Design and Topology Optimization of in fill Pattern For Orthopedic Application By Additive Manufacturing

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Abstract- *A significant requirement for complex geometry or structural topology of orthopedic application for achieving the mechanical properties and the functional gradient of the geometry is an important case consideration of design and manufacturing processes. The fabrication of porous metals has been extensively explored over decades, however only limited controls over the internal architecture can be achieved by the conventional processes. Recent advances in additive manufacturing have provided unprecedented opportunities for producing complex structures to meet the increasing demands for implants with customized mechanical performance. At the same time, topology optimization techniques have been developed to enable the internal architecture of porous metals to be designed to achieve specified mechanical properties at will. Thus implants designed via the topology optimization approach and produced by additive manufacturing is a great interest. For this experiment to design and topological optimization on the various infill pattern shape at different infill density percentage such as 30%, 50% and 70%. Then factors and variables consider for to select optimum infill pattern such as weight, infill percentage, Orientation of printing, temperature, nozzle feed speed and infill gap distance, these are particulars and parametric factors consider for this experiment.*

Keywords- Additive manufacturing, Sustainable product design, Infill pattern design, Topology Optimization; Infill density rate, Orthopedic application; porous structure, Optimum infill pattern.

I. INTRODUCTION

Additive Manufacturing (AM) which is known as 3D printing has rapidly grown in recent years and has been widely used Behind AM, but Fused Deposition Modelling (FDM) is the most used one. This technology requires a CAD file, usually Stereo Lithography (STL), to build the complex models from thermoplastic material like ABS. From the STL file, FDM creates a tool path, and prints the model layer by layer, as shown in Figure 1.1. The print head extrudes the filament through the heated nozzle. The material solidifies when it reaches the tray. The structure is built in a specific tool path which can be set up by the commercial software. Figure 1 shows the most commonly used one which is the perimeter filled with 45° straight lines. In addition, the second layer is similar but rotated by 90°. [1-3].

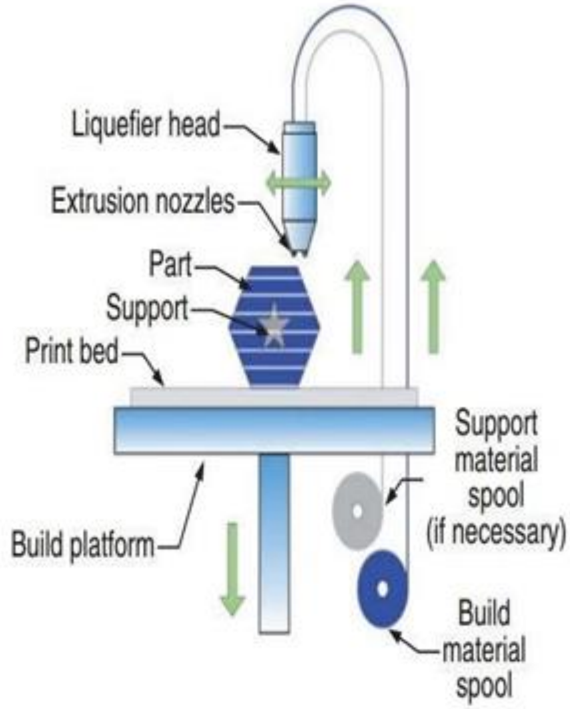


Figure 1. Fusion Deposition Modelling Process

Jamian et al. studied the behavior of a hollow box under compression test to get specific energy absorption of 5 different samples. The material was made from pure aluminum. Those samples were fabricated by making holes in different locations distributed along the height of the crush boxes. A Universal Testing Machine (UTM) was used to do compression tests. Displacement control of 1.5 mm/min was performed on all samples until they reached maximum displacement of 200 mm. The SEA was evaluated experimentally for all samples and it was observed that the SEA depends on the distribution of the trigger holes.[4].

Mohsenizadehet al. also studied the behavior of aluminum square tubes under the compression test but they used 2 samples filled with conventional foams and auxetic foams and one empty square tube sample. Their investigation was done to evaluate the maximum capacity of energy absorption.[5].

Maliarisand Elias S. explored the mechanical behavior of stochastic lattice structures using compression tests. Their samples were made stochastically by using Voronoi tessellation technique. The irregular cell geometries that fabricated using 3D printing. Photosensitive resin material was used in this case.[6]

Carlton**.**et.al. studied the heterogeneous structural behavior of a one-unit cell. The specimens were created using Selective Laser Melting (SLM). They used different lattice topologies to study the mechanical properties and the deformation response. Six types of single unit cells made from Ti64 alloy were tested under compression test. Load-displacement curves were captured and compared.[7].

Sing *et al***.** explored the SLM method to create two types of specimens including square pyramid and truncated cube and octahedron. There were two designs for each specimen that were different in diameter. They chose 0.6 mm and0.8mm for each specimen.[8].

Speck *et al*. used the conventional method to build up lattice metal structures. The deformation shaping of the hexagonal perforated sheet was performed to create the core structures, Due to the restriction on the material fluidity during deformation, metal was a good choice for this fabrication method. The sheet of 304 stainless steel (SS) was selected to fabricate the tetrahedral lattice structures.

The SS face sheets were joined to the lattice core using a transient liquid phase approach. The core was coated with polymer-based cement and Ni-25Cr- 10P braze alloy powder. Then the sandwich was heat treated in a vacuum. This was to enhance the mechanical properties like improving joint ductility. The results were compared with aluminum honey comb structure.[9].

II. MATERIALS AND METHODS

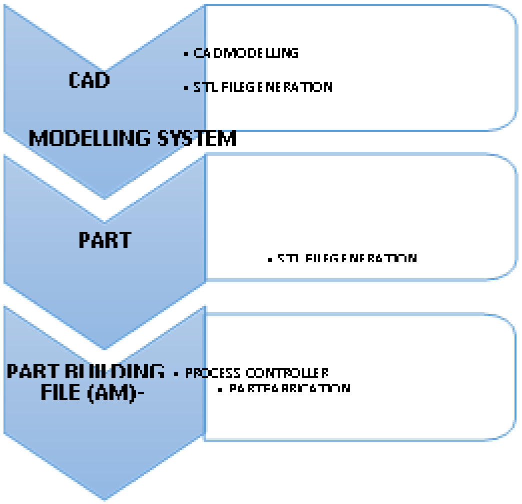


Fig. 2. Methodology flow chart

Infill pattern in 3D printing refers to the structure that is printed inside the model. By using slicing software, an infill pattern for an object can be defined in various percentage and shapes. The 3D model is design by CAD modelling software such as Auto CAD, Catia V5, Solid Works, and CREO etc. the infill pattern is designed and customized the infill variables by Standard Triangular Language (STL) Software. The STL software is generally used to manipulate and conversion of CAD file to. Stl format. For that UTIMAKER CURA 4.0being used by worldwide. With the helping of this software various in fill patterns topology has been create dat different infill density such as 30%, 50%,70%.

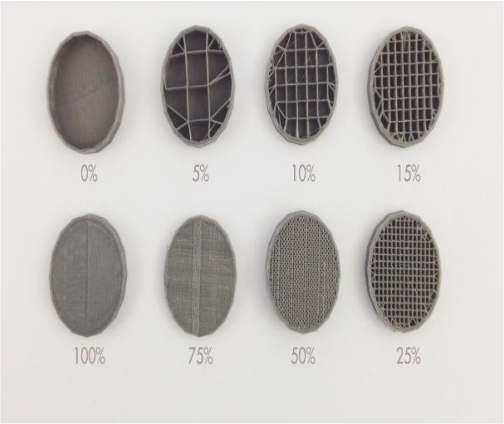


Fig. 3.Infill Density

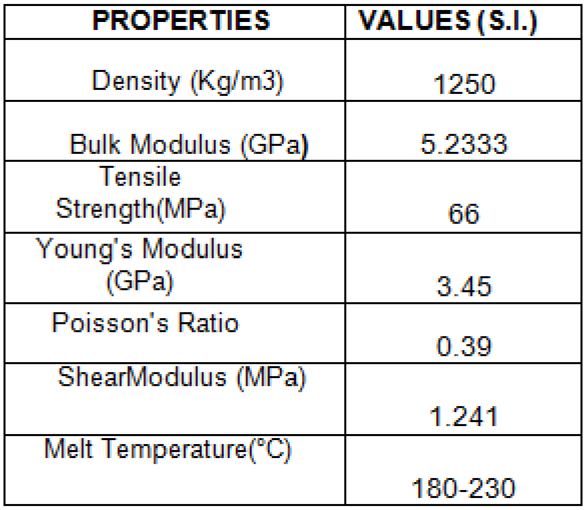
The 3D part has done by CAD modelling software CATIA V5. The product is saved in the format of .dwg, The CURA 4.0 is used to convert the .dwg format to .stl file format of machine accessible code. Test specimen and fabrication for the compression test specimen is fabricate by using Additive Manufacturing(FDM) process with the ASTM D695 Standard.

SPECIMENDIMENSION

The Block specimen has been fabricated with the customize variable as different infill patterns at different infill density rates. The mentioned standard specimen dimension is 12.7 x 12.7 x 12.7 mm. Material: Polylactic Acid (PLA).

Fig. 4 FDM Machine

Table 1. Design of experiments



PROPERTIES	VALUES (S.I.)
Density (Kg/m3)	1250
Bulk Modulus (GPa)	5.2333
Tensile Strength(MPa)	66
Young's Modulus (GPa)	3.45
Poisson's Ratio	0.39
ShearModulus (MPa)	1.241
Melt Temperature(°C)	180-230

The below shown figure is FDM machine which is used to fabricate specimen.

Fig.5. Fabricated Specimens

III. EXPERIMENTAL PROCEDURE

The four designs of polymer lattice structure were tested using Instron 5500 R, universal testing machine, which has a maximum load capacity of 150 KN. Figure illustrates this testing machine. It has an industrial software which is Bluehill2. This software is provided by Instron which can post-process the data. The data were saved in an excel file which has load and deformation results. Load-displacement curves can be plotted using an excel file. As mentioned, each configuration has three specimens to consider the uncertainty. A Quasi-static compression test was performed on the specimens under displacement control of 0.5 mm/min. The specimens were compressed up to 12 mm crush length, which is 60% of the total height. The specific energy absorption (SEA) was calculated from the load-displacement curve. It is defined as the area under the load- displacement curve divided by the sample mass. To calculate that area, the cumulative trapezoidal integration was implemented using an excel worksheet. The boundary condition was set to be free-free butit was observed that the behavior of the bottom was almost fixed and the top was free for all specimens, as shown in the observation of boundary condition has been captured using Time-Lapse video. The upper push rod which pushes the top face of the upper push rod which pushes the top face of the specimen very slowly is made from stainless steel to avoid friction. However, the base has a rough surface which 16 makes the bottom face of the specimen fixed. Also, the applied load was continuously crushing and keeping the bottom face immobile.

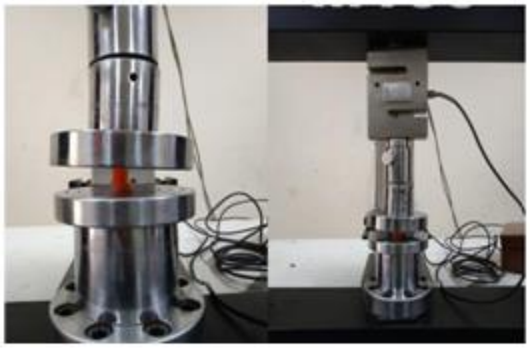


Fig.6. Compression testing

Fig. 7. Specimen after Compression test

IV. RESULT AND DISCUSSION

The following table values has been observed and reveals the compression strength accordingly.

TABLE.2. COMPRESSIONSTRENGTH VALUES

SL. NO	INFILL PATTERN	INFILL DENSITY (%)	COMP. STRENGTH (MPa)
1	Concentric	30	290.047
		50	293.237
		70	298.286
2	Grid	30	308.626
		50	308.728
		70	308.789
3	Gyroid	30	308.785
		50	308.792
		70	313.694
4	Triangular	30	308.787
		50	308.807
		70	308.890
5	Tri-Hexagonal	30	308.787
		50	308.789
		70	308.791
6	Zig-Zac	30	308.402
		50	308.767
		70	308.795

The above tabulated compression strength values have been taken by the compression testing on respected specimens.

RESULT GRAPH LOAD VS. CROSS HEAD TRAVEL

The following graph has been taken from the UTM machine. In the graph interpret the results for testing specimen which is subjected to compression testing.

Table.3 Optimized Parameters

SL. NO	Infill density (%)	Infill pattern	Comp. strength (MPa)
1	30	Tri-Hexagonal	308.787
2	50	Triangular	308.801
3	70	Gyroid	313.694

V. CONCLUSION

This section presents the experimental work and the compression strength results. Load- displacement curve is very significant in this section to evaluate the absorbed energy or the SEA. Eighteen specimens were used for each test including compression test. The specimens are block structure with bottom center with vertical support. The compression strength vs infill patterns have been consideration for topology optimization.

In this work, the effect of infill pattern and density on mechanical properties have been optimized. The results in the FDM process show that,

- The GYROID infill pattern with 70% density shows the highest compression strength, with the value of 313.694MPa.
- The result reveals very tiny difference in printing time between infill patterns in both 30%, 50% and 70%density.
- Printing time for grid and concentric infill patterns are nearly the same. When increasing density, the concentric pattern takes a lesser time for printing the object.

The orthopedic application or implantation of bone porous structure manufacturing, the best infill pattern has to be concern and consideration less weight with better functionality under the mechanical loads condition.

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