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Comparison of the thermomechanical performance of tubular absorber geometries for CSP

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PROMES



Introduction

- ▶ CSP will play a role in the energy transition: it is expected to produce 13–15% of the world's electricity by 2050 [1].
- ▶ The SiCSun project aims to increase the temperature of solar power plant receivers (>900 °C) in turn to improve the conversion efficiency of these plants.
- ▶ Reaching such high temperatures requires the use of more efficient materials. Silicon carbide (SiC) appears to be a good candidate [2].
- ▶ It is also necessary to obtain a high heat exchange coefficient between the heat transfer fluid and the high absorber tube: use of a fluidised particle bed [3].

Objectives:

- ▶ Determining the appropriate receiver geometry
- ▶ Minimising the probability of rupture
- ▶ Identifying areas of concentrated stress

SiCSun receiver model

insolated area
fluidised bed
SiC tube

particules outlet (900 °C)

particules inlet (300 °C)

Control settings:

- ▶ irradiance
 $E_{\text{solar,e}} = 320 \text{ kW m}^{-2}$
- ▶ particle temperature exponential profile
 $T_{\text{p,in}} = 300 \text{ °C}$
 $T_{\text{p,out}} = 900 \text{ °C}$
- ▶ part. | tube exchange coef.
 $h_{\text{p|t}} = 1200 \text{ W K}^{-1} \text{ m}^{-2}$

Losses modeling:

- ▶ natural convection:
 $\Phi_c = hS\Delta T$
 $h_{\text{pc}} = \frac{1}{2} Gr^{\frac{1}{4}} \frac{\lambda}{L_{\text{wall}}}$
 $h_{\text{pc}} = 7.5 \text{ W K}^{-1} \text{ m}^{-2}$
- ▶ radiative:
 $\Phi_r = \epsilon\sigma(T_{\text{wall}}^4 - T_{\infty}^4)$

Probability of rupture:

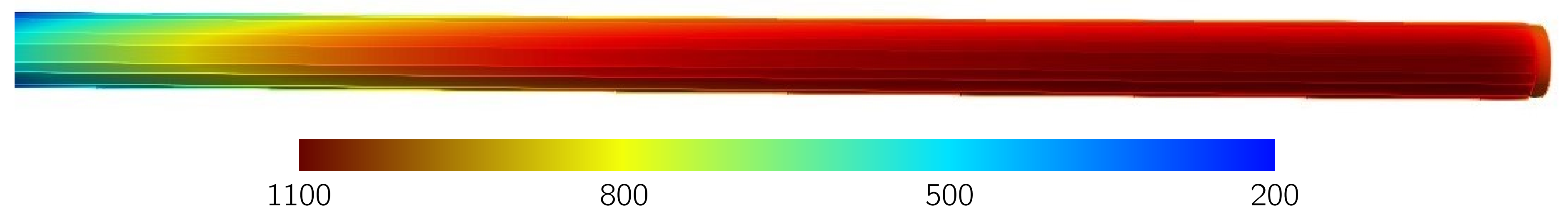
- ▶ Weibull model
 $P_r(\sigma) = 1 - e^{-\frac{V_{\text{tube}}}{V_0} \left(\frac{\sigma_m}{\sigma_0}\right)^\omega}$

Modeling conditions:

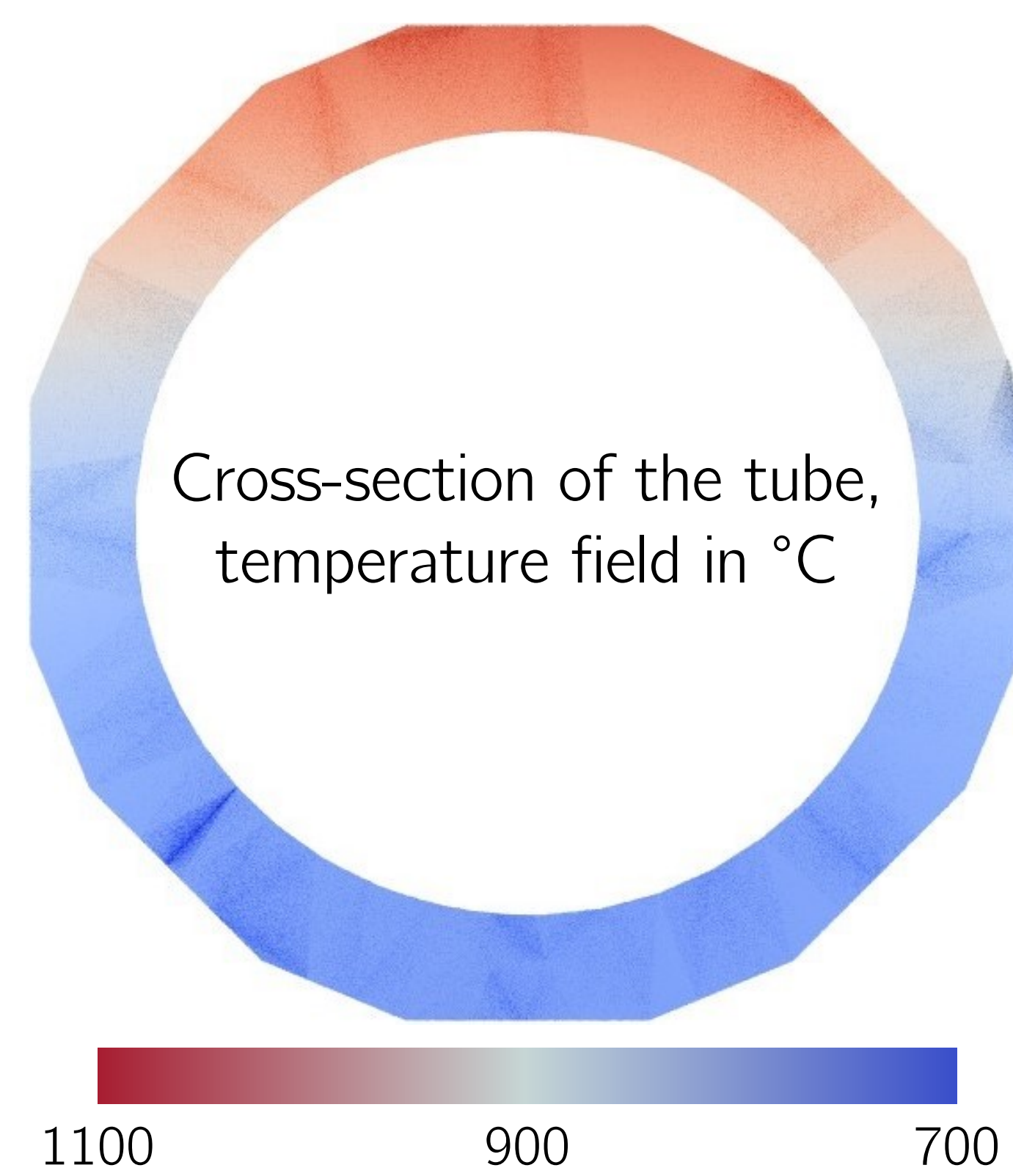
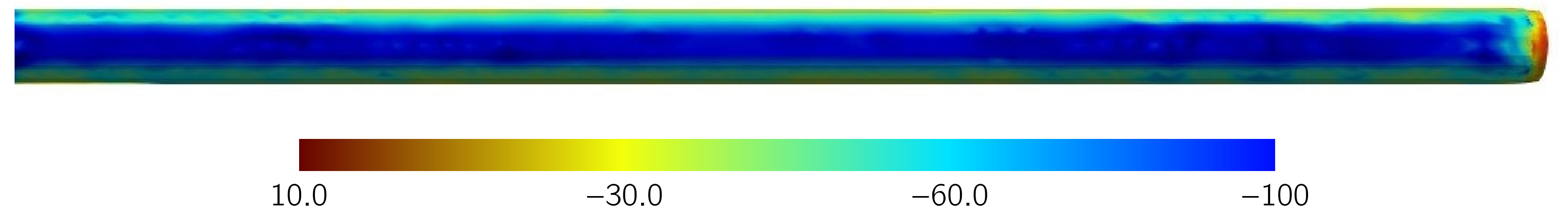
- ▶ unidirectional solar flux
- ▶ off-centred geometries insolated on thin side

General view of temperature and stress fields for a centred hexadecagonal tube

View of the insolated side, temperature field in °C

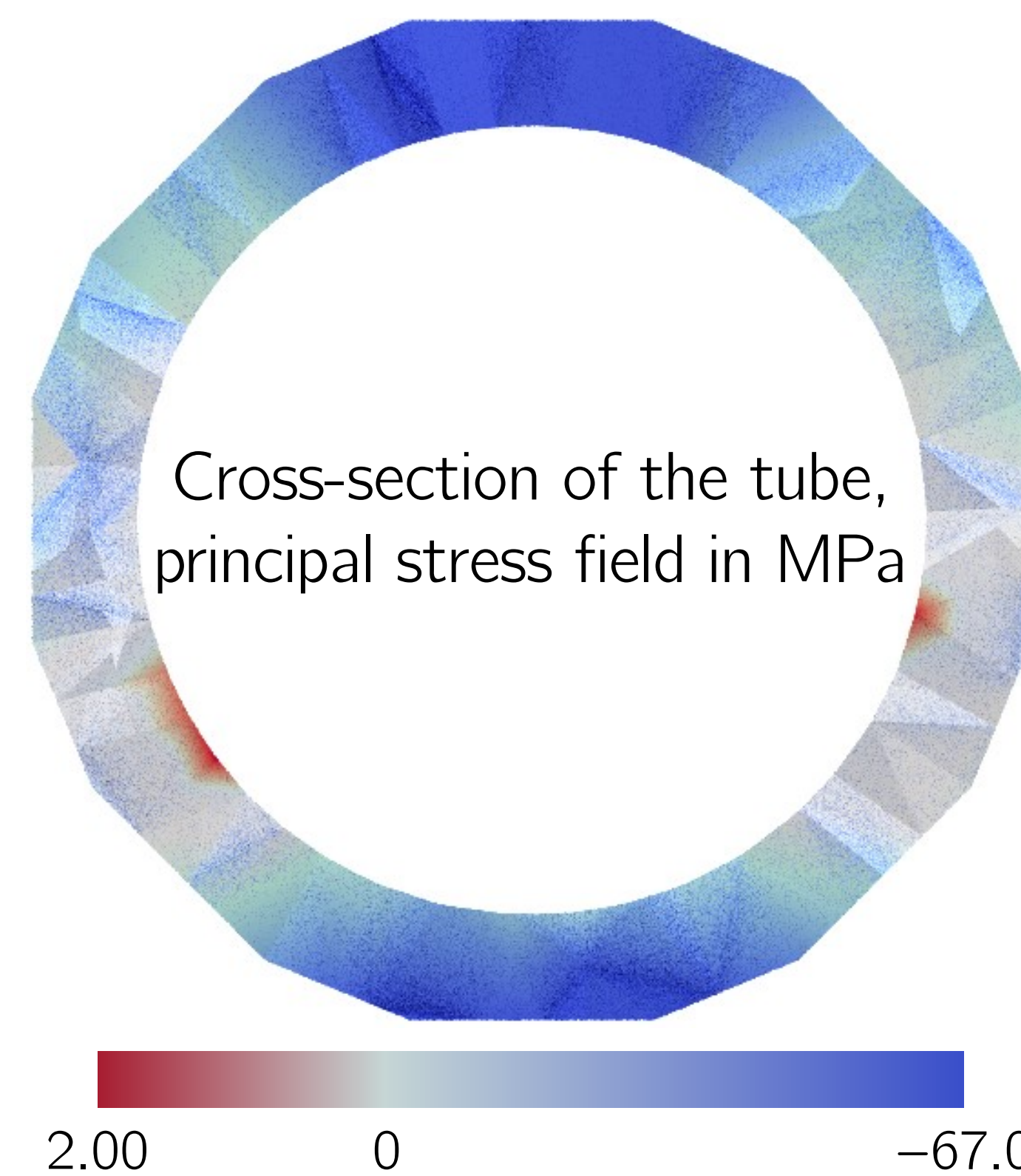


View of the insolated side, stress field in MPa



- ▶ Maximum temperature of 1100 °C
- ▶ No significant radial temperature gradient
- ▶ Temperature difference of about 400 °C between the insolated side and the back of the tube
- ▶ Maximum stress of $-1.0 \times 10^8 \text{ Pa}$ (tensile stress)
- ▶ Homogeneous stress distribution on the insolated side

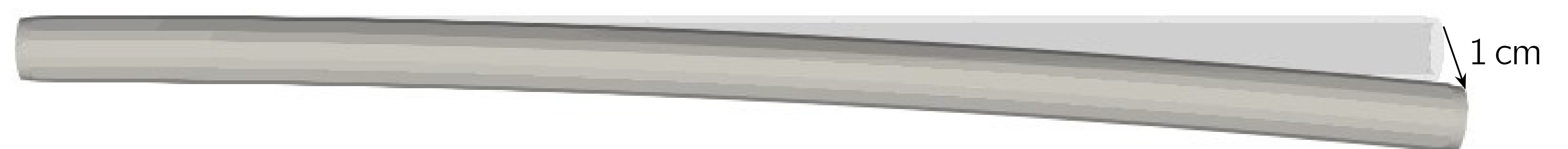
Summary of results



Geometry	Principal stress	Probability of rupture
Octagon	Centred	108 MPa
	Off-centred	114 MPa
Hexadecagon	Centred	103 MPa
	Off-centred	119 MPa

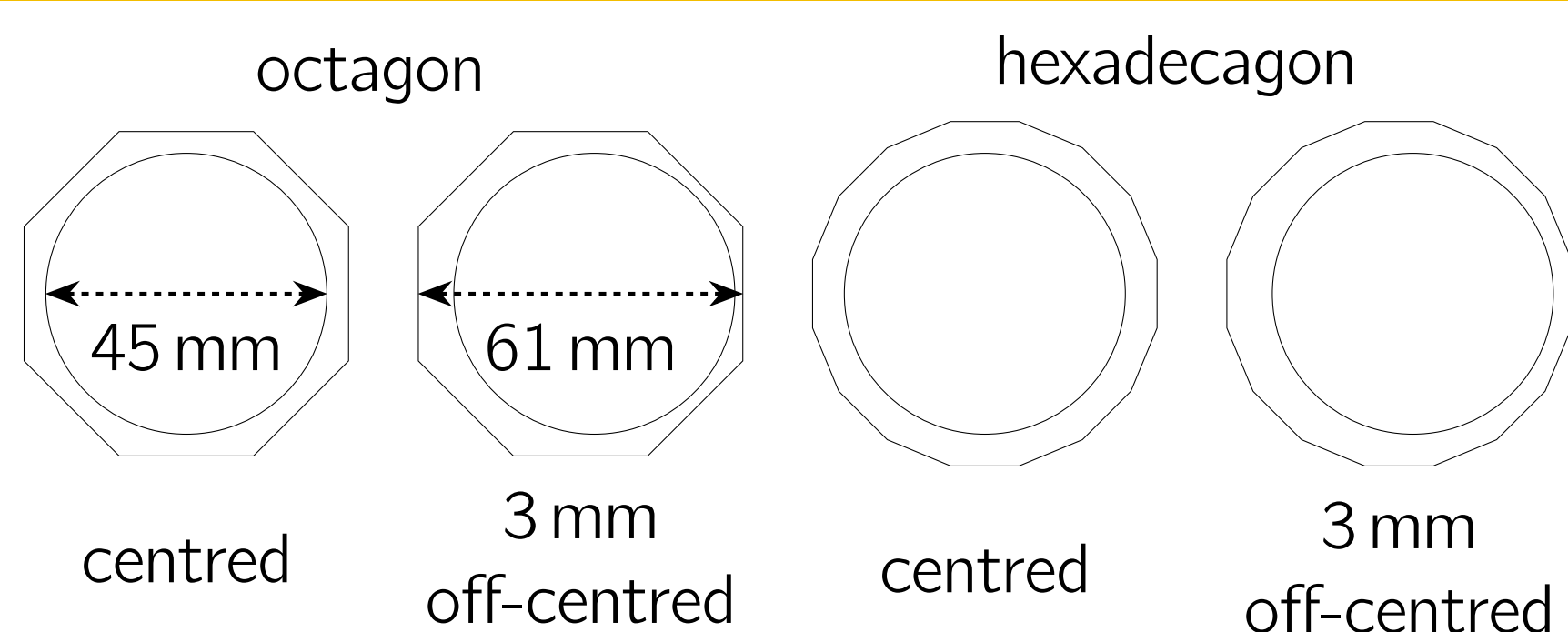
Summary of modeling results for different geometries

- ▶ Very few compression zones (in red)
- ▶ Majority of tensile stress
- ▶ Highest stresses on insolated and rear side



Overall deformation in relation to the reference position, the deformation is exaggerated.

Achievable geometries with Boostec®



Bibliography

- [1] P. Viebahn *et al.*, "The potential role of concentrated solar power CSP in Africa and Europe—A dynamic assessment of technology development, cost development and life cycle inventories until 2050" . In: *Energy Policy* 39.8 (2011), pp. 4420–4430.
- [2] Florian Bonzoms *et al.* "Thermomechanical characterization of brazed SiC assemblies for receivers of CSP plants" . *Solar Energy Materials and Solar Cells*, vol.266, pp. 112697, 2024.
- [3] Cédric Leray *et al.* "Design and proof of concept of an innovative very high temperature ceramic solar absorber" . *SolarPaces* 2016, vol.266, pp. 030032, 2017.

Conclusion

- ▶ The maximum stress is a tensile stress, which reaches -100 MPa , but is still far below the tensile strength of SiC (about 210 MPa)
- ▶ Compressive stresses are negligible compared to the compressive strength of SiC (about 3 GPa)
- ▶ The insolated side and the opposite side are the two areas mainly under tensile stress
- ▶ Global deformation is about 1 cm in all situations
- ▶ Centred geometries generate less stress than off-centred ones
- ▶ The centred hexadecagon outperforms other geometries

Outlook and advice

- ▶ The tube must have as many faces as possible and a centered geometry
- ▶ The rear panel should be insolated to prevent radiative losses and reduce the temperature gradient between the front and rear panels
- ▶ Absorber tube fastening system must allow for deformation of at least 1 cm