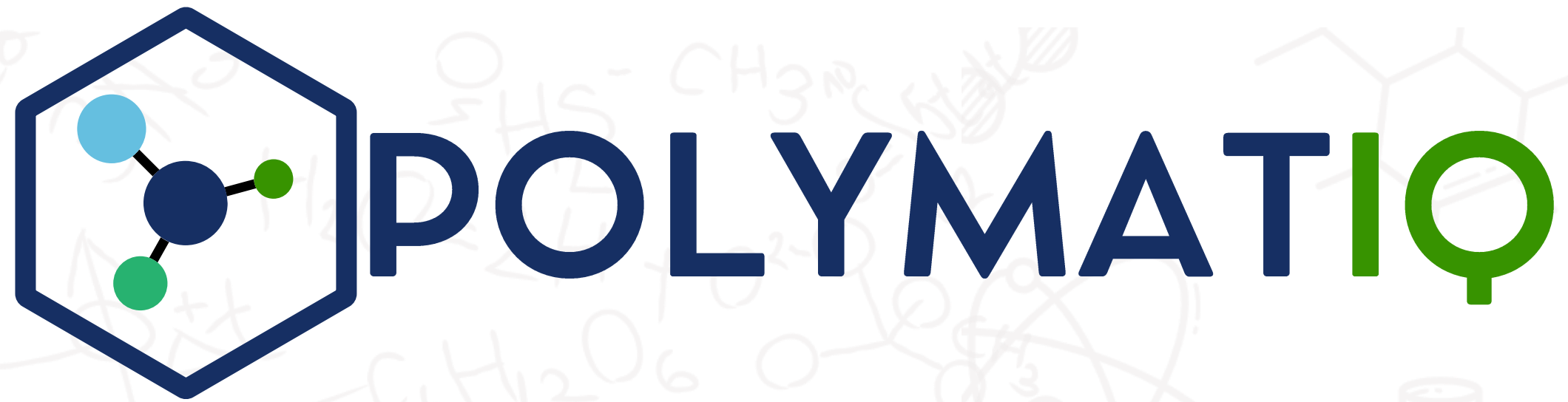




Thermomechanical properties of architected materials

Research Internship:

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Agenda



Problem Statement

Hazards in Electric Vehicles

EVs are the future, but they come with serious thermal safety challenges, and that's why our research matters



Electric Vehicles (EVs) introduce electrical, thermal, and chemical hazards. The most critical is thermal runaway (TR) in Li-ion batteries, which can propagate across cells and cause fire or explosion.

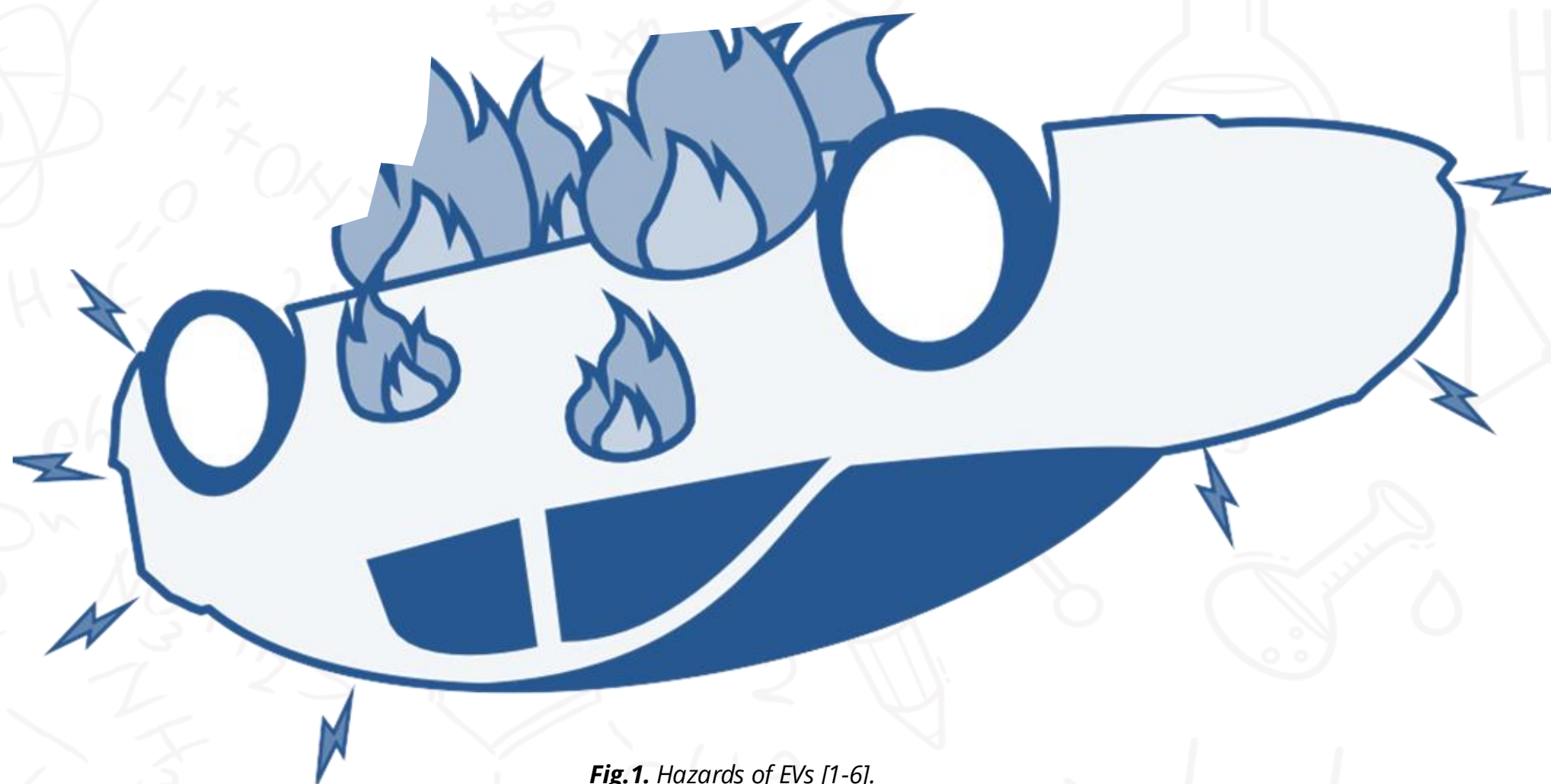
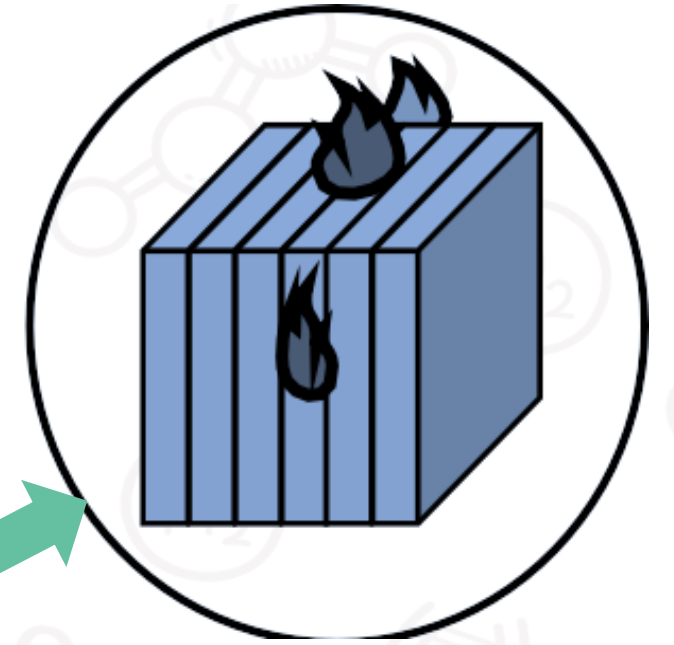


Fig.1. Hazards of EVs [1-6].

Electrical Hazard

HV components unsafe to touch after impact.



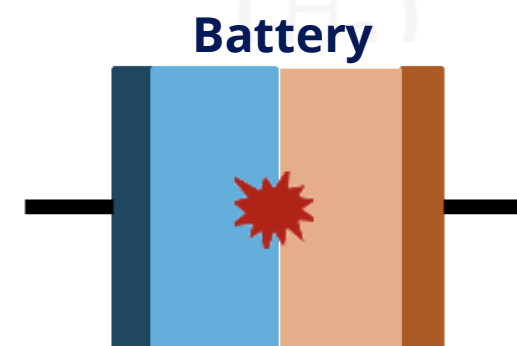
Chemical Hazard

Toxic gases (CO, HF, HC)
released during runaway.



Thermal Hazard

Overheating triggers separator failure and thermal runaway, leading to fire or explosion



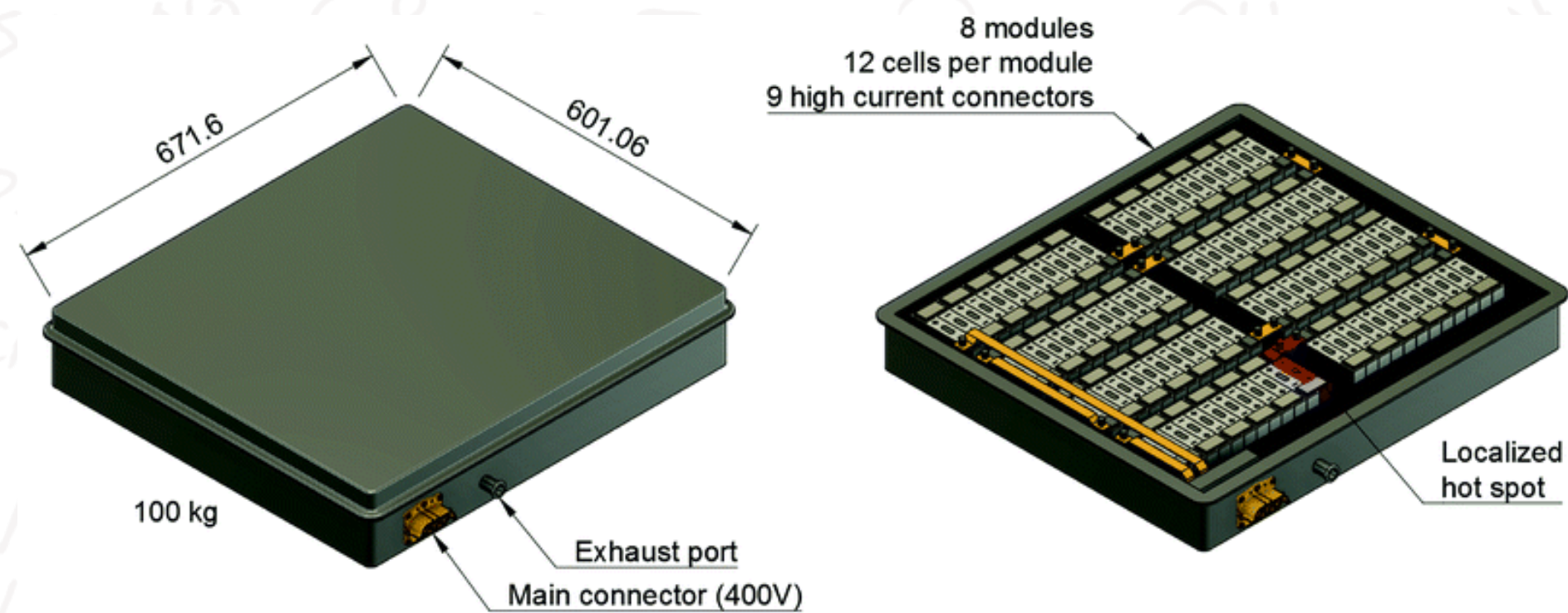


Fig 3. Drawing of a hypothetical PHEV battery-pack to demonstrate the safety issues: (left) including complete casing, (right) with upper part of the casing removed. A possible hot spot is shown in red. Dimensions in mm [8].



Fig 4. Tested cell before and after the thermal runaway experiment. On the fresh cell, the burst-plate of the cell is hidden below the white sticker. After a thermal runaway the cell is heavily damaged: the burst plate is open, the plastic insulation of the terminals is melted, and the cell casing is deformed by the pressure inside the cell [8].

State of Art

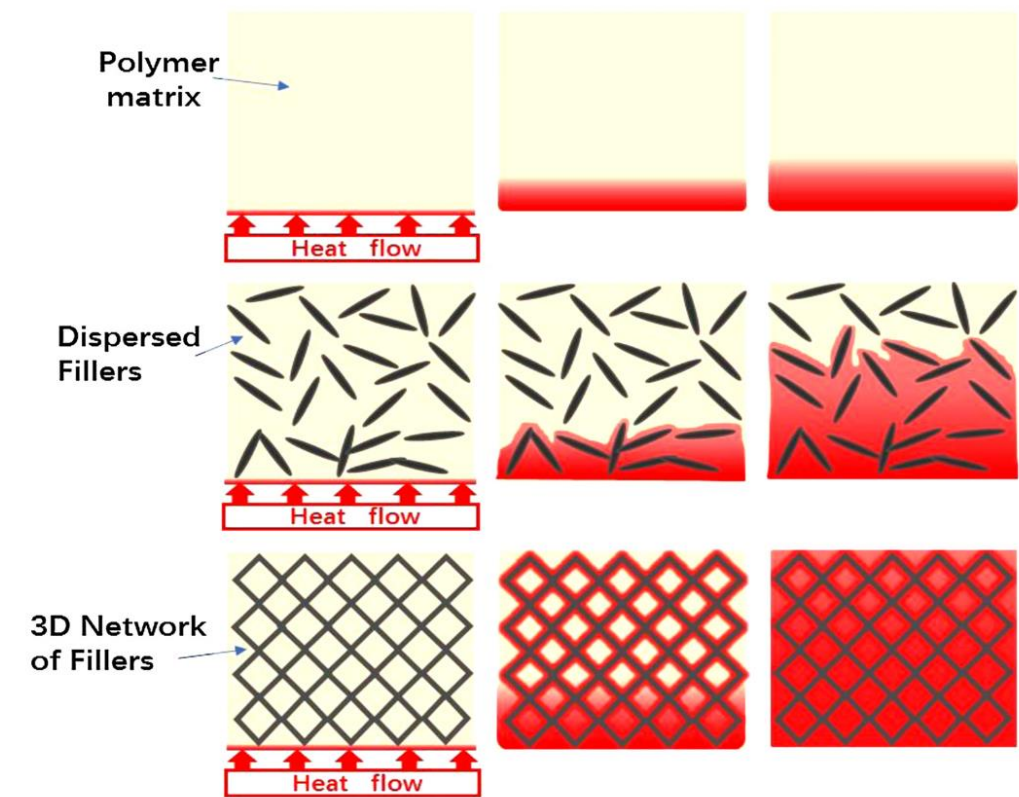


Fig 5. Schematic Diagrams of heat transport in a pure polymer, a polymer composite filled with a traditional dispersed filler, and a composite filled with a 3D interconnected network of fillers [8].

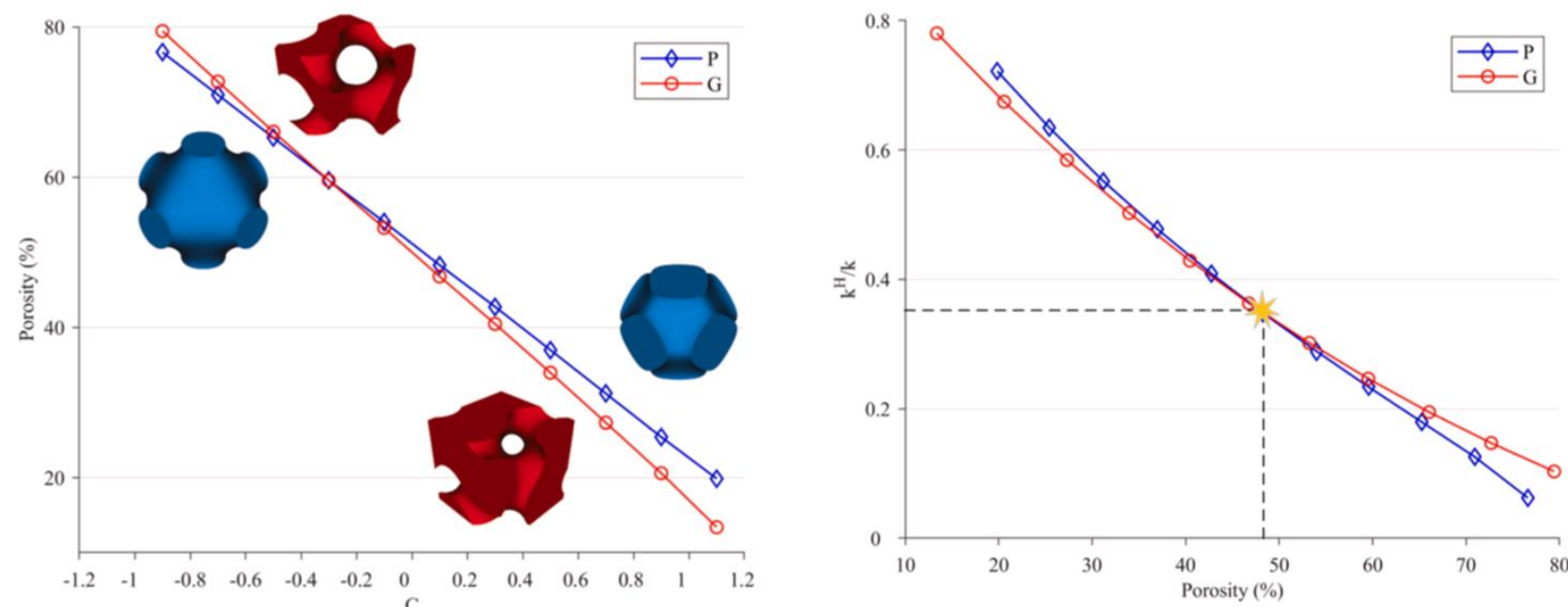


Fig 6. Functional relationships of P-Type and G-Type TPMS with C values. Fig. 3. The normalized thermal conductivity coefficients of P-type and G-type TPMS with different porosities [9].

State of Art

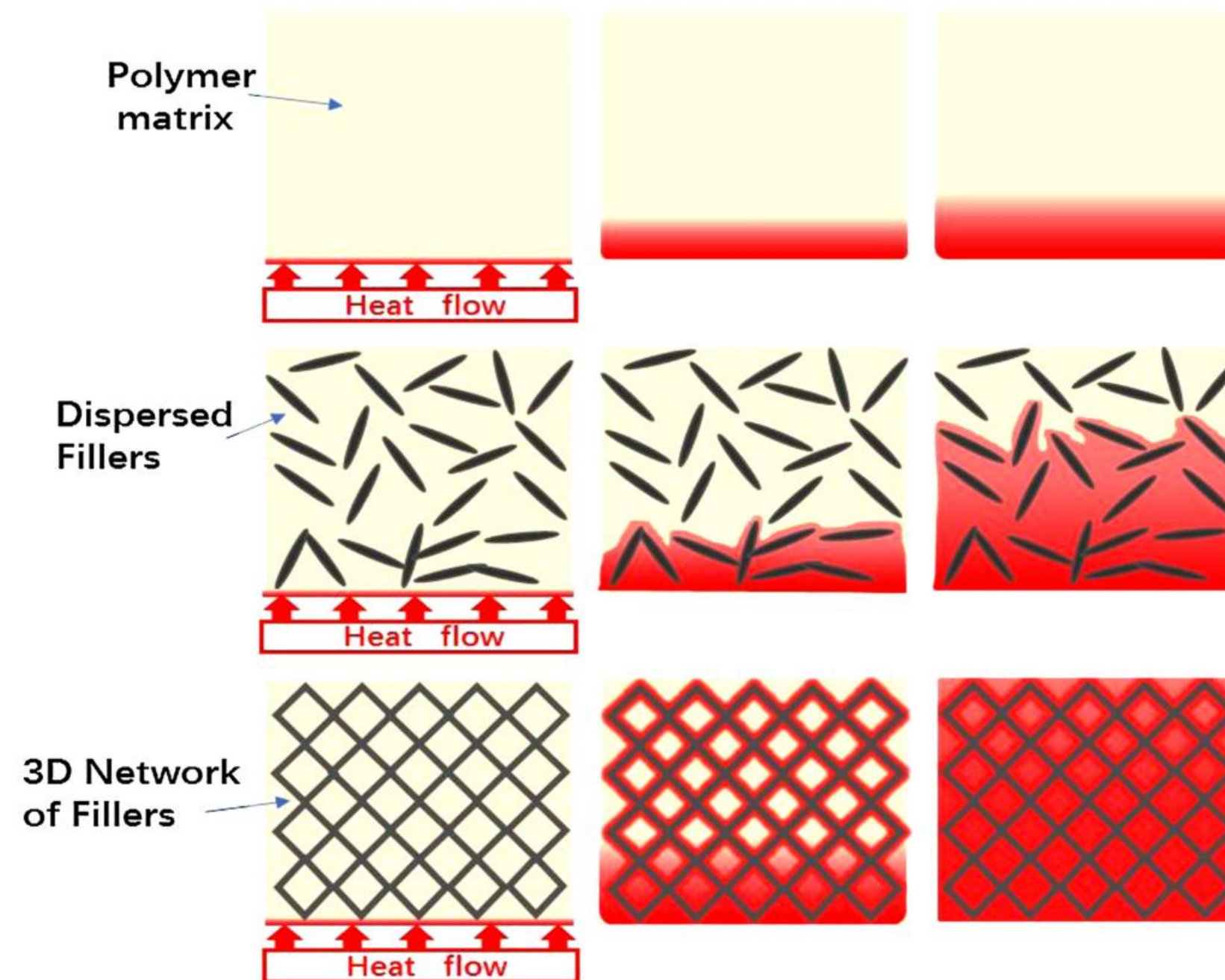


Fig 5. Schematic Diagrams of heat transport in a pure polymer, a polymer composite filled with a traditional dispersed filler, and a composite filled with a 3D interconnected network of fillers [8].

State of Art

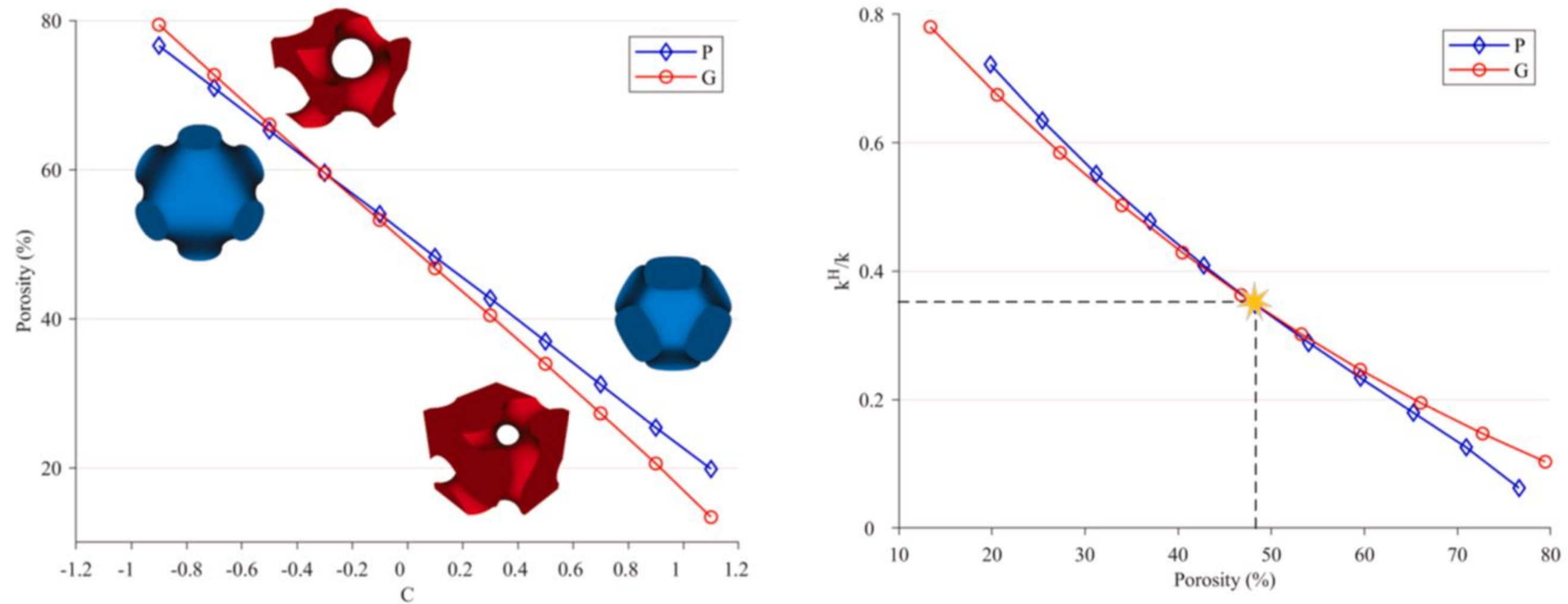
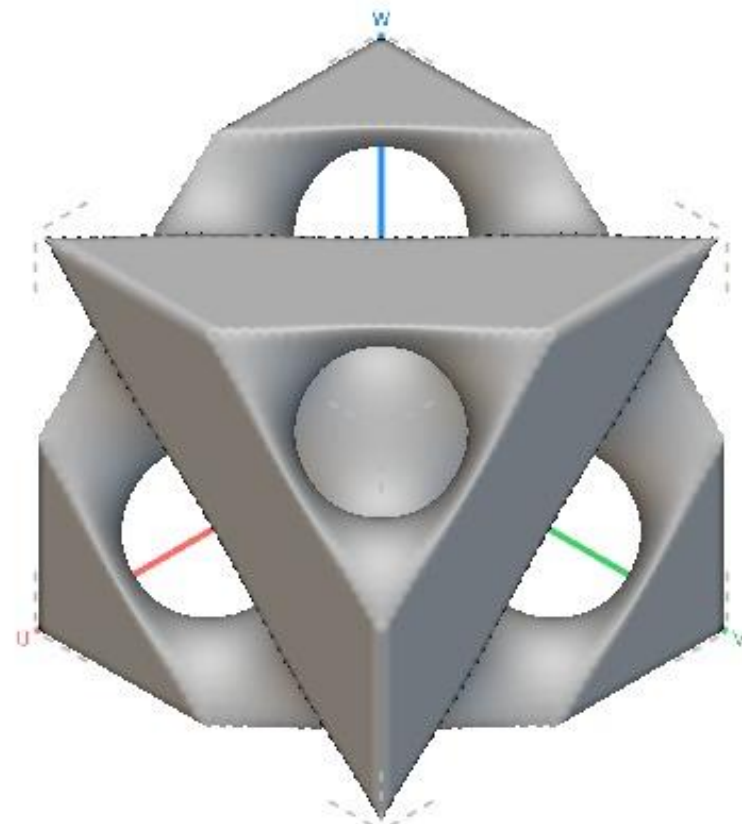


Fig 6. Functional relationships of P-Type and G-Type TPMS with C values. **Fig. 3.** The normalized thermal conductivity coefficients of P-type and G-type TPMS with different porosities [9].

Diamond



Gyroid

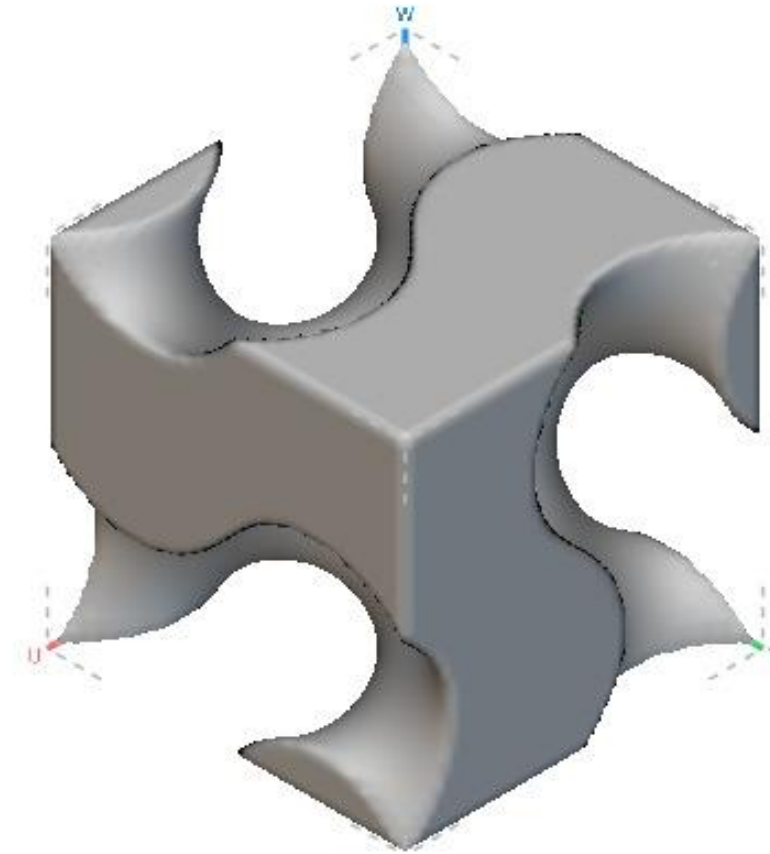


Fig 7. Examples of TMPS structures widely used in thermal-mechanical studies

Objectives

General Objective

To thermo-mechanically characterize architected porous TPMS samples (Gyroid and Diamond) manufactured in Onyx and Nylon, quantifying how topology and base material affect their effective thermal conductivity and mechanical response (stress-strain behavior)

Specific Objectives

1. Design and model Gyroid and Diamond TPMS structures based on prior thermomechanical findings.
2. Design and manufacture 7m-thick architected samples using two polymer matrices (Onyx and Nylon), ensuring consistent geometry, porosity and print settings across all samples.
3. Characterize the effective thermomechanical properties of each topology-material combination using the improved thermal apparatus and a universal mechanical testing machine.
4. Perform mechanical testing (stress-strain) on the same samples to obtain properties such as elastic modulus, strength, and failure strain under uniaxial loading.
5. Compare and analyze thermal and mechanical results across topologies (Gyroid vs. Diamond) and materials (Onyx vs. Nylon) to identify trade-offs and the most promising combinations for multifunctional thermal-management applications.

Methodology

01

Research & Investigation

02

Sample Design

03

Manufacturing

04

Thermal Testing

05

FEA Simulation

06

Validation & Analysis

Research & Investigation

01

Sample Design

02

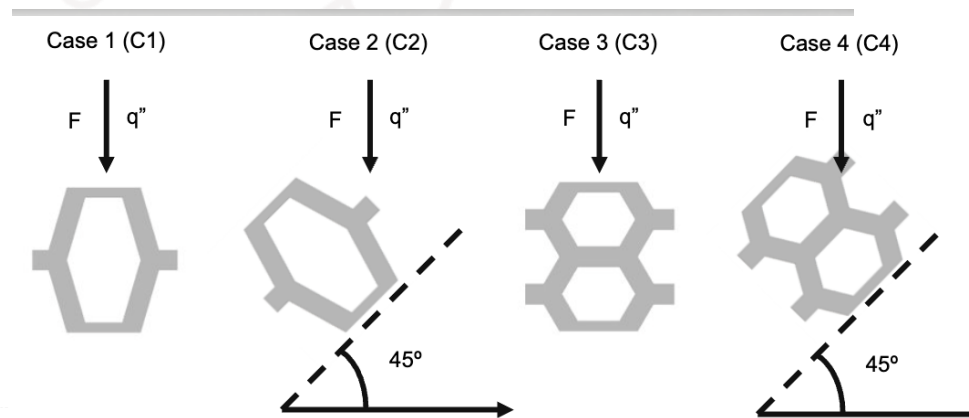
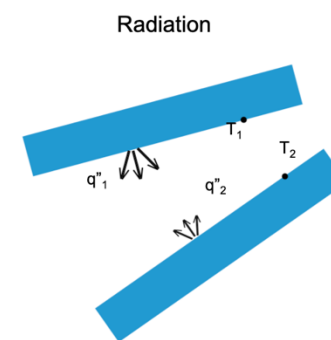
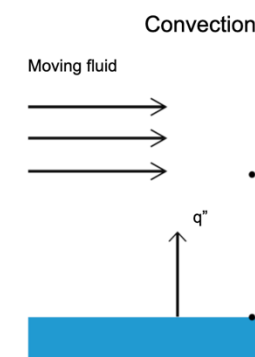
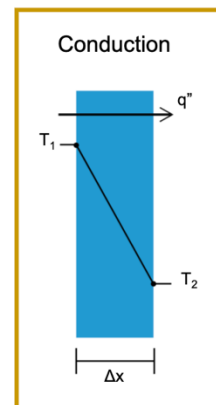
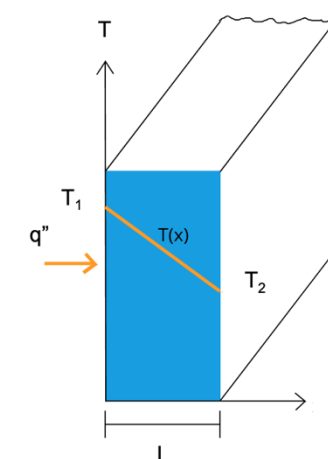


Fig 8.. Heat Transfer Mechanisms (Modified from [10]).

Fig 9. Factorial Design experiments for porous samples [11].



Fourier's law:

Thermal conductivity ($Wm^{-1}K^{-1}$)

$$k = \frac{q'' L}{T_2 - T_1}$$

Heat flux (W/m^2)

Length (m)

Temperature difference (K)

gy optimization (Chi et al., 2024)
osites (Zhang et al., 2020) [9].



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in partial fulfillment of the requirements for the degree of

Fig 10.. Heat conduction mechanism [12-15].

Three-dimensional interconnected networks for thermally conductive

Topology	Max $k_{norm} * U_{norm}$ factors		Significant factors	$k_{norm} * U_{norm}$	$\langle k \rangle \langle U \rangle$ change with respect to lowest value
	Angle (°)	UCs			
HH	45	2	UCs and I	4.28691	0%
SH	45	2	UCs	5.59247	26%
RH	45	2	UCs	4.32532	1%
BL	0	2	UCs	5.32576	22%
SL	45	2	Angle and UCs	7.09928	49%
TL	0	2	UCs	4.61481	7%
DT	0	2	Angle	6.00714	33%
GT	45	2	None	6.01629	34%
ST	45	2	Angle and UCs	5.64059	27%

Reference work: Rosa
— Thermomechanics
architected materials

Table 1. Maximum effect of factors that produce the best thermal conductivity times strain energy, effect of interaction lines, significance at 95% confidence level, $k_{norm} * U_{norm}$, and difference of $\langle k \rangle \langle U \rangle$ with respect to the lowest value [11].

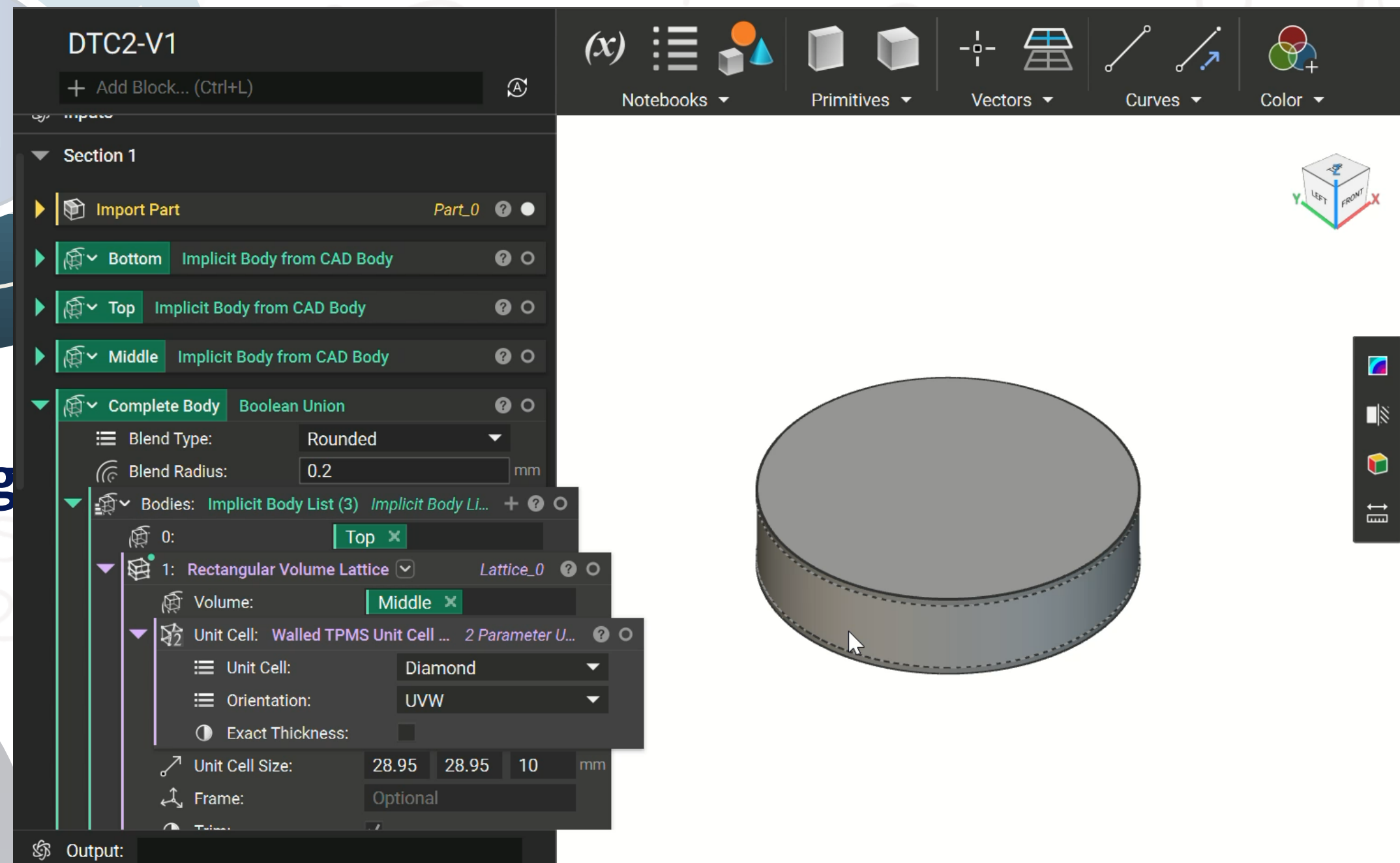
Research & Investigation

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Sample Design

Manufacturing

03



Video 1. Ntop Porous Sample Example

Fig 12. CAD 7mm Solid Disk model

Research & Investigation

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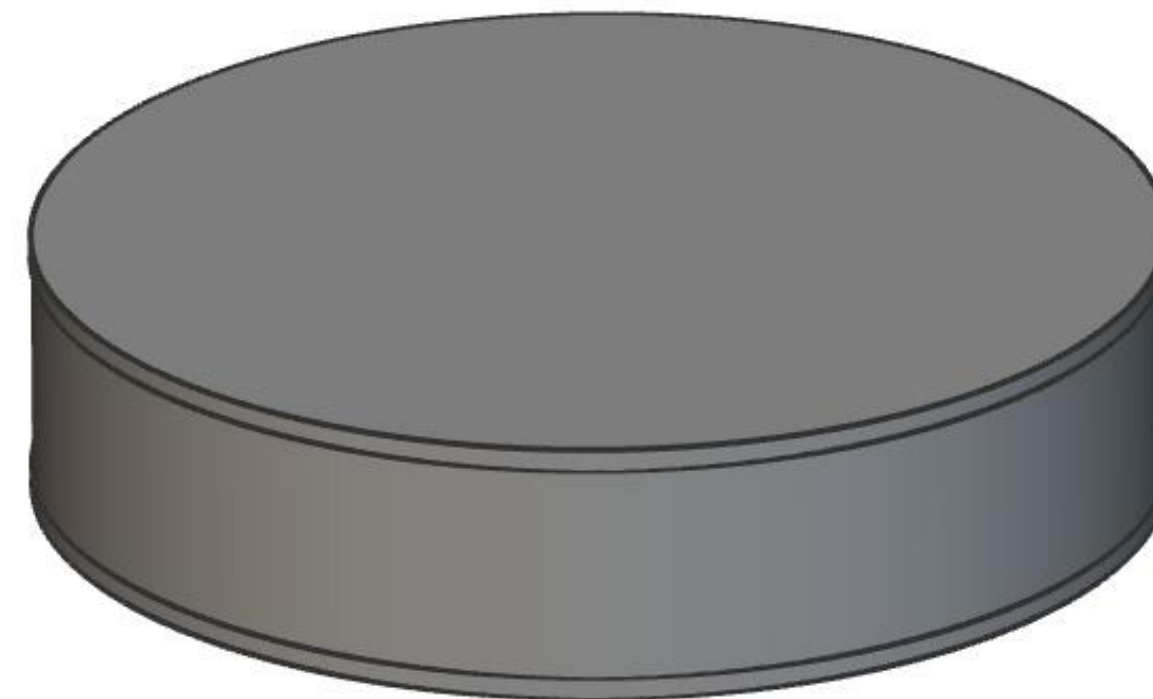


Fig 13. Sandwich Sample 1mm+10m+1mm

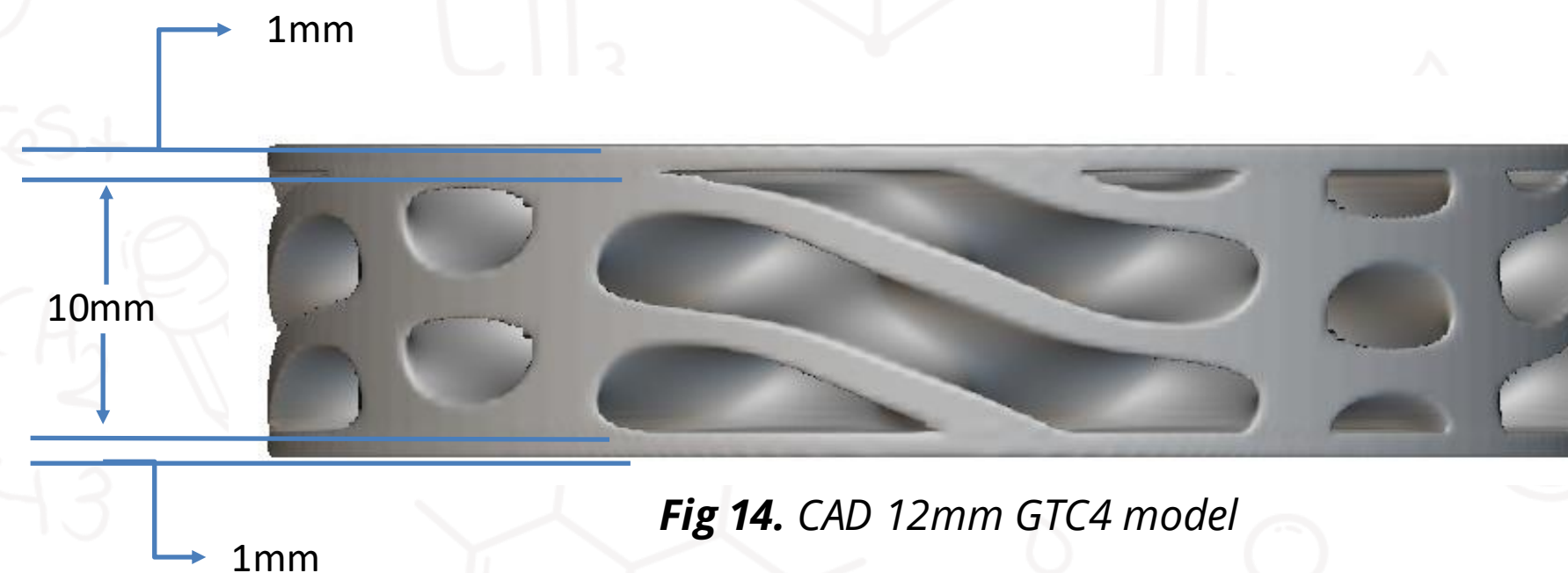


Fig 14. CAD 12mm GTC4 model

02

Sample Design

Manufacturing

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Thermal Testing

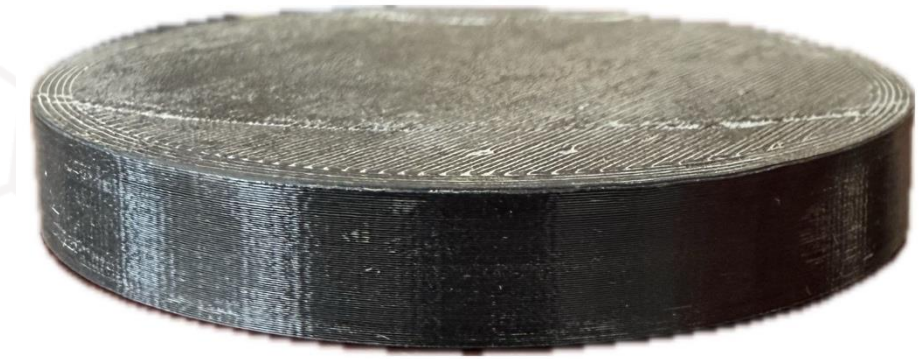


Fig 15. 7mm Printed solid PLA sample

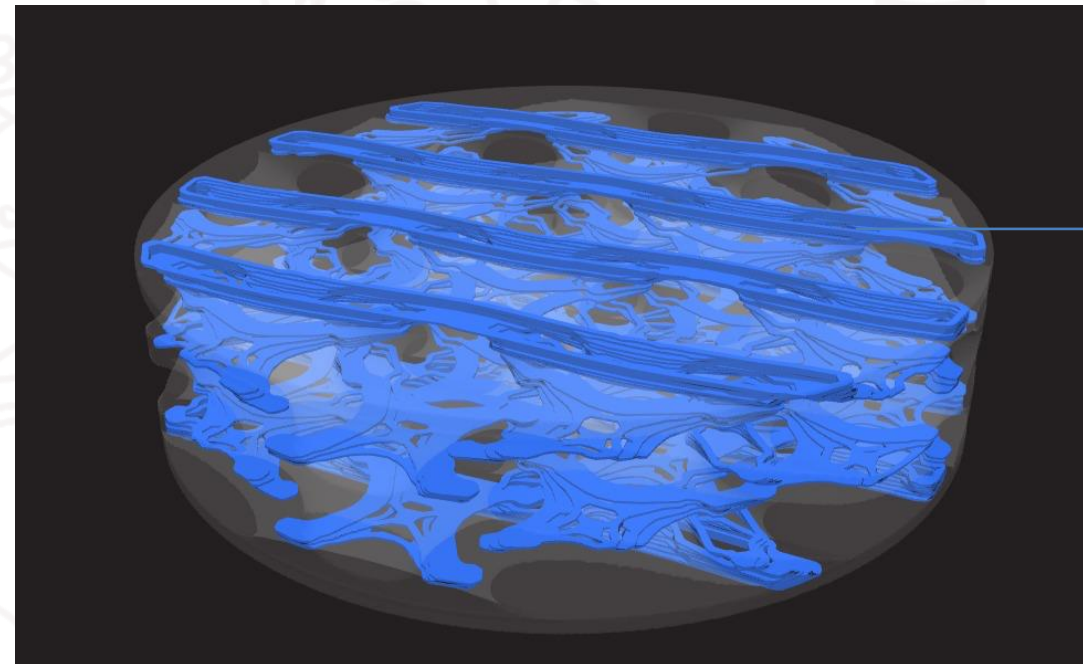


Fig 16. 12mm Architected sample (matrix and reinforcement) x-ray

Carbon Fiber 5 layers
Reinforcement

1mm

10mm

1mm

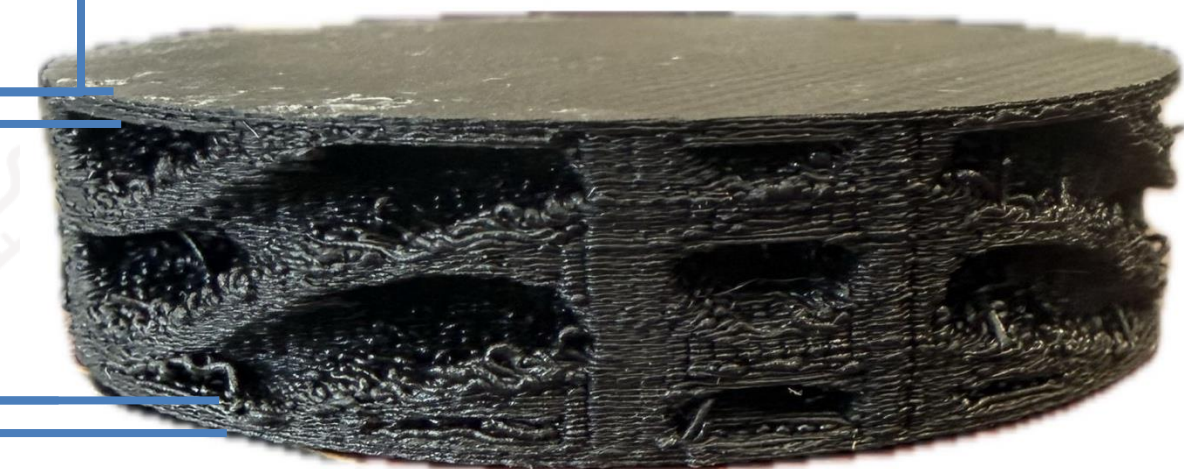


Fig 17. 12mm Printed Architected sample (matrix and reinforcement)

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de MonterreyInstitute of Advanced
Materials for Sustainable
Manufacturing

POLYMATIQ

Research & Investigation

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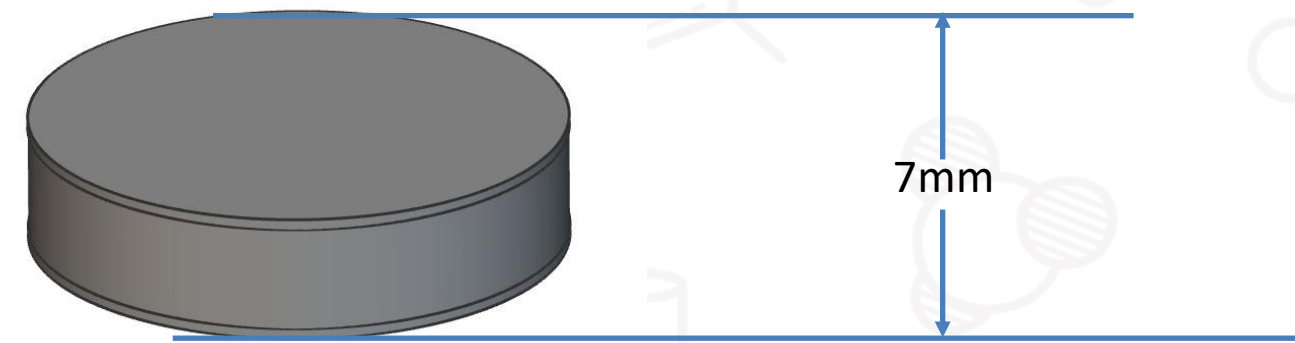


Fig 18. CAD sample Sandwich Arrangement

$$\bar{\rho}_{porous} = \frac{m_s}{m_T}$$

$$\bar{\rho}_M = \bar{\rho}_{porous} \times \bar{\rho}_{M \rightarrow porous}$$

$$\bar{\rho}_R = 1 - \bar{\rho}_M$$

Fig 19. Volume Fraction calculation used to control sample architecture

02

Sample Design

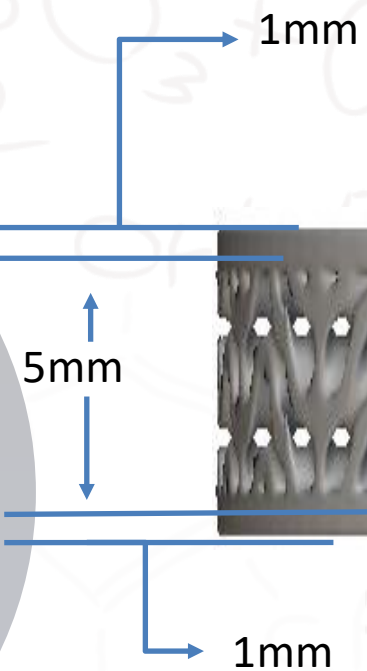


Fig 20. CAD sample of DTC3 7mm



Fig 21. CAD sample of GTC4 7mm

Manufacturing

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Sample Design

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1mm
5mm
1mm



Fig 20. 7mm Printed GTC4 Onyx & Nylon sample

04

Thermal Testing



Fig 21. 7mm Printed DTC3 Onyx & Nylon sample



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04

Thermal Testing

A Simulation

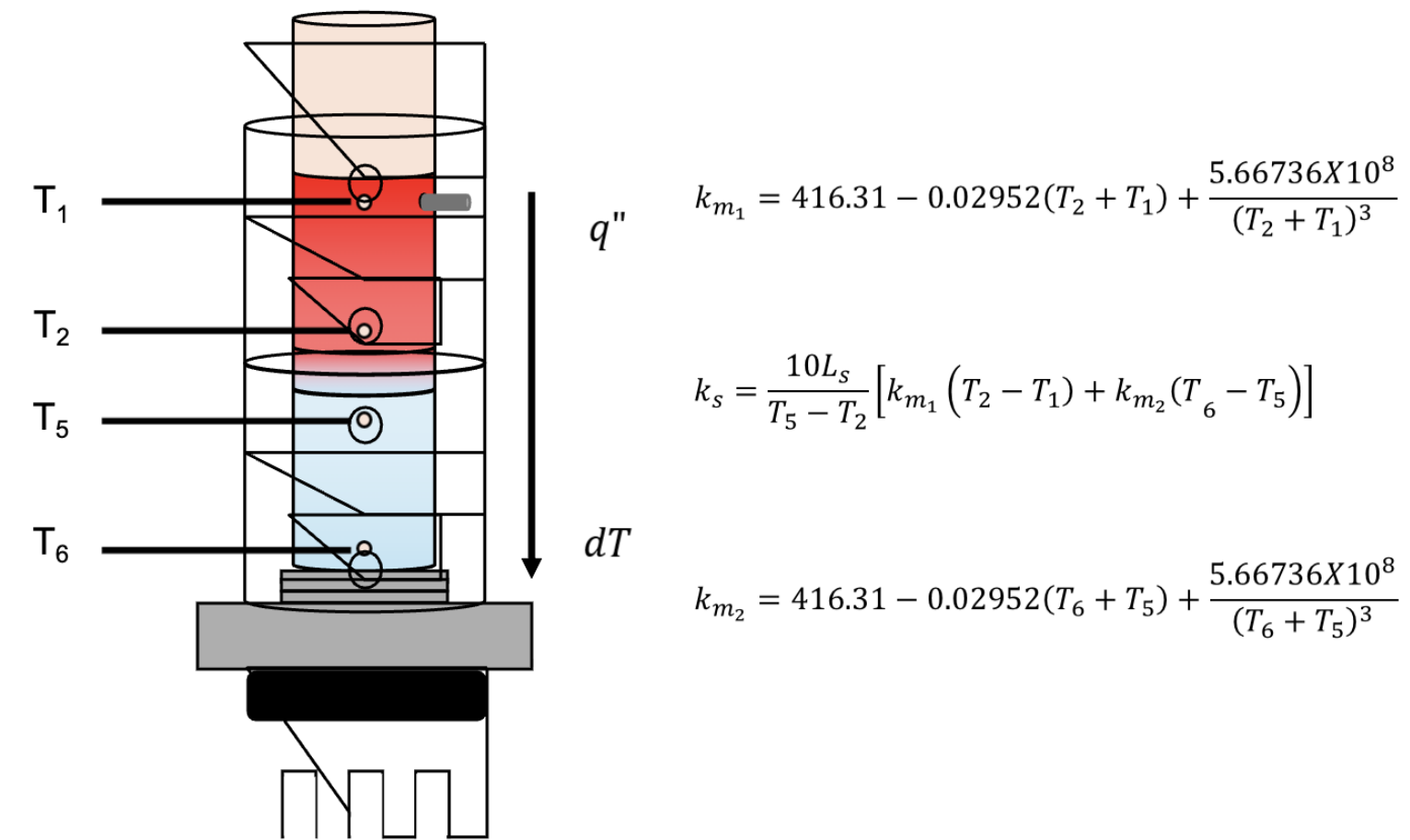


Fig 22. Heat Transfer Apparatus Schematic Part I [11].

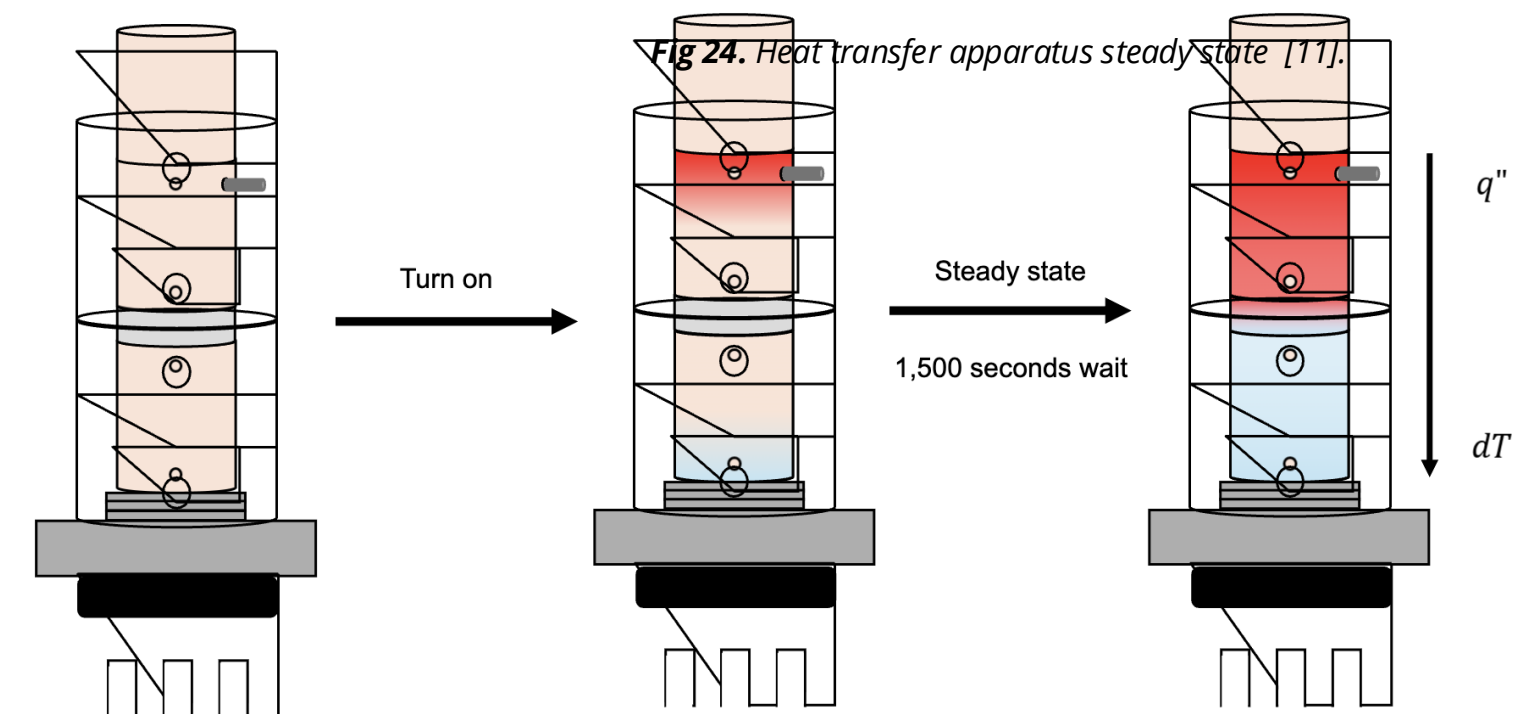


Fig 23. Heat Transfer Apparatus Working Steps [11].

Manufacturing

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Thermal Testing

A Simulation

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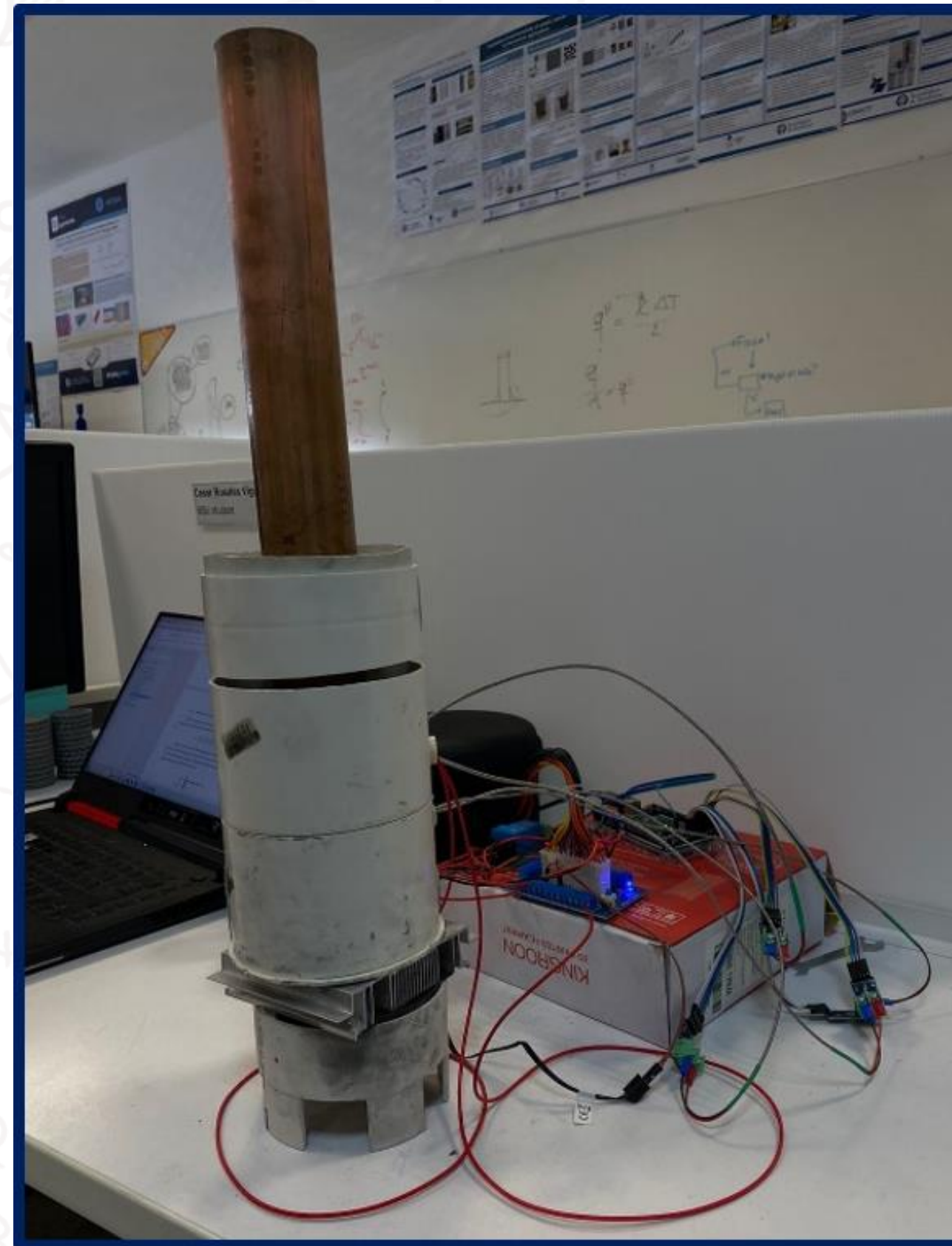


Fig 24 . Previous Heat Transfer Apparatus + Circuit Board [16].

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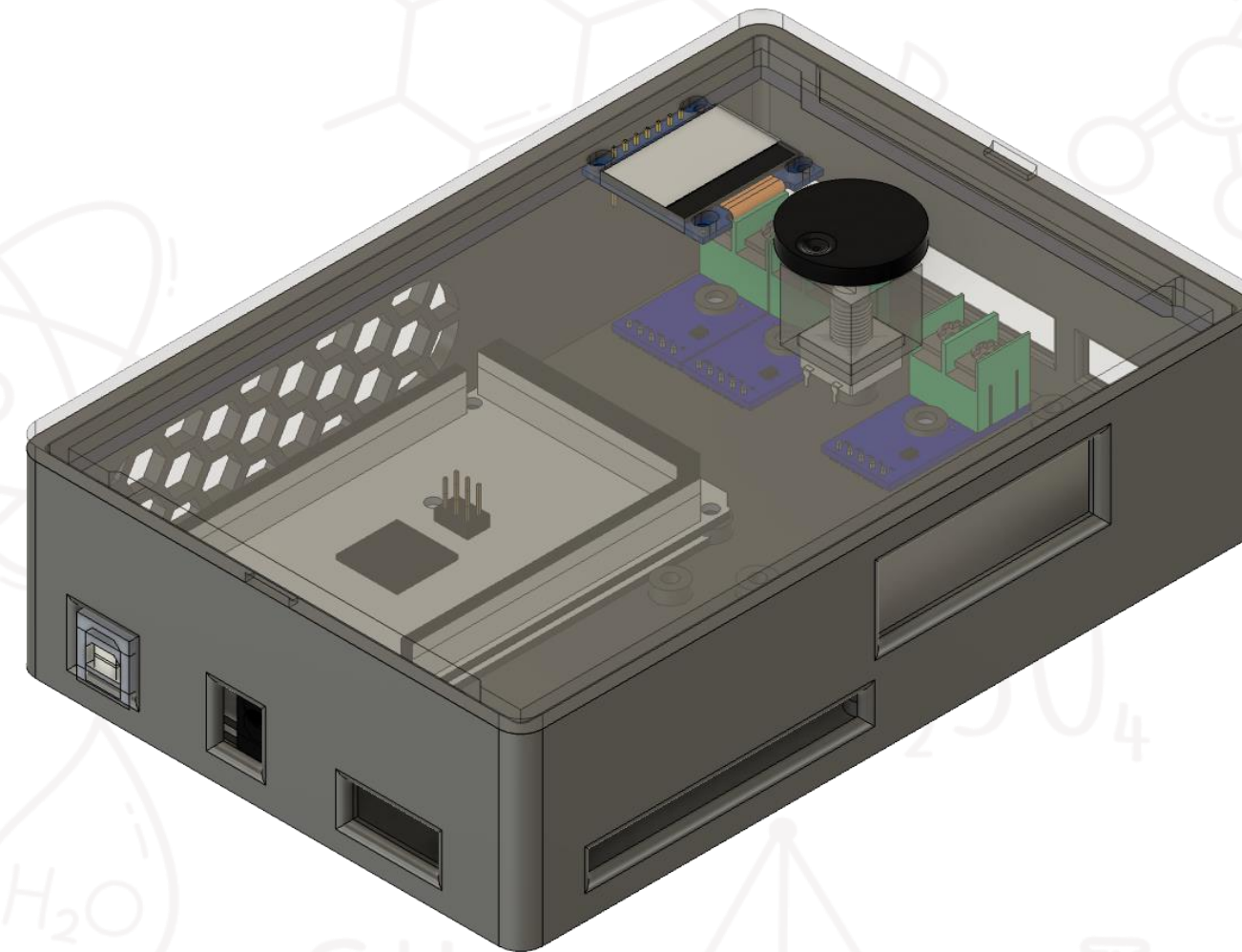


Fig 25. Circuits Enclosure CAD design – Isometric View

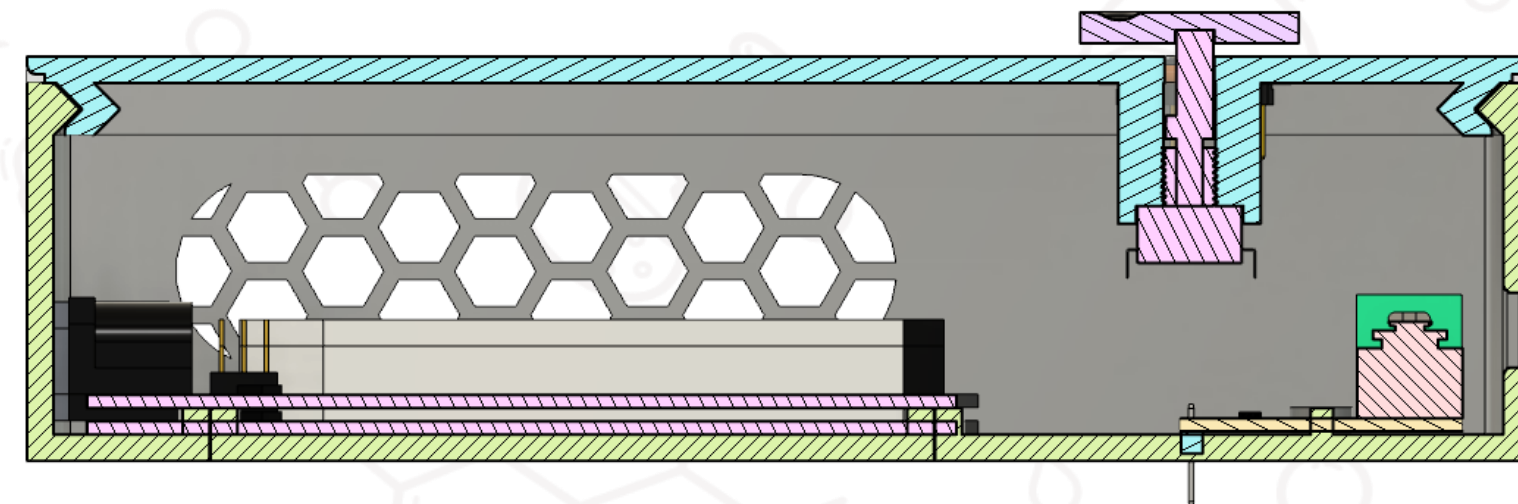


Fig 26. Circuits Enclosure CAD design – Cross Section View

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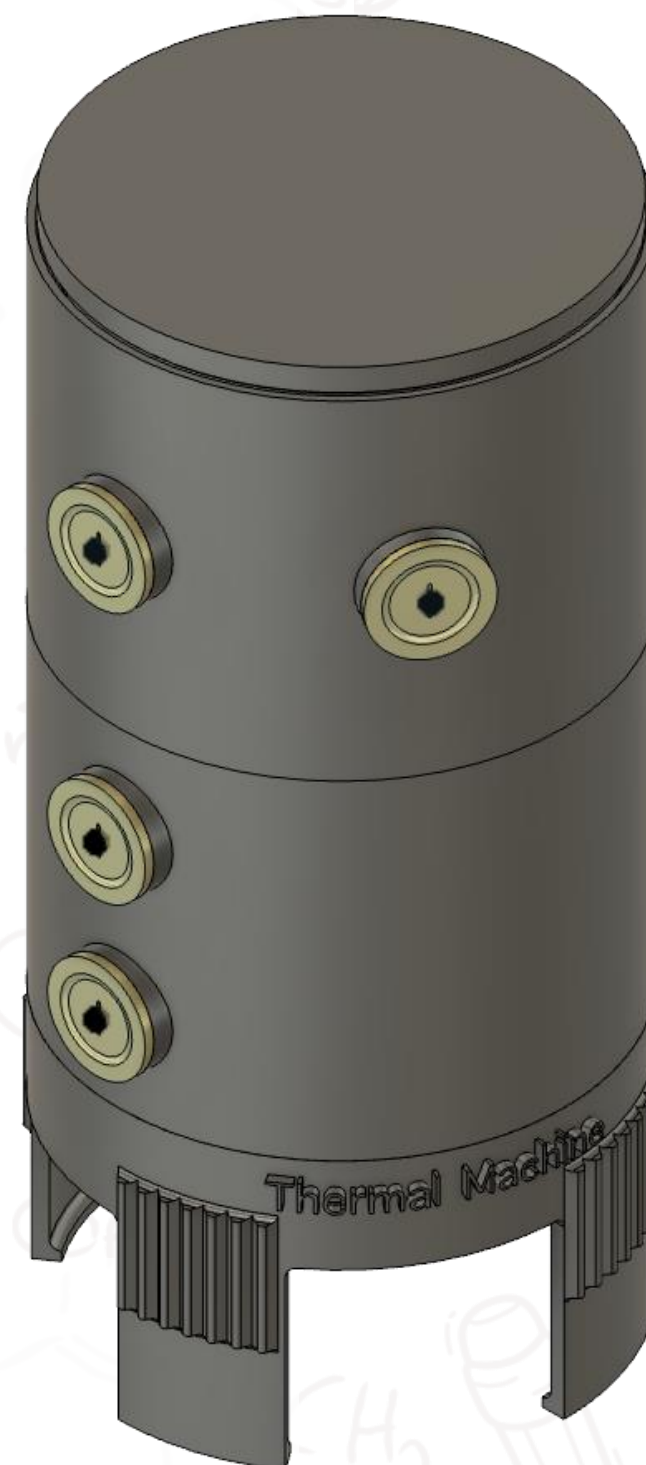


Fig 27. CAD Heat Transfer Apparatus – Isometric View

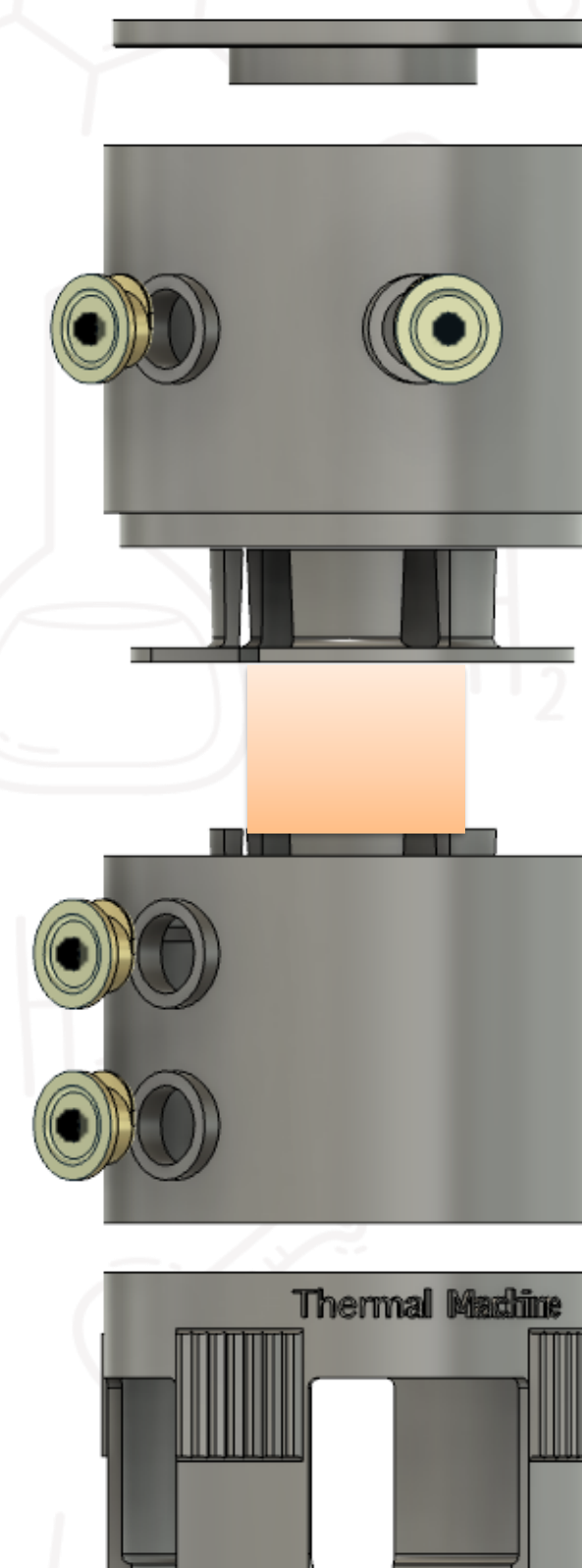


Fig 28. CAD Heat Transfer Apparatus – Exploded View

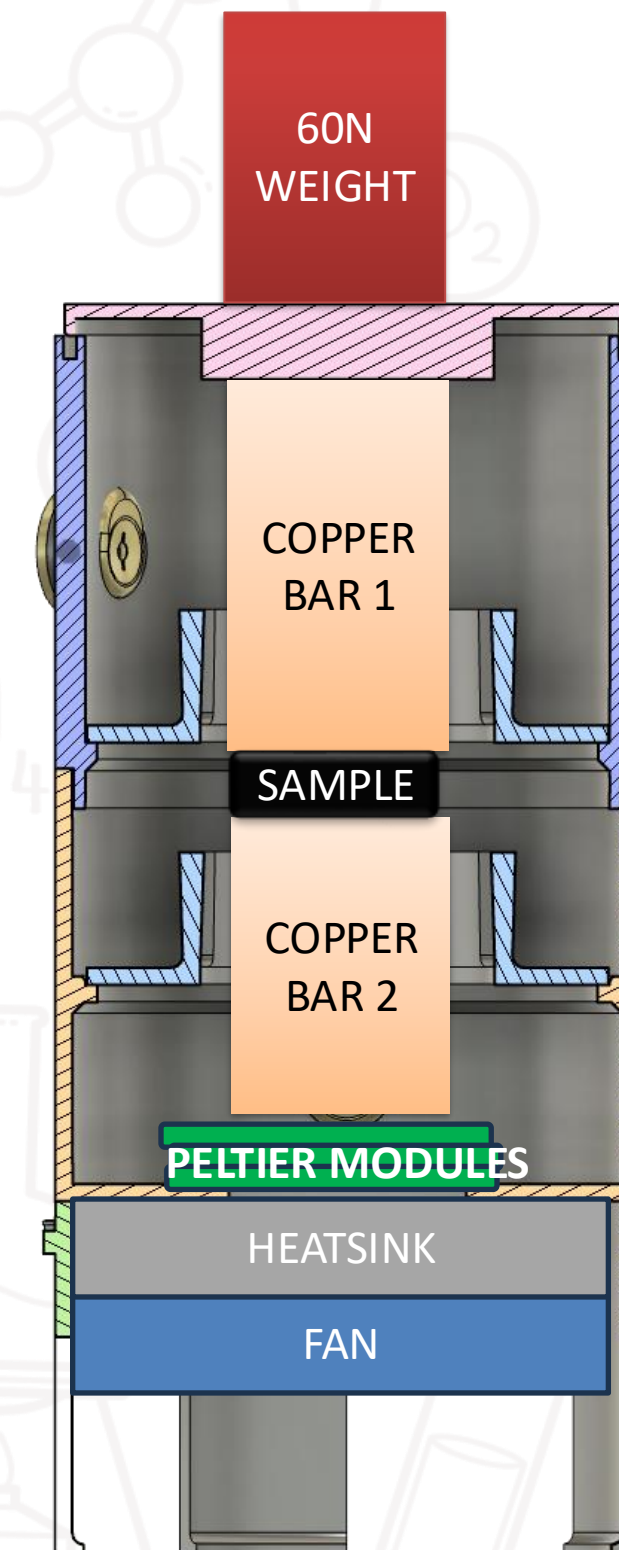


Fig 29. CAD Heat Transfer Apparatus – Cross-sectional View

Manufacturing

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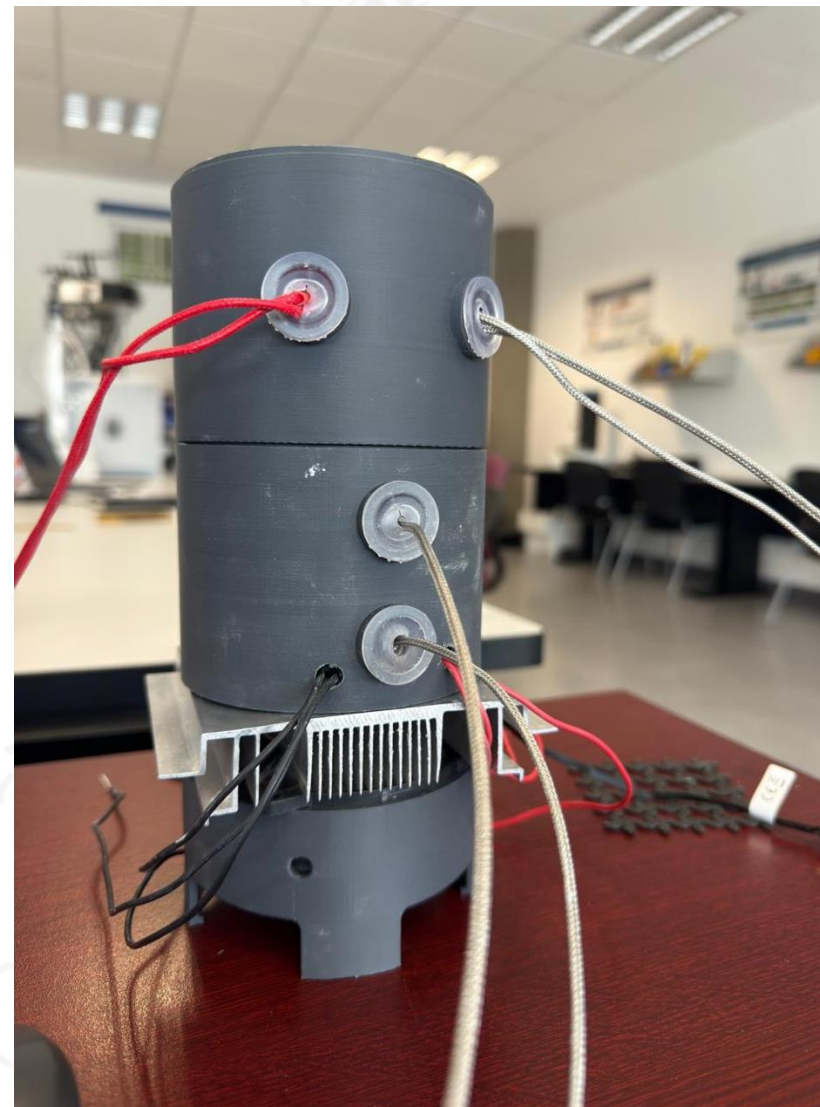


Fig 30. Heat Transfer Apparatus - V2

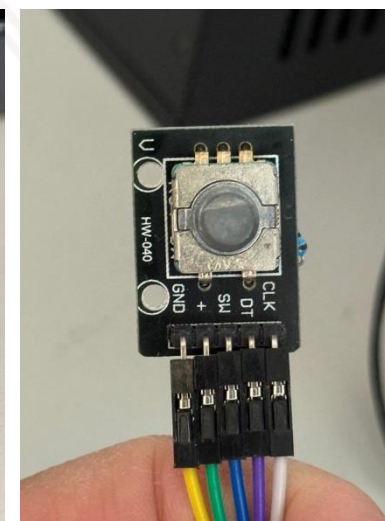
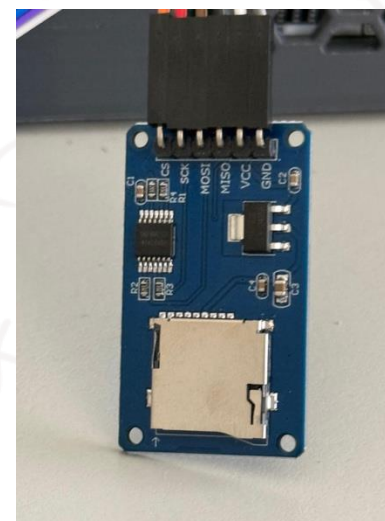


Fig 32. Circuits Case Outside

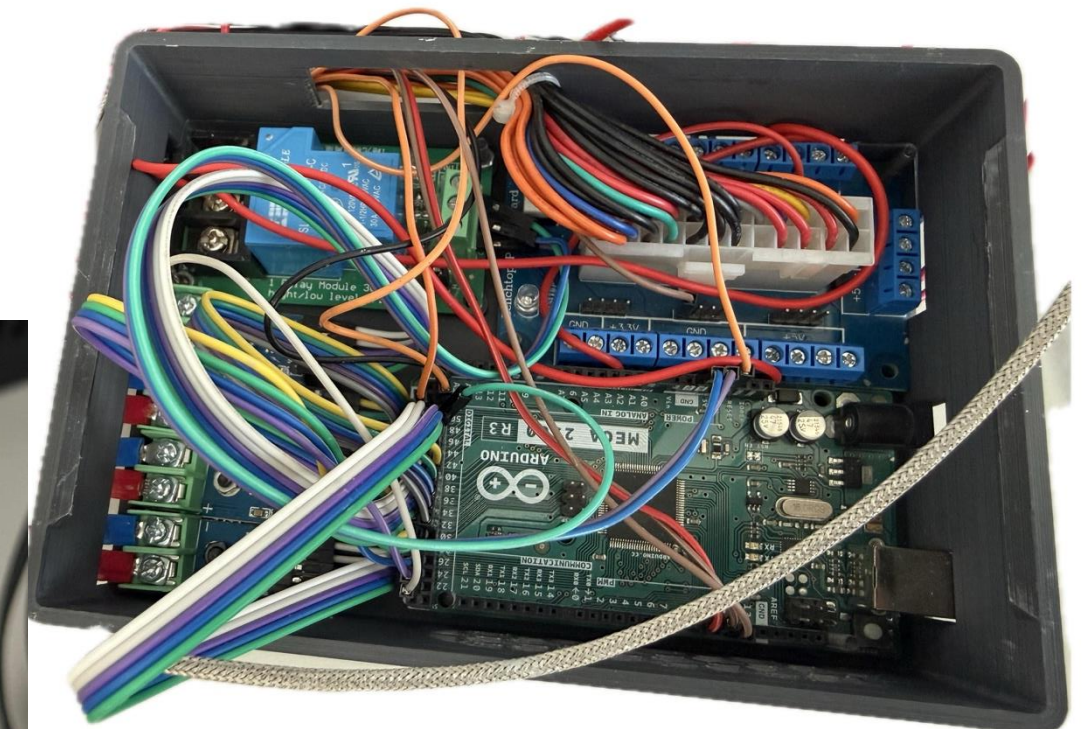


Fig 33. Circuits Case Inside

04

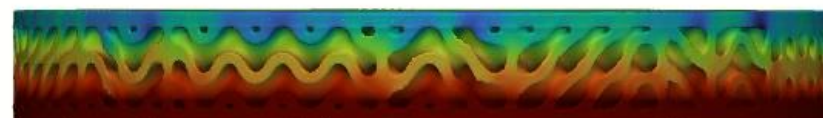
Thermal Testing

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FEA
Simulation

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Validation



Video 2. DTC3 Directional Deformation in Z axis demonstration

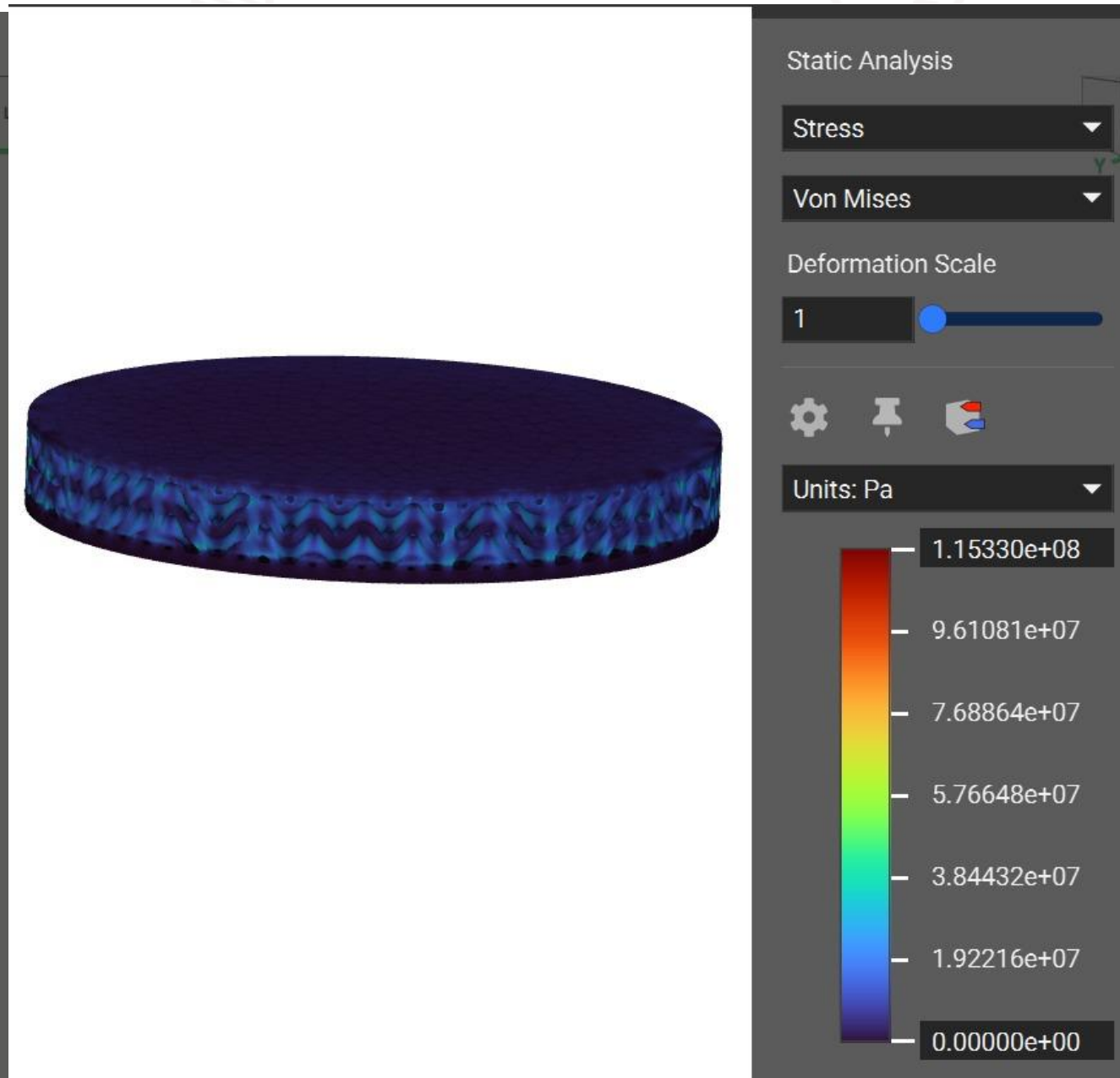
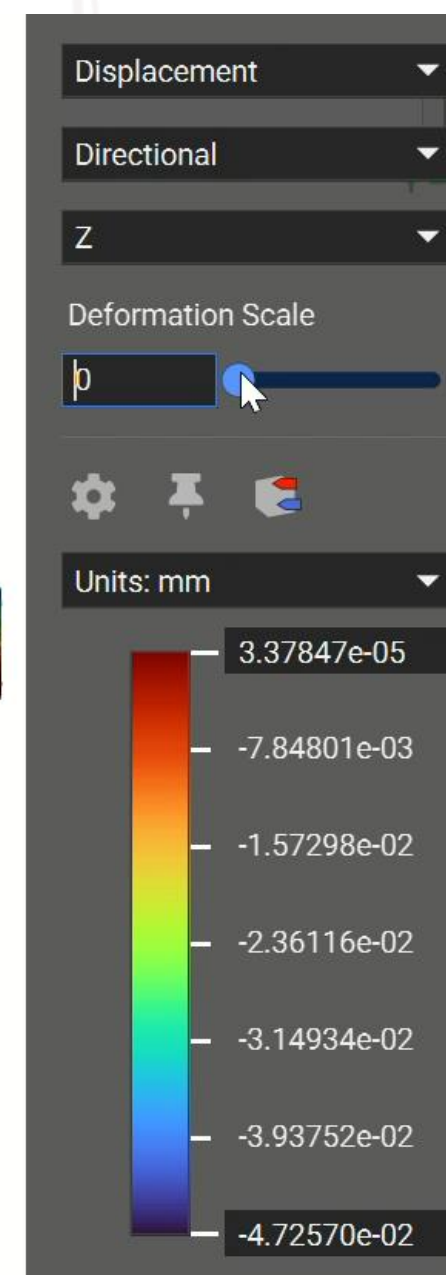


Fig 34. DTC3 Von Mises Stress

Results

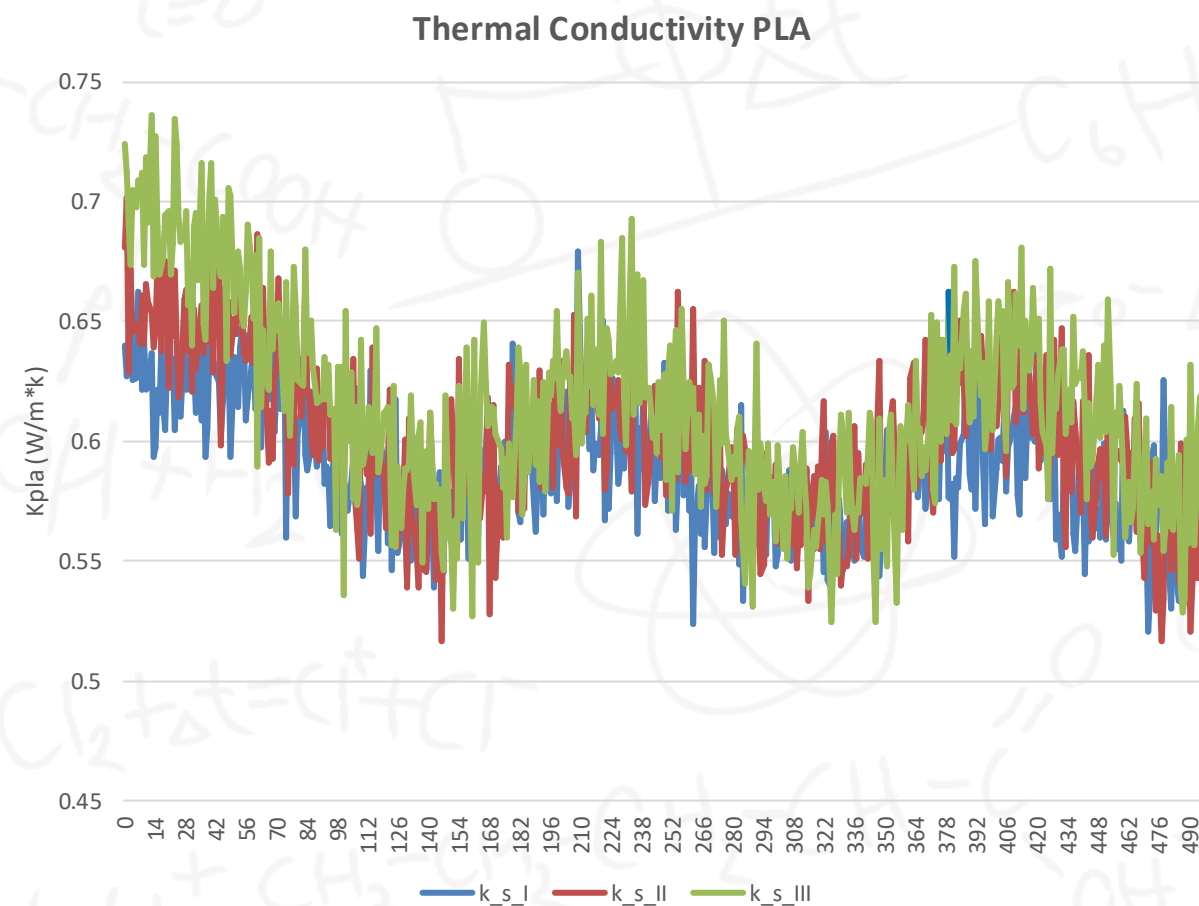


Fig 33. PLA thermal conductivity with three replicates

Series	Mean (W/m*k)
k_{s_I}	0.590118395
k_{s_II}	0.601770701
k_{s_III}	0.614941055
Samples Average	0.602276717

Table 2. PLA thermal conductivity with three replicates



Video 3. Thermal machine sample set-up

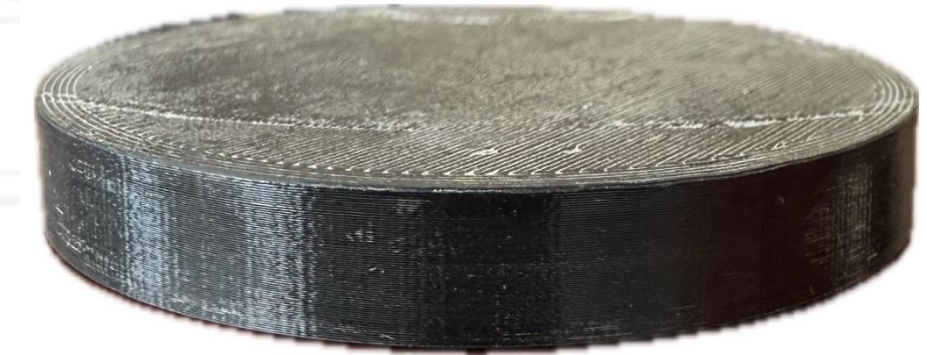


Fig 34. 7mm Printed solid PLA sample

Results Onyx



Fig 35. 7mm Printed GTC4 Onyx sample

Run #	GTC4	DTC3
1	1.616007	1.1023040
2	1.57892792	1.1145302
3	1.62073015	1.0931288
Average	1.60522169	1.103321



Fig 38. 7mm Printed DTC3 Onyx sample

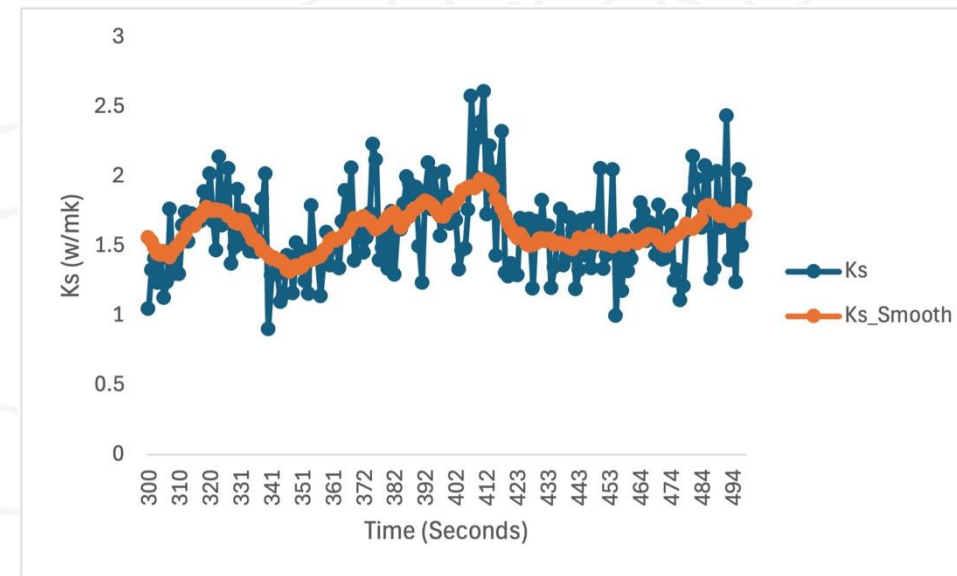


Fig 36. RUN 1 – Smoothen Data

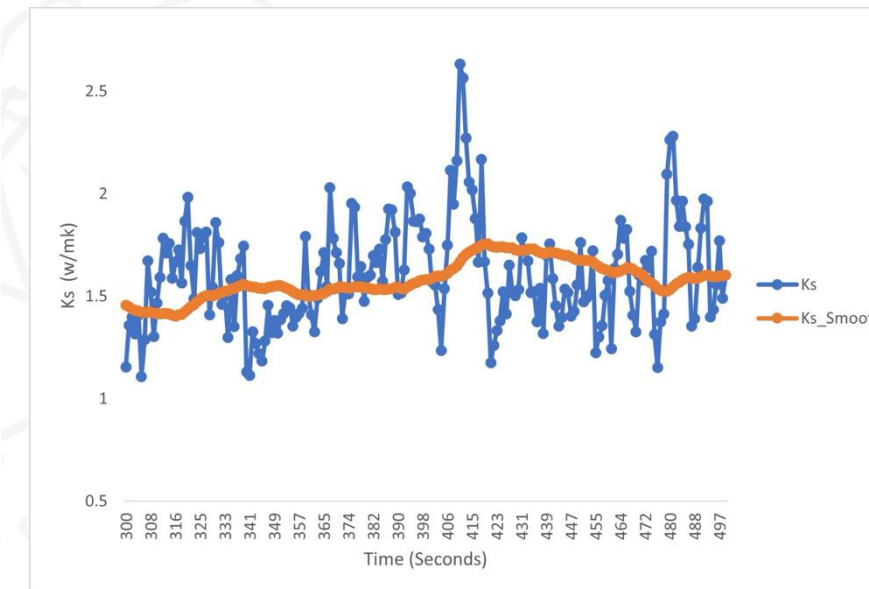


Fig 37. RUN 2– Smoothen Data

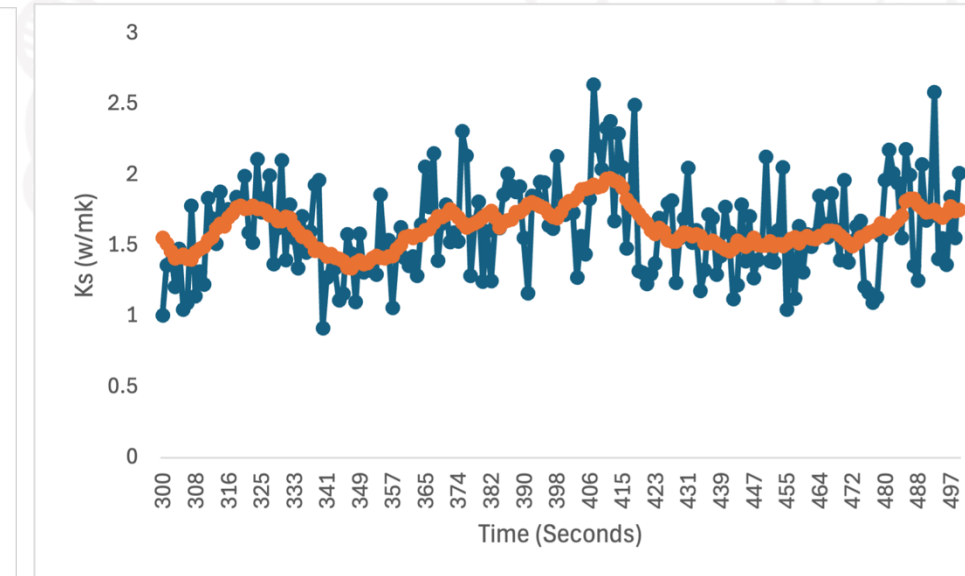


Fig 38. RUN 3 – Smoothen Data

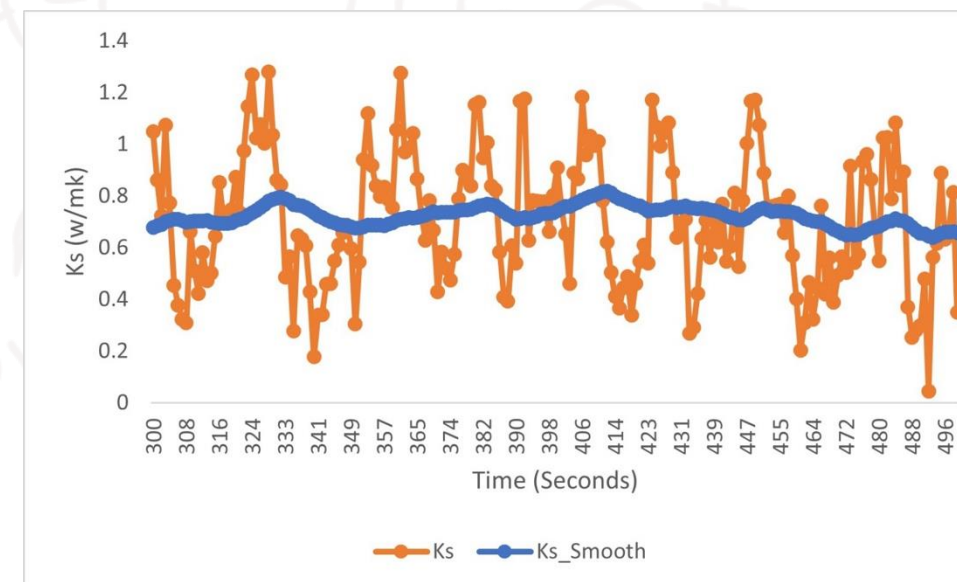


Fig 39. RUN 1 – Smoothen Data

Fig 40. RUN 2– Smoothen Data

Fig 41. RUN 3 – Smoothen Data

Results Nylon



Fig 42. 7mm Printed GTC4 Nylon sample

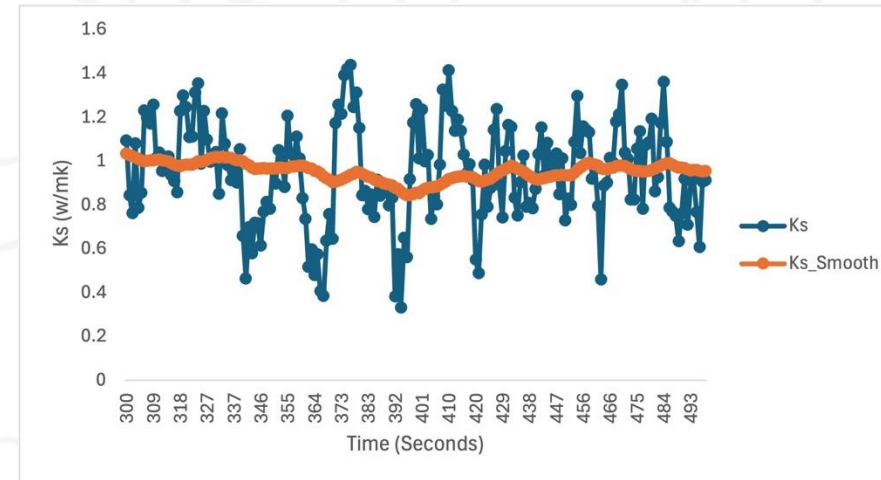


Fig 43. RUN 1 – Smoothen Data

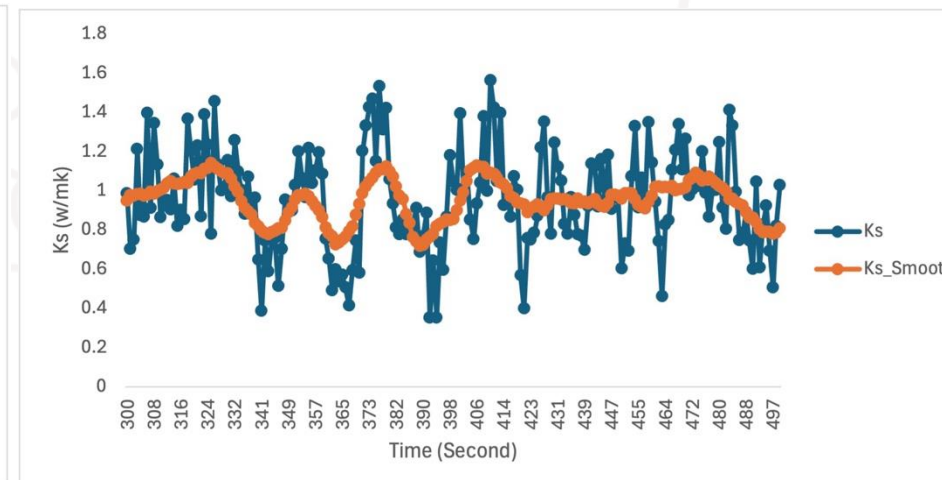


Fig 44. RUN 2– Smoothen Data

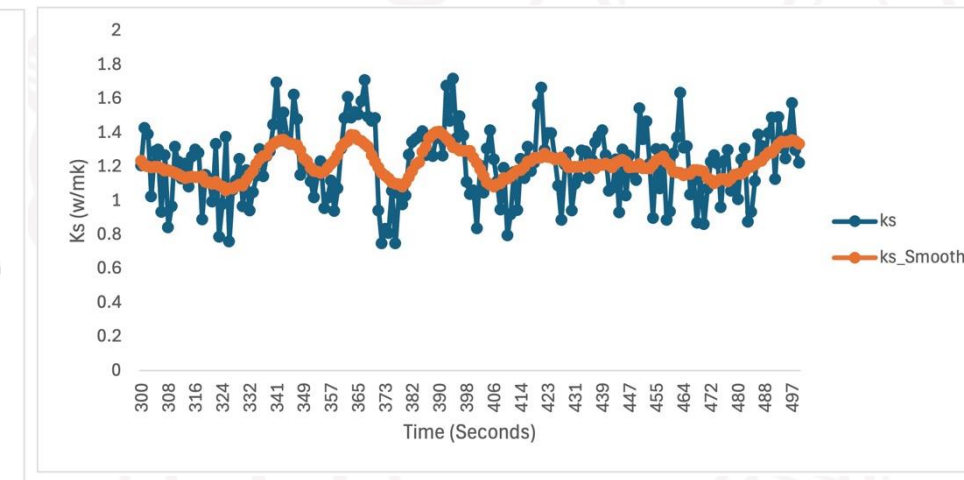


Fig 45. RUN 3 – Smoothen Data

Run #	GTC4	DTC4
1	0.95330903	0.6596645
2	0.94974399	0.6570936
3	1.21521961	0.7643234
Average	1.0394	0.69369383



Fig 46. 7mm Printed DTC3 Nylon sample

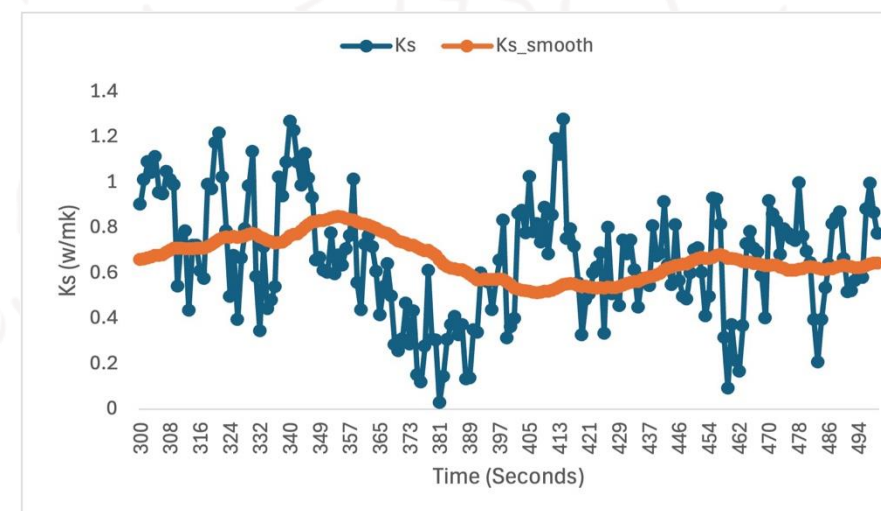


Fig 47. RUN 1 – Smoothen Data

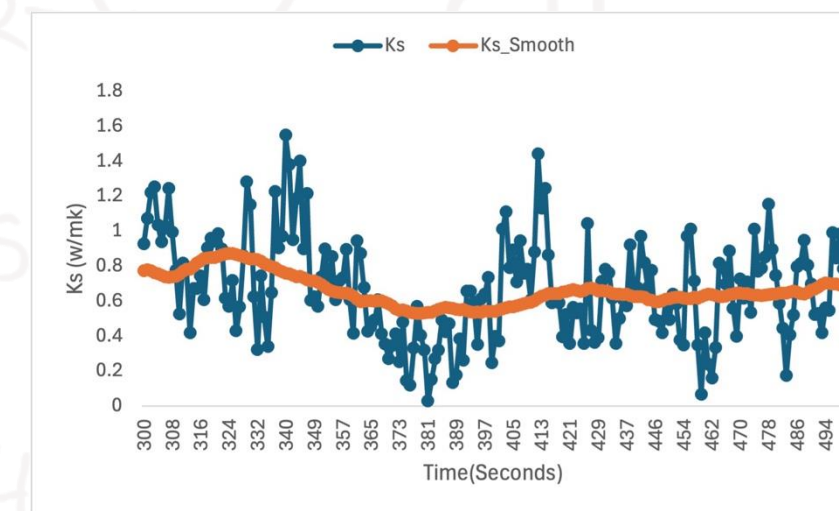


Fig 48. RUN 2– Smoothen Data

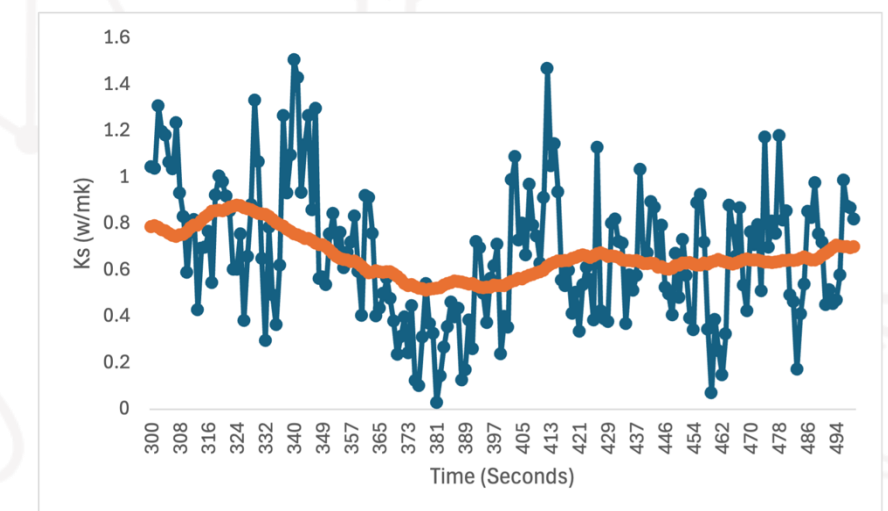


Fig 49. RUN 3 – Smoothen Data

Conclusion

- The redesign and optimization of the heat-transfer apparatus resulted in a more stable, safer, and user-friendly system, significantly improving the repeatability of the measurements. The closed structure, improved component alignment, and better thermal insulation reduced experimental variation between consecutive tests.
- The tests performed on the sandwich-type samples (1 mm solid – 5 mm porous – 1 mm solid) demonstrated that this geometry is suitable for thermal characterization of architected materials. The structure allowed for a uniform heat path and consistent temperature gradients throughout the steady-state period.
- Onyx exhibited a stable and reliable thermal behavior, with effective thermal conductivity values aligned with those reported in the literature for polymer matrices reinforced with chopped fibers. Beyond its thermal performance, Onyx also showed strong mechanical stability, making it a promising material for applications requiring both structural strength and thermal control

Future Work

First Stage of the project:

- Perform mechanical stress tests on the selected topologies and materials
- Perform FEA validation of the thermal and mechanical results, comparing experimental heat-flow behavior with simulation outputs to assess model accuracy .
- Extended thermo-mechanical analysis to new lattice variations printed in Onyx and Nylon, identifying architectures with improved heat transfer and stiffness

Second Stage:

- Investigate reinforcement alternatives, such as localized fiber paths or CNT-enhanced filaments, to determine whether selective reinforcement can improve conduction or structural integration.
- Scale promising designs to functional applications, such as battery spacers or lightweight thermal management components, and evaluate their response under cycling and environmental loading

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