DESIGN AND OPTIMIZATION OF 3D PRINTED LATTICE STRUCTURE TO ENHANCE HEAT DISSIPATION

A PROJECT REPORT

Submitted in partial fulfillment for the award of the degree of

Bachelor of Technology

in

Mechanical Engineering

by

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School of Mechanical Engineering

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April, 2022

DECLARATION BY THE CANDIDATE

I hereby declare that the project report entitled "**DESIGN AND OPTIMIZATION OF 3D PRINTED LATTICE STRUCTURE TO ENHANCE HEAT DISSIPATION"** submitted by me to Vellore Institute of Technology University, Vellore in partial fulfillment of the requirement for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering** is a record of bonafide project work carried out by me under the supervision of **Prof. Ranjeet Kumar**. I declare that this report represents my concepts written in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I further declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed. Further I affirm that the contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Place: Vellore
Date: 26/04/2022

SOJITRA DIPTESH MUKESHBHAI

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BONAFIDE CERTIFICATE

This is to certify that the project report entitled "**DESIGN AND OPTIMIZATION OF 3D PRINTED LATTICE STRUCTURE TO ENHANCE HEAT DISSIPATION"** submitted by **SHELADIYA KISHAN KANTIBHAI (18BME0245)** to Vellore Institute of Technology University, Vellore, in partial fulfillment of the requirement for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering** is a record of bonafide work carried out by him/her under my guidance. The project fulfills the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Ranjit

Project Guide **Head of the Department**

Internal Examiner **External Examiner**

ACKNOWLEDGEMENT

I express my profound gratitude to my project Guide Dr. Ranjeet Kumar, Associate Professor Sr Grade 1, School of Mechanical Engineering, VIT, enabling me to complete the project thesis, “DESIGN AND OPTIMIZATION OF 3D PRINTED LATTICE STRUCTURE TO ENHANCE HEAT DISSIPATION”. We would like to thank the School of Mechanical Engineering (SMEC), VIT, Vellore for giving me opportunity to Bachelor in Mechanical Engineering and Project work. I am greatly thankful to my guide Dr. Ranjeet Kumar for his kind support and guidance to successfully complete my project work. I have highly benefited by this project work and have gained a lot of knowledge about various processes and techniques used in project. I would also like to thank our friends who helped us a lot in terms of moral and technical knowledge.

Place : Vellore

Date : 26/04/2022

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Additive manufacturing is expanding its manufacturing capabilities since it is a futuristic and widely used approach to solve complex design problems. It provides flexibilities in manufacturing process. This study focuses on heat dissipation. Structured porous materials show great potential as extended surfaces which is useful in convection operation. According to previous research, a laminar flow of coolant provides better cooling capabilities compare to turbulent flow. Therefore, Cooling can be achieved by flowing coolant into a lattice structure. The aim is to study the behaviour of different lattice structures in convection and develop optimized lattice structure that gives smooth flow of coolant which results into better cooling performance. 3D model will be created to understand the study and various simulation will be done in order to perform optimization of lattice structures with respect to flow analysis, convection and strength.

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HT	Heat Transfer
AM	Additive Manufacturing
DfAM	Design for Additive Manufacturing
SLS	Selective Laser Sintering
CSB	Centre Symmetry Bezier
U.C.	Unit Cell
Temp.	Temperature

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Recently, additive manufacturing provides freedom to create complex geometry. Additive manufacturing is modern method in which a 3D object is created layer by layer adding materials from digital designs. It is a process that can be useful to achieve various unusual physical properties including optical, mechanical, electro-magnetic and thermal properties with artificially designed metamaterials. It can save a lot of materials since it does not have subtractive methods of manufacturing such as machining process and cutting process. Even it can save time for preparing process planning, tooling and machining.

Lattice structure is a part of design for additive manufacturing (DfAM). Lattice structure is included a network of truss including struts or plates interconnected to each other. There are few kinds of lattice structures including foams, honeycombs and similar constructions.

As many studies shown that enhancement of thermal properties of structures. The aim to print different type of lattice structure to compare their properties for cooling capabilities. Based on studies, a thermal metamaterial was designed to act as a thermal insulator as well as a heat exchanger by enforcing coolant flow through the lattice structure. Cooling capacity changes with respect to porosity of structure, materials and design of unit-cell. This study aims to create lattice structure by considering mentioned aspects and more. Optimization of structure will be done by comparing results which is obtained by changing different parameters.

1.2 PROJECT DESCRIPTION

Nowadays, common cooling method is via convection which is by flowing air or coolant near to the heat source. For that system needs cooling channel according to source. However, there are unique ways, which can only be useful because of additive manufacturing as it gives much more freedom to design complex geometry. By using AM, geometries can be created with internal cooling channels or designs with lattice structures. Lattice structure can be useful as path to flow coolant. This study aims to create battery pack with lattice structure for battery thermal management system. Optimized lattice structure will be identified via comparing more than one lattice structures.

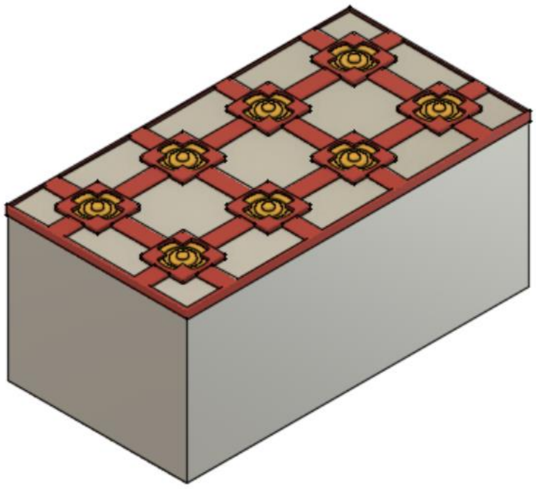


Figure-1.1 Initial battery pack for experiment

1.3 LITERATURE REVIEW & KNOWLEDGE GAINED FROM IT

→ **Comparison between the various fin profile using solid works**

Fins are mainly used to increases the quantity of heat transfer by improving the rate of convection heat transfer. Based on the reviewing different research papers, it can observe that the quantity of heat transferred by the fins is related to the different parameters, which are height of the fins, angle of the fins and the area covered by the fins.

An increase in the length of the fin or reduce in the spacing between the fins increased the thermal performance and temperature, decreasing the heat sink's capacity. Fins, when arranged longitudinally than circular or annular, are much more efficient as it has improved HT and lower back pressure.

Comparison of different design of fins: -

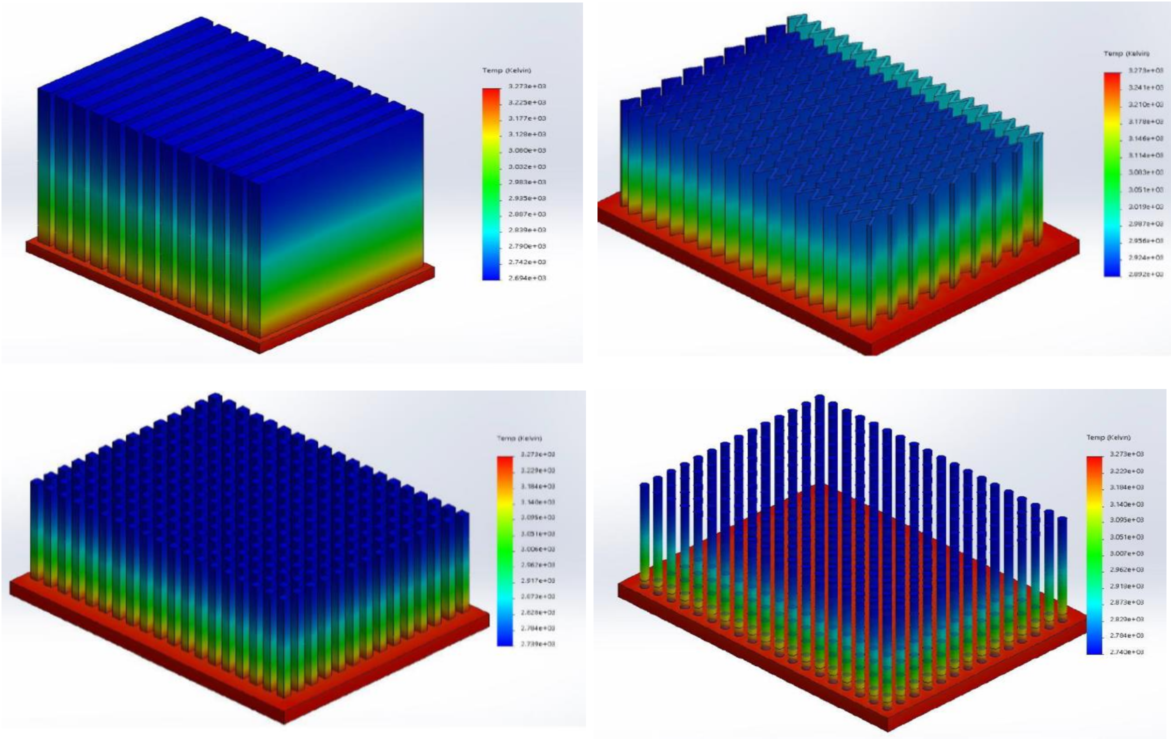


Figure 1.2 Comparison of convection simulation results on different shape of fins. [1]

The temperature difference is maximum for the plain rectangular fin as it covers more area. Therefore, the plain rectangular fin has the highest heat transfer. The rectangular pin fins have a higher transfer in comparison to the cylindrical fins due to the shape as the rectangular pin fin covers more surface area.

→ **Comparison of a lightweight X-type and periodic cellular metallic lattice**

Research paper is about a lightweight X-type lattice produced with the metal sheet folding and presents its thermo-fluidic characteristics in single-phase forced convection. For fixed porosity, thermal conductivity and Reynolds number, the X-type lattice provides overall heat removal capacity up to two times higher than reference periodic cellular materials. The X-type lattice results in a large scale spiral primary flow, which interacts with several secondary flows. However, the X-type lattice causes roughly three times higher pressure drop than reference periodic cellular materials for a given Reynolds number.

Overall, superior heat transfer is achieved by the X-type lattice for a fixed pumping power.

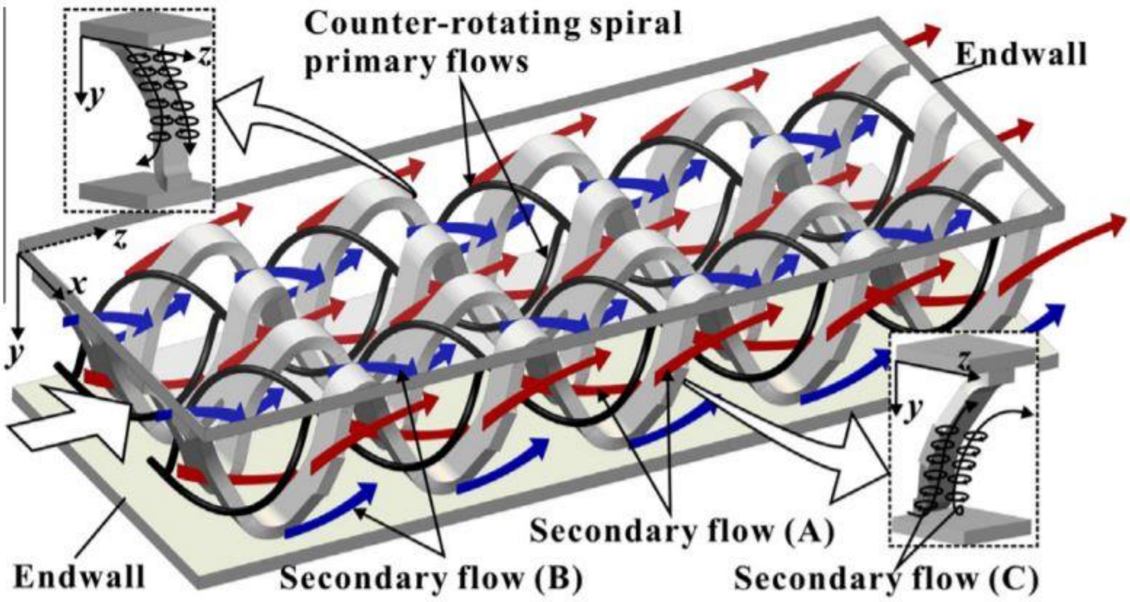


Figure 1.3 Flow direction in given study. [2]

→ **Benefits of 3D printed battery thermal management systems in heat dissipation**

The proposed system takes advantage of 3D-printing technology to embedded heat fins in the cooling channel. Using 3D-printing technology for the manufacture of battery thermal management systems allows for greater complexity and novelty in the design of the coolant flow domains, in order to achieve high heat transfer coefficient by the coolant. Having a high heat transfer coefficient at the coolant side allows the use of lower conductive materials in the body of the battery pack. The results of this research show that the system is less sensitive to the flow rate when the coolant inlet temperature is similar to the environment temperature.

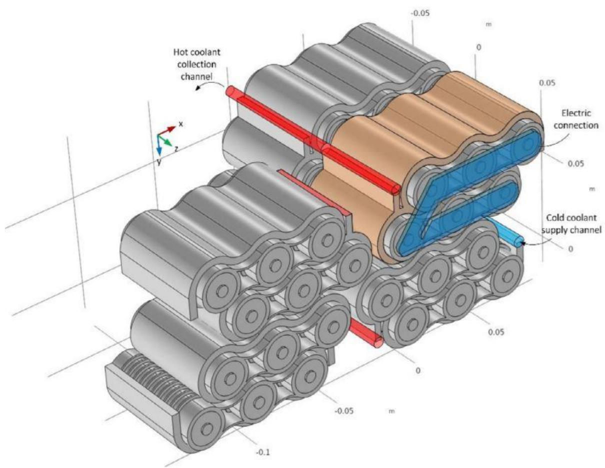


Figure 1.4 Portion of the proposed polymer-based battery pack with a highlighted module that is the building block of the proposed pack. [3]

→ **Design and additive manufacturing of thermal metamaterial with high thermal resistance and cooling capability**

A lattice-based thermal metamaterial was developed to obtain high thermal resistance and cooling capability. By insulating the lattice structure. It is possible to obtain high thermal resistance property. As picture depict, flowing coolant through lattice structure provide better cooling capabilities compare to simple coolant channels. Result of cooling experiment: Study shows that lattice structure indicates better cooling as compare to solid.

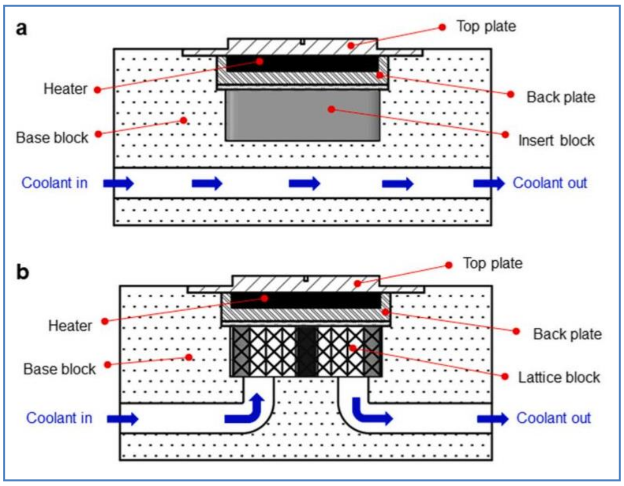


Figure 1.5 (a) with a solid insert and a straight channel. (b) with a lattice insert and curved channels.[4]

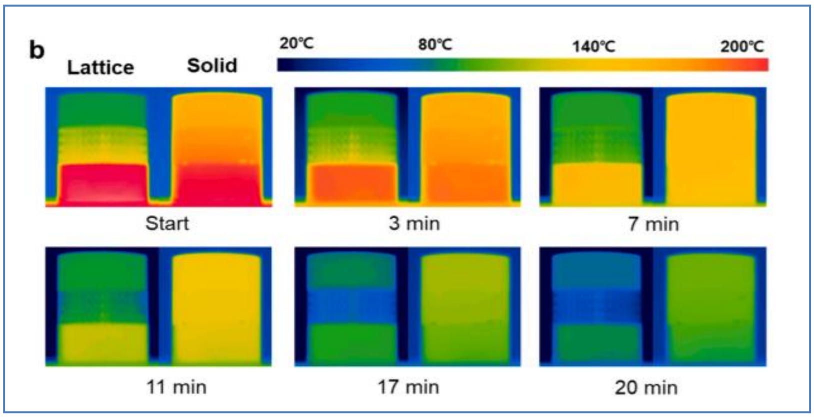


Figure 1.6 Stepwise temperature distributions during the cooling stage. [4]

→ **Structure impact on heat dissipation property:**

Structured porous materials show great potential as extended surfaces in heat-exchange applications which also require design for load-bearing capability.

Some Research indicates that by changing porosity or structural design, highly enhanced heat dissipation can be achieved. the effect of porosity is studied by changing the ligament diameter. Past experiments used numerical approach to compare the results. A method was demonstrated for utilizing the simulation results, which assume perfect surface efficiency, to predict the performance of LFMs with non-ideal surface efficiency, based on the conduction resistance of the ligaments.

The result shown that the thermal behavior of the ligaments closely matches that of cylindrical fins in cross flow and that this analogy can be used to calculate the overall surface efficiency.

→ **Effects of porosity and Coolant flow:**

Another research had indicated that surface efficiency is directly proportional to surface area of the inner structure which intersects with the coolant fluid flow (air flow). which provides great foundation for enhanced dissipation system.

The research was to observe the effects of fluid flow and porosity on heat liberation rate. Different porosities (70% to 95%) and fluid flow rate were tested under same circumstance were tested and the results indicated that the heat dissipation was highest at the porosity of 95% and it was linearly proportional to the porosity and it varied highly depending on the coolant flow type.

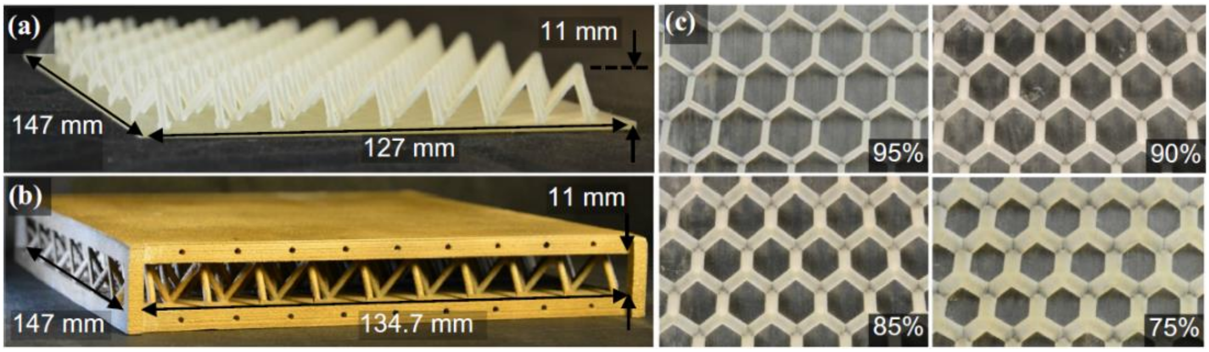


Figure 1.7 Photographs of 95% porosity tetrahedral (a) polymer and (b) metal LFM samples used for hydraulic experiments and thermal experiments, respectively; (c) a top-down view of the LFM structure is shown for the samples of differing porosity used for hydraulic testing. [5]

1.4 GAPS IN LITERATURE

- Most of work done so far by only analytical and computational methods. There is few researches done by experimentation.
- Additive manufacturing can provide freedom to create structure with in-built channels.
- Cooling capacity depends on porosity and surface area. Additive manufacturing can allow fabricating with more porosity and surface area within constant volume compare to conventional method.

1.5 OBJECTIVE OF THE PROJECT

Since, many factors are highly dependent on the lattice structure, by considering these factors, it is possible to create an optimum lattice structure which has all the desired properties and provides enhanced heat liberation. The objective of this study is to create and compare a highly porous structure with the balance of high strength and low density and the air channels should be in such a way that it minimises the flow resistance to maximise the heat dissipation rate. Computational analysis will be done to perform design optimization.

CHAPTER 2

METHODOLOGY AND EXPERIMENTAL WORK

2.1 METHODOLOGY

- Create unit-cell by using rhino grasshopper software to identify many features such as porosity, and surface area.
- Cad modelling is done with software such as Fusion 360, and Solidworks.
- Material selection with respect to literature review.
- In order to measure and improve strength, we did structural simulation on Fusion360.
- To understand heat transfer analysis, Ansys fluent is used.
- Optimization in design will happened accordingly

2.2 UNIT-CELL & DESIGN

2.2.1 PARAMETERS

Here, we have created 4 types of unit-cells by Rhino Grasshopper software. Parameters such as porosity, surface area and strut radius are mentioned in table-1.

Sr No.	Name of U.C.	Strut radius	Porosity	Effective surface area (mm^2)
1	Centre Symmetric Bezier	1.2mm	83.30	315.78
2	Dodecahedron	1.2mm	84.02	412.03
3	BC star tetrahedron	1.2mm	85.45	435.30
4	Tricut structure	1.2mm	75.98	340.41

Table-1. Parameters of unit cells

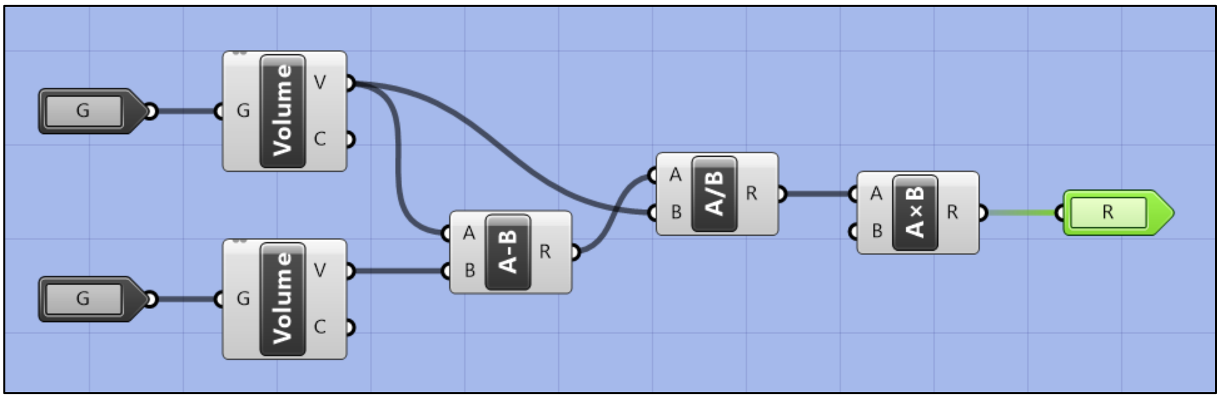
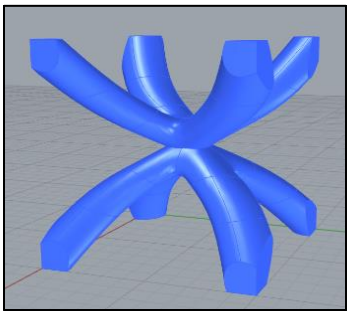


Figure-2.1 Porosity Cluster in Grasshopper

2.2.2 ALGORITHM & IMAGES

This section depicts images and algorithms of unit cells which are designed by using rhino grasshopper software.

- Centre Symmetric Bezier



Centre symmetric: - Initially, 6 points curve was created for higher accuracy and to find these points, Bezier curve function is used, where points are (0,0,0), (1,0.633,2), (2,1.205,4), (3,1.778,6), (4,2.530,8), (5, 5,10). Next, create a circular array with number of arrays 4 in 360° direction. Then, multipipe function use to design pipes, which radius is 1.2 mm. Scale function used in z direction with 0.5 friction value. Lastly, mirror operation was done to create symmetric in z-axis.

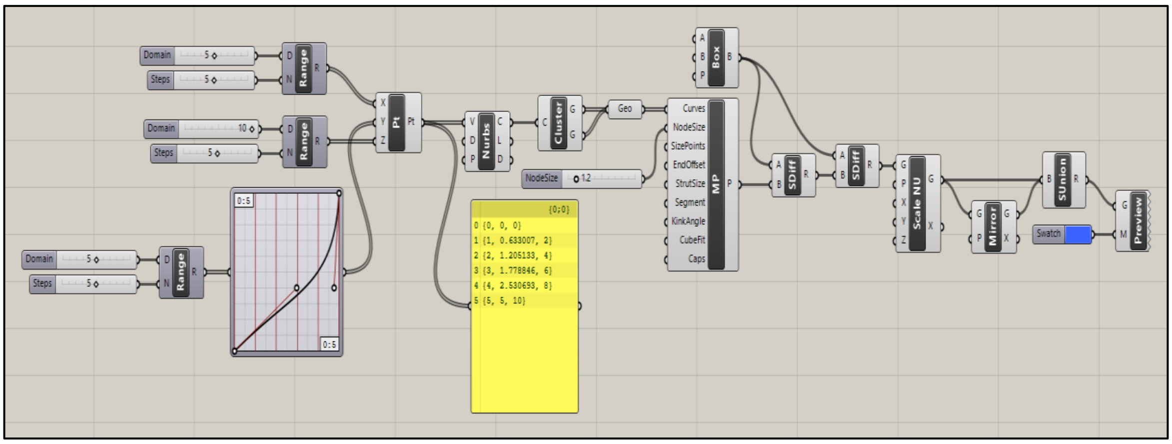
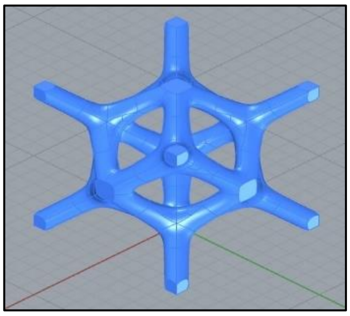


Figure-2.2 Grasshopper Algorithm and Unit cell of CSB

- Dodecahedron



Dodecahedron: - To begin with, in grasshopper, feature of unit-cell was used to create all curves of this cell. Afterwards, with the help of multipipe function, all pipes were made, where its radius was set as 1.2 mm.

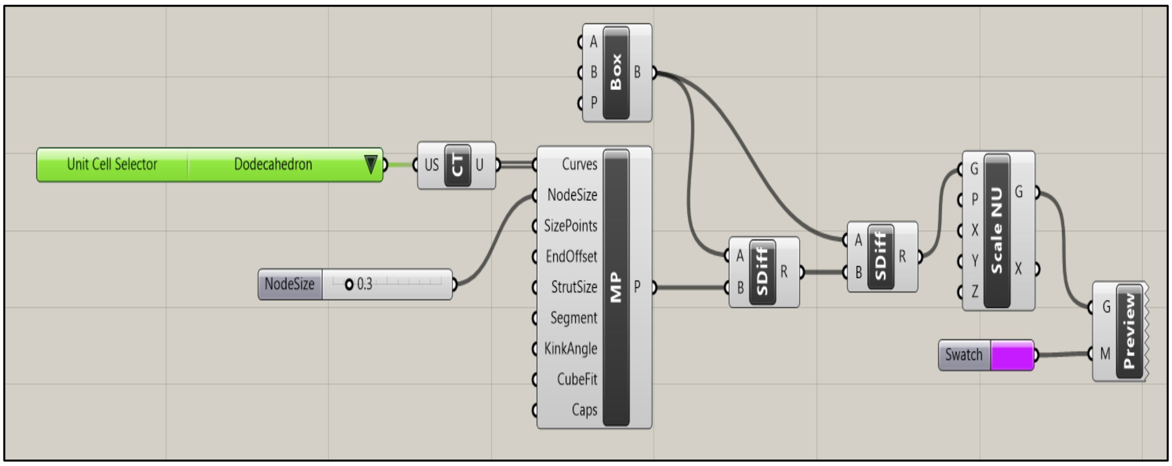
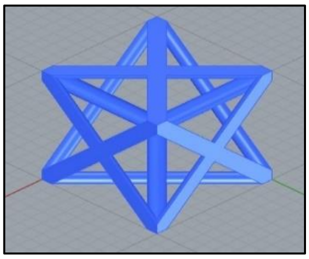


Figure-2.3 Grasshopper Algorithm and Unit cell of Dodecahedron

- BC star tetrahedron



BC star tetrahedron: - At starting point, two diagonal lines were created in face and body of the cube each. Then circle with 1.2 mm radius extrude in direction of line for both lines. Consequently, with the help of mirror and rotate tools, all the faces and body diagonals were created in cube.

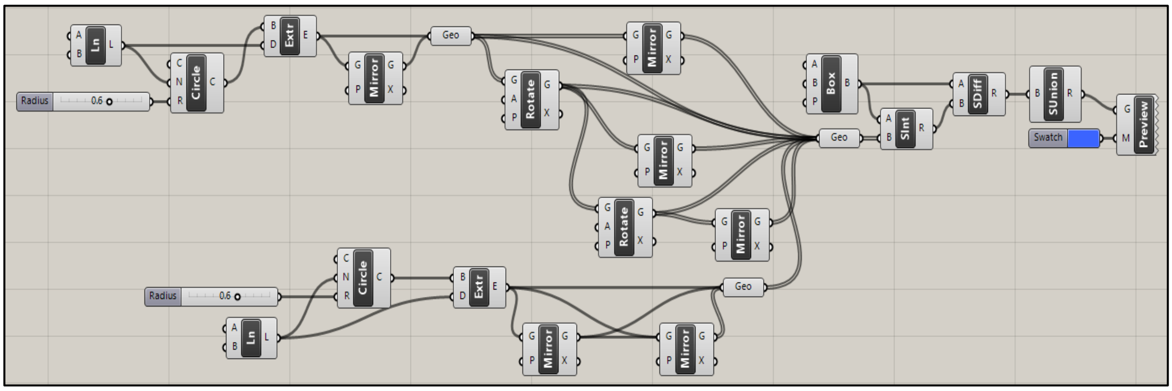
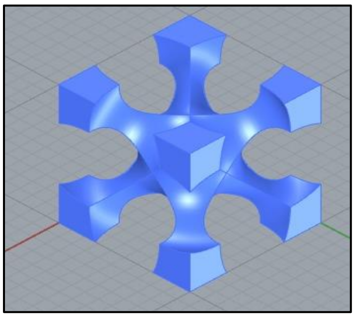


Figure-2.4 Grasshopper Algorithm and Unit cell of BC star tetrahedron

- Tricut structure



Tricut structure: - At first, 3 circular pipes were created in all three plans XY, YZ, ZX. Subsequently, it was extruded as a cut from $1cm^3$ box.

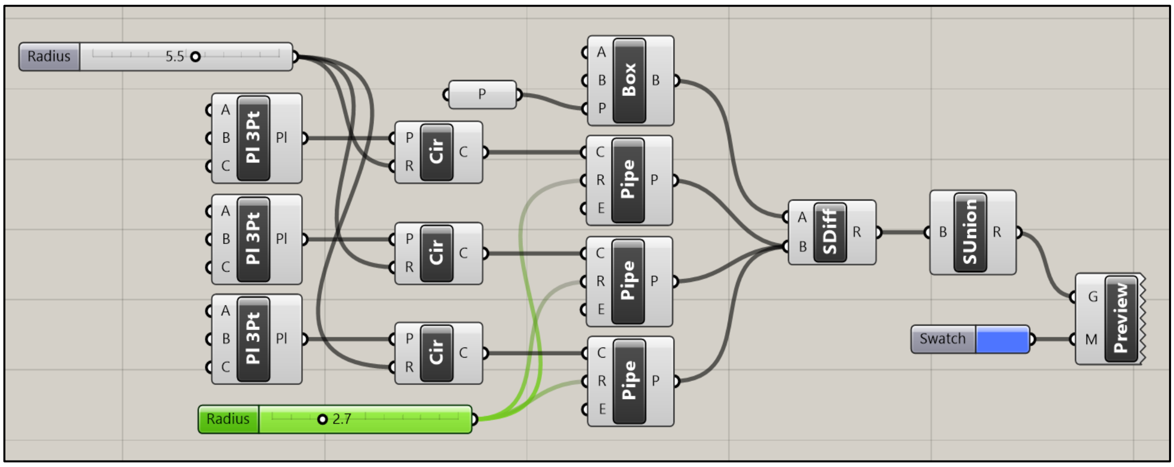


Figure-2.5 Grasshopper Algorithm and Unit cell of Tricut structure

2.3 CAD DESIGN & DIMENSIONS

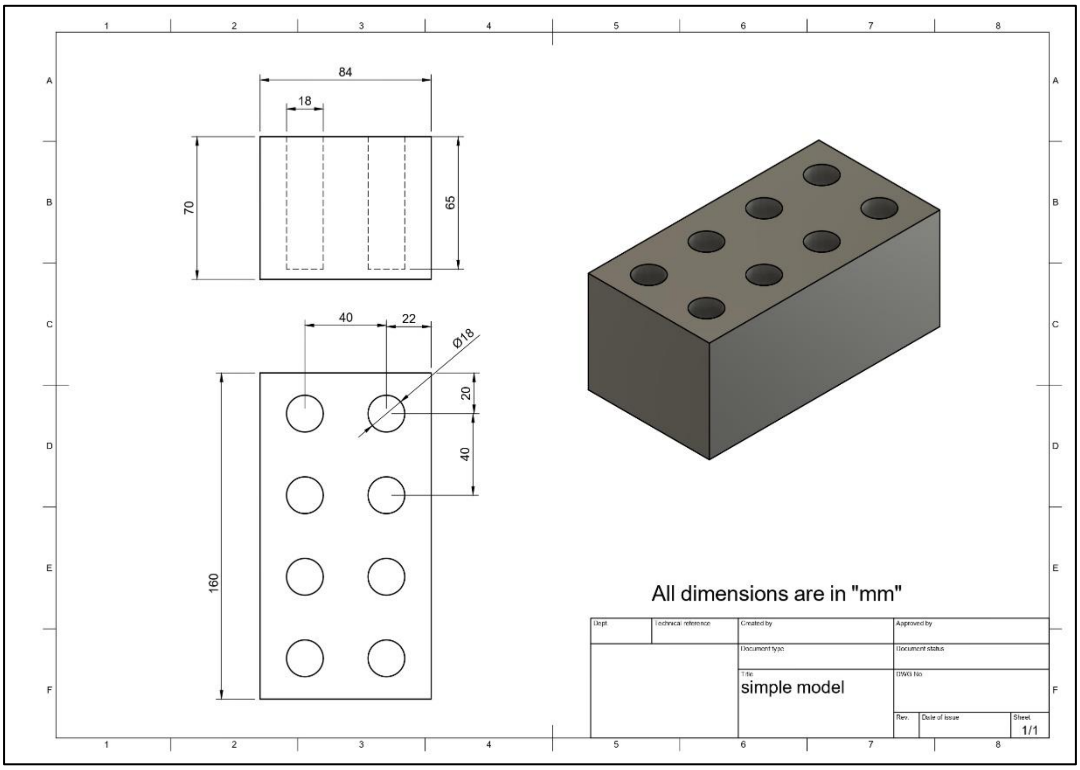


Figure-2.6 Basic CAD design with dimensions

- **Centre Symmetric Bezier**

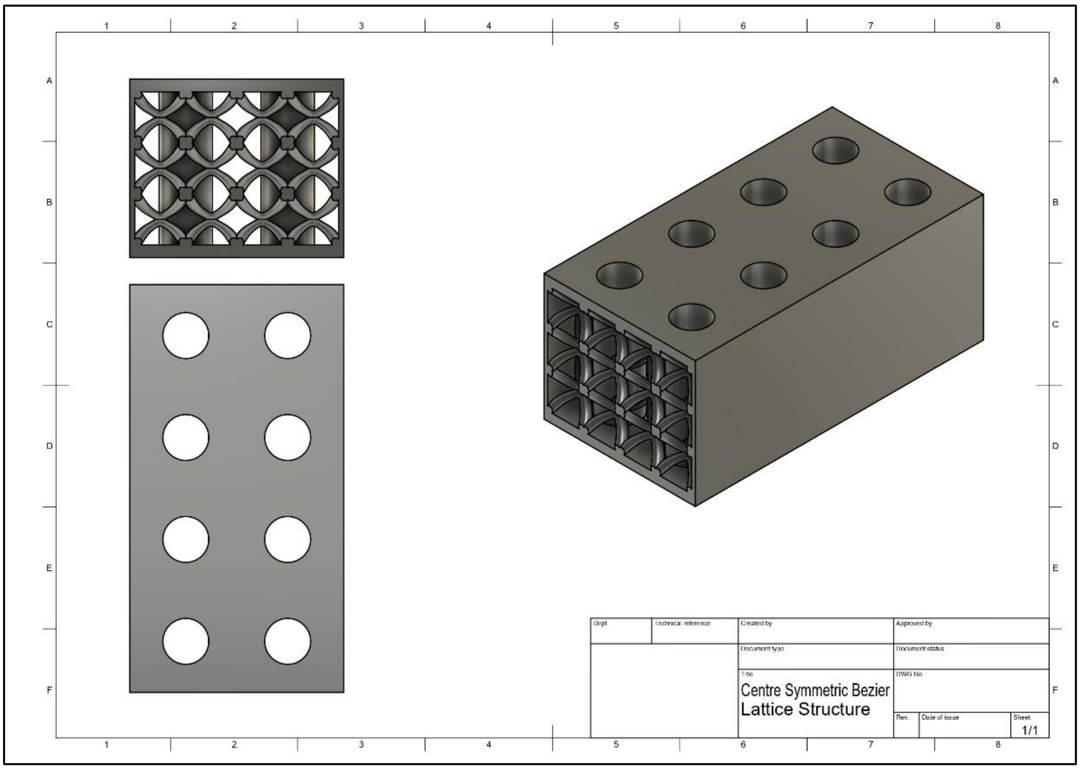


Figure-2.7 CSB lattice structure CAD design

- **Dodecahedron**

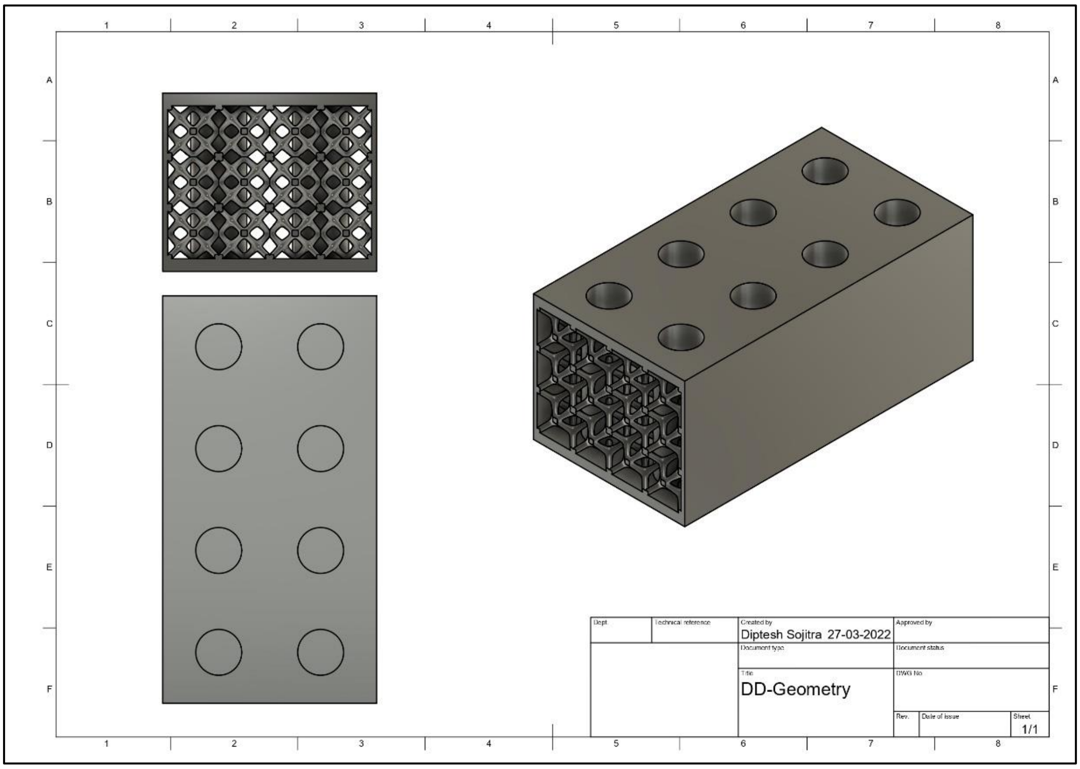
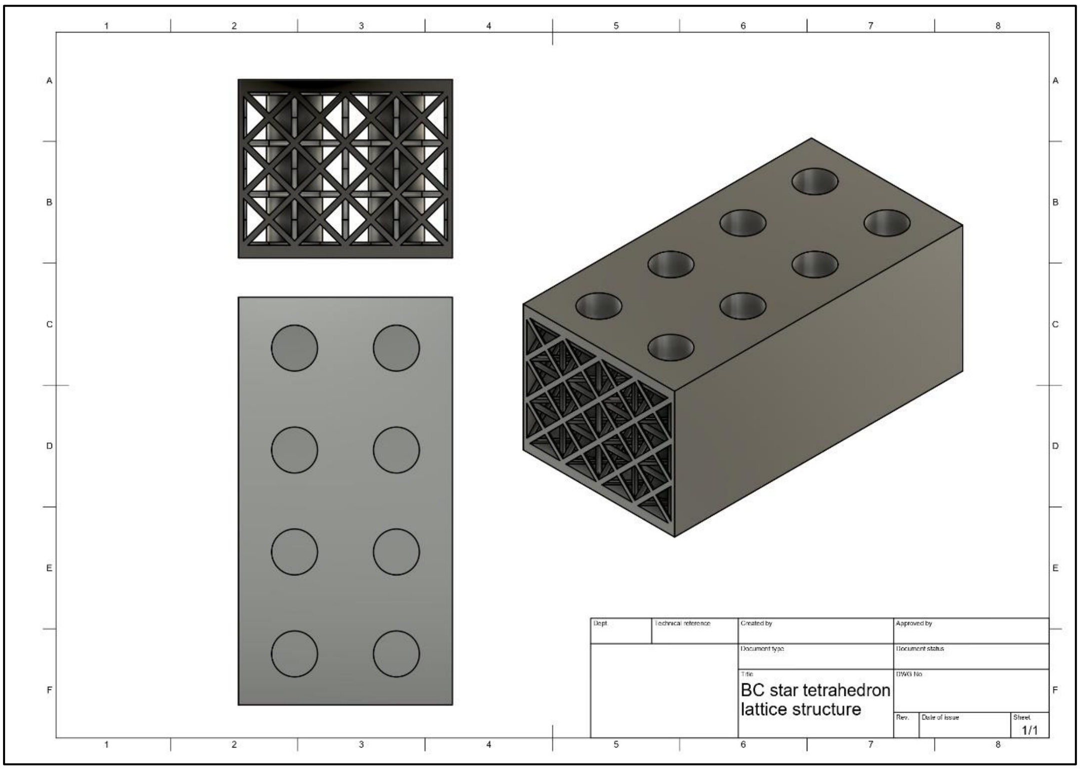


Figure-2.8 Dodecahedron lattice structure CAD design

- **BC star tetrahedron**



lFigure-2.9 BC star tetrahedron lattice structure CAD design

- **Tricut structure**

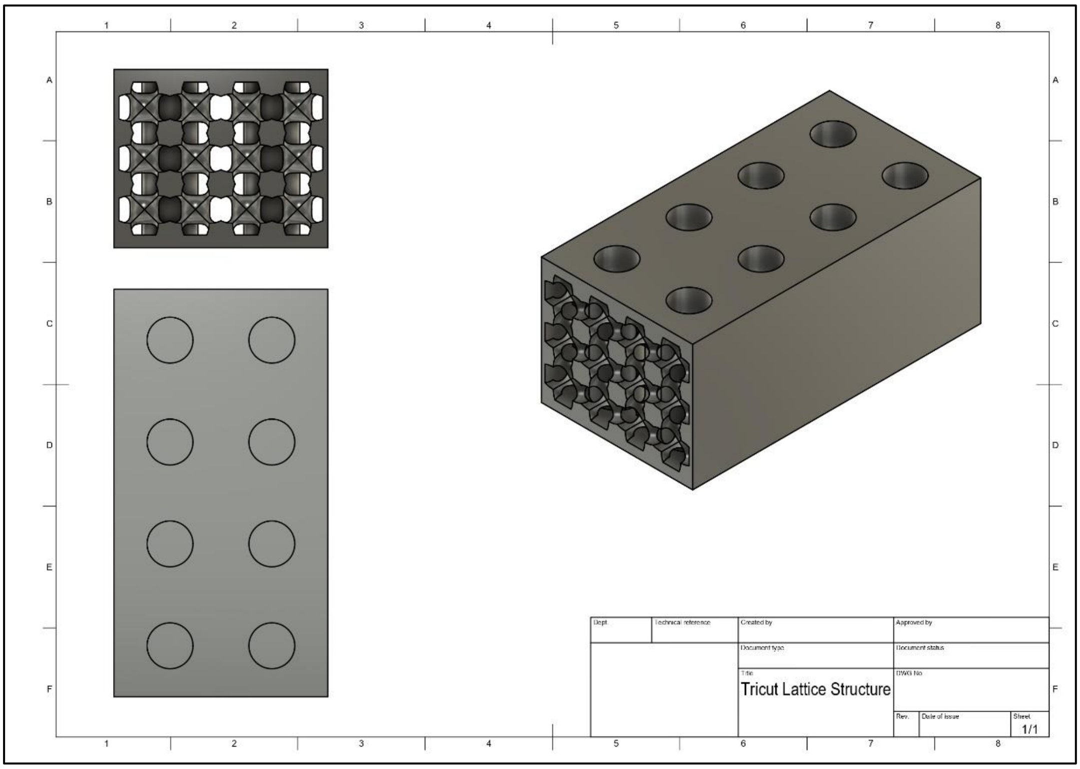


Figure-2.10 Tricut lattice structure CAD design

2.4 MATERIAL SELECTION

Nowadays, majority of metal 3D printing is manufactured using Selective Laser Sintering (SLS). Plenty of materials namely Stainless steel, Tool steel, Titanium, Inconel 625, Cast iron, Nickel, Cobalt, Aluminium, are most compatible in SLS. Among these materials, aluminium has highest heat co-efficient which more suitable factor for our study. As aluminium has several alloys from which aluminium-1050 has highest heat co-efficient (229 W/ m K).

SR NO.	Material	Heat Coefficient (W / m K)	Young's Modulus (GPa)
1	Stainless Steel	25	190
2	Tool Steel	65	210
3	Titanium	17	106
4	Inconel 625	15	205.8
5	Iron (Cast)	55	41
6	Nickel	92	207
7	Cobalt	69	205
8	Aluminium (1050)	222	71

Table-2. Material properties

Sr. No	Aluminium alloy	Thermal Conductivity (W / m K)
1	1050	222
2	6060	166
3	6061	152
4	6063	201

Table-3. Material properties of aluminium alloys

2.5 STRUCTURAL ANALYSIS

This stress analysis is done on each geometry by applying 40N force distribution on upper face as shown in figure-12. As lattice structure is significant factor for heat dissipation so that it is important to assure that structure does not deforms under normal load condition. Resultant data of structural analysis is given in the table.4 and stress distribution amongst all four-design mentioned from figure-13 to figure-16.

Sr No.	Name of U.C.	Stress (MPa)	Strain	Displacement (mm)
1	Centre Symmetric Bezier	0.09797	2.201×10^{-6}	5.255×10^{-5}
2	Dodecahedron	0.1409	3.444×10^{-6}	4.427×10^{-5}
3	BC star tetrahedron	0.1045	2.406×10^{-6}	3.782×10^{-5}
4	Tricut structure	0.1134	2.442×10^{-6}	3.043×10^{-5}

Table-4. Result of stress simulation

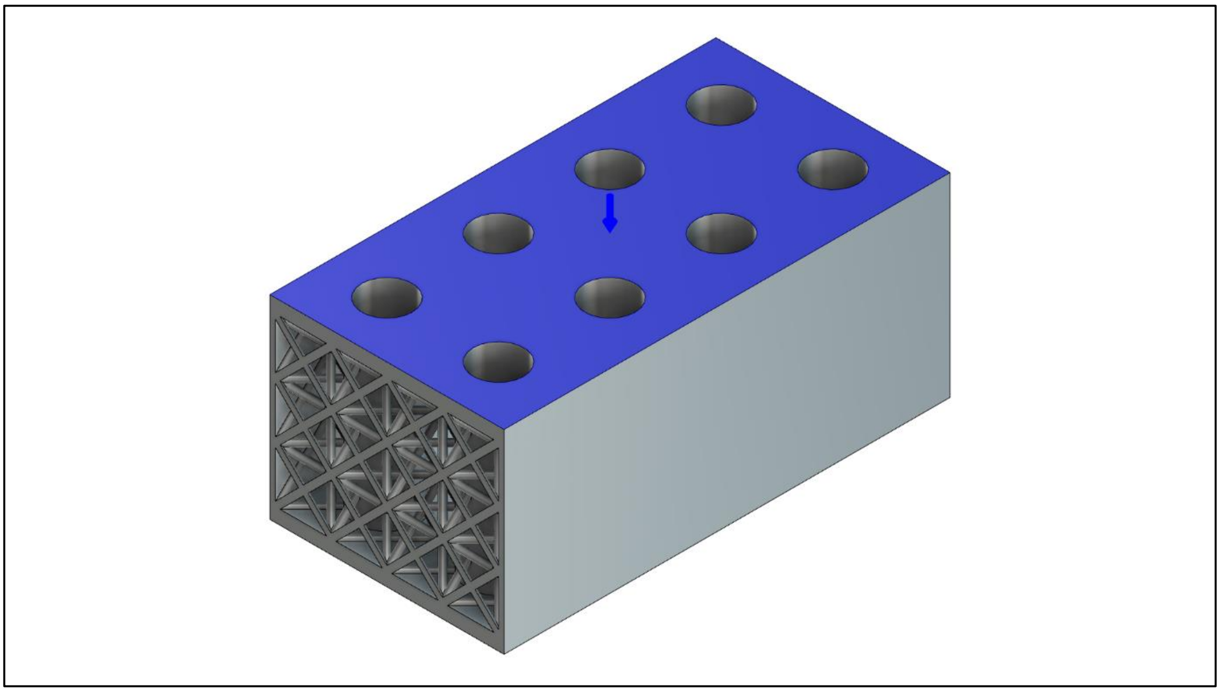


Figure-2.11 Load bearing surface during each stress simulation

- Centre Symmetric Bezier

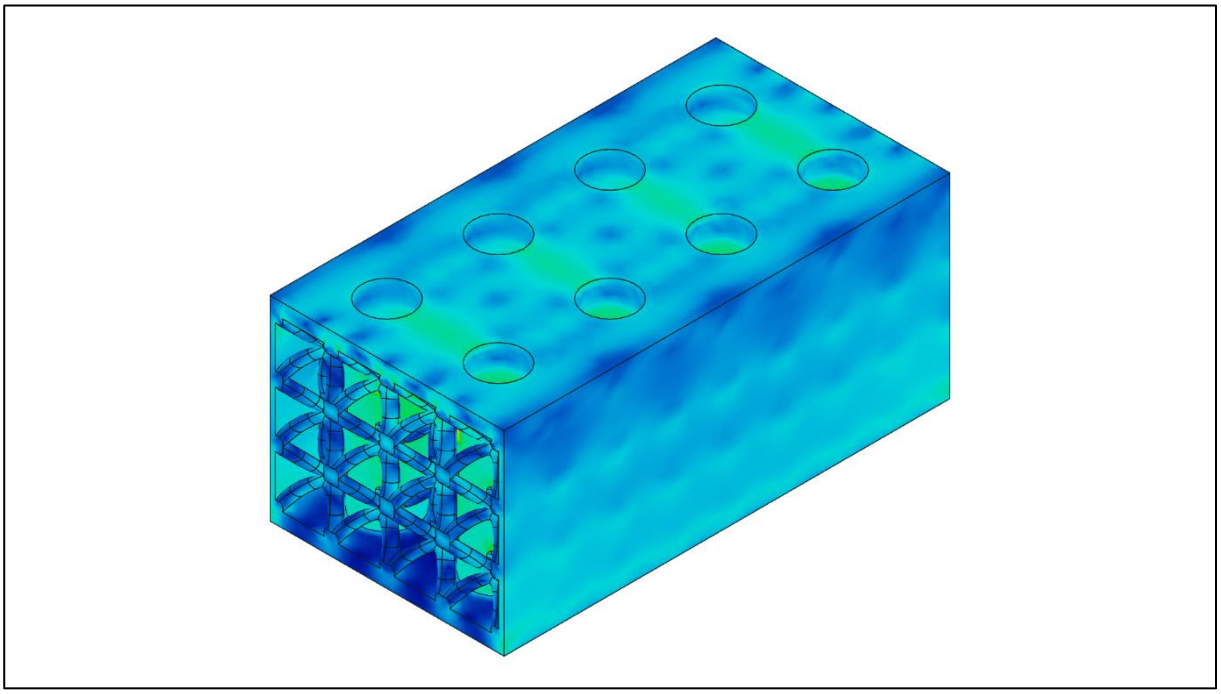


Figure-2.12 Von mises stress distribution in CSB

- Dodecahedron

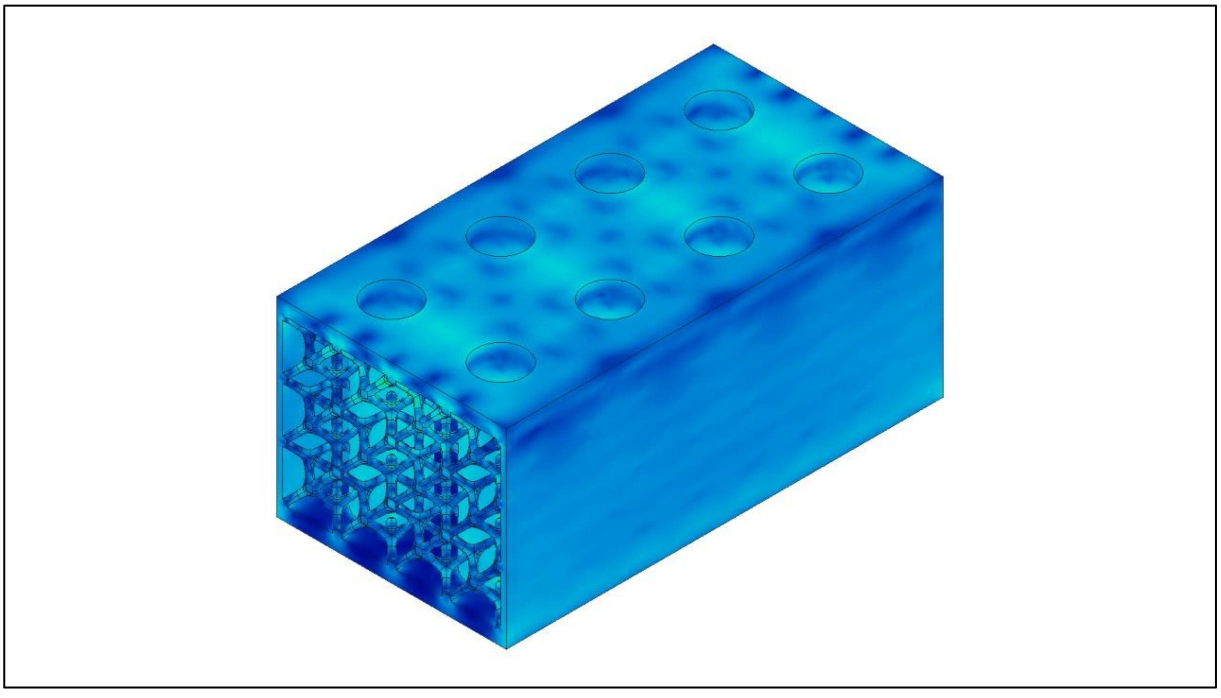


Figure-2.13 Von mises stress distribution in Dodecahedron

- BC star tetrahedron

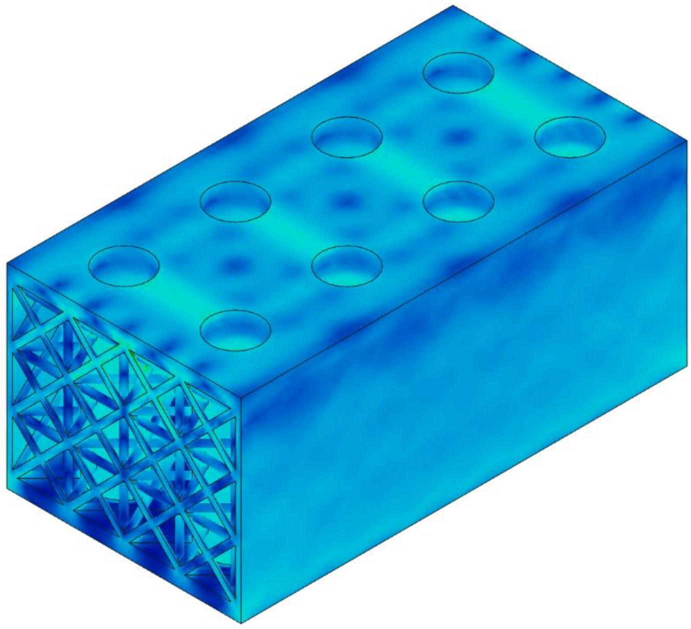


Figure-2.14 Von mises stress distribution in BC star tetrahedron

- Tricut structure

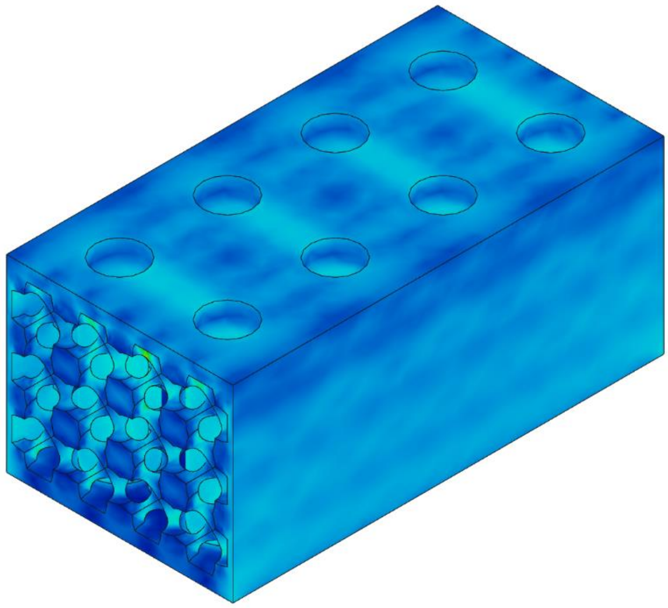


Figure-2.15 Von mises stress distribution in Tricut structure

2.6 HEAT TRANSFER SIMULATION

2.6.1 DESCRIPTION AND BOUNDARY CONDITIONS

This study of heat transfer is done with ANSYS fluent to find temperature distribution and heat transfer rate through the various geometry which is mentioned in geometry section. There is total four structures with different internal lattice structures. We are comparing various design. Therefore, to achieve fair comparison in this study, boundary condition and physical properties should be equal during analysis. Figure.17 below shows inlet and outlet in geometry during analysis. In this study, Air is used as coolant which passes through the geometry. Furthermore, Aluminium-1050 is assigned as material to geometry during all four studies. Figure.19 illustrate both fluid and geometry domain. Here, hot surfaces which act as heat sources during studies are mentioned in Figure.18 Properties of both material which is used in studies mentioned in below table.5. All boundary conditions, such as inlet velocity of air, outlet pressure, temperature of hot surfaces, are indicated in table.6.

Material	Thermal conductivity (W/ m k)	Density (kg/m^3)	Specific heat (J/ kg K)
Air	0.0242	1.225	1006.4
Aluminium-1050	222	2710	871

Table.5 - Properties of materials which is used in analysis

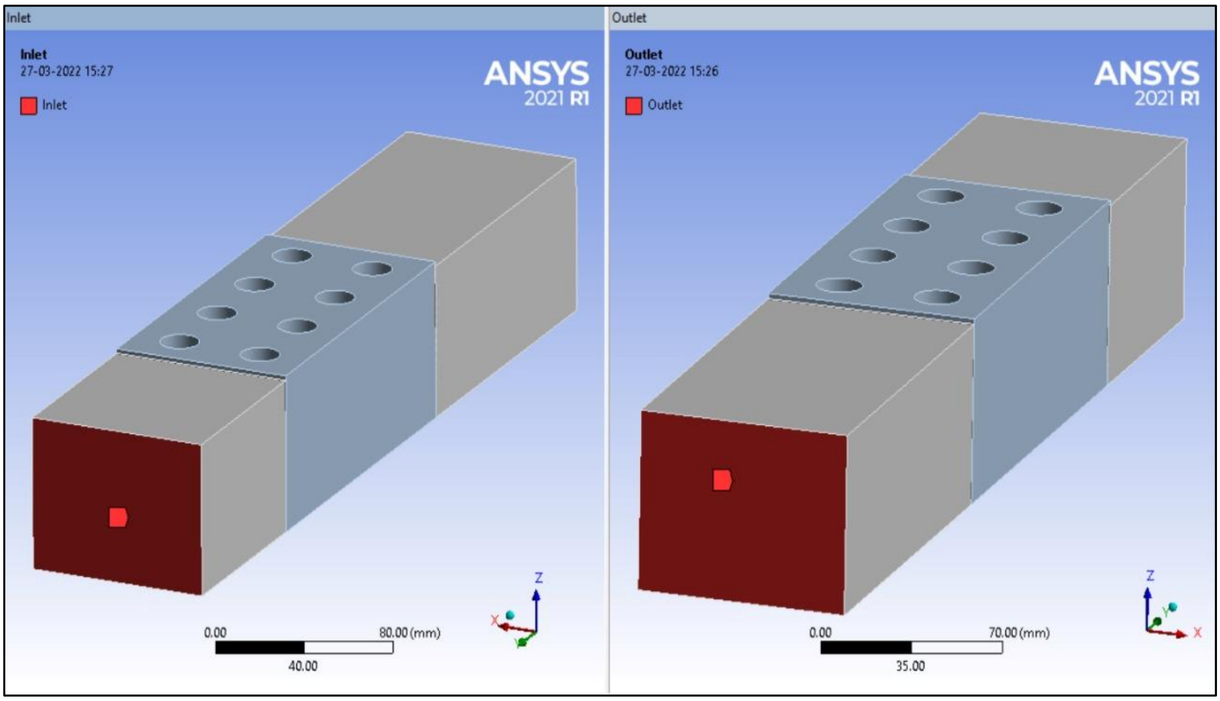


Figure-2.16 Inlet and Outlet during heat transfer study in Ansys Fluent.

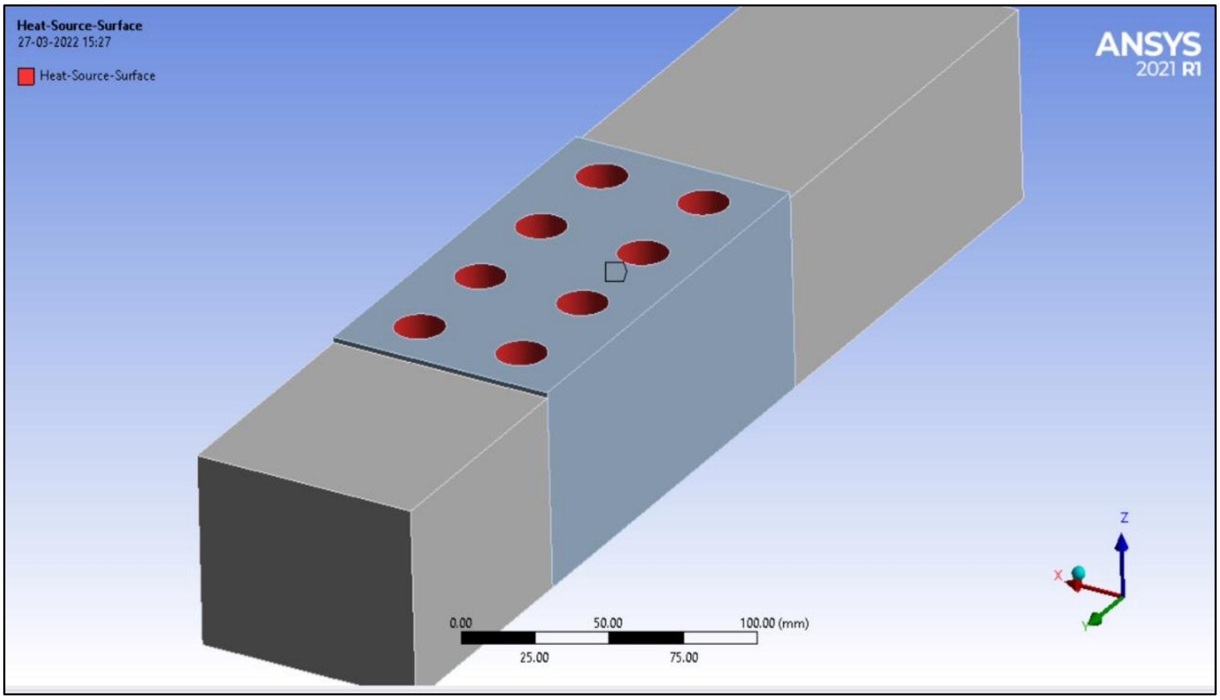


Figure-2.17 Heat source surface area

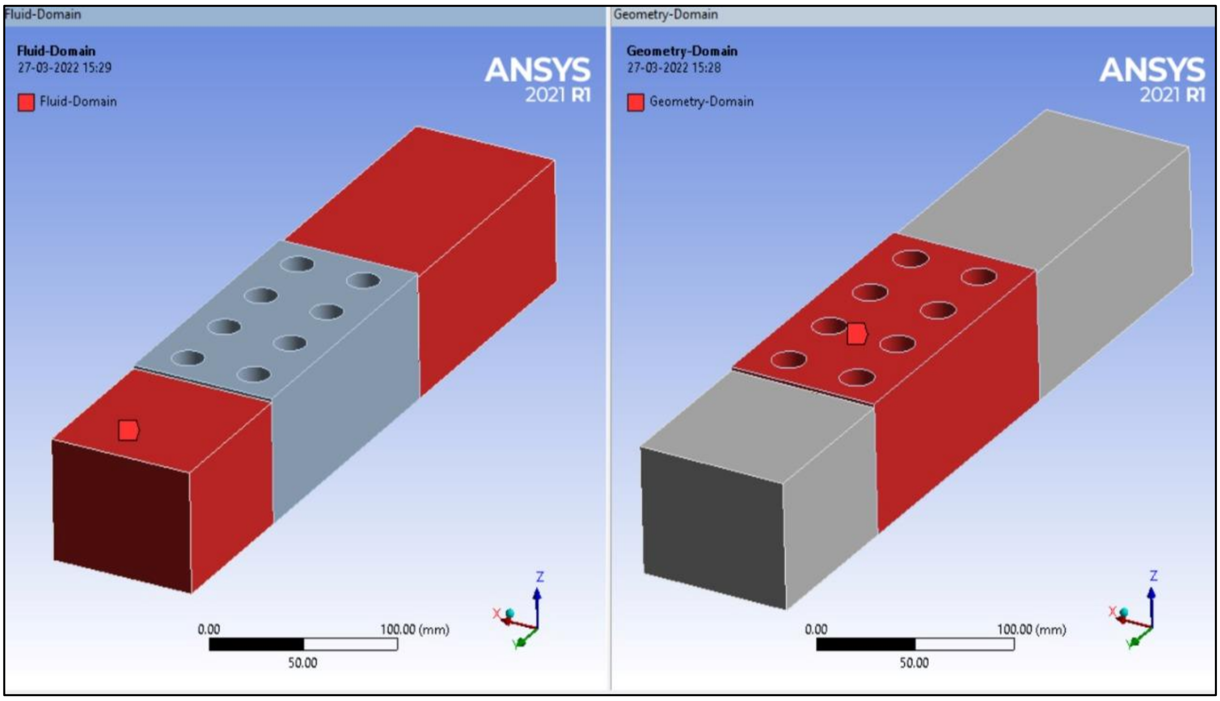


Figure-2.18 Fluid domain (left) & Geometry domain (right)

Boundary	Value	Type
Inlet	15m/s @300K	Velocity-inlet
Outlet	Atmospheric pressure (1.013 bar)	Pressure-outlet
Hot surface (Heat source)	343K	Wall

Table.6 - Boundary condition in simulation

In general, lithium-ion batteries can be charged in an environment up to 45°C and discharged in temperatures as high as 75°C. According to given data, heat transfer study is proposed at 70 °C for analysis. Inlet velocity is taken as 54kmph (15 m/s) @ 300K which is average vehicle speed with ambient temperature.

2.6.2 TEMPERATURE DISTRIBUTION

Here, temperature distribution contours are represented from Figure.20 to Figure.27. These contours are showing temperature distribution at middle plane in geometry in top (XY) & right (YZ) planes.

- **Centre Symmetric Bezier (CSB):**

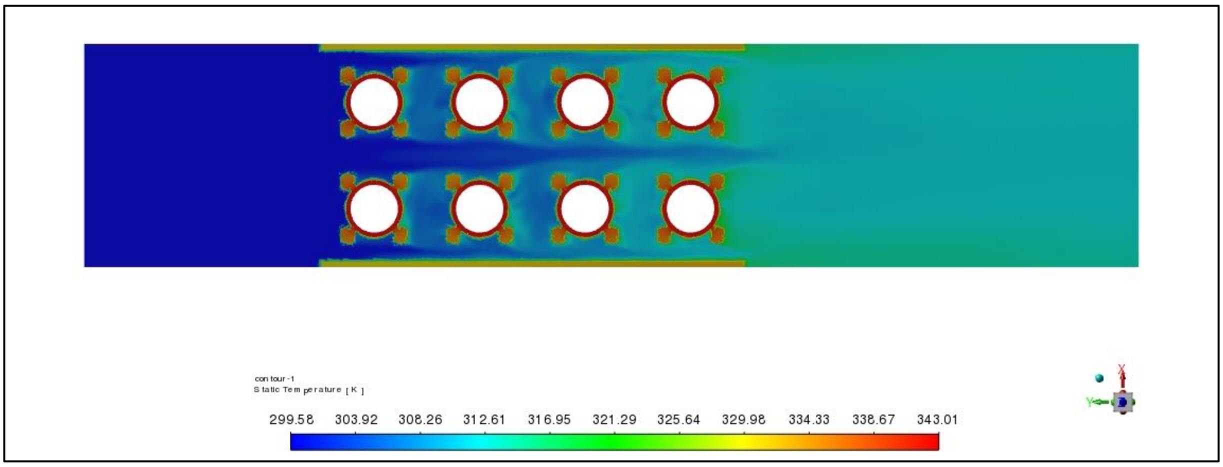


Figure-2.19 Top view of Temp. Contour (CSB)

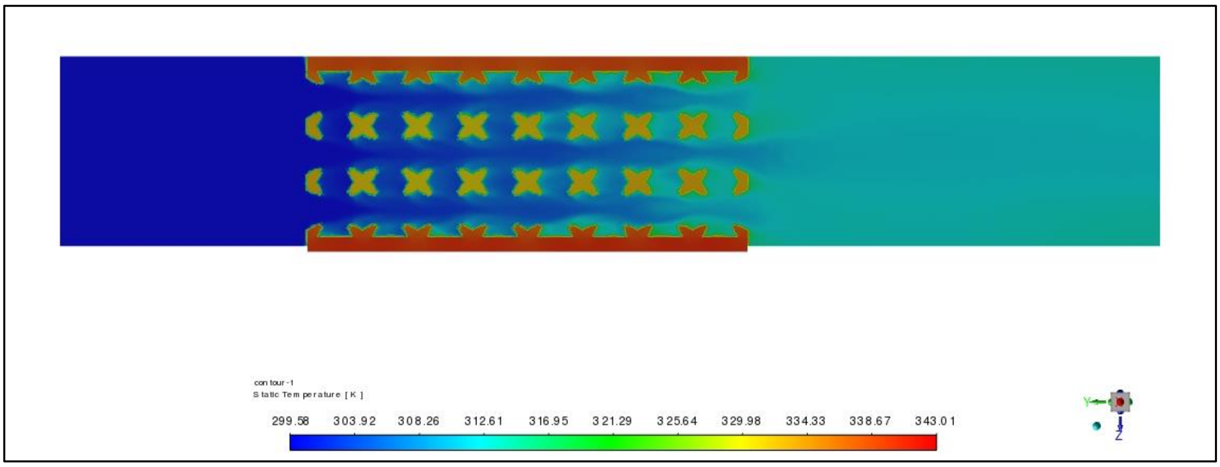


Figure-2.20 Front view of Temp. Contour (CSB)

- **Dodecahedron**

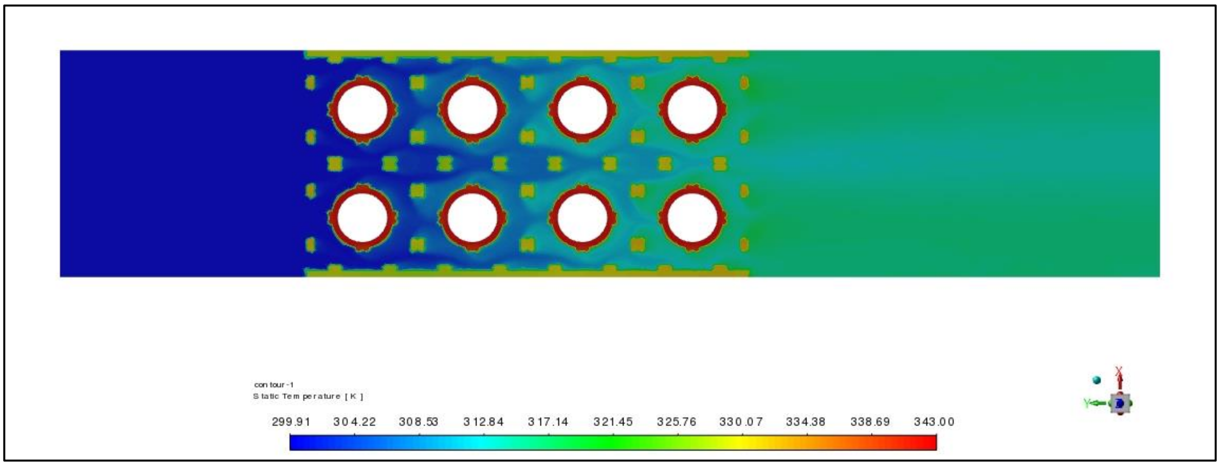


Figure-2.21 Top view of Temp. Contour (Dodecahedron)

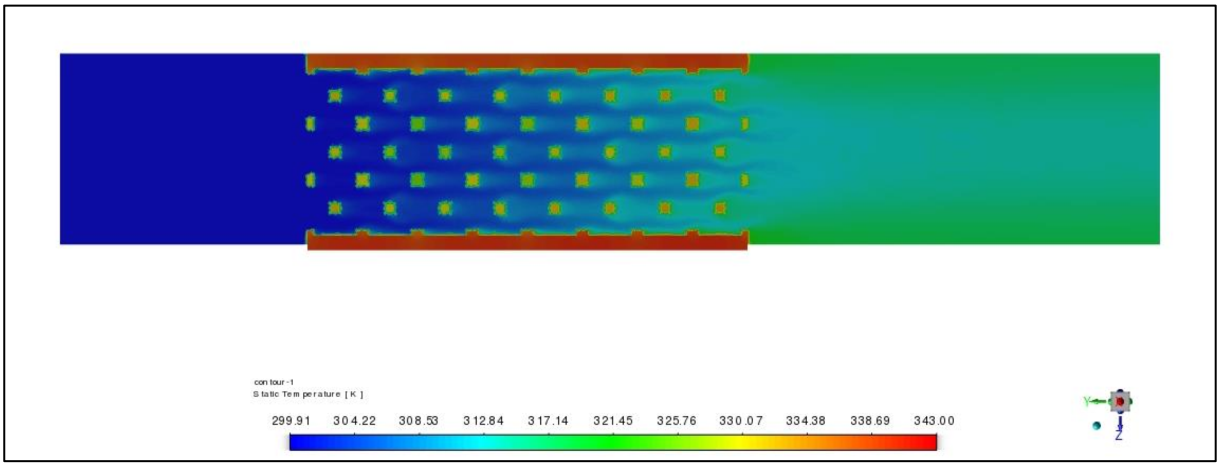


Figure-2.22 Front view of Temp. Contour (Dodecahedron)

- **BC star tetrahedron**

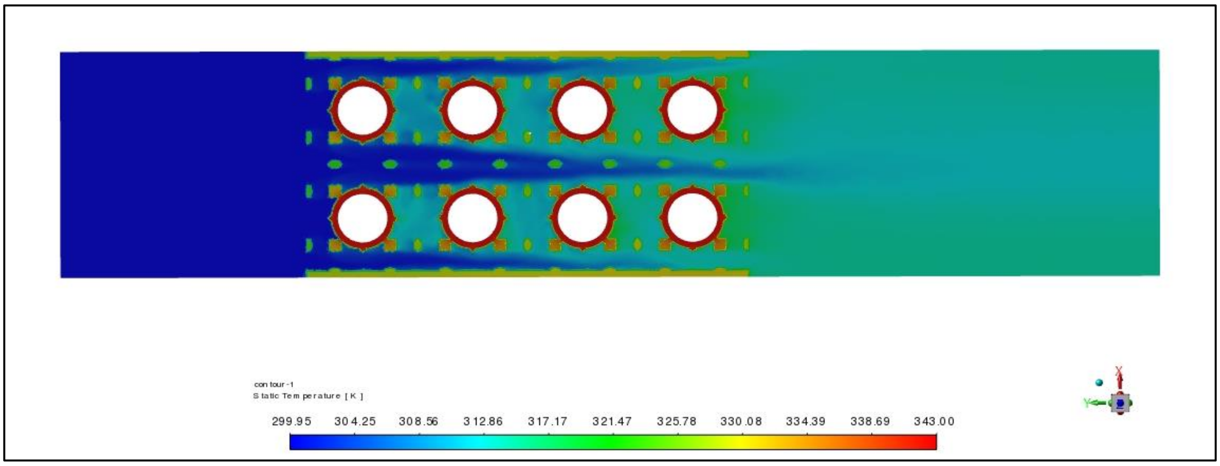


Figure-2.23 Top view of Temp. Contour (BC star tetrahedron)

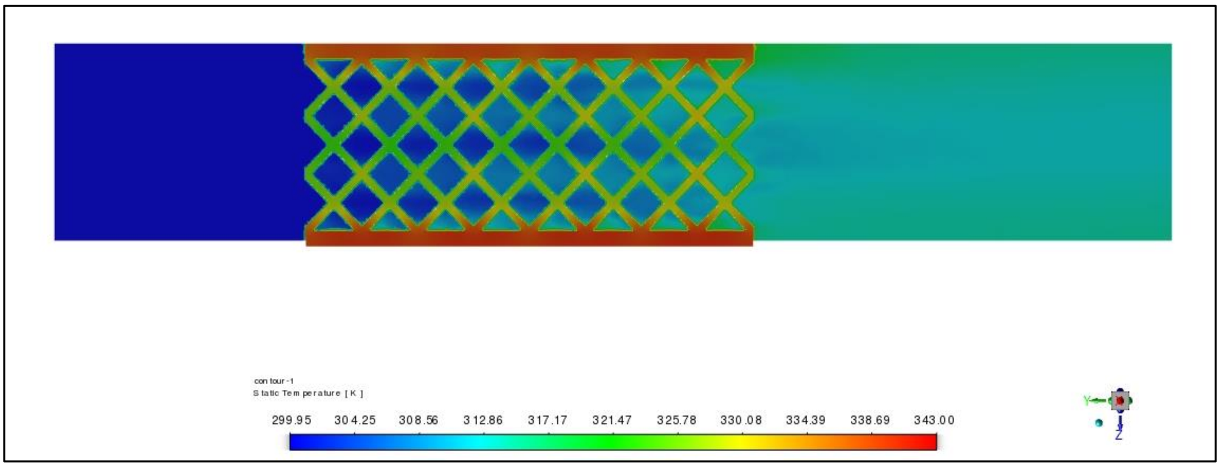


Figure-2.24 Front view of Temp. Contour (BC star tetrahedron)

- **Tricut structure**

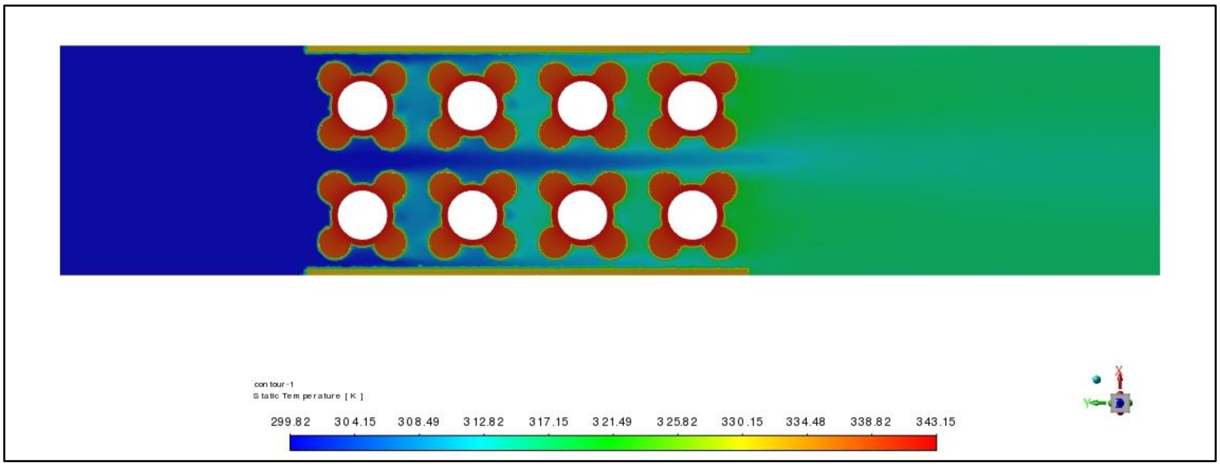


Figure-2.25 Top view of Temp. Contour (Tricut structure)

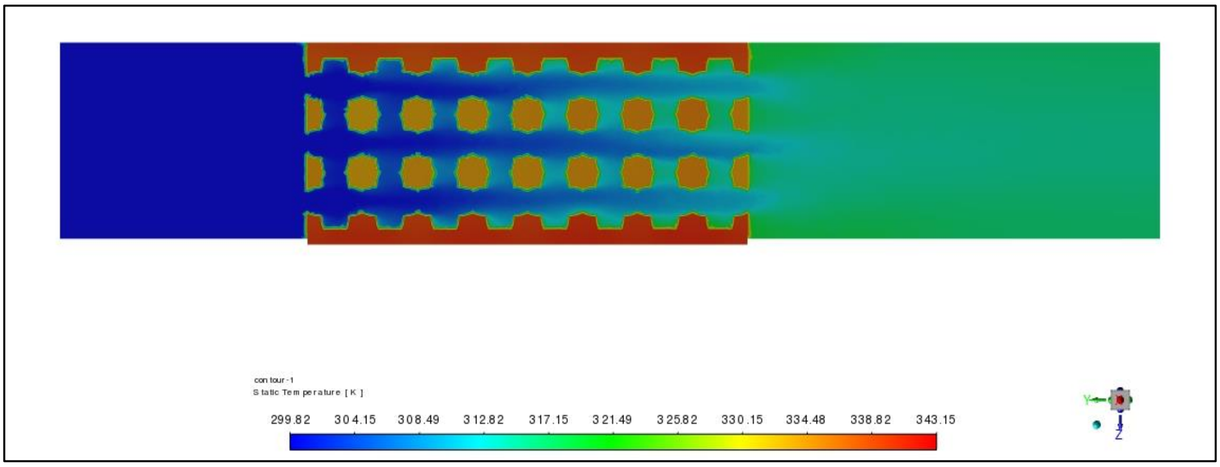


Figure-2.26 Front view of Temp. Contour (Tricut structure)

2.6.3 HEAT TRANSFER CALCULATION

For these studies, it is assumed that entire system is thermally isolated. Coolant air is passing in Y-direction through the structures with initial temperature of 300K at inlet. For outlet temperature, we have taken average temperature at outlet plane. As per energy conversation law, heat dissipated by structure is equivalent to the heat gain by the air in this system which can be calculated by the given formula;

$$Q=\dot{m}\times c\times\Delta T$$

$\dot{m}$ = mass flow rate (kg/s)

c = specific heat capacity (J / kg. K)

ΔT = temperature difference between outlet and inlet (K)

From all four analysis, inlet and outlet temperatures are obtained that is described in table.7.

SR No.	Name	Inlet Temp. (K)	Outlet Temp. (K)	Heat Transfer (J/s)
1	Centre Symmetric Bezier	300	314.3	1487.09
2	Dodecahedron	300	317.25	1795.20
3	BC star tetrahedron	300	315.45	1627.76
4	Tricut structure	300	318.17	1888.80

Table.7 – Observed data from ANSYS simulation

2.6.4 REYNOLDS NUMBER CALCULATION

$$R_e = \frac{\rho V L}{\mu}$$

ρ = Fluid density = 1.225 kg/m^3

V = Fluid velocity (m/s)

μ = Fluid viscosity (kg/ m. s)

L = characteristic linear dimension = 4*(Area)/(Perimeter) = 75.15 x 10^{-3} m

SR No.	Name	Velocity(m/s) @Outlet plane	Reynolds Number @Outlet plane
1	Centre Symmetric Bezier	19.15	98520
2	Dodecahedron	18.86	97028
3	BC star tetrahedron	19.21	98829
4	Tricut structure	22.99	118275

Table.8 – Reynolds numbers @Outlet plane

2.6.5 VELOCITY CONTOURS

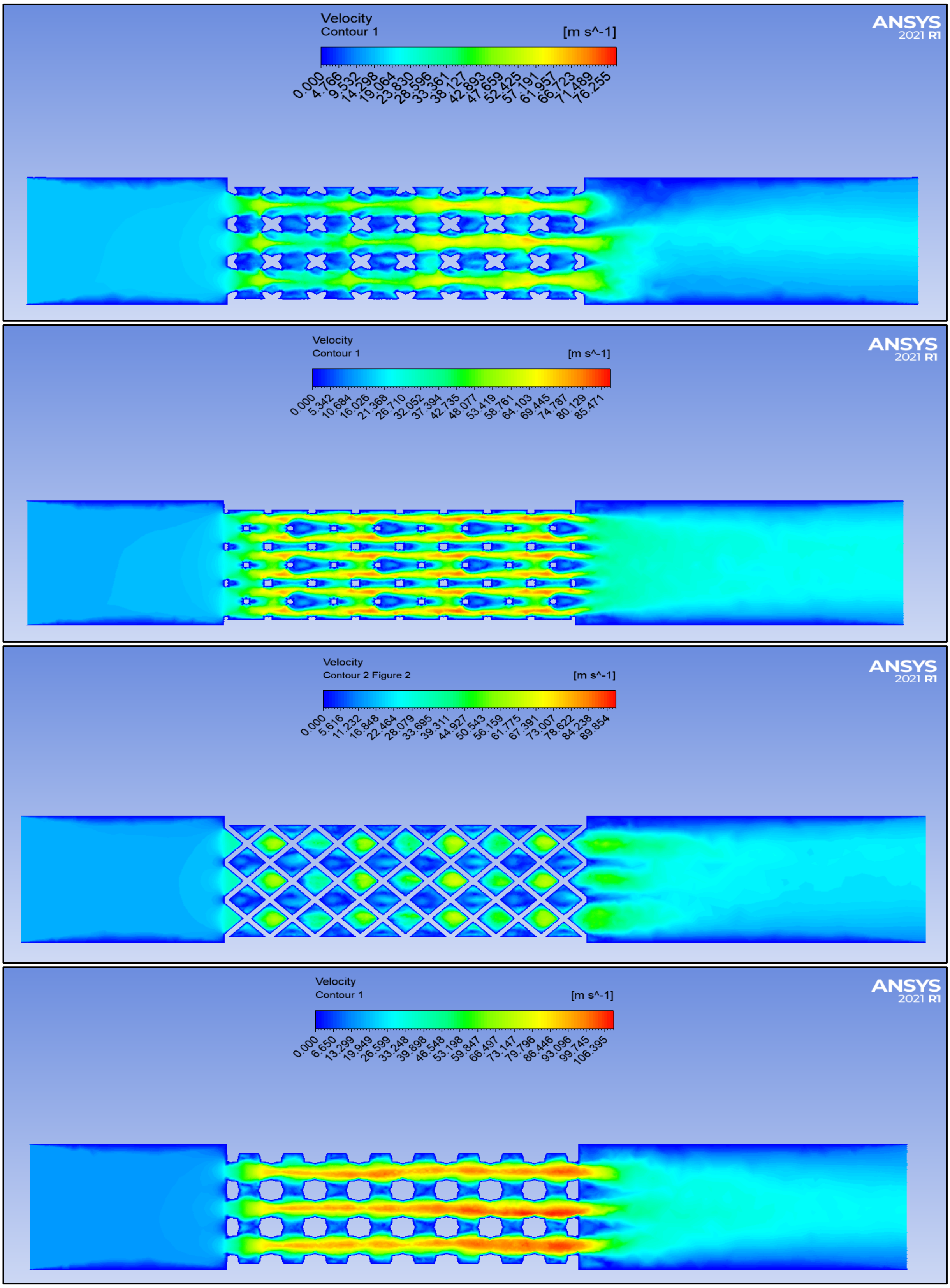


Figure-2.27 Velocity contours a) CSB b) Dodecahedron c) BC star tetrahedron d) Tricut structures

CHAPTER 3

RESULTS AND DISCUSSION

After carefully studying simulation data and results, it depicts that Tricut lattice structure has Higher heat transfer value compared to others. The outlet temperature is observed at value of 318.17K. The heat transfer value of this structure obtained which is 1888.80 J/s. The heat transfer amount of Tricut structure is 27.01%, 5.21% and 16.03% higher than CSB, Dodecahedron and BC star tetrahedron respectively. Additionally, Tricut lattice structure show better heat transfer compare to CSB because it has higher effective surface area. While having low porosity and effective surface area compare to BC star tetrahedron and Dodecahedron, Tricut shows better heat transfer because it has smooth and less obstacles path for fluid to pass which leads to less turbulent. Under turbulent flow conditions, the increase in heat transfer rate is more significant than that under laminar flow conditions [8]. The turbulent effects become a dominant factor over secondary flow at higher Reynolds number. Therefore, with maximum turbulence, Tricut structure achieves highest heat transfer compare to others.

CHAPTER 4

CONCLUSIONS

In conclusion, there are four type of lattice geometry created by using rhino grasshopper and Fusion 360 followed by stress simulation which is done by also Fusion 360 software. While we have used Ansys mechanical and fluent for the operations like pre-processing, meshing, and post processing of heat transfer simulation. There are four types of lattice structures have been used for analysis study namely Centre Symmetric Bezier, Dodecahedron, BC star tetrahedron and Tricut structure. Among them, simulations depict that tricut structure has better heat dissipation compare to others with following reasons such as higher turbulence, better surface area and porosity.

4.1 SCOPE FOR FUTURE WORK

This study will be helpful to get insight of heat dissipation through the lattice geometry and may lead towards innovative solution for cooling problems. As additive manufacturing is providing freedom of design and there are so many various types of lattice structure. To perform on analysis and experimental work on lattice structure can be helpful to achieve optimum lattice for better heat dissipation according to its applications. Area of applications like battery management system, Heat sink, Heat exchanger, where this type of solution may bring better performance.

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PLAGIARISM REPORT

DESIGN AND OPTIMIZATION OF 3D PRINTED LATTICE STRUCTURE TO ENHANCE HEAT DISSIPATION

by Diptesh Sojitra

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Individual Contribution	Rutvik (18BME0059)	Kishan (18BME0245)	Diptesh (18BME2056)
Literature Review	✓	✓	✓
Design (Rhino & Fusion 360)	-	✓	✓
Material Selection	✓	-	-
Structural Analysis (Fusion 360)	✓	✓	-
Heat Transfer Analysis (Ansys Fluent)	-	-	✓
Final Documentation	✓	✓	✓

Table.9 – Individual Contribution in the project

Verified by

(Signature of the Guide)

PROGRAMME OUTCOMES ATTAINED

Programme Outcomes	Attainment Level
PO_1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	LOW
PO_2: Problem Analysis: Identity, formulate, review research literature, and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.	HIGH
PO_3: Design/Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations.	NA
PO_4: Conduct Investigations of Complex Problems: Use research-based knowledge and research methods including design of experiments, analysis, and interpretation of data, and synthesis of the information to provide valid conclusions for complex problems	HIGH
PO_5: Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.	HIGH
PO_6: The Engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	NA

PO_7: Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.	NA
PO_8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	MEDIUM
PO_9: Individual and Teamwork: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.	HIGH
PO_10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	HIGH
PO_11: Project Management and Finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	NA
PO_12: Life-long Learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.	NA

Verified by

Ranjit

(Signature of the Guide)