This procedure depends on the nature of the derived unit cell, where surface-dominant unit cell configurations were converted using a uniform surface extrusion (wrapping) function to preserve the surface geometry.
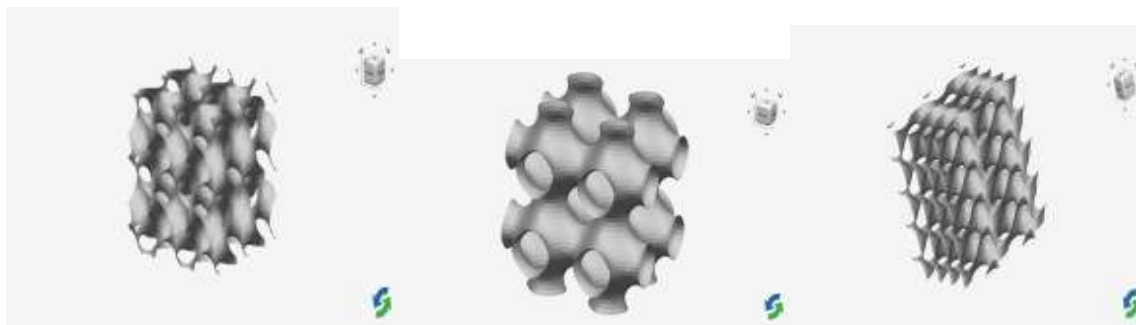
Type 1   **Type 2**   **Type 3**

Fig 1 Design of scaffold structure

The above unit cells are designed with the help of software.

Experiment

| Type 1 | Type 2 | Type 3 |

Fig 2 printed samples

When constructing the scaffold, consideration must be paid to the outer contour of the model, in particular for instances of partial rendering of the unit cell to low thickness tolerances. It would be too thin to be adequately printed by the FDM printer and would likely break off from the wider scaffold. It is to perform robust thickness analysis of the wider structure to ensure the integrity of the model relative to the tolerances of the printresolution.
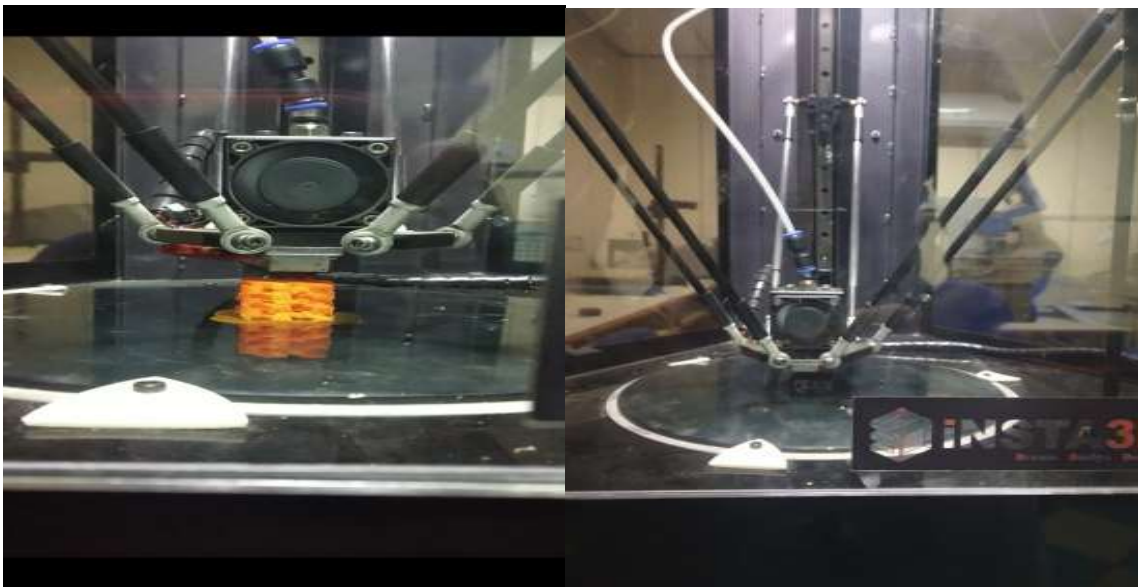
Fig 3 Instabot-S2 Machine

Parameters

Speed

1.Travel speed(mm\s) = 130

2.Infill speed(mm\s)=40

Quality

1.Intial layer thickness(mm)=0.3

2.Layer height(mm)   =0.2

Infill

1.Infill density (%) = 10

Mechanical Testing

The scaffolds are mechanically tested in compression mode by using Fine Testing Machine. Scaffold samples (Width 25 mm, height 25 mm) are tested applying a Cross Head Speed of 0.5 mm to 200 mm per min and capacity 100 kN. The compression tests are conducted with the universal testing machine. The load is applied to the cross section of the specimens, and changes are observed before and after compression.

Fig 4 Universal Testing Machine

Table 1: results of compression test

TYPE OF SCAFFOLDS	LOAD (kN)	DISPLACEMENT (mm)
Type 1	0.94	2.163
Type 2	2.06	6.947
Type 3	2.99	8.987

Result and Discussion

Compressive Strength

The Load vs Deflection for each of the scaffold, the maximum load bearing capacity of each scaffold is recorded and it is maximum in case of Type 3 modified scaffold structure. As an overall outcome of the research, microstructure with better mechanical properties to replace the damaged bone tissues is identified.

Conclusion

From the Table of Load vs Deflection for each of the scaffold, the maximum load bearing capacity of each scaffold is recorded and it is maximum in case of Type 3 modified scaffold structure. The fabricated 3D artificial bone scaffolds of different models are characterized and evaluated. As an overall outcome of the research, microstructure with better mechanical properties to replace the damaged bone tissues is identified.

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