A REPORT

ON

MODELING, SIMULATION AND FABRICATION OF LATTICE BASED IMPLANT

SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

Anurag Mishra	**1802740904**
Avichal Singh	**1802740908**
Bhanu Pratap Singh	**1702740038**
Divyanshu Verma	**1702740049**

Under the Guidance of

Dr. Tarun Bhardwaj

Assistant Professor

Department of Mechanical Engineering

AJAY KUMAR GARG ENGINEERING COLLEGE GHAZIABAD

ACKNOWLEDGEMENT

We would like to thank Assistant Professor Dr. Tarun Bhardwaj who has given us this invaluable opportunity and supporting me all the time. We learned many things from him for two years studying at AJAY KUMAR GARG ENGINEERING COLLEGE. It is really my pleasure to work under his supervision. We also extended my thanks to other faculty members of the Mechanical Engineering Department, for their valuable support, whenever it requires to us.

Anurag Mishra
Avichal Singh
Bhanu Pratap Singh
Divyanshu Verma

Department of Mechanical Engineering
AJAY KUMAR GARG ENGINEERING COLLGE
GHAZIABAD

ABSTRACT

Orthopedic regenerative medicine is the latest trend in biomedical sector. Designing of bone scaffolds and implants is a challenging step followed by its fabrication and surgical implantation. Lattice structure based designs are desirable candidates for healing or replacing the damaged bones, as they provide larger surface area for osseointegration. Additive manufacturing has the potential to fabricate these complex lattice structures. In these work SolidWorks 2020 CAD software is used for modelling the hollow cubical lattice structure which are then scaled while maintaining the same overall size and volume. After designing Finite Element Analysis (FEA) is performed to investigate the compressive behaviors of the lattice structures using the Ansys FEA package. The compressive modulus of porous scaffolds for stainless steel and TI-6Al-4V are calculated and compared with that of compact bone.

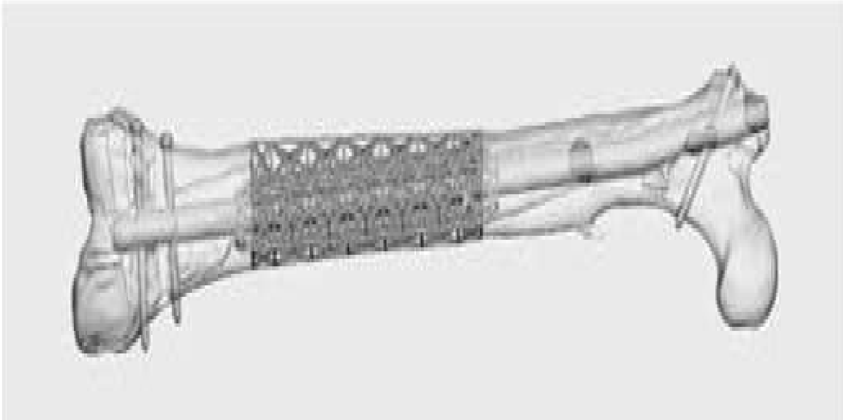
INTRODUCTION

- ## IMPLANT

  - It is a medical device manufactured to replace a missing biological structure, support a damaged biological structure, or enhance an existing biological structure.

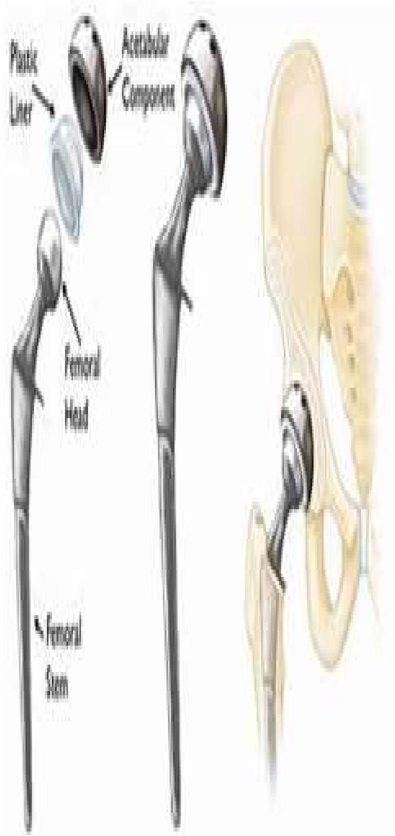
  - Implants are required for large segmental damaged bones because they cannot heal themselves, as against the small damaged bones which have the ability of self healing.

  - The main goal of implants is to help patients with disabilities to return to normal function for the longest possible duration. Further, implants can be used either to augment existing performance of the body or to replace missing tissues, organs or parts of the body.



Dental Implant

Cranial Implant



Orthopedic Implant

Unit cell & Scaffold

The unit cell is the smallest part, that repeated regularly in three dimensions to creates the scaffold

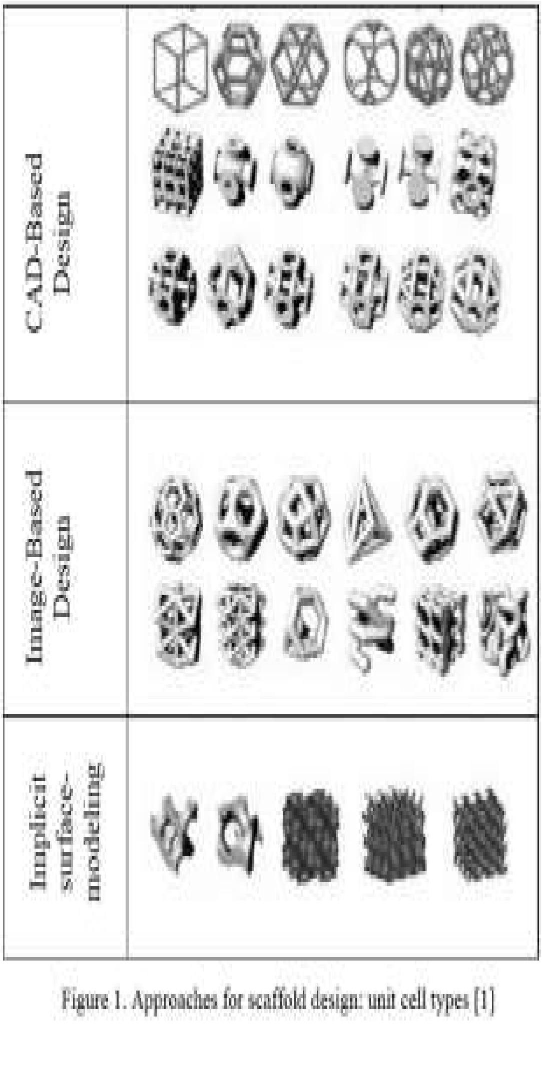
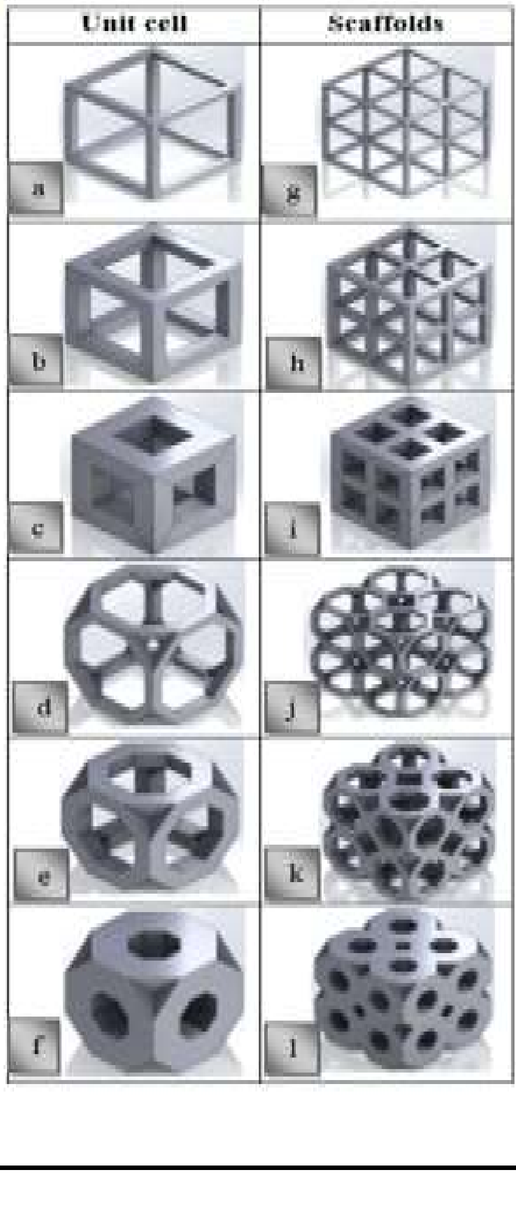


Figure 1. Approaches for scaffold design: unit cell types [1]



Use & Advantage of Scaffold

- Use to make a bridge between the gap of two ends of damaged bone.
- Porous scaffold is best for the growth (proliferation) and deposition (vascularization).
- Porous scaffold are also good in osseointegration(the direct structural and functional connection b/w living bone and surface of load bearing artificial implant.

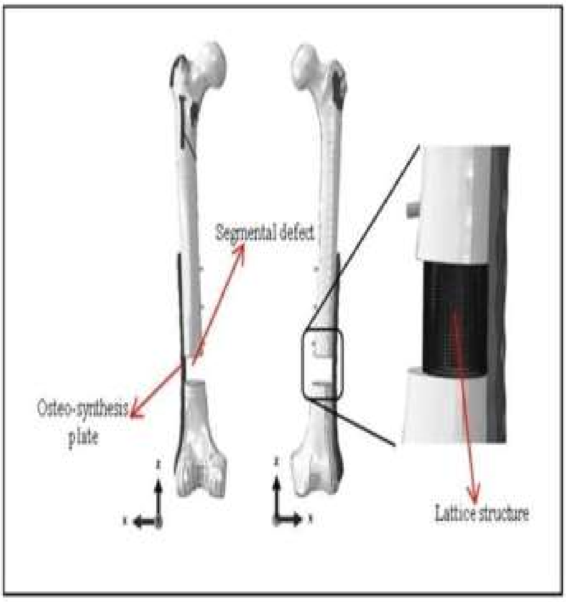
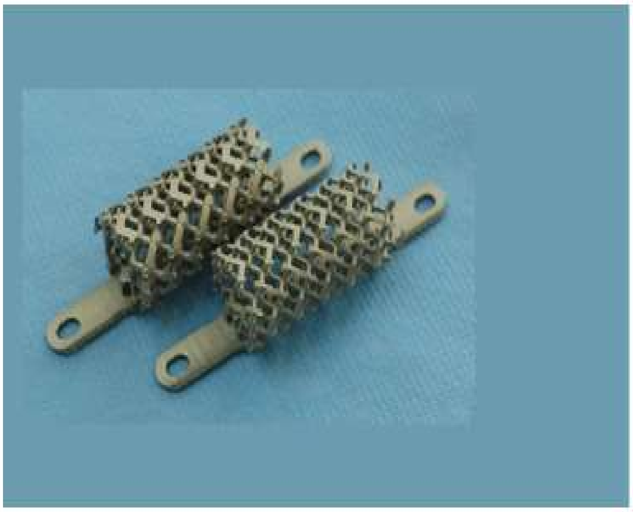


Fig. 1. Model of the femur bone and segmental defect with the applied osteo-synthesis plate and filled with lattice structure based implant [3].



Lattice Based Implant

Additive Manufacturing

- The process of joining materials to make objects from 3D model data, usually layer by layer.
- Commonly known as 3D printing.
- Manufacturing components with virtually no geometric limitations or tools.

Advantages of Additive Manufacturing

- It has the capability to fabricate external as well as internal architecture.
- Cost effective, low wastage, rapid manufacturing of parts or components that can be customized basis.

Techniques used to manufacture Porous Scaffold

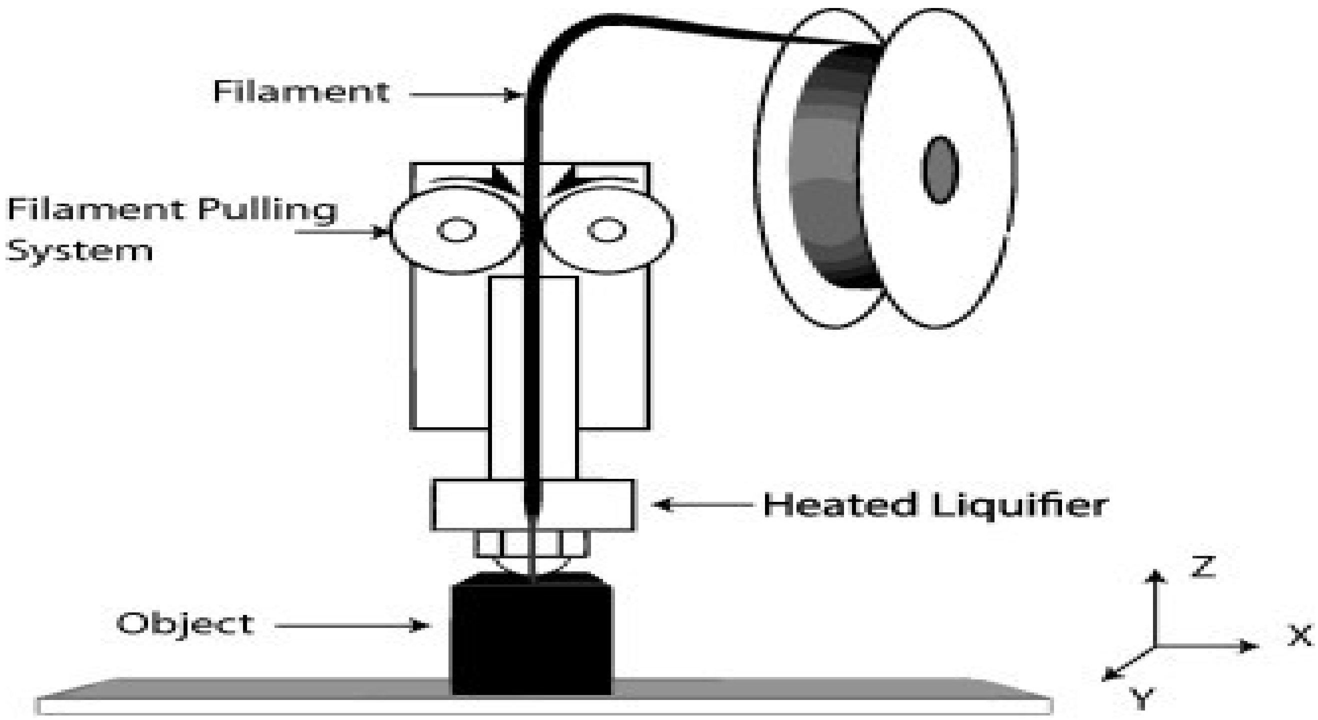
- Fused Deposition Modeling
- Selective Laser Melting
- Selective Laser Sintering
- Electron Beam Melting
- Direct Laser Deposition

Fused Deposition Modeling (FDM)

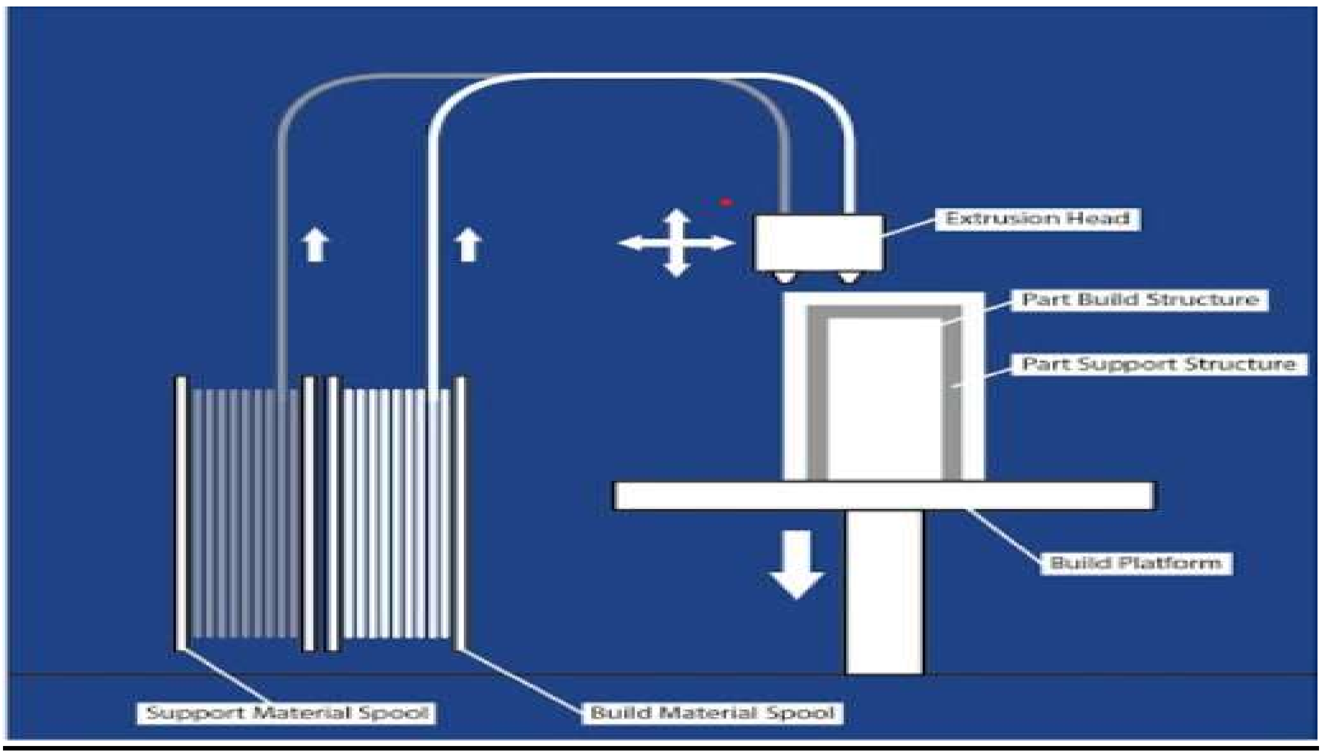
- FDM Printer use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, to create a 3D object.

- **Polymers Printed by FDM**

- PLA (Polylactic Acid)
- ABS (Acrylonitrile Butadiene Styrene)
- PET (Polyethylene terephthalate)
- Nylon
- TPU (Thermoplastic polyurethane)
- PU (polyurethane)



Filament
Filament Pulling System
Heated Liquifier
Object
Z
X
Y



Extrusion Head
Part Build Structure
Part Support Structure
Build Platform
Support Material Spool
Build Material Spool

DESIGN & METHODLOGY

- Lattice based part designed in SolidWorks (CAD software) & import in Ansys (simulation software).
- Two rigid plates are modeled, assembled with lattice part.
- Surface to surface contact has been selected and the contact properties are taken as friction coefficient of 0.2 with normal behavior of hard contact.
- To simulate the boundary conditions, the lower plate is kept fixed and the upper plate is given a downward displacement of 0.01 mm.

FINITE ELEMENT ANALYSIS (FEA)

- Design geometry is a lot more complex; and the accuracy requirement is a lot higher. We need – To understand the physical behaviours of a complex object (strength, heat transfer capability, fluid flow, etc.) – To predict the performance and behaviour of the design; to calculate the safety margin; and to identify the weakness of the design accurately; and – To identify the optimal design with confidence.

- FEA is used to simulate the compressive behavior of lattice structures.
- Compressive behavior of designed scaffold must be predicted before actual fabrication, to reduce the cost of experimentation and material.
- In this analysis, compressive behavior & strength of the lattice structures will be simulated.

Literature Review

Sr No.	Paper Description	Remarks
1.	**Finite Element Modeling and Analysis of Implant Scaffolds** **By- T Bhardwaj, SP Singh, M Shukla.** International Conference on…, 2017	• Geometry of structure such that Elastic modulus is in the range of Elastic modulus of the cortical bone (3-30-GPa) • By porous structure, surface area is increase. It helps to cell in growth & vascularization.
2.	**Lattice modeling and Finite Element Simulation for Additive Manufacturing of Porous Scaffolds** **By- T Bhardwaj, SP Singh, M Shukla - ….** International Conference on ….., 2017	• To avoid the stress shielding effect, low dense porous scaffolds are manufactured that provide cell attachment, mechanical stability and fluid perfusion. • Effect of unit size scaling results in generating more surface area for same porosity that leads to more bone regeneration

Sr No.	Paper Description	Remarks
3.	**Additively manufactured porous metallic biomaterials** **By-Amir A Zadpoor - 2019**	• Porous metallic biomaterials with topologically ordered unit cells have improving bone tissue regeneration and preventing implant-associated infections. • Discussed how the huge (internal) surfaces of AM porous biomaterials and their pore space could be used respectively for surface bio-functionalization and accommodation of drug delivery vehicles so as to enhance their bone tissue regeneration performance and minimize the risk of implant-associated infections. We conclude with a general discussion and by suggesting some possible areas for future research.

Sr No.	Paper Description	Remarks
4.	**Additively manufactured functionally graded biodegradable porous zinc** **By - Y Li 1, P Pavanram 2, J Zhou 1, K Lietaert 3, F S L Bobbert 1, Yusuke Kubo 2, M A Leeflang 1, H Jahr 4, A A Zadpoor - 2020**	• Two uniform AM porous Zn designs with diamond unit cell. • Cylindrical specimens were fabricated from pure Zn powder by using a powder bed fusion technique, followed by a comprehensive study on their static and dynamic biodegradation behaviors, mechanical properties, permeability, and biocompatibility. Topological design, indeed, affected the biodegradation behavior of the specimens, as evidenced by 150% variations in biodegradation rate between the three different designs. • Using topological design of AM porous Zn for controlling its mechanical properties and degradation behavior is thus clearly promising, thereby rendering flexibility to the material to meet a variety of clinical requirements.

5.	**Direct Laser Deposition - Additive Manufacturing of Ti-15Mo Alloy: Effect of Build Orientation Induced Surface Topography on Corrosion and Bioactivity** **By- T Bhardwaj, M Shukla, NK Prasad, CP Paul** Published in- Metals & Materials …., 2020 Springer	• Examined the higher content of refractory metals(Mo, Nb & Ta) in Ti alloy. • But select Ti (15%)Mo due to better density as compare to other alloy composition. • To optimize the DED-LAM process parameters for minimum dilution, RSM technique is used
6.	**Biomaterials & Scaffolds for tissue engineering** **Author of article – Fregal J. O'Brien**	• Biomaterials are generally categorized in three 1.-Ceramic, 2-Synthetic Polymer, 3 - Natural Polymer • Scaffold should have a balance between mechanical properties and porous architecture which allows cell infiltration and vascularization & it is the key to success of any scaffold. • Improvement in vascularization strategies is one of the area requiring the most extensive research in the field of tissue engineering.

<u>CONCLUSION from Literature review</u>

- There are different approach of generating lattice for AM, CAD, Image and implicit based. Implicit based lattice is preferred now a days as it reduces weight whilst maintaining optimal performance.
- Polymer based lattice have a balance between mechanical properties and porous architecture which allows cell infiltration and vascularization
- Design of AM porous Zn for controlling its mechanical properties and degradation behavior.
- FEA is performed for static load, pressure to get stress deformation curve, which will decrease the physical manufacturing cost .
- Increase in more surface area for same porosity increases the chances of bone regeneration.

Research Gap

- FEA has been performed to simulate only the compression behaviour of lattice structure but we shall also perform to simulate the tensile and fatigue behaviours of lattice structure.

- Impact testing of polymer based lattice will also performed.

- We also measure the rate of decomposition of scaffold material which is easily consume by our body because due to excess decomposition of material causes adverse effect on body.

Research Objective

- To design the lattice structure which have high porosity with desire mechanical properties.

- The lattice structure in which the better interconnected network that helps in proliferation and vascularization.

- The scaffold is biodegradable it allow the body's own cells, over time, to eventually replace the implanted scaffold. Scaffold and constructs are not intended as permanent implants. The scaffold must therefore be biodegradable so to allow cell to produce their own extracellular matrix.

Research methodology

- Lattice based part designed in **SolidWorks**(CAD software) & import in **Ansys**(simulation software).

- **Two rigid plates** are modeled, **assembled** with lattice part.

- Surface to surface contact has been selected and the contact properties are taken as friction coefficient of 0.2 with normal behavior of hard contact.

- To simulate the boundary conditions, the **lower plate** is kept **fixed** and **the upper plate** is given a downward **displacement** of **0.01 mm.**

Research Framework

Specify the need of polymer scaffold.

Design of unit cell.

Design of lattice structure.

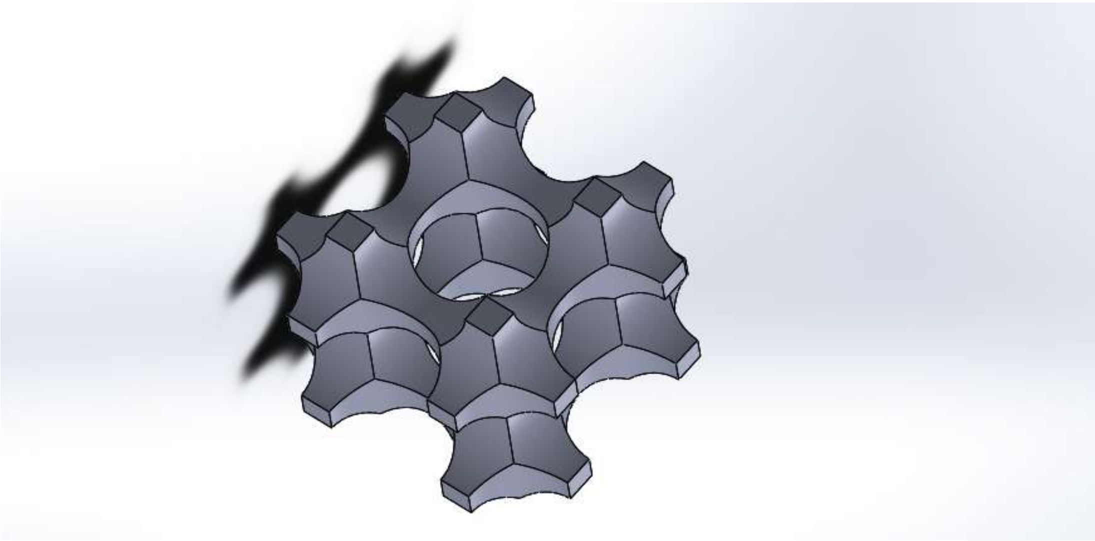
Selection of biocompatible material.

Analysis of mechanical properties of lattice structure.

Manufacturing the implant by additive manufacturing.

IMPLICIT LATTICE

UNIT CELL



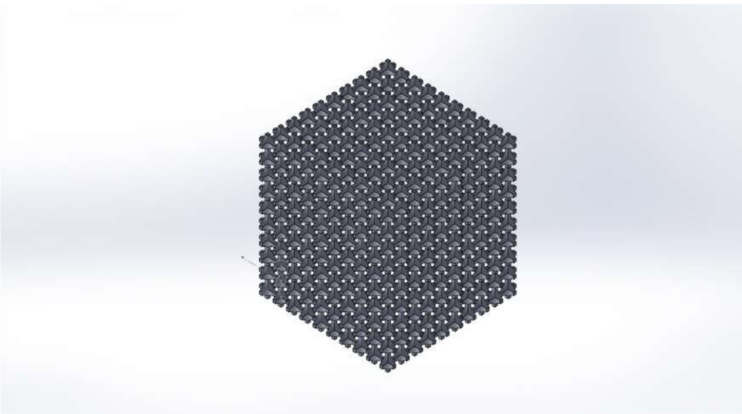
CUBIC LATTICE WITH CYLINDRICAL EXTRUDE CUT.

DIMENSION = 20*20*20.

POROSITY = 51.10% (internal radius = 0mm).

= 71.94% (internal radius =0.5mm).

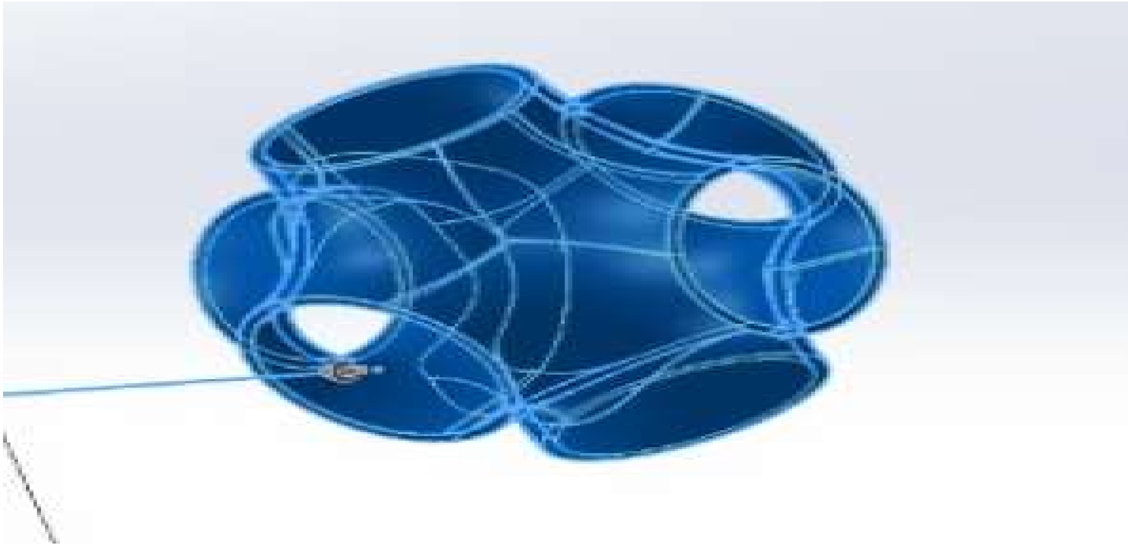
= 82.60% (internal radius =0.3mm).



LATTICE STRUCTURE

IMAGE LATTICE

UNIT CELL



Surface modelling with smooth circular opening from 6 faces of cube.

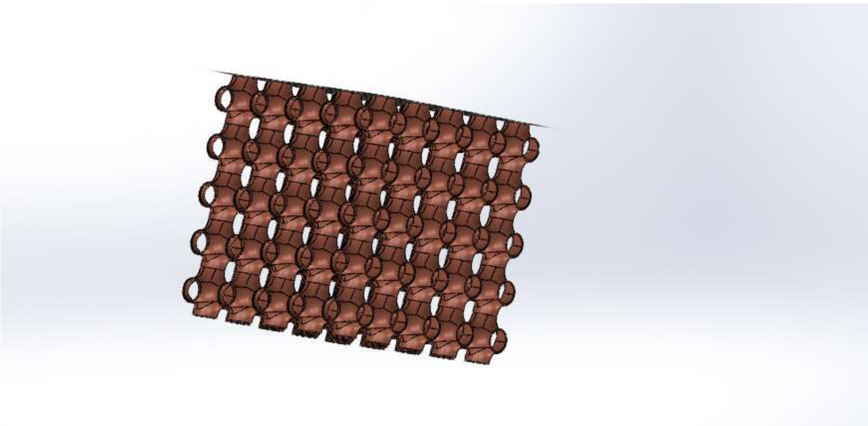
DIMENSION = 20*20*20.

POROSITY = 54.27% (THICKNESS=6MM).

= 66.94% (THICKNESS=7MM).

= 78.38% (THICKNESS=8MM).

= 87.75% (THICKNESS=9MM).



LATTICE STRUCTURE

Methodology

- Part designed in SolidWorks and imposed in Ansys in IGES file format.

- Ti6Al4V is assigned as a material (Elastic modulus – 114GPa and Poission's ratio – 0.34).

- Mess is generated of 0.034mm.

- Force (10N) is applied on one face while keeping the opposite face as the fixed support.

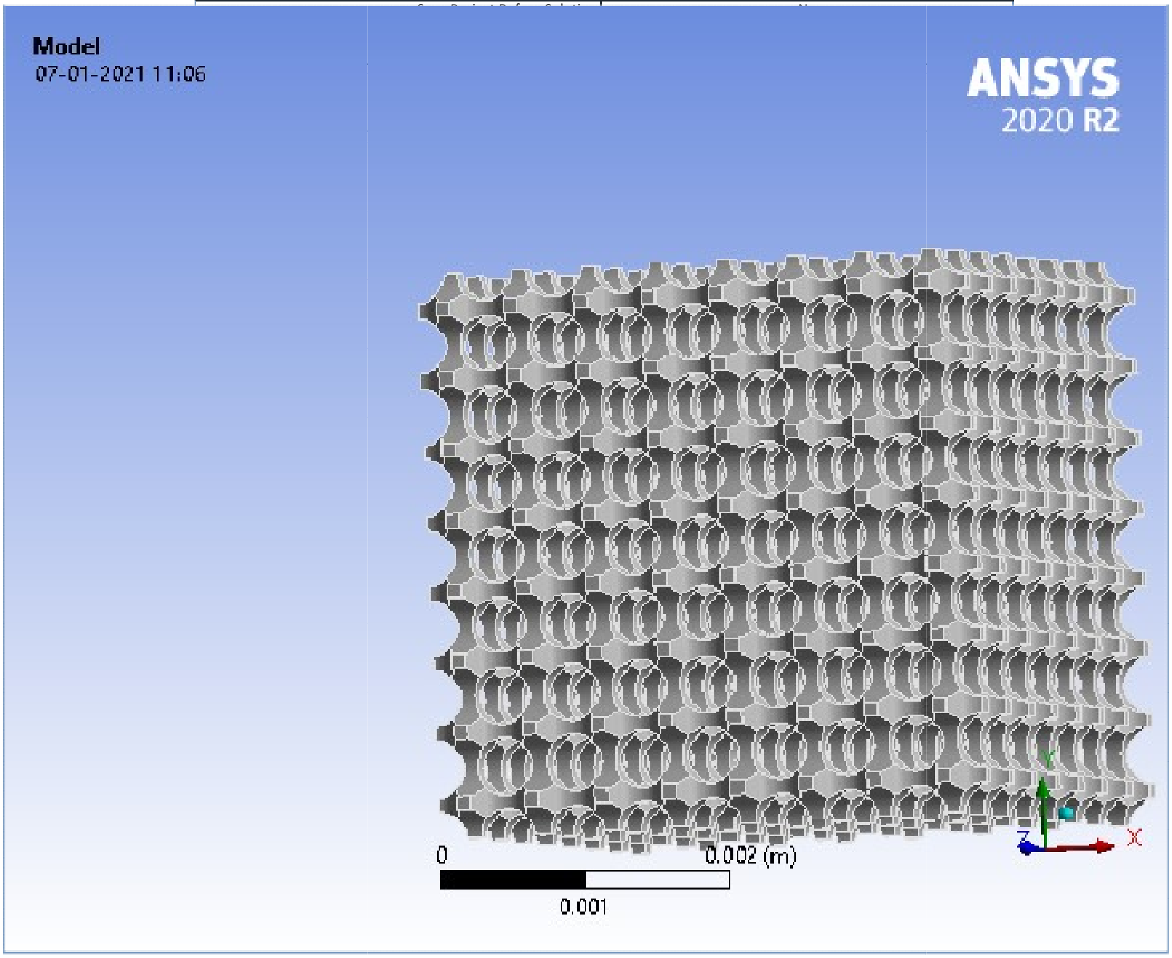
- Different solution tools like total deformation, Equivalent stress & Equivalent strain based on Von-misses criteria is used.

- Required result is obtained.

ANSYS

Project*

First Saved	Wednesday, January 6, 2021
Last Saved	Wednesday, January 6, 2021
Product Version	2020 R2



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\divya\OneDrive\Documents\implicit structure compressive report_files\dp0\SYS\DM\SYS.scdoc
Type	SpaceClaim
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	4.e-003 m
Length Y	4.e-003 m
Length Z	4.e-003 m
Properties	
Volume	1.3831e-008 m^3
Mass	6.1256e-005 kg

Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	69547
Elements	31098
Mesh Metric	None
Update Options	
Assign Default Material	No
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	Yes
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Clean Bodies On Import	No
Stitch Surfaces On Import	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Object Name	*SYS\Solid*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1

Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Material	
Assignment	Titanium Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	4.e-003 m
Length Y	4.e-003 m
Length Z	4.e-003 m
Properties	
Volume	1.3831e-008 m³
Mass	6.1256e-005 kg
Centroid X	1.5e-003 m
Centroid Y	1.5e-003 m
Centroid Z	-1.5e-003 m
Moment of Inertia Ip1	1.6229e-010 kg·m²
Moment of Inertia Ip2	1.6229e-010 kg·m²
Moment of Inertia Ip3	1.6229e-010 kg·m²
Statistics	
Nodes	69547
Elements	31098
Mesh Metric	None
CAD Attributes	
PartTolerance:	0.00000001
Color:143.149.175	

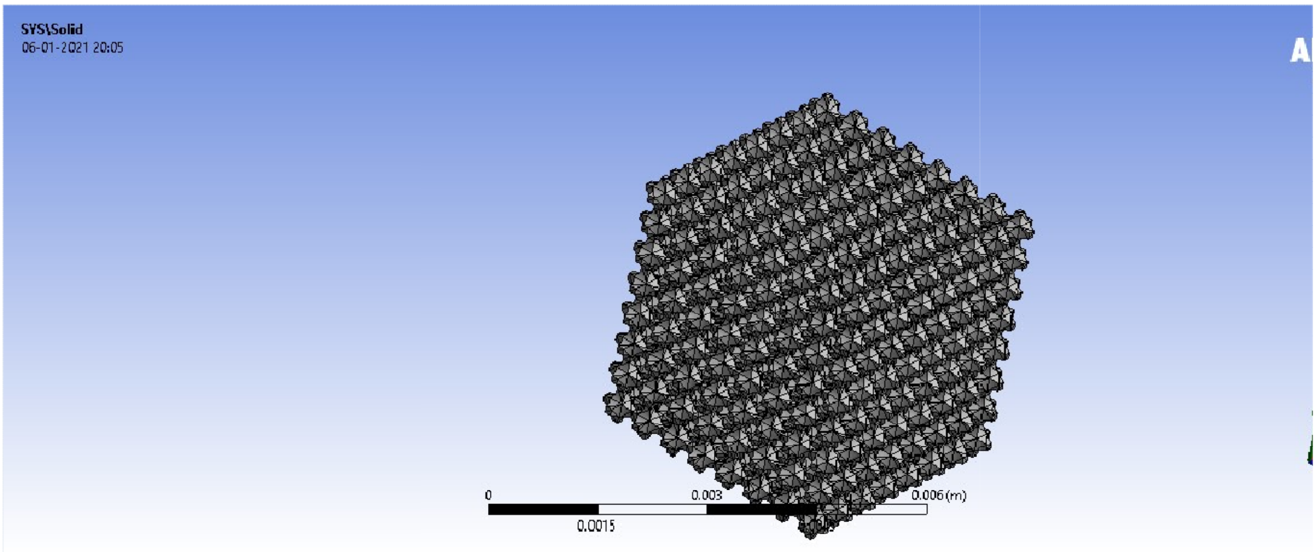


TABLE 3

Model (A4) > Geometry > Parts

FIGURE 1
Model (A4) > Geometry > SYS > Solid > Image

TABLE 4
Model (A4) > Materials

Object Name	*Materials*
State	Fully Defined
Statistics	
Materials	2
Material Assignments	0

FIGURE 2

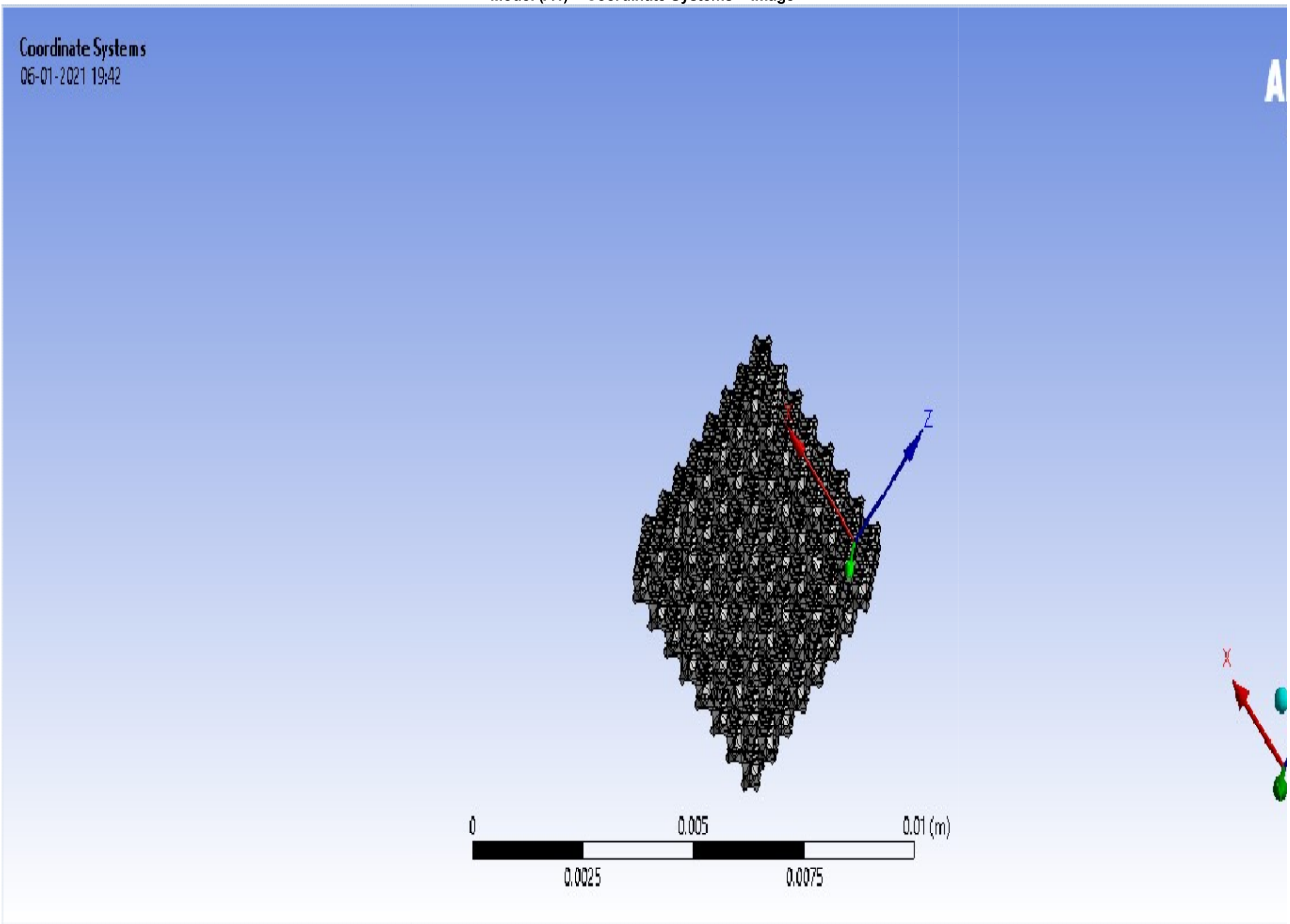
als > Image

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Coordinate Systems

TABLE 5
Model (A4) > Coordinate Systems > Coordinate System

FIGURE 3
Model (A4) > Coordinate Systems > Image



Mesh

TABLE 6
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled

Element Size	Default
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	6.9282e-003 m
Average Surface Area	1.1781e-007 m²
Minimum Edge Length	1.e-004 m
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	69547
Elements	31098

FIGURE 4
Model (A4) > Mesh > Image

Static Structural (A5)

TABLE 7
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 8
Model (A4) > Static Structural (A5) > Analysis Settings

Number Of Steps	1.

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off
Solver Pivot Checking	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Quasi-Static Solution	Off
Rotordynamics Controls	
Coriolis Effect	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Combine Restart Files	Program Controlled
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Program Controlled
Advanced	
Inverse Option	No
Contact Split (DMP)	Off
Output Controls	
Stress	Yes
Surface Stress	No
Back Stress	No
Strain	Yes
Contact Data	Yes
Nonlinear Data	No
Nodal Forces	No
Volume and Energy	Yes
Euler Angles	Yes
General Miscellaneous	No
Contact Miscellaneous	No
Store Results At	All Time Points
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	C:\Users\divya\OneDrive\Documents\implicit structure compressive report_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Contact Summary	Program Controlled
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	64 Faces	
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		-10. N (ramped)
Y Component		0. N (ramped)
Z Component		0. N (ramped)

TABLE 9
Model (A4) > Static Structural (A5) > Loads

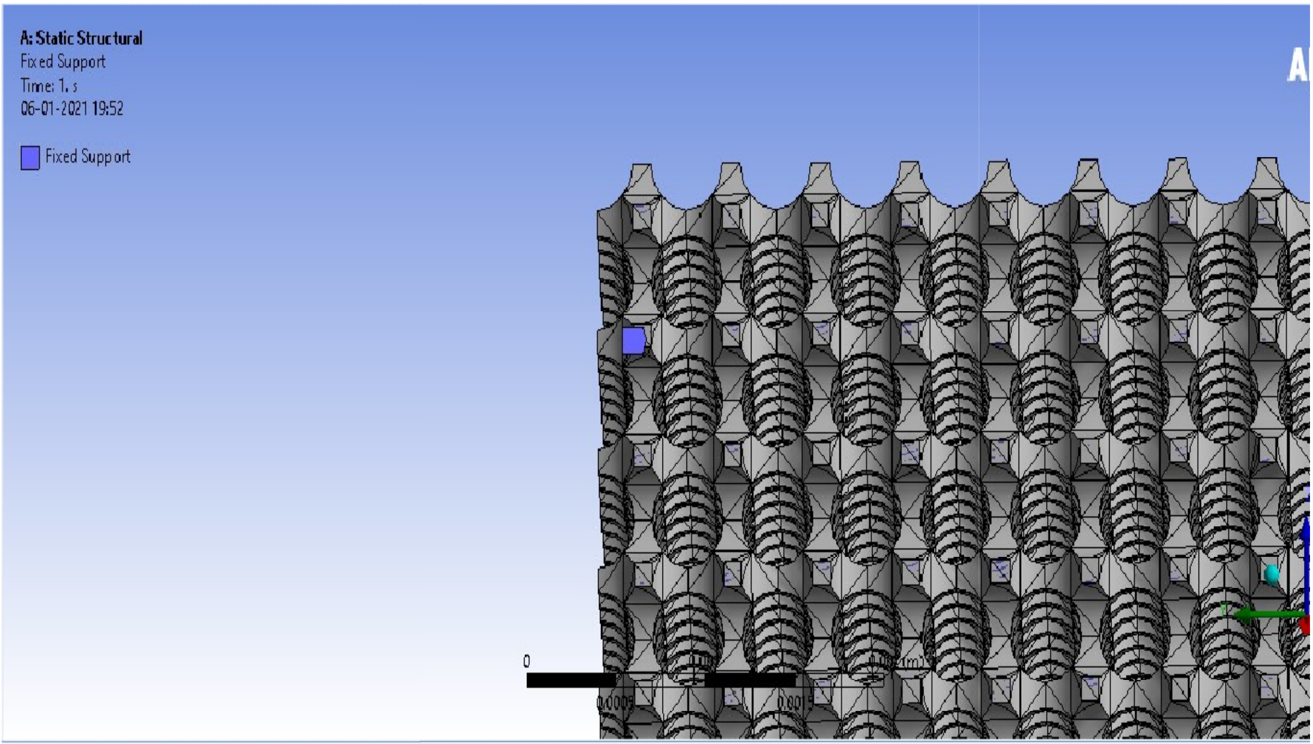
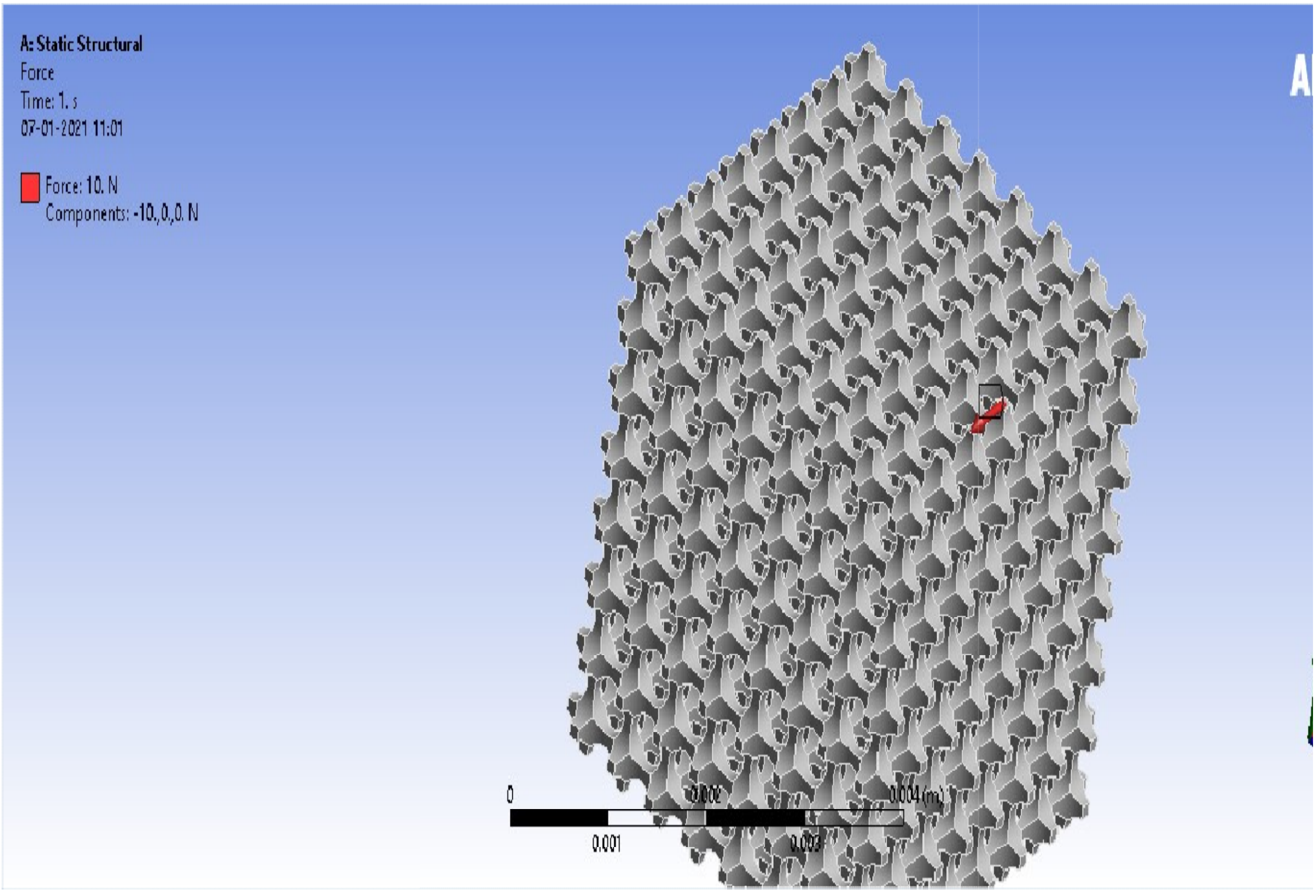


FIGURE 6
Model (A4) > Static Structural (A5) > Force

FIGURE 7
Model (A4) > Static Structural (A5) > Force > Image



Solution (A6)

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done
MAPDL Elapsed Time	12. s
MAPDL Memory Used	816. MB
MAPDL Result File Size	21.125 MB
Post Processing	
Beam Section Results	No
On Demand Stress/Strain	No

Object Name	*Solution Information*

TABLE 10

State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Identify Element Violations	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

Model (A4) > Static Structural (A5) > Solution

TABLE 11
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

TABLE 12
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. m	7.3698e-007 m/m	53173 Pa
Maximum	2.639e-007 m	1.8159e-004 m/m	1.8789e+007 Pa
Average	1.2969e-007 m	4.2338e-005 m/m	3.7462e+006 Pa
Minimum Occurs On	SYS\Solid		
Maximum Occurs On	SYS\Solid		
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [m]	Maximum [m]	Average [m]
1.	0.	2.639e-007	1.2969e-007

FIGURE 9
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation > Image

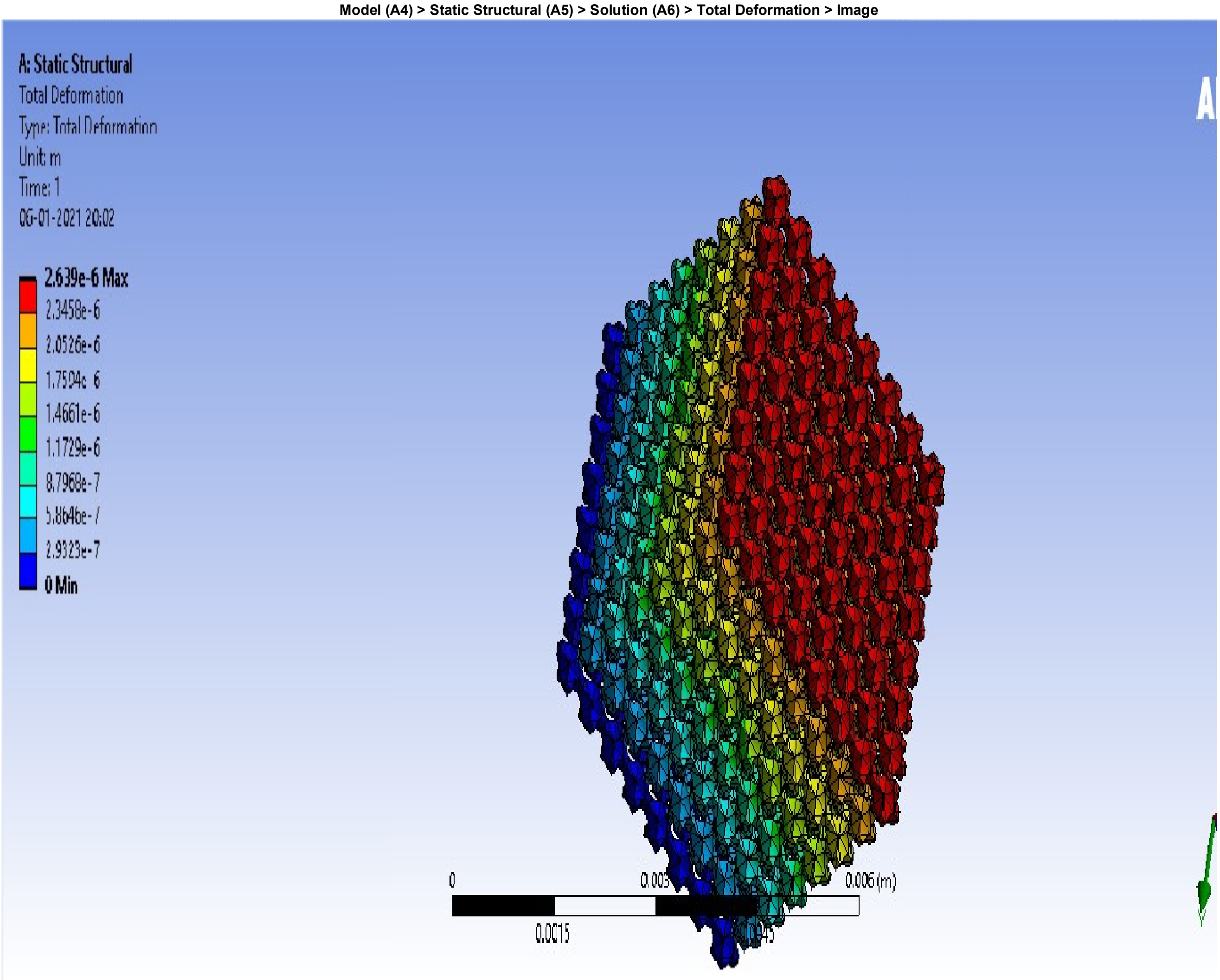


TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Elastic Strain

Time [s]	Minimum [m/m]	Maximum [m/m]	Average [m/m]
1.	7.3698e-007	1.8159e-004	4.2338e-005

FIGURE 11
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Elastic Strain > Image

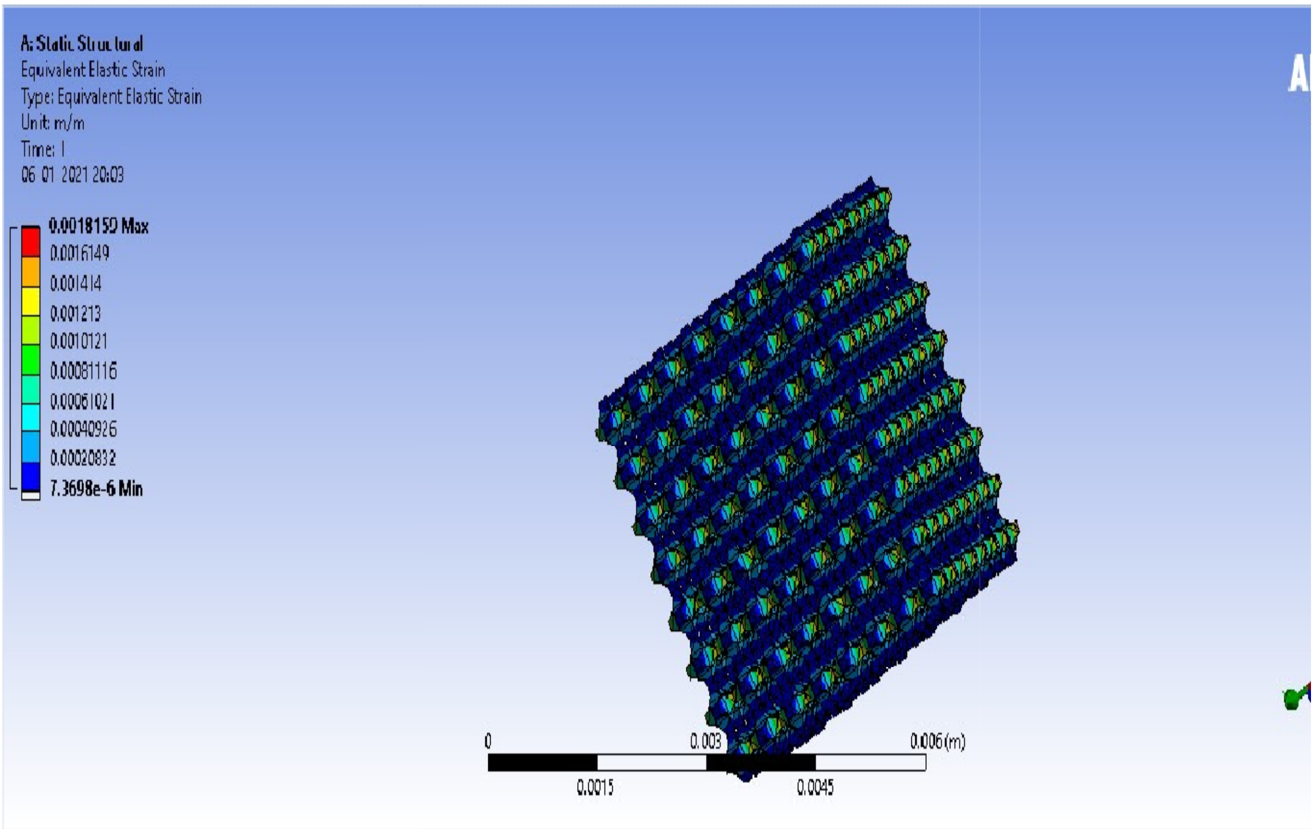
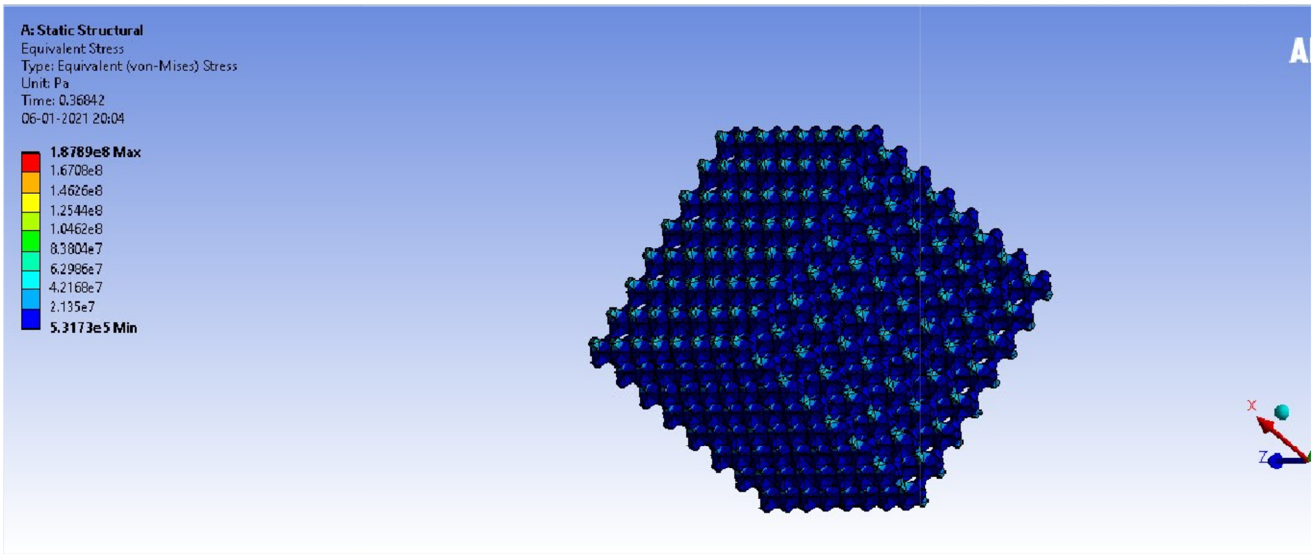


TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1.	53173	1.8789e+007	3.7462e+006

FIGURE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress > Image



Material Data

Titanium Alloy

TABLE 16
Titanium Alloy > Constants

Density	4429 kg m^-3
Coefficient of Thermal Expansion	9.4e-006 C^-1
Specific Heat	522 J kg^-1 C^-1
Thermal Conductivity	21.9 W m^-1 C^-1
Resistivity	1.7e-006 ohm m

TABLE 17
Titanium Alloy > Color

Red	Green	Blue
88	72	117

TABLE 18
Titanium Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa 0

TABLE 19
Titanium Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
1.07e+009

TABLE 20
Titanium Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
1.1e+009

TABLE 21
Titanium Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
1.17e+009

TABLE 22
Titanium Alloy > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22

TABLE 23
Titanium Alloy > Isotropic Elasticity

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa	Temperature C
1.04e+011	0.36	1.2381e+011	3.8235e+010	

TABLE 24
Titanium Alloy > Isotropic Relative Permeability

Relative Permeability
1

References:-

Additively manufactured porous metallic biomaterials

Amir A Zadpoor[1]

Affiliations

•PMID: 31701985

•DOI: 10.1039/c9tb00420c

Additively manufactured functionally graded biodegradable porous zinc

Y Li[1], P Pavanram[2], J Zhou[1], K Lietaert[3], F S L Bobbert[1], Yusuke Kubo[1], M A Leeflang[1], H Jahr[4], A A Zadpoor[1]

Affiliations

•PMID: 31993592

•DOI: 10.1039/c9bm01904a

Additively manufactured functionally graded biodegradable porous zinc

Y Li[1], P Pavanram[2], J Zhou[1], K Lietaert[3], F S L Bobbert[1], Yusuke Kubo[1], M A Leeflang[1], H Jahr[4], A A Zadpoor[1]

Affiliations

•PMID: 31993592

•DOI: 10.1039/c9bm01904a

•] Q. Chen and G. A. Thouas, "**Metallic implant biomaterials**," Materials Science and Engineering R, vol. 87, pp. 1-57, 2015. [4] Y. F. Zheng, X. N. Gu and F. Witte, "Biodegradable metals," Materials Science and Engineering R, vol. 77, pp. 1-34, 2014.

•**Finite Element Modeling and Analysis of Implant Scaffolds** Tarun Bhardwaja , Surya Pratap Singha , Mukul Shukla, Mechanical Engineering Department Motilal Nehru National Institute of Technology Allahabad, India

- **Biomaterials & Scaffolds for tissue engineering Author of article – Fregal J. O'Brien**