Thermo-Mechanical Structural Optimisation of a Chemical Propulsion Satellite Thruster Using Lattice Structures

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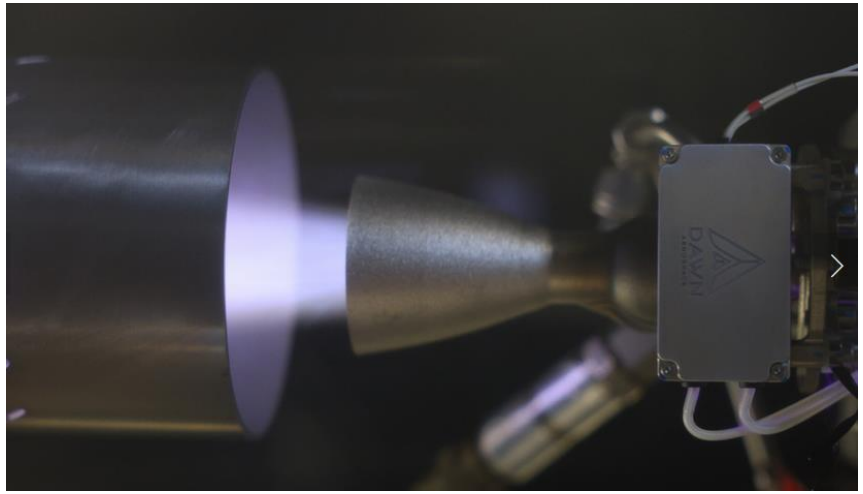
B20 Thruster

Small satellite applications



Advanced Design of High Entropy Alloys Based Materials for Space Propulsion

Funded by the Horizon 2020 Framework Programme of the European Union

Work motivation

- Small satellite space thrusters are designed to provide force for short time periods.
- New generation of thrusters will be made with High Entropy Alloy (HEA) materials.
- Predicting damage initiation for this kind of metallic structure subjected to thermal shock is of fundamental importance.
- The preliminary thermal-stress analysis is mandatory in order to understand the complex failure mechanism of the space thruster.
- An optimisation analysis of the material distribution along the combustion chamber thickness can lead to an improvement of the thermal-stress response.

B20 Thruster sketch

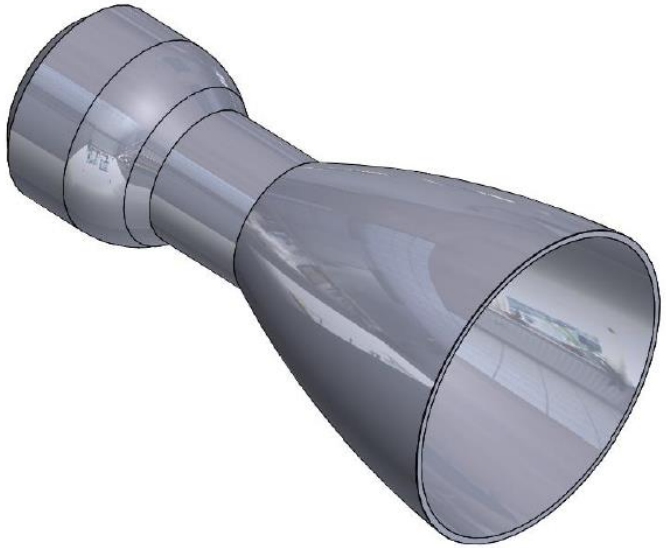
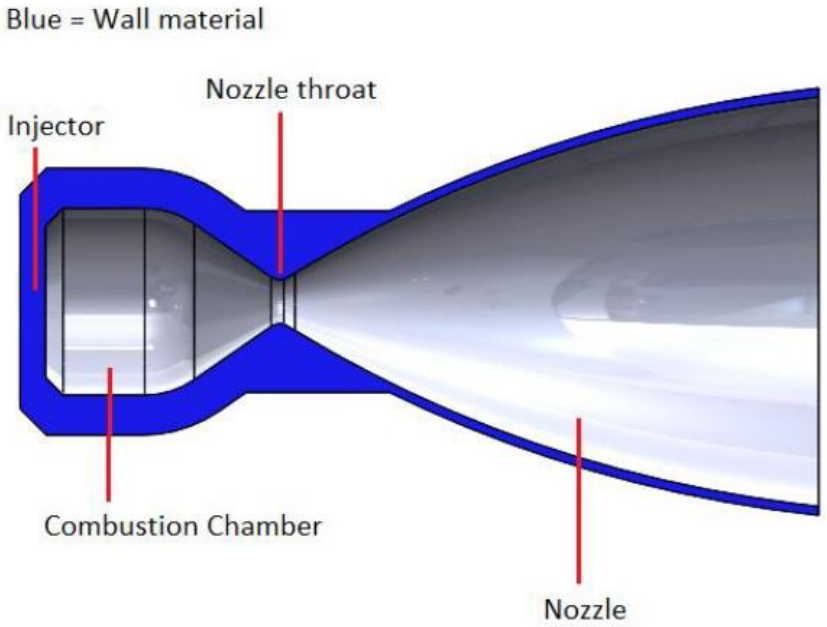


Figure 1: DA13-1



Design based on the following materials:

- C103 (Niobium-hafnium-titanium based)
- High Entropy Alloy (Refractory type, Molybdenum and niobium based)

Mechanical and thermal loads

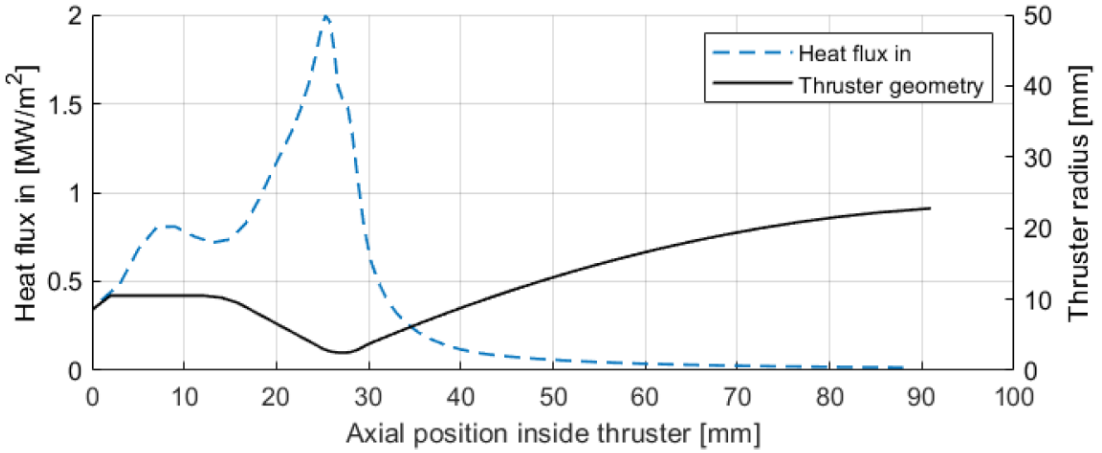


Figure 6: Heat flux distribution in thruster (At steady state, hot walls)

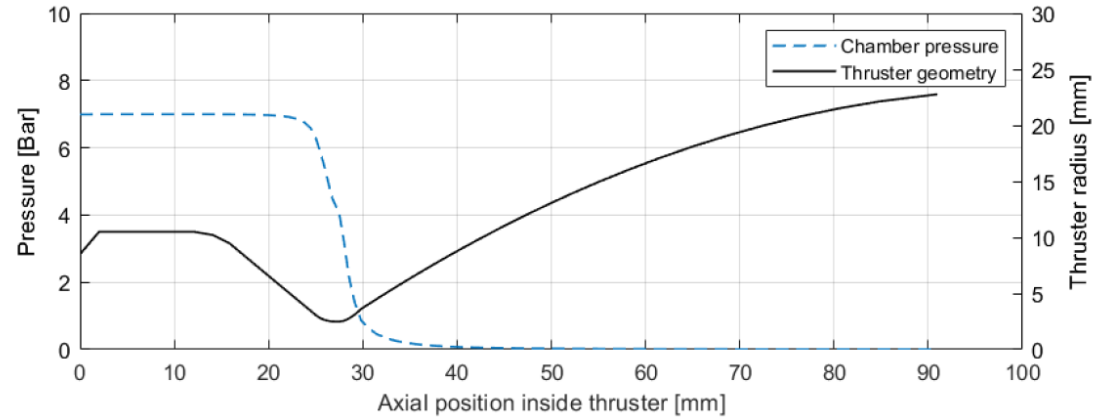
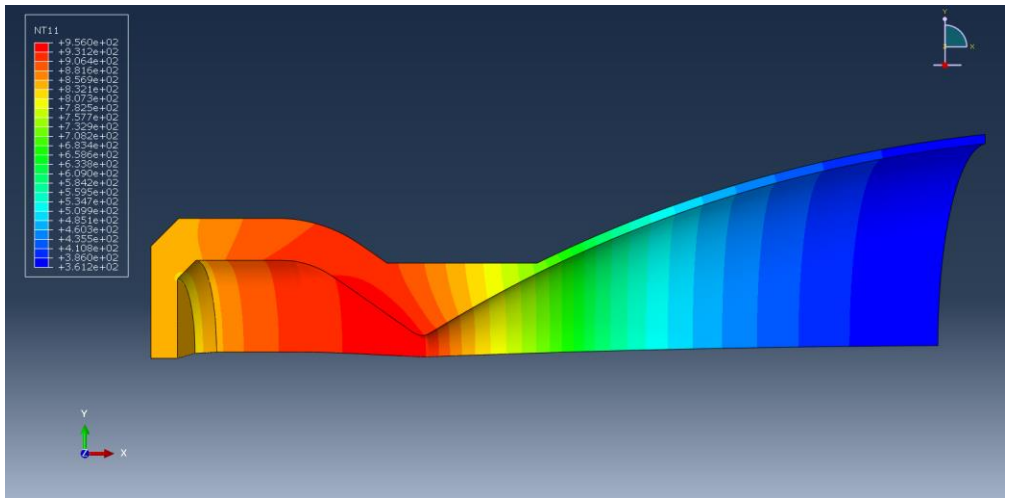
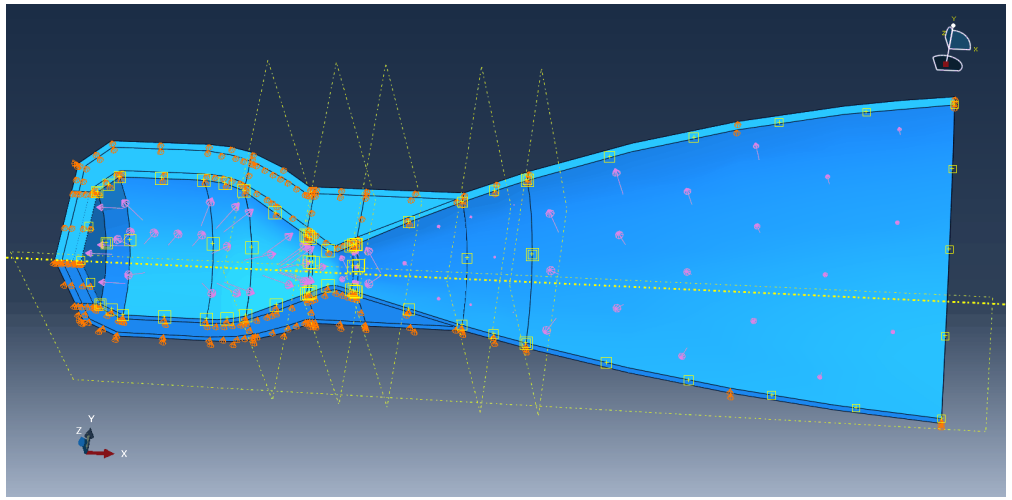
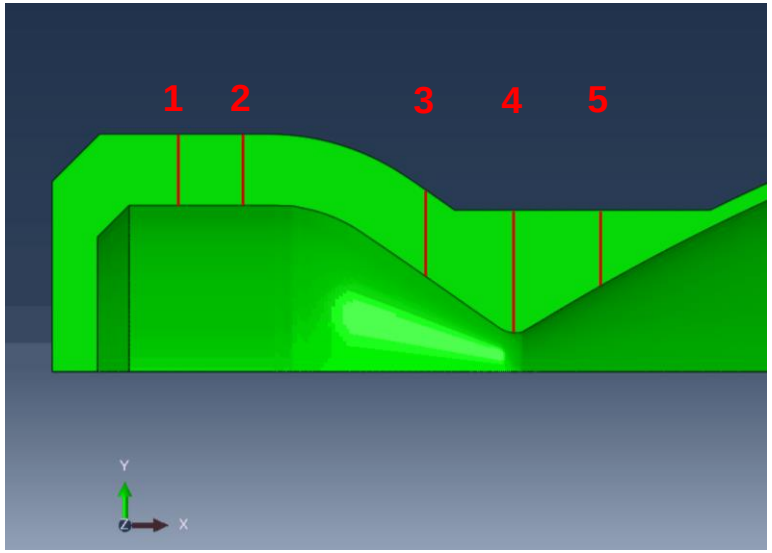


Figure 4: Pressure distribution in thruster (Maximum expected operating pressure)

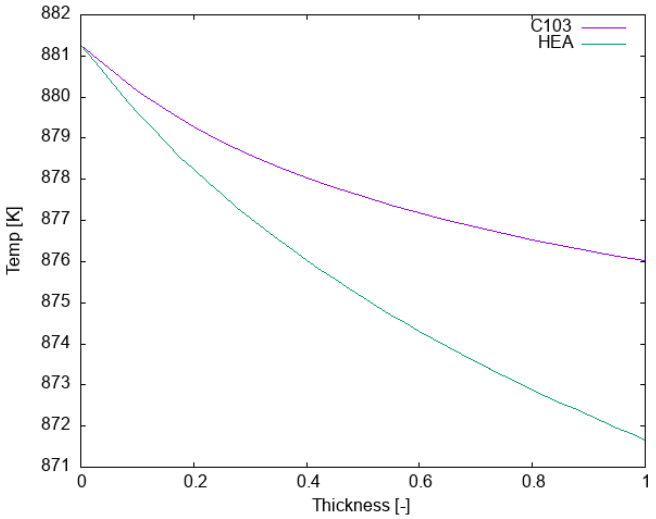




Temperature



1



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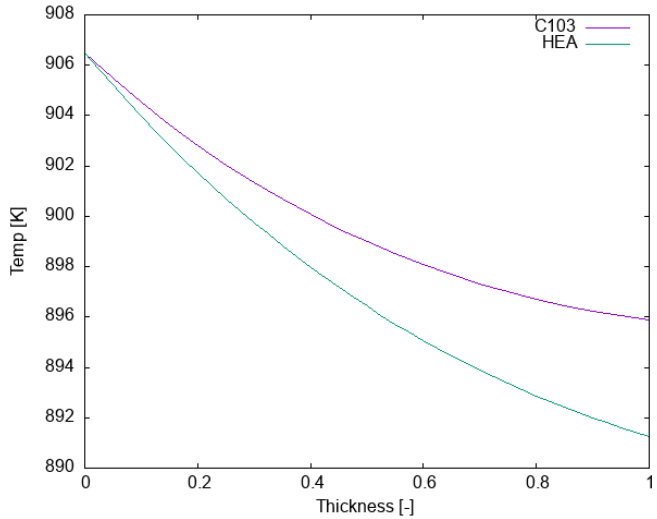

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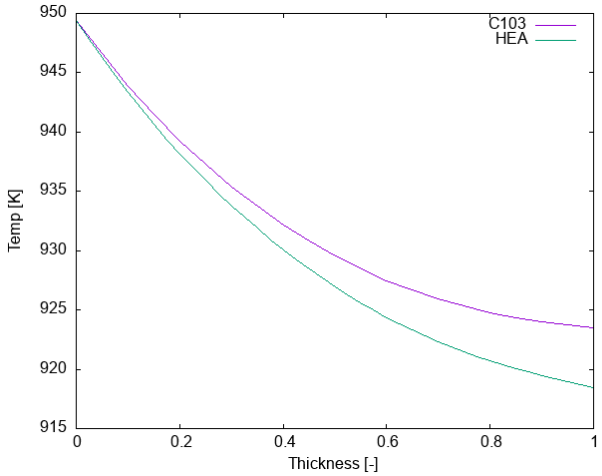

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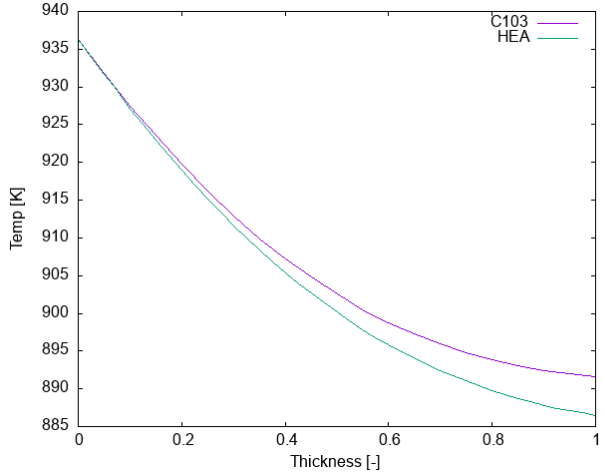

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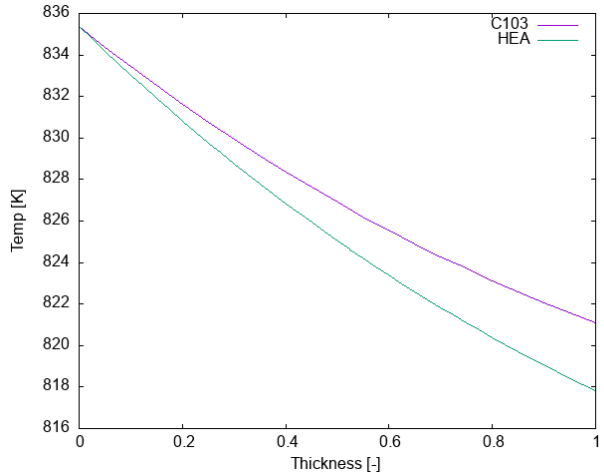
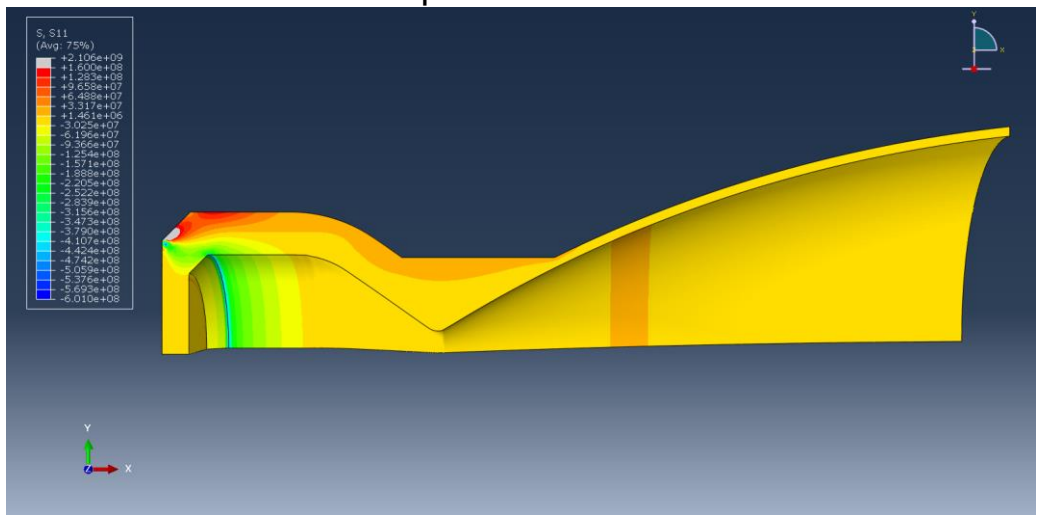
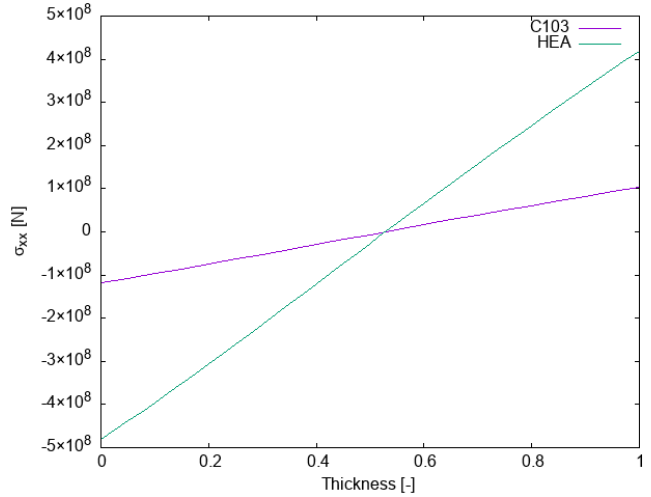


Axial stress

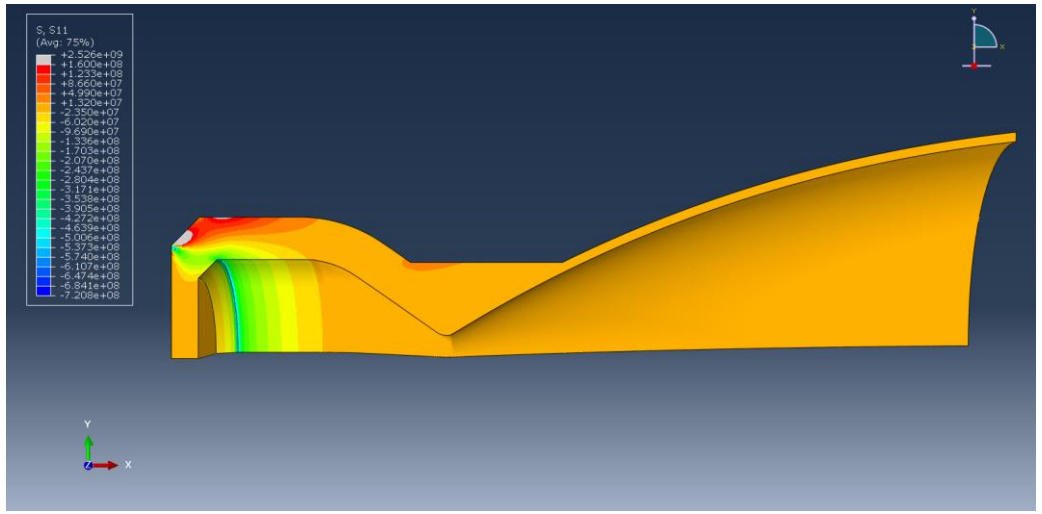
Temperature load 50 %

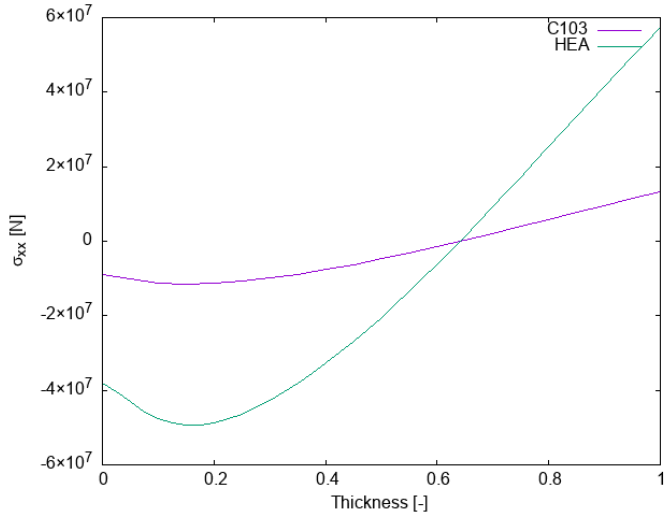




Combustion chamber

Temperature load 60 %

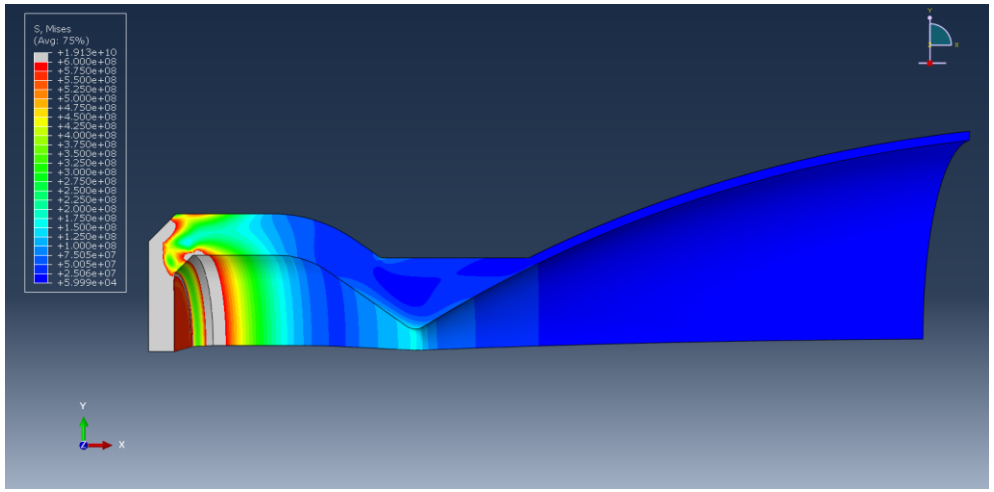


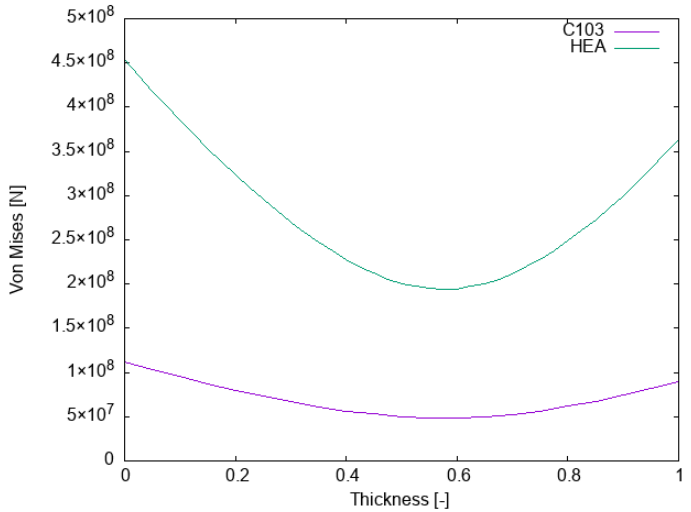


Throat

Von Mises stress

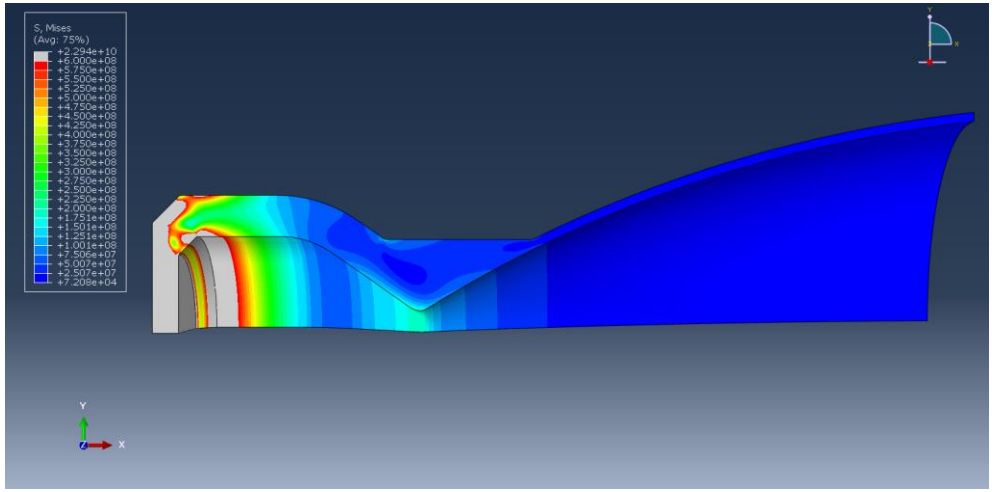
Temperature load 50 %

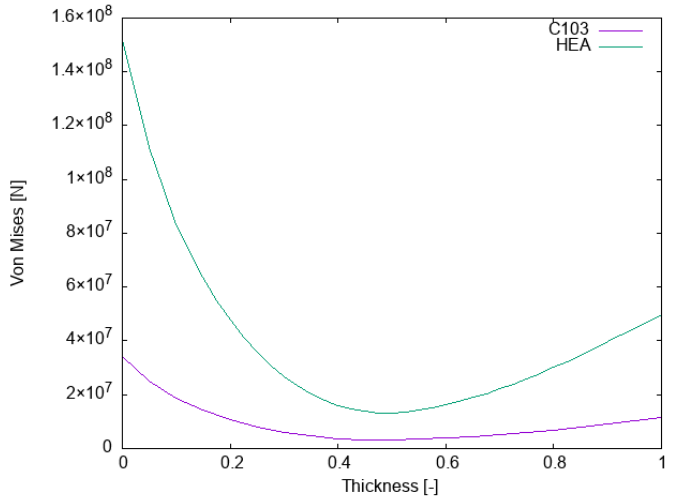




Combustion chamber

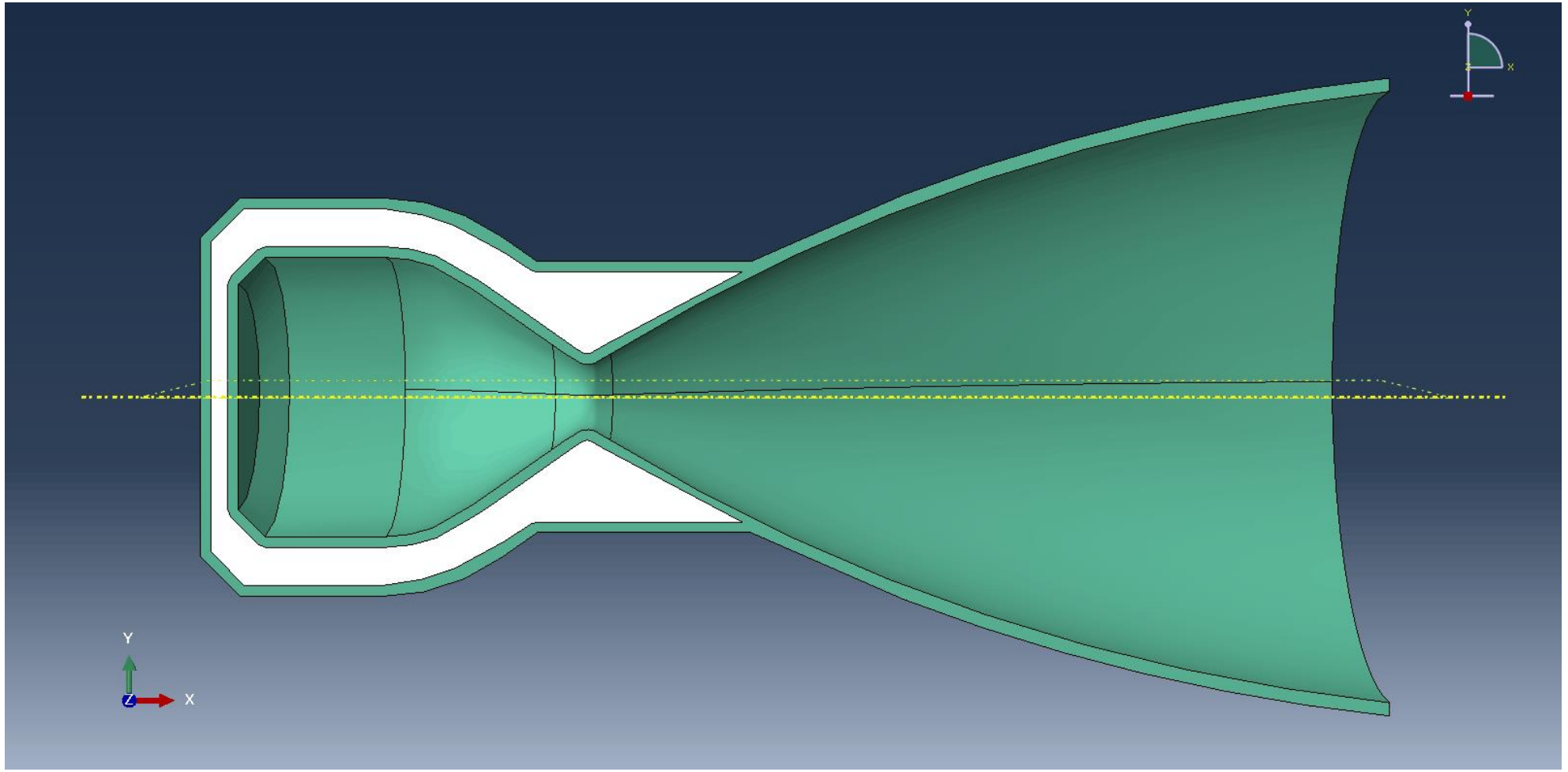
Temperature load 60 %



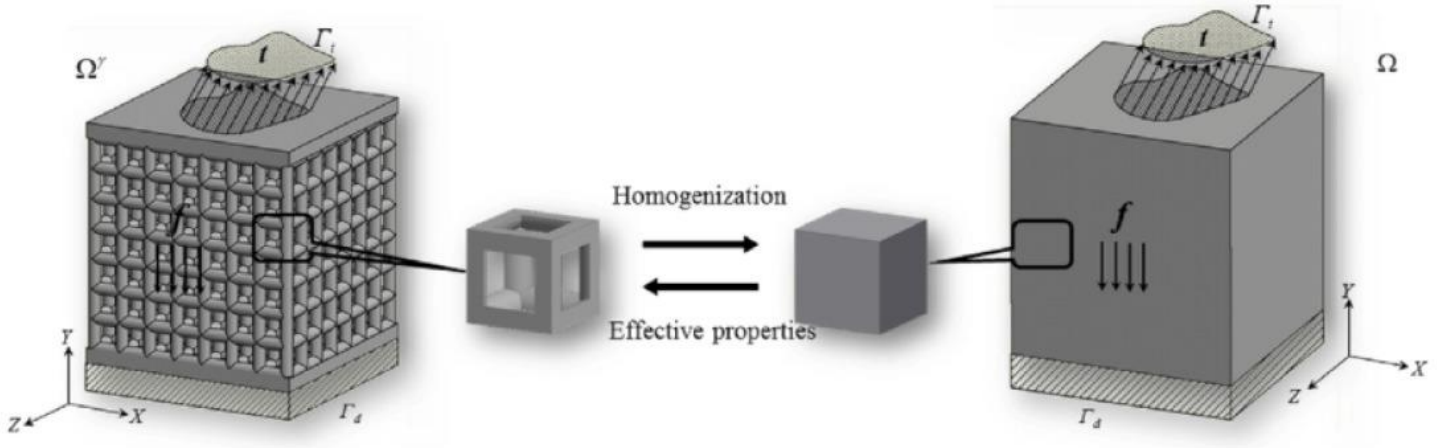


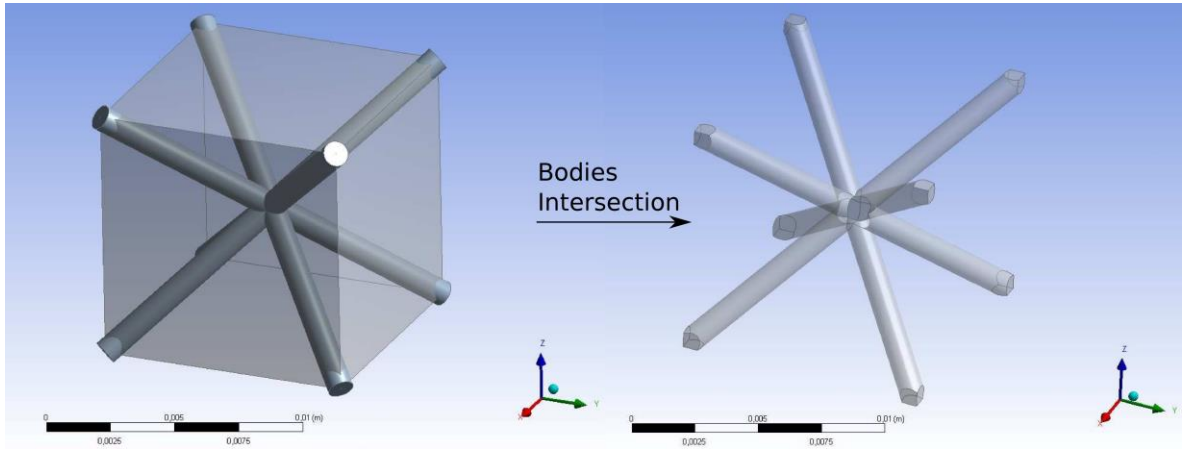
Throat

Lattice structure zone definition

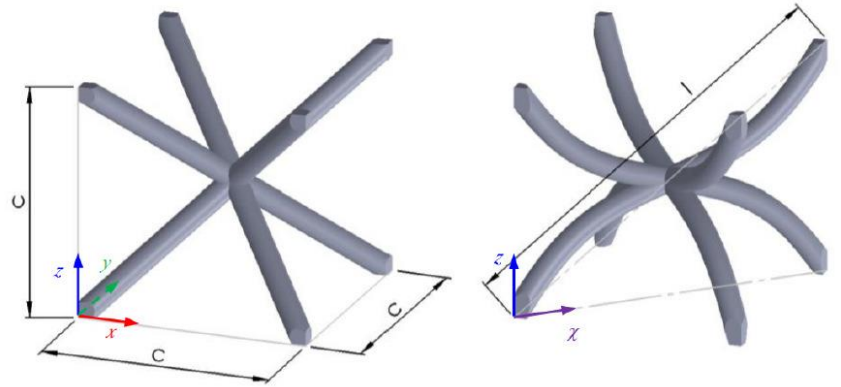


Homogenisation procedure

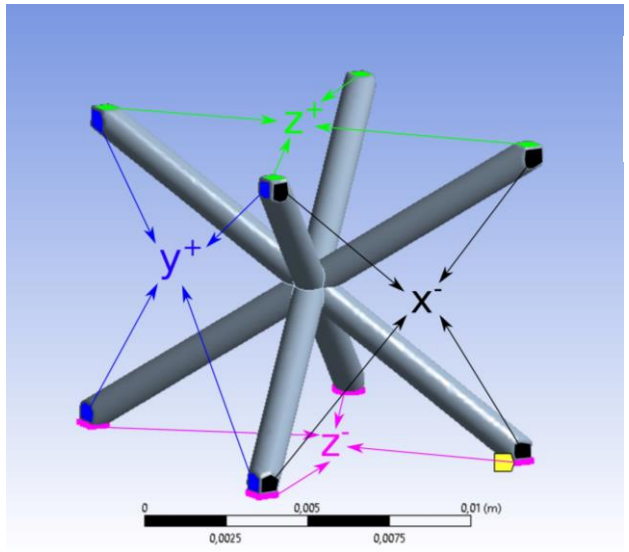




Struts waviness concept



Homogenisation procedure



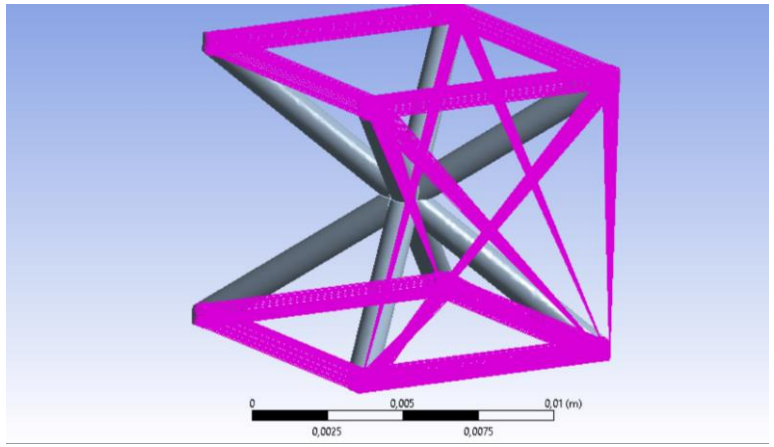
$$\sigma^{z}_{equivalent} = \frac{\sum F^{z}_{reaction}}{A_{equivalent}} \qquad \sigma = E\epsilon$$

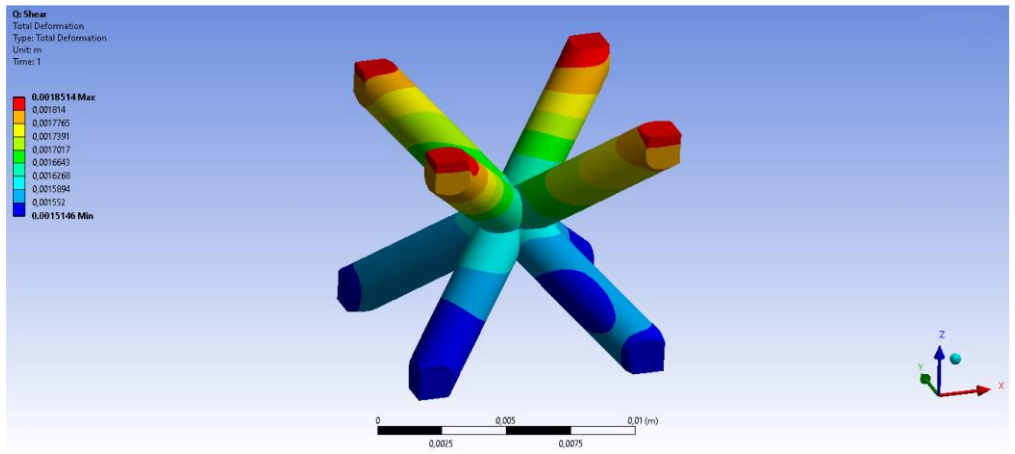
$$\tau^{zx}_{equivalent} = \frac{\sum F^{zx}_{reaction}}{A_{equivalent}} \qquad \tau = G\epsilon$$

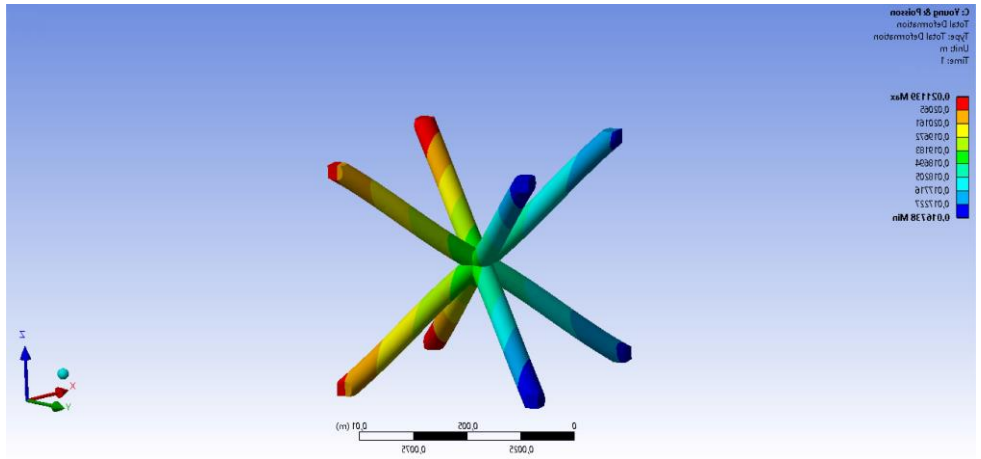
$$\nu = -\frac{\epsilon_{transverse}}{\epsilon_{loading}}$$

$$q = \kappa \frac{\Delta T}{d} \qquad \epsilon = \alpha \Delta T$$

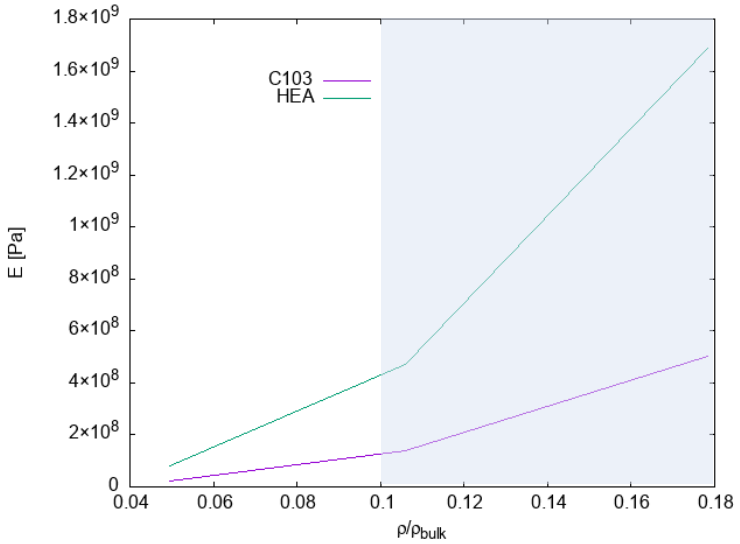
$$u_i^+ - u_i^- = \Delta \quad ; \quad \Delta = u_{ref}^+ - u_{ref}^-$$

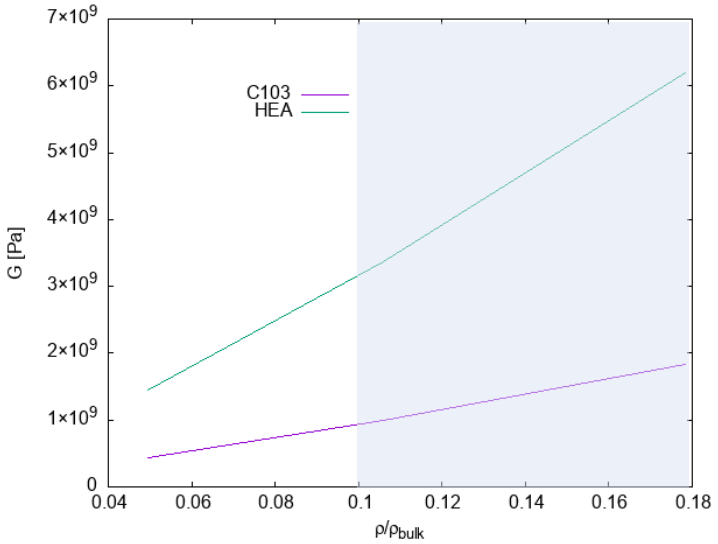


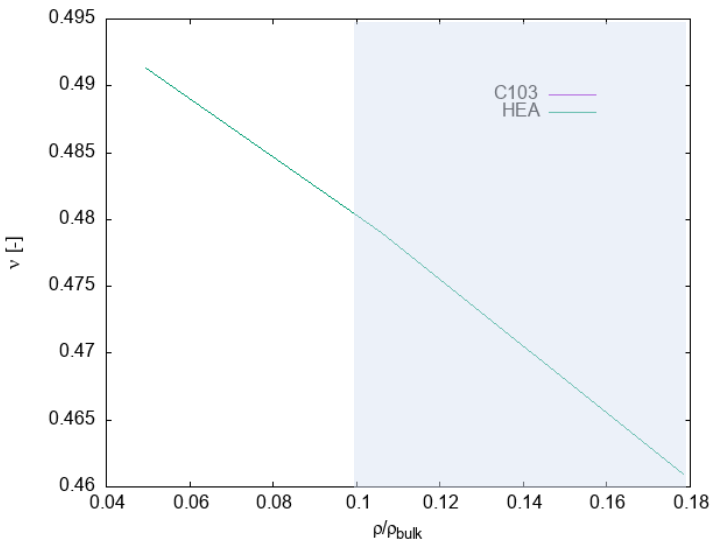


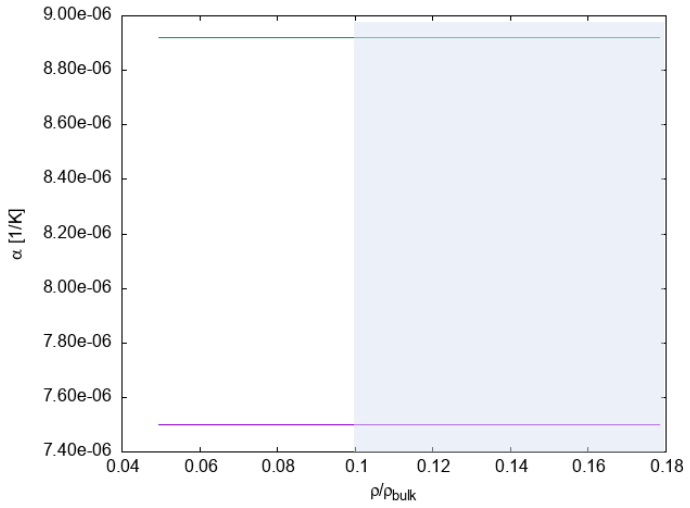


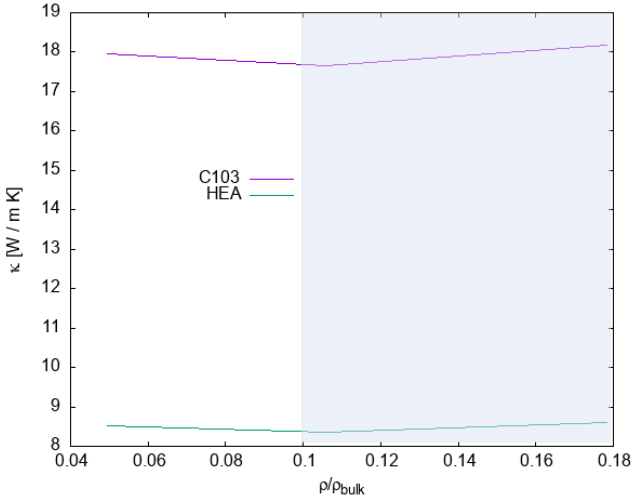
Homogenised thermo-mechanical properties of the BCC cell







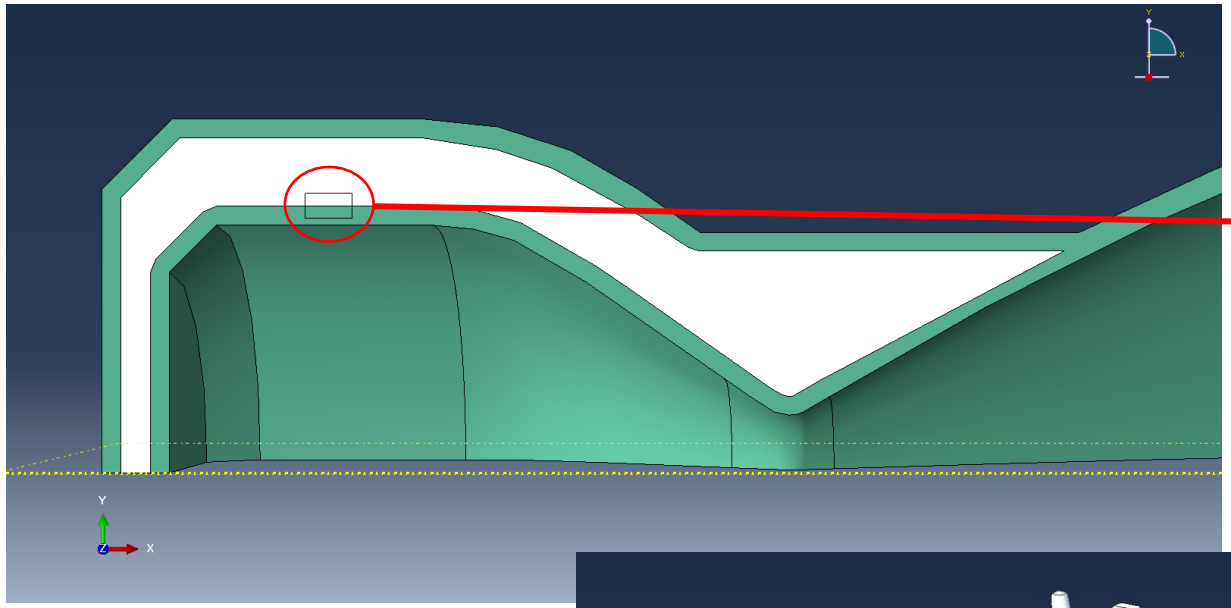




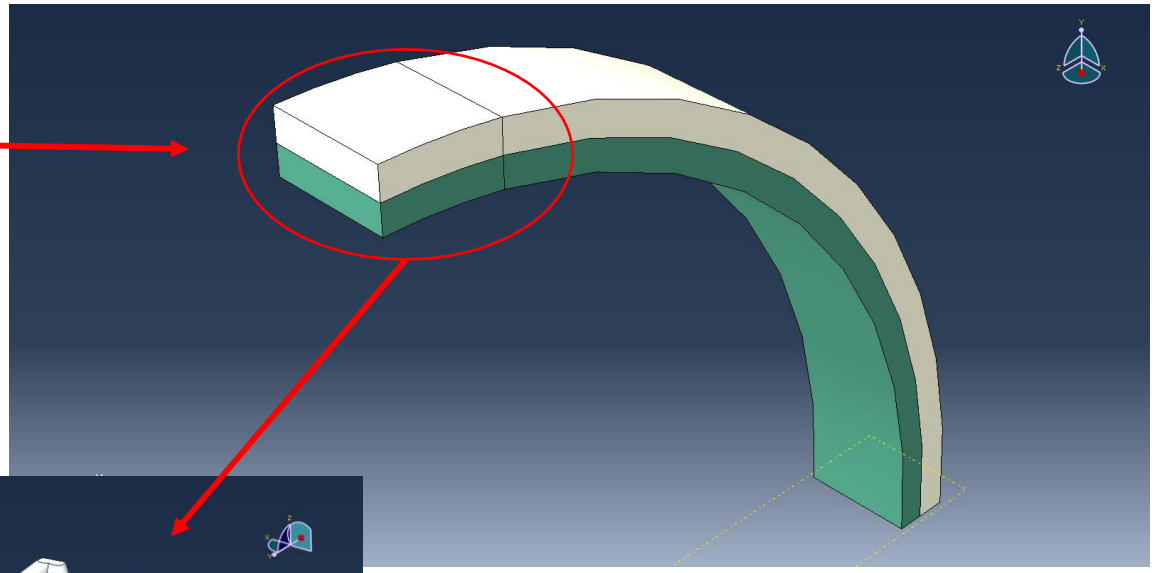
Typical lattice density for industrial applications

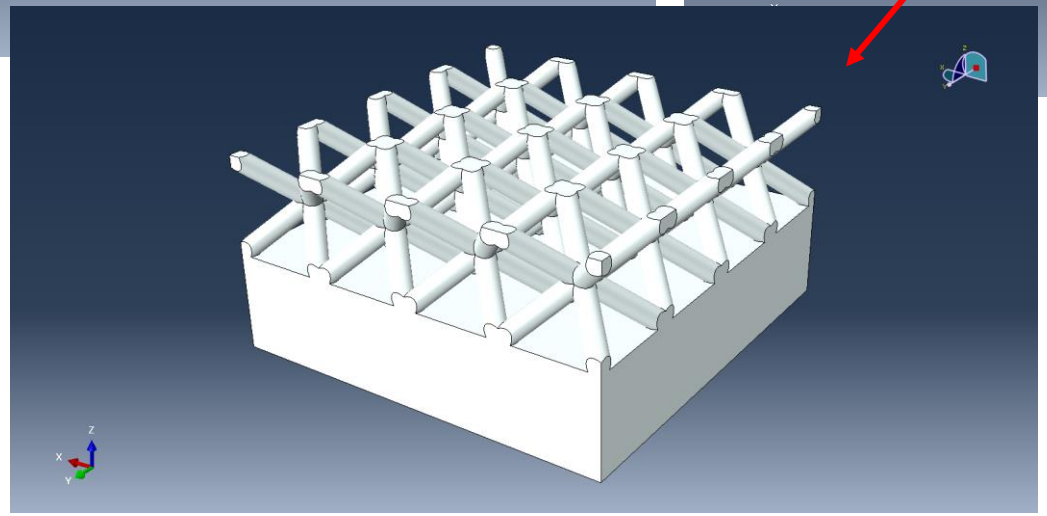
Multiscale analysis

Step 1



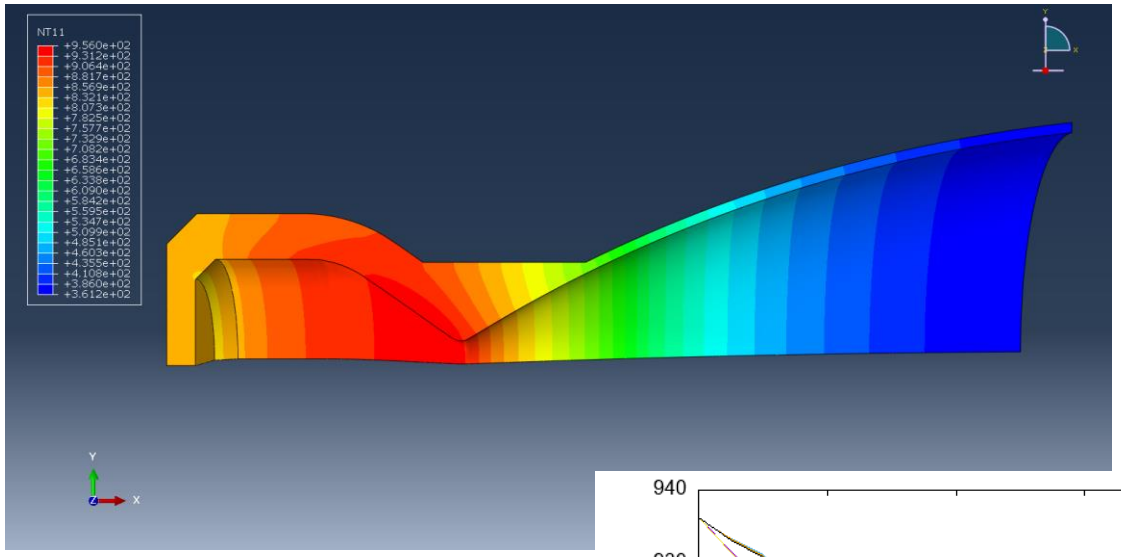
Step 2

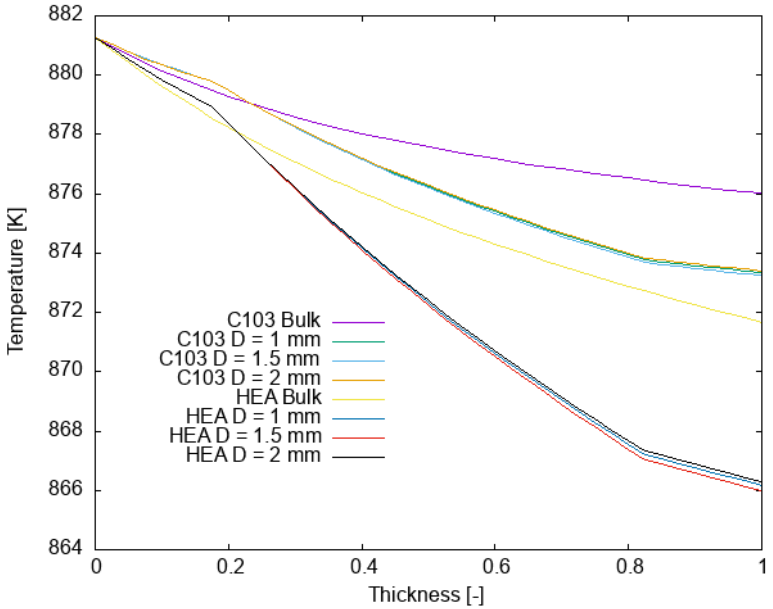




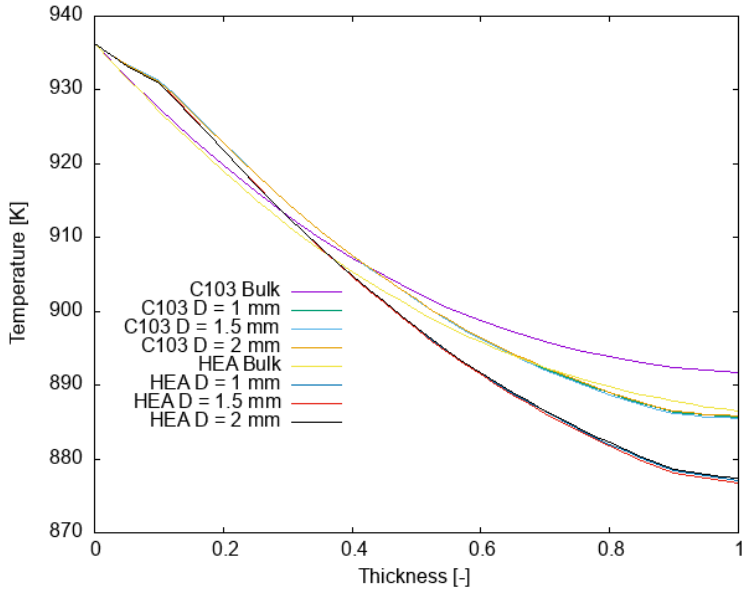
Step 3

Temperature





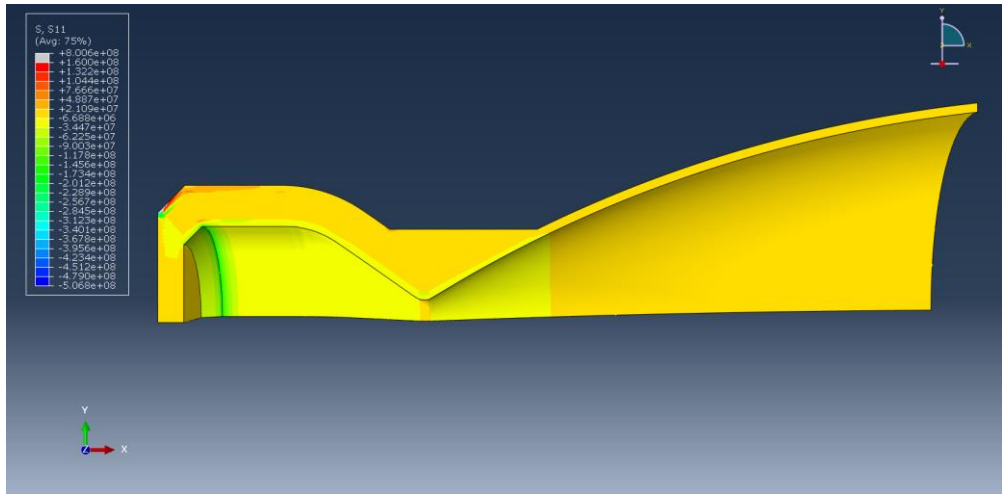
Combustion chamber

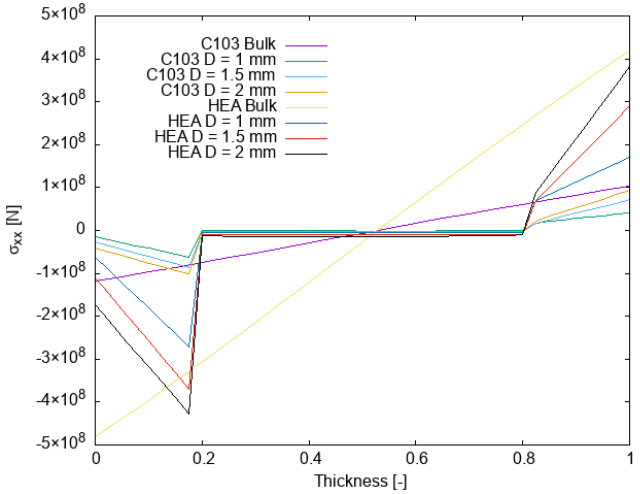


Throat

Axial stress

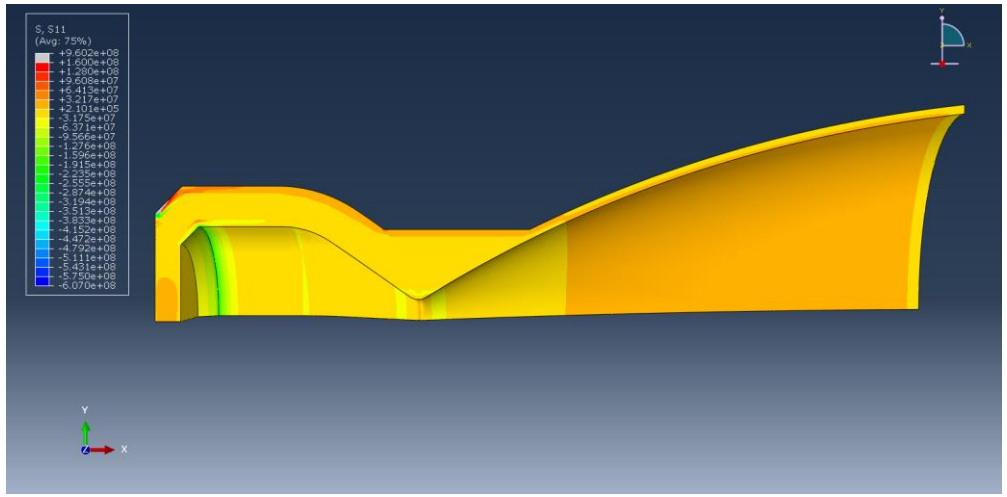
Temperature load 50 %

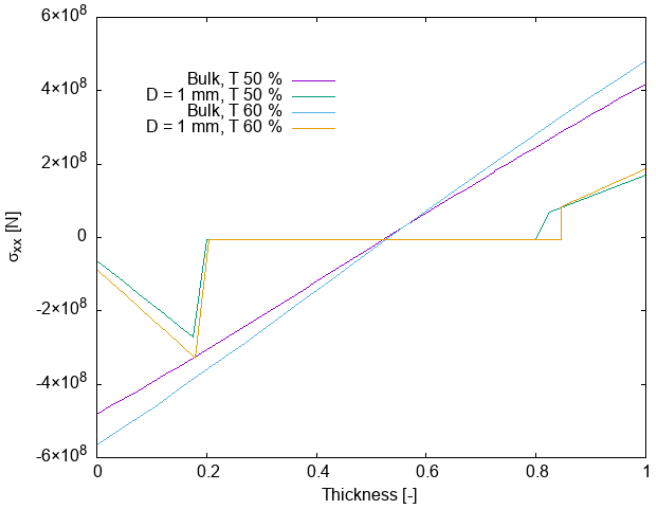




Temperature load 50 %

Temperature load 60 %

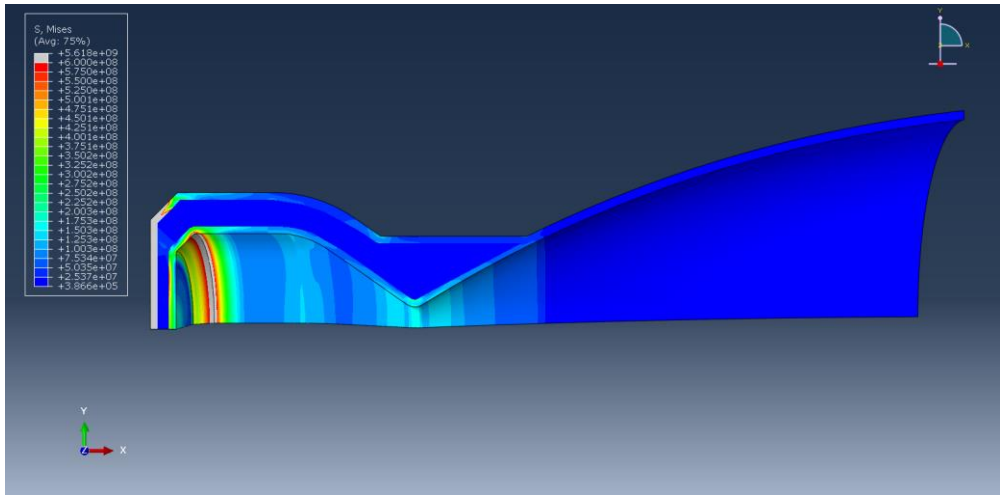


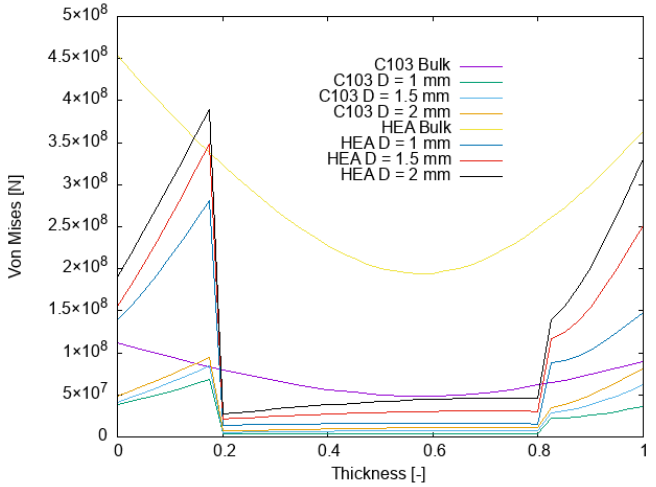


HEA material

Von Mises stress

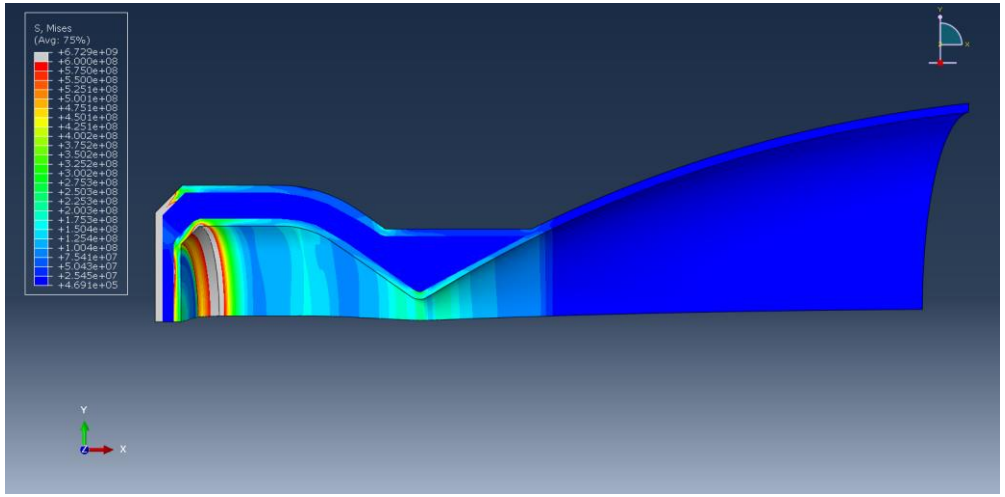
Temperature load 50 %

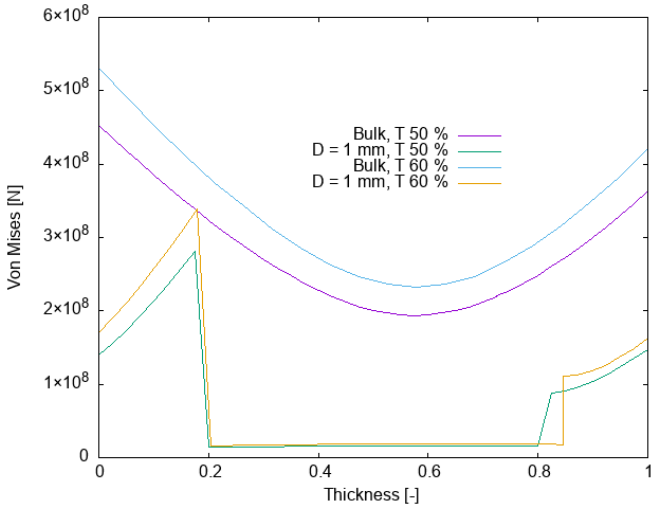




Temperature load 50 %

Temperature load 60 %

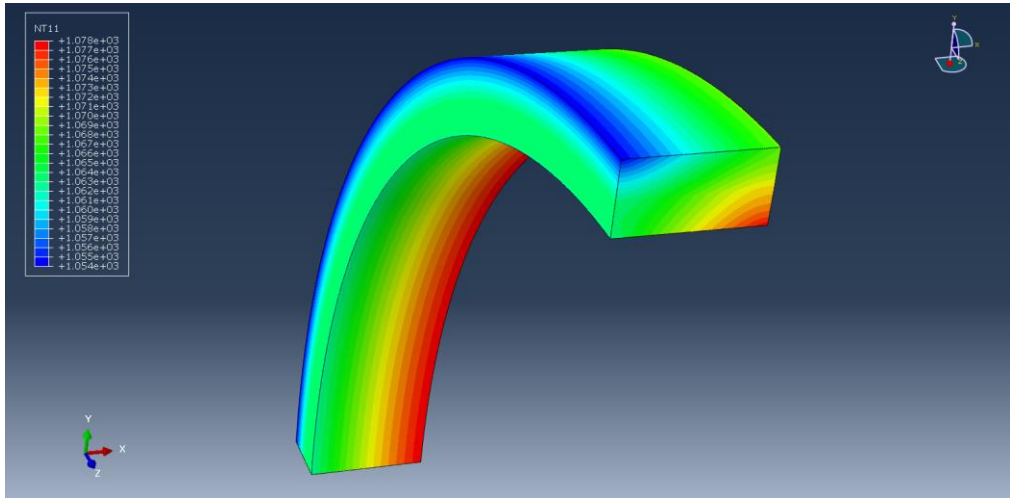




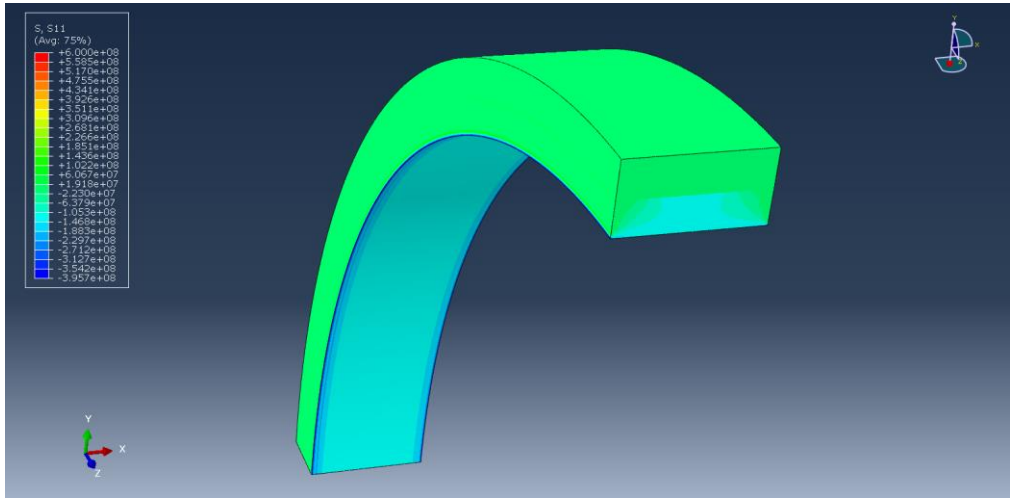
HEA material

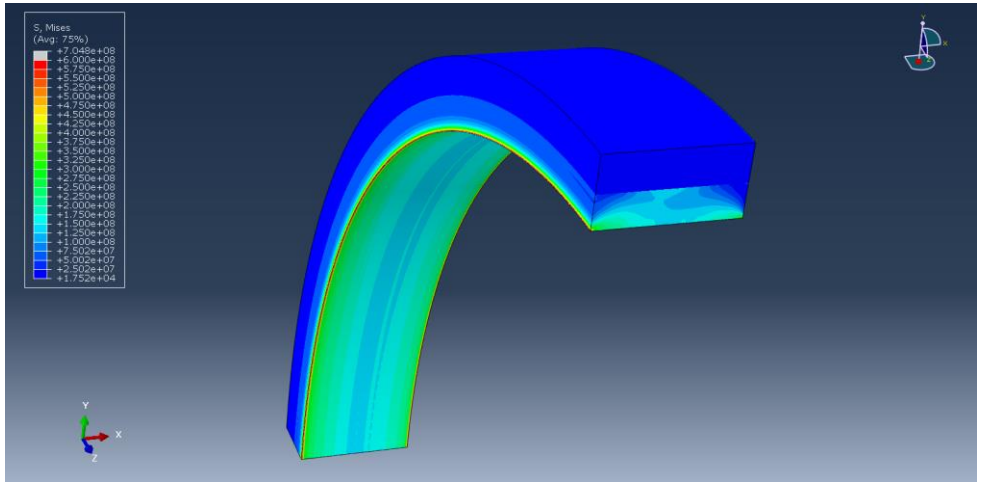
Multiscale- step 2

Temperature



Axial stress

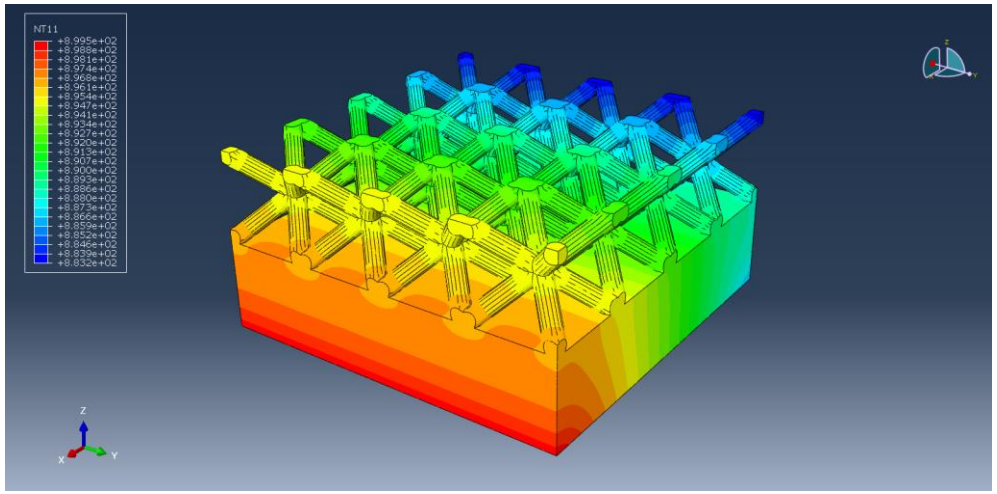




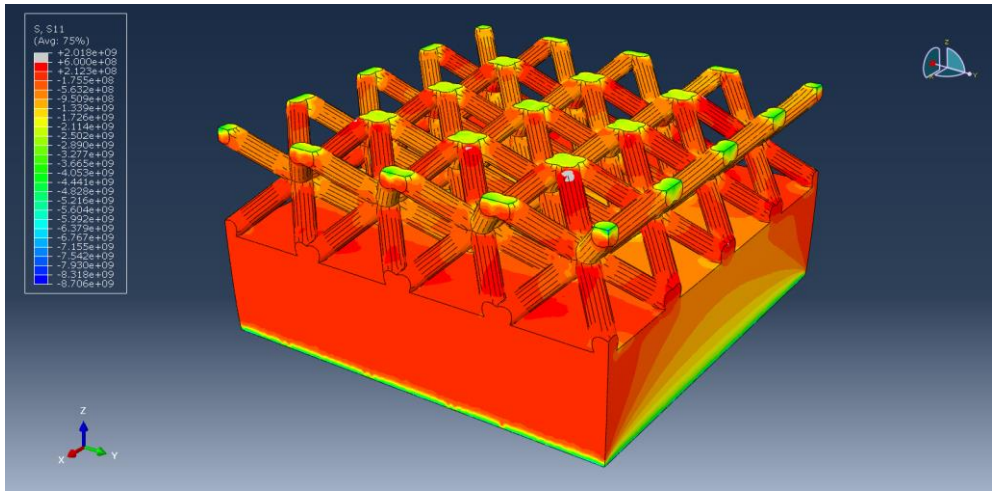
Von Mises stress

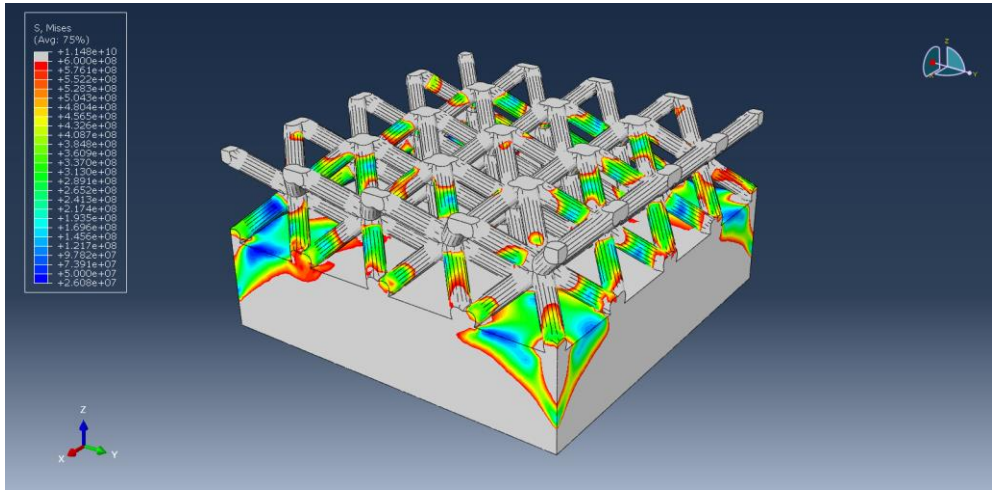
Multiscale- step 3

Temperature



Axial stress





Von Mises stress

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Conclusions

- The High Entropy Alloy (HEA) materials are a powerful design option for structures which works in harsh environments and with high thermal-stress loads.
- Lattice structures are an ideal candidate for the weight reduction optimisation of aerospace structures.
- Homogenisation numerical techniques are necessary in order to speed up the analysis on the macroscale of the space thruster.
- The use of lattice structures permits to reduce the thermal load transmitted along the combustion chamber thickness.
- In future work the plastic response and damage initiation of the lattice cells will be evaluated and an optimisation on the lattice architecture will be conducted.


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