8th AIGE-IIETA INTERNATIONAL CONFERENCE
AND 18th AIGE CONFERENCE

Thermal gradients - evaluations for the receiver of a disc solar concentrator

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Objective of the work

- Preliminary tests on the disc concentrator - chemical looping for syngas production
- Material selection to work at high temperature with high variability of temperature gradients (metal alloys)

Preliminary work on the chemical looping using a Solar Concentrator

Solar Power

Methane
(eventually)

Chemical Looping
by making use of iron oxides

Concentrating solar power facility
on the Energy Center rooftop

Hydrogen or a syngas

H_2

Reduction Reaction

Suitable range of temperature for pure reduction is between 1400-1600° C [4].

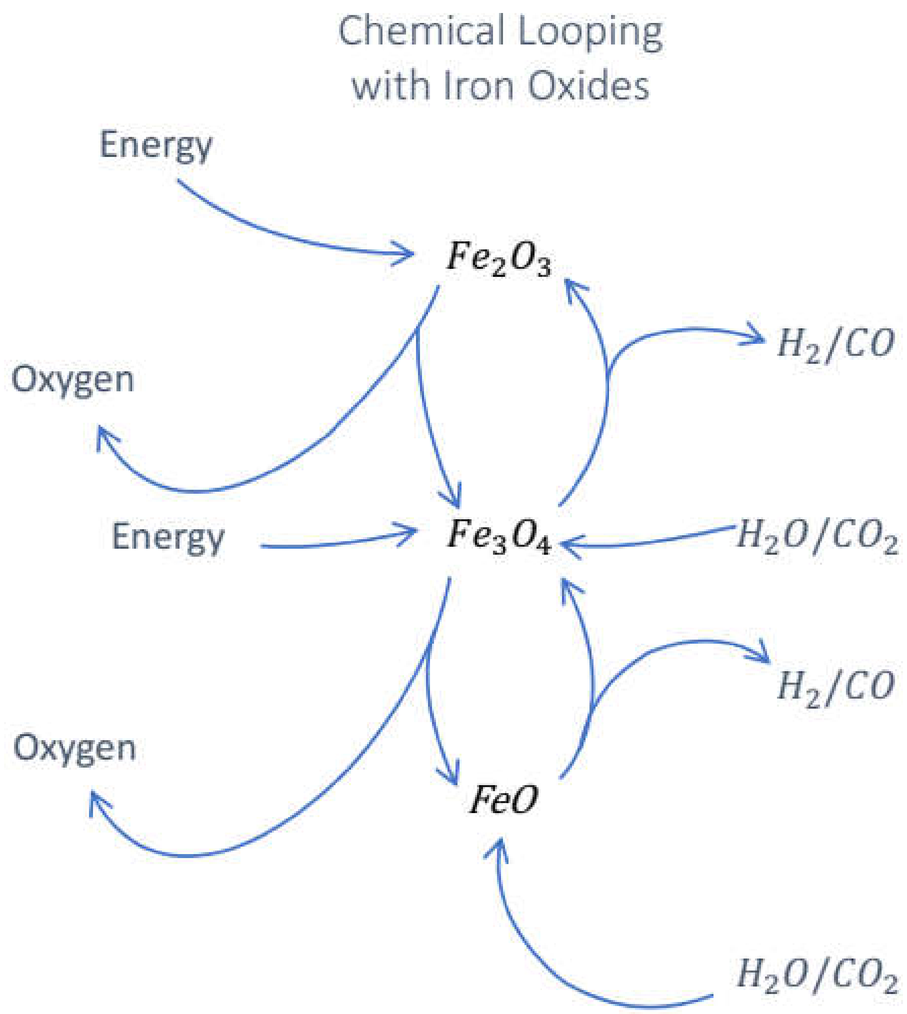
Complete reaction from Fe3O4 to FeO has zero Gibbs free energy around 2400 °C in air [5].

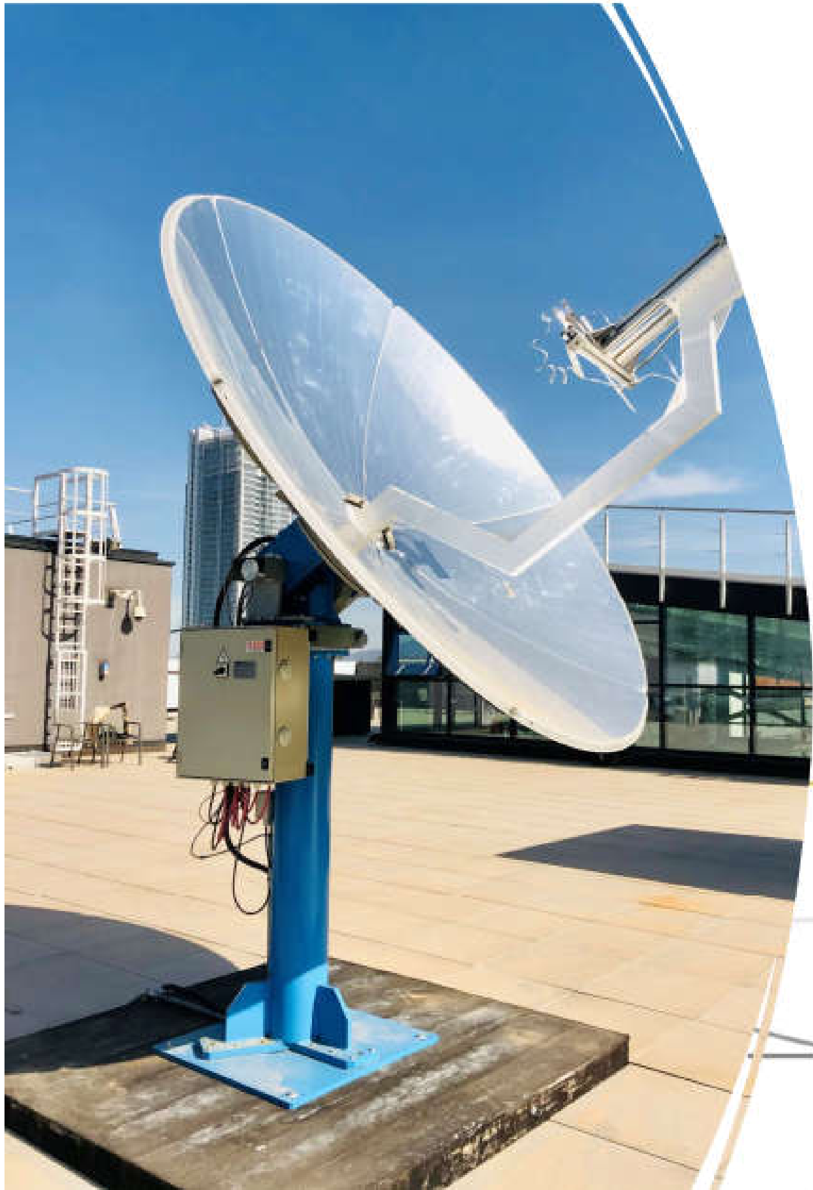
By adding methane to the reducing atmosphere it is possible to lower the temperature range: 600-1000°C [6].

Chemical Looping Combustion (CLC)

Methane Chemical Looping Reforming (MCLR)

Chemical Looping Partial Oxidation (CLPO)

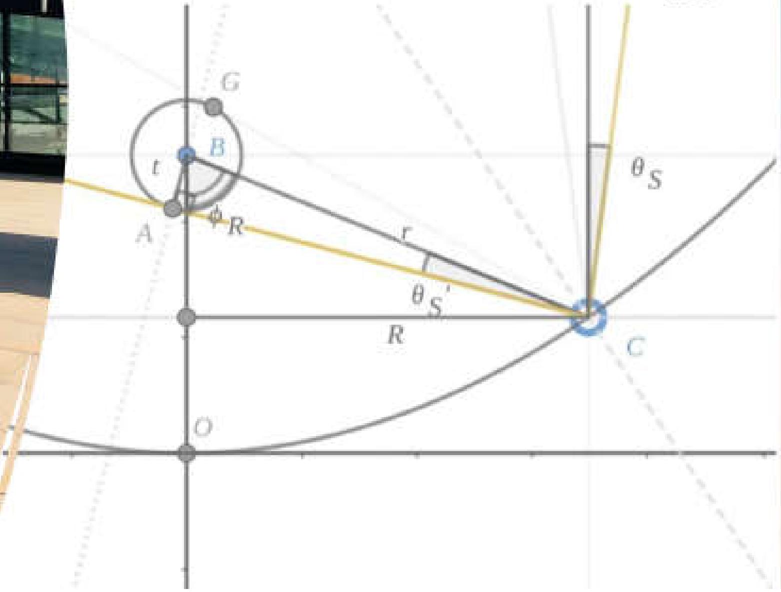


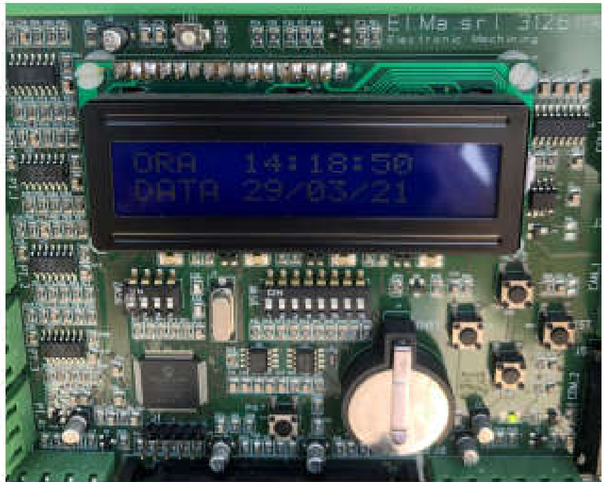


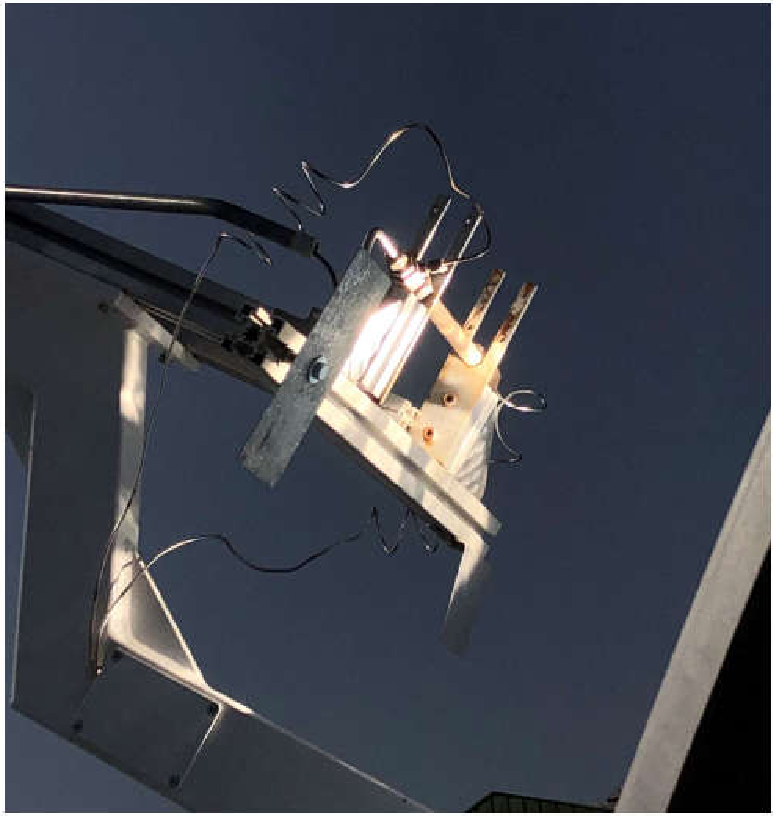
Solar Concentrator

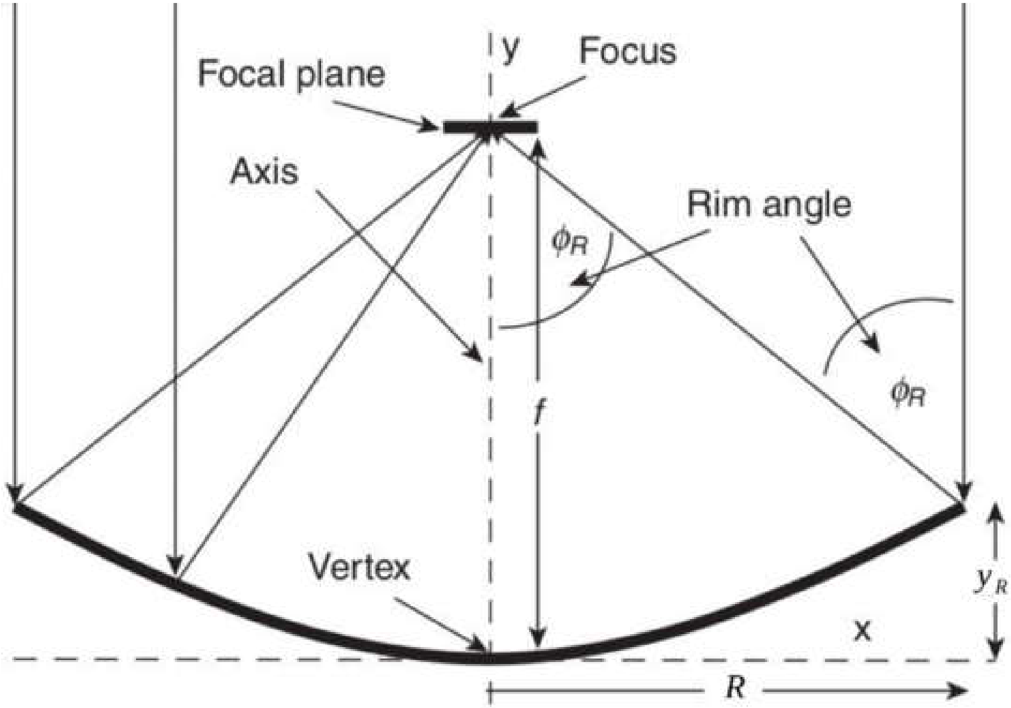
Test Bench in real conditions

Dish diameter:	D_c	2370 mm
Depth of the dish:	y_R	370 mm
Dish Area:	A	4.5 m^2 [2]
Power:	P	2.8 kW [2]





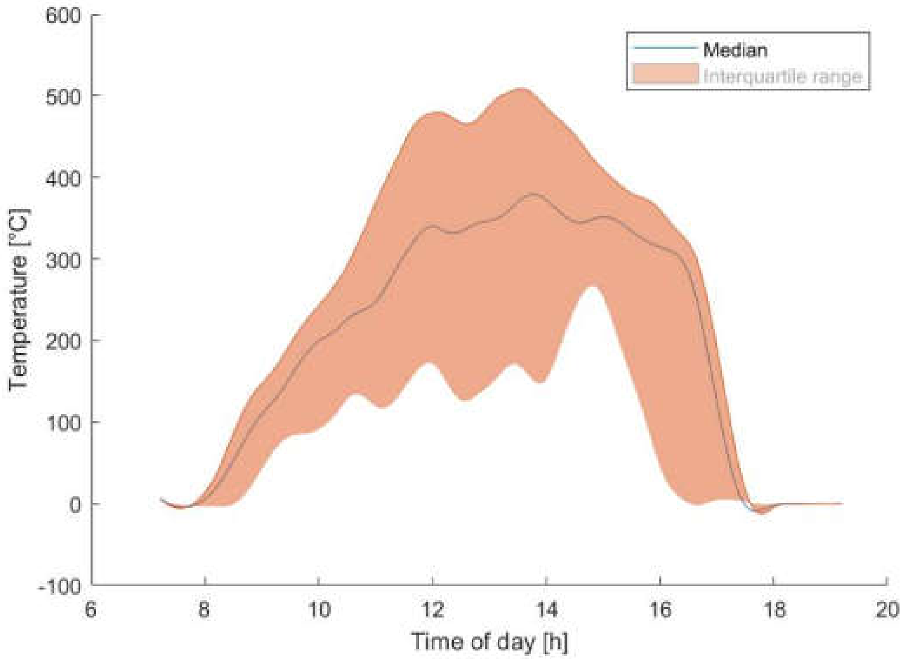




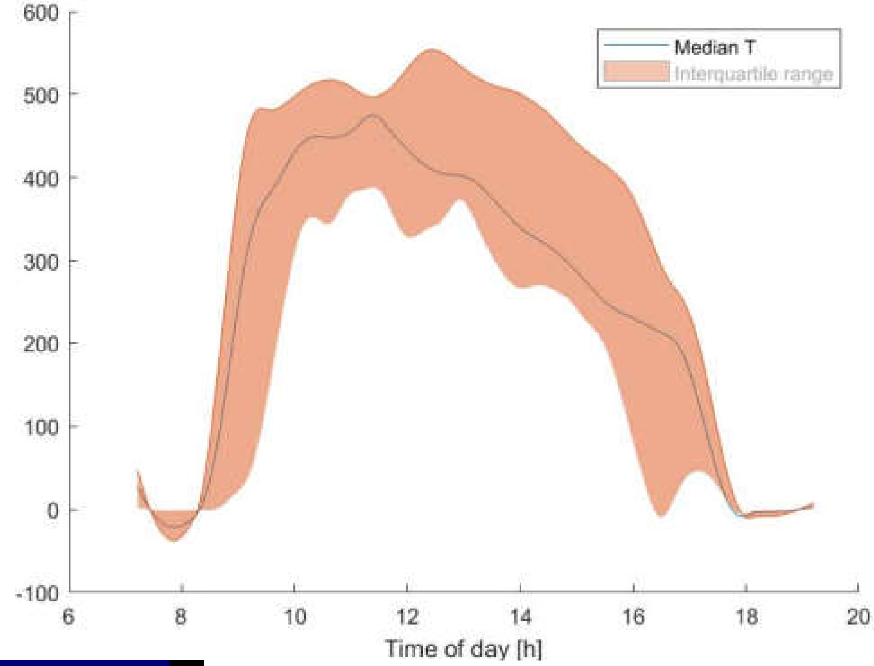
Focal plane
y
Focus
Axis
Rim angle
ϕ_R
ϕ_R
f
Vertex
y_R
x
R

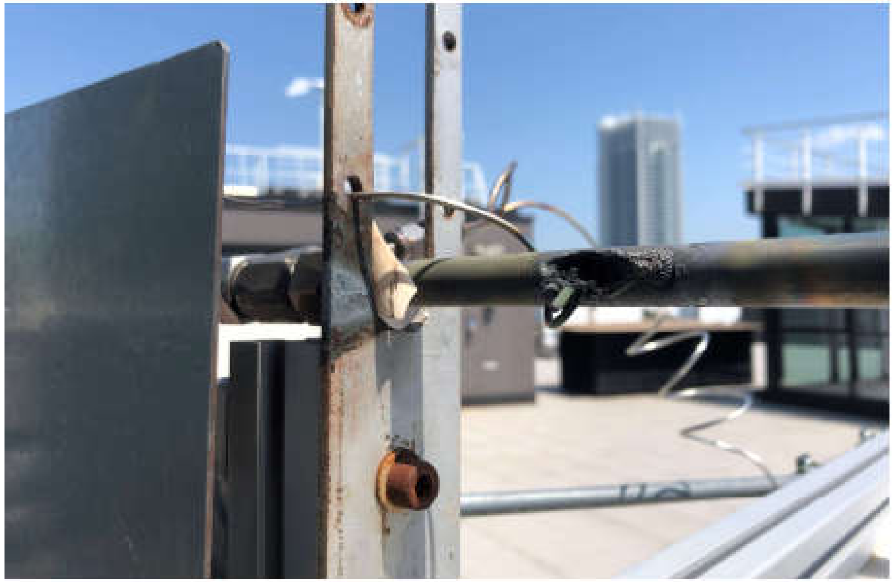
Solar Concentrator: measured temperatures

March



April





Experimental Tests: #3, #4, #5

Material selection to work at high temperature with high variability of temperature gradients (metal alloys)

The main prerequisites are:

- High corrosion resistance
- Suitable physical and mechanical properties such as conductivity, hardness, toughness and structural stability (at high temperatures)
- Manufacturability
- Affordability
- High flux density tolerance

Materials that meet the above points include ***metal alloys*** and ***ceramic materials***.

Focus on the ***metal alloys:***

	INCONEL 740H	ALLOY 625	ALLOY 800H	Haynes 230
T melting	1288-1362 °C	1290-1350 °C	1357-1385 °C	1301-1371 °C
Elastic modulus (E)	186 GPa (@T=600°C) 178 GPa (@T=700°C) 169 GPa (@T=800°C)	170 GPa (@T=650°C) 160 GPa (@T=760°C) 148 GPa (@T=870°C)	157.7 GPa (@T=600°C) 150.1 GPa (@T=700°C) 141.3 GPa (@T=800°C)	175 GPa (@T=600°C) 168 GPa (@T=700°C) 159 GPa (@T=800°C)
Yield strength ($\eth_{snerv}$)	742 MPa (@Tamb) 608 MPa (@T=700°C) 547 MPa (@T=800°C)	414-517 MPa (annealed, @Tamb) 357.2 MPa (@T=800 °C)	150 MPa (@Tamb) 109 MPa (@T=700°C) 90 MPa (@T=760 °C)	415 MPa (@Tamb) 265 MPa (@871 °C) 294 MPa (@T=1000°C)
Coefficient of linear expansion (α_L)	15.7 $\frac{\mu m}{m\,°C}$	15.5 $\frac{\mu m}{m\,°C}$	18 $\frac{\mu m}{m\,°C}$	15.3 $\frac{\mu m}{m\,°C}$
Density (ρ)	8050 kg/m^3	8422 kg/m^3	7940 kg/m^3	8968 kg/m^3
Specific heat (c)	573 J/kgK	600 J/kgK	460 J/kgK	465 J/kgK
Thermal conductivity (k)	22.1 W/mK	15.7 W/mK	11.5 W/mK	16.4 W/mK

Simplifying assumptions:

-Gas flowing inside the receiver has been approximated to air

-Heat transport in the fluid (air) due to only advection while thermal diffusion phenomena in this region are considered negligible

-Fully developed air flow

-Spatially and temporally constant properties assessed at a temperature of 800 °C

-One-way heat transfer along the axial direction

-Average radiation equal to Ia= 800 W/m²

Reynolds number

$$\mathrm{Re}=\frac{\rho*u*D}{\mu}$$ Laminar Flow regime

Nusselt number constant to 3.66 – $h=\frac{Nu*k}{D}$

Thermodynamics of the problem and numerical discretization

Receiver side

$$\rho_M cp_M \frac{\partial Tm}{\partial t} = k_m \frac{\partial^2 Tm}{\partial x^2} + q_{irr} - \frac{h\ Aint\ (Tm - Ta)}{Vm}$$

Fluid side

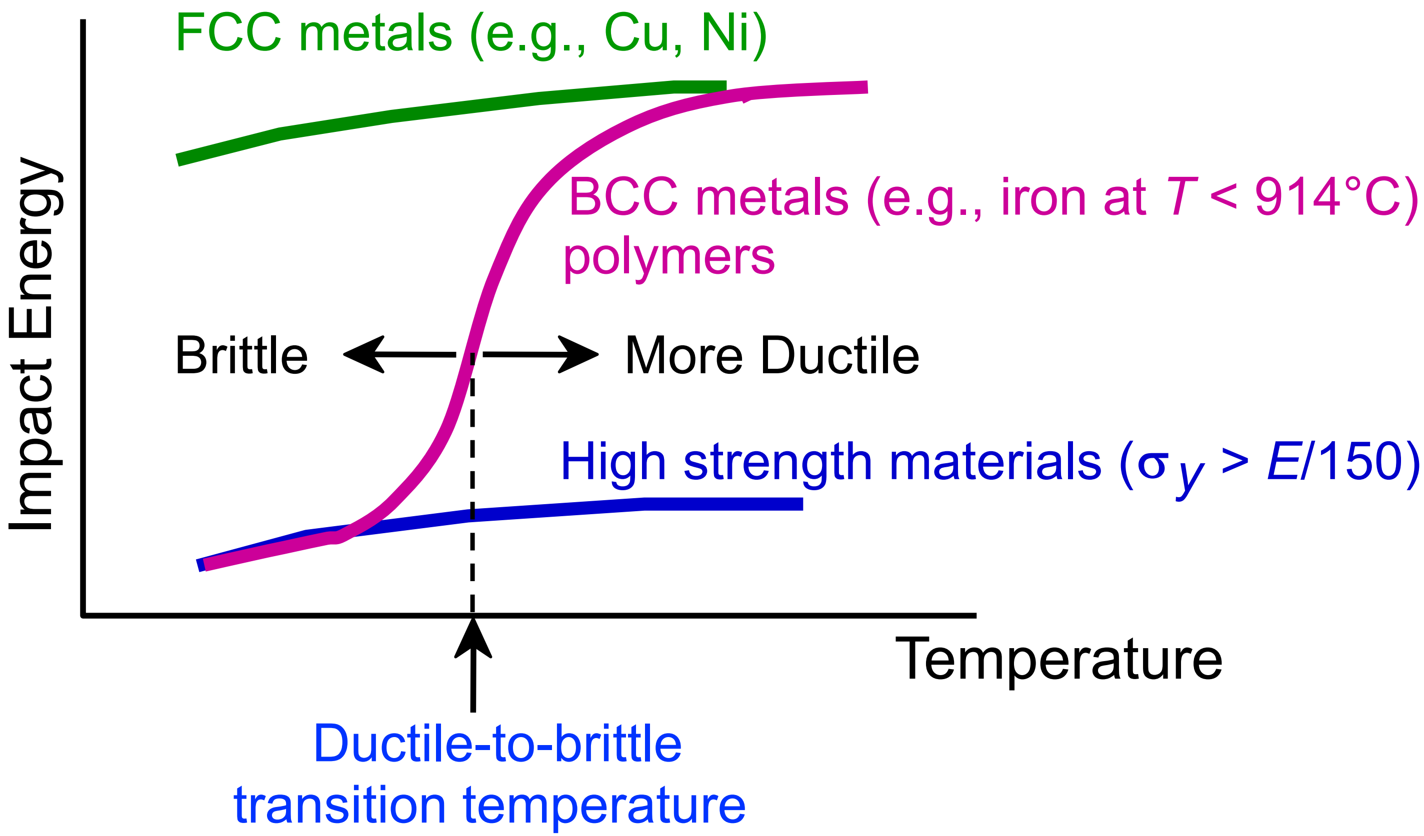
$$\rho_a cp_a \left(\frac{\partial Ta}{\partial t} + u \frac{\partial Ta}{\partial x} \right) = \frac{h\ Aint\ (Tm - Ta)}{Va}$$

The equations were discretized using an explicit Euler time derivative discretization method and spatially using the centred finite difference method for the conduction and an upwind scheme for the advective term.

Initial condition: Tm(x,t=0)= Ta(x,t=0)=25 °C
Material boundary conditions: adiabatic extremes $-k \frac{\partial Tm}{\partial t} = 0$

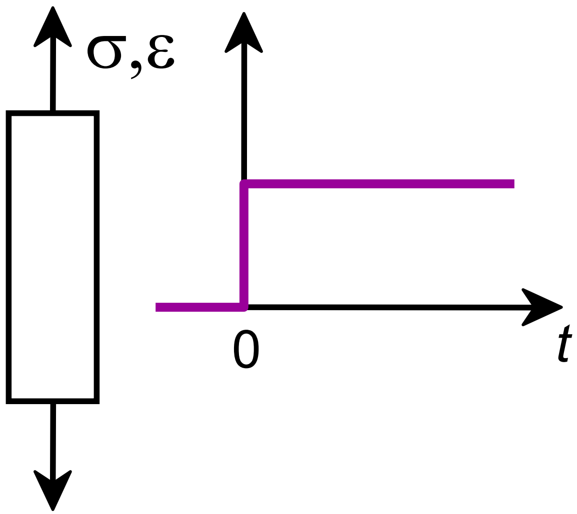
Failure mechanisms

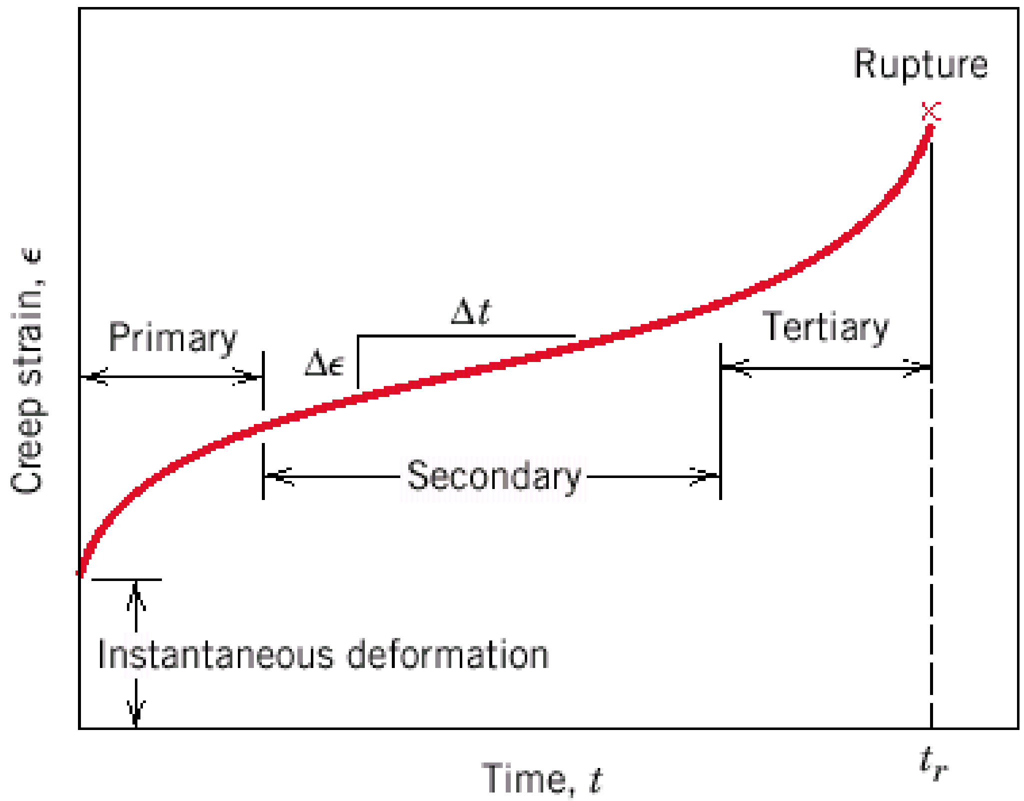
- Fracture
- **Fatigue**
- **Creep**
- Corrosion
- Buckling
- Melting
- Thermal shock
- Wear



For steel

Creep





Primary Creep: slope (creep rate) decreases with time.

Secondary Creep: steady-state i.e., constant slope.

Tertiary Creep: slope (creep rate) increases with time, i.e. acceleration of rate.

Analysis of material behavior

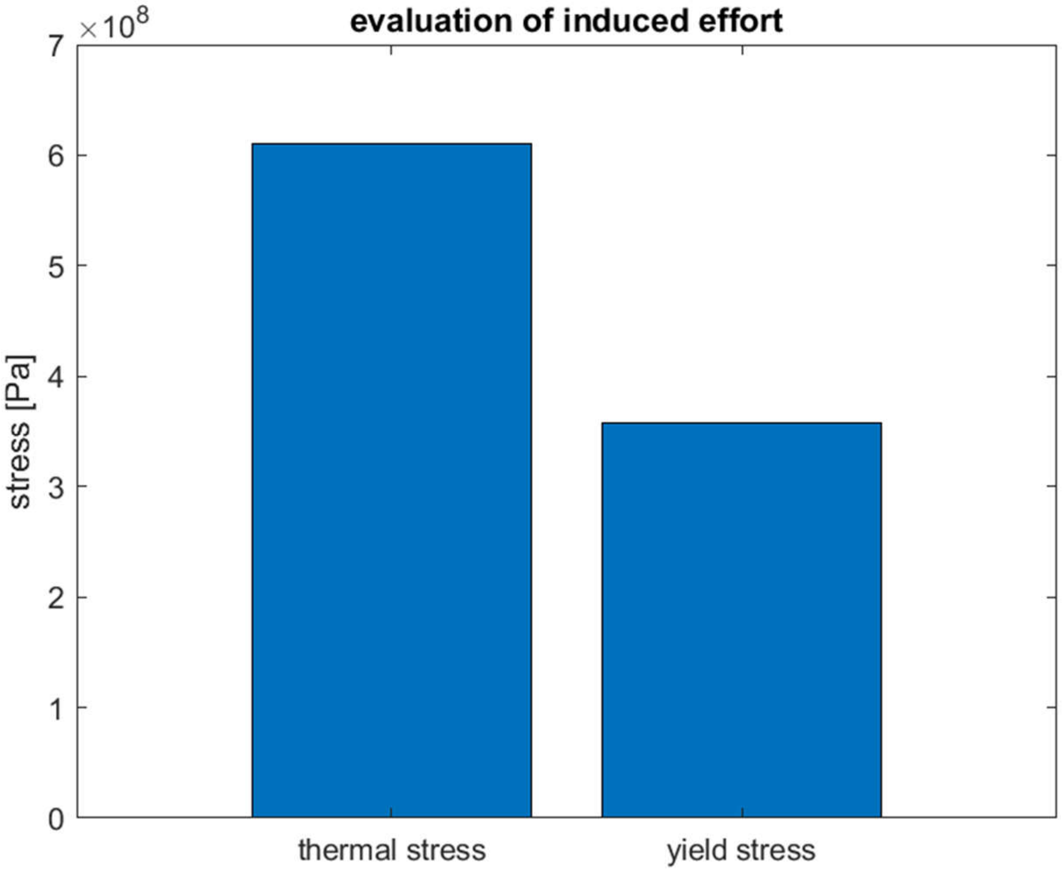
Spatial course of the temperature at the end of the transient and the temporal course of the most stressed section are the model Output.

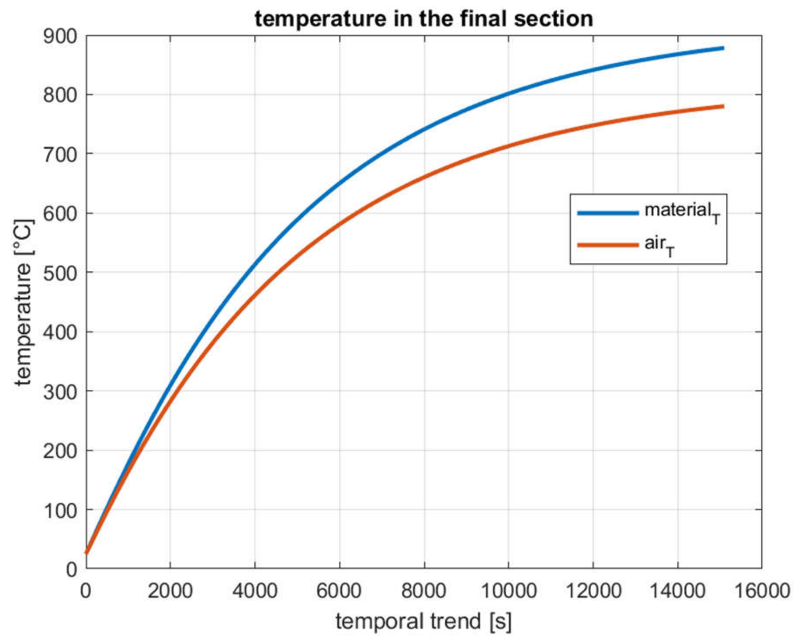
The thermal stress induced by the temperature gradient is evaluated at the end of the transient (most extreme working condition)

$$\eth_{th} = E * \alpha_L * \Delta T$$

If this stress exceeds the yield stress, i.e. the condition in which the elastic bonds in the material change, causing it to deform (fatigue behavior is omitted).

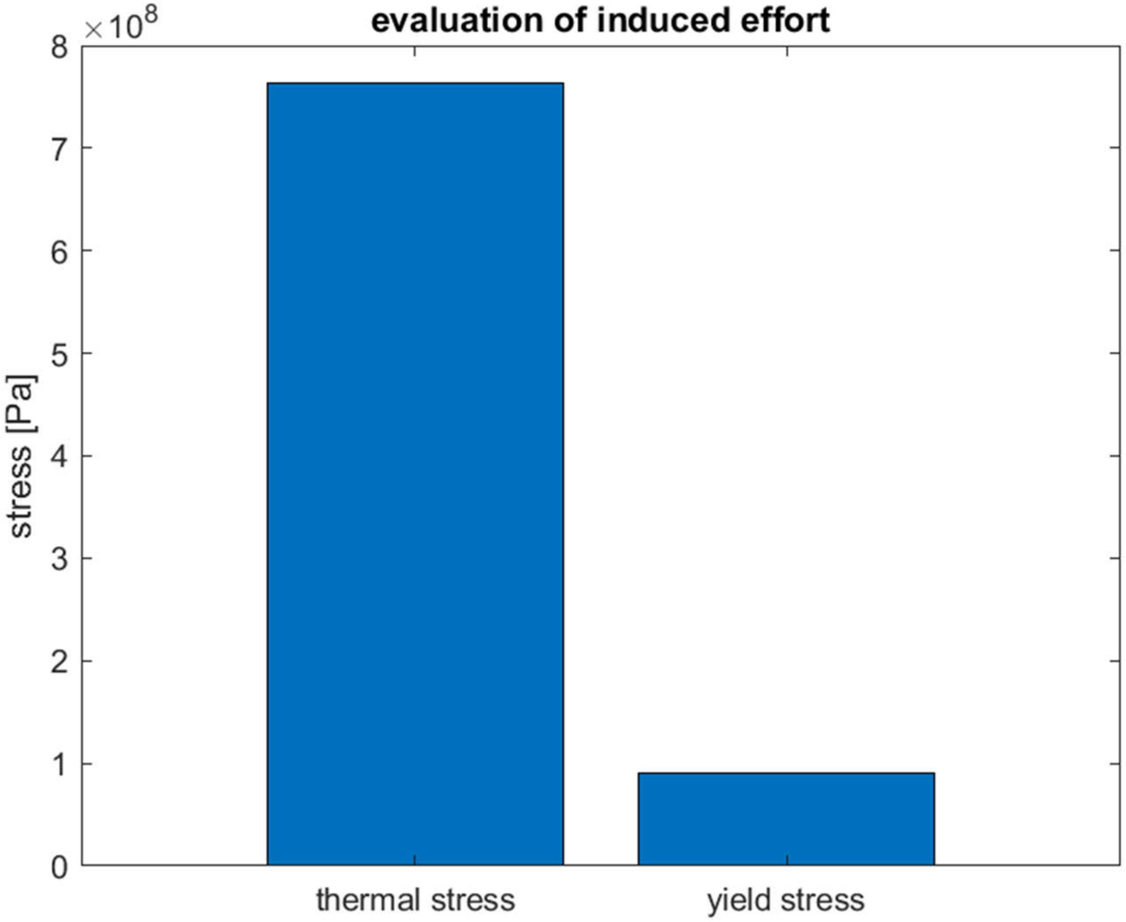
ALLOY 625

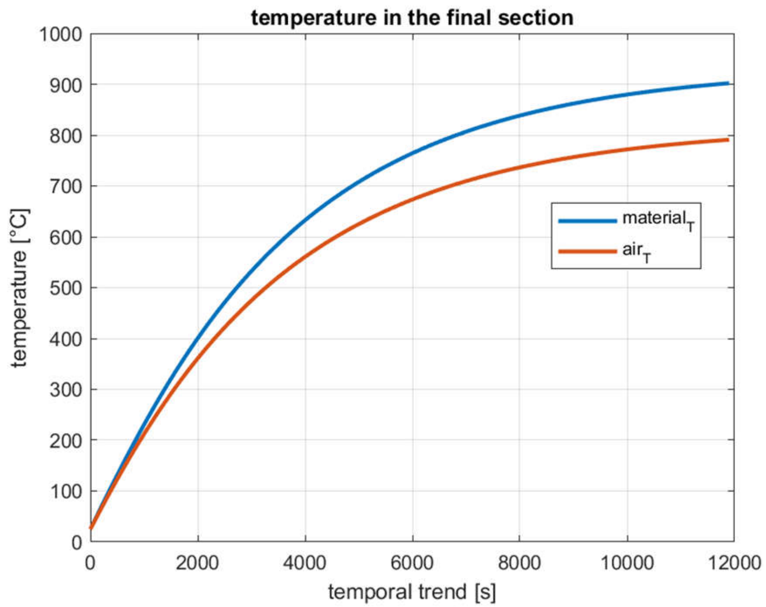




Biot = 0.0019

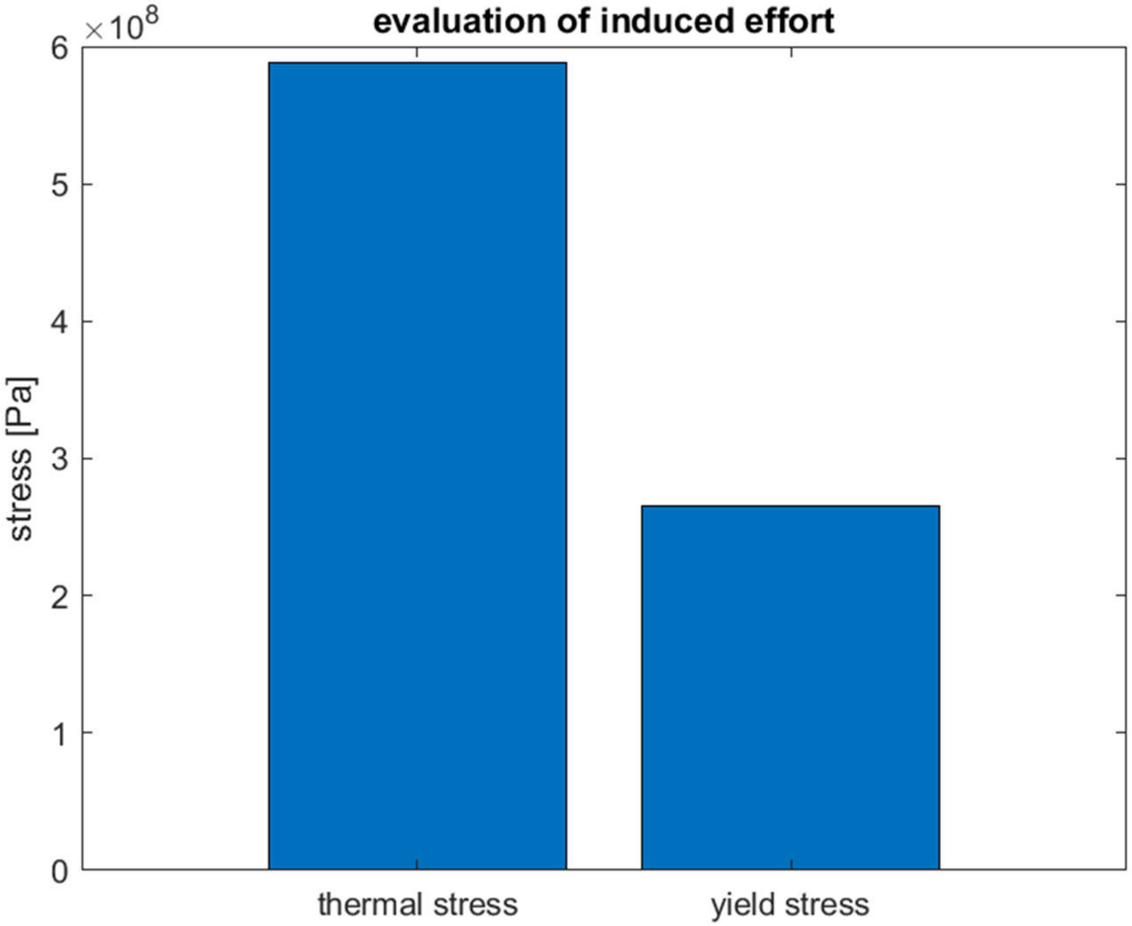
ALLOY 800H

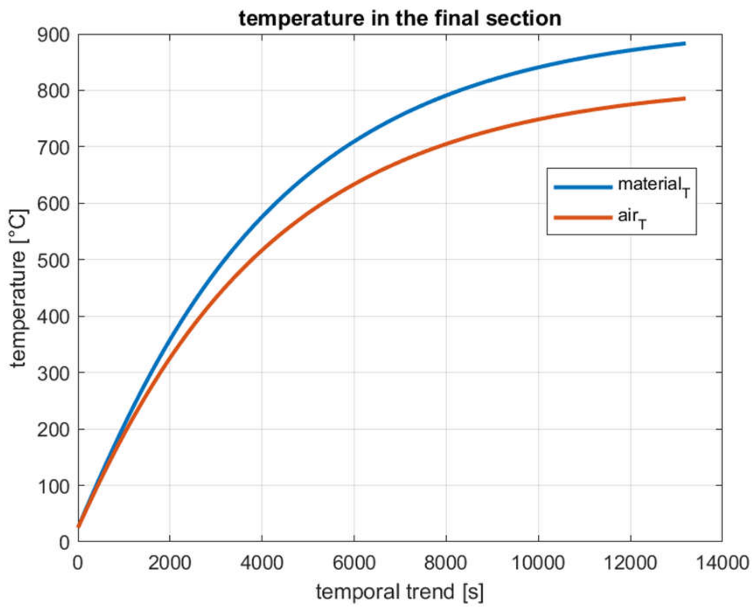




Biot = 0.0026

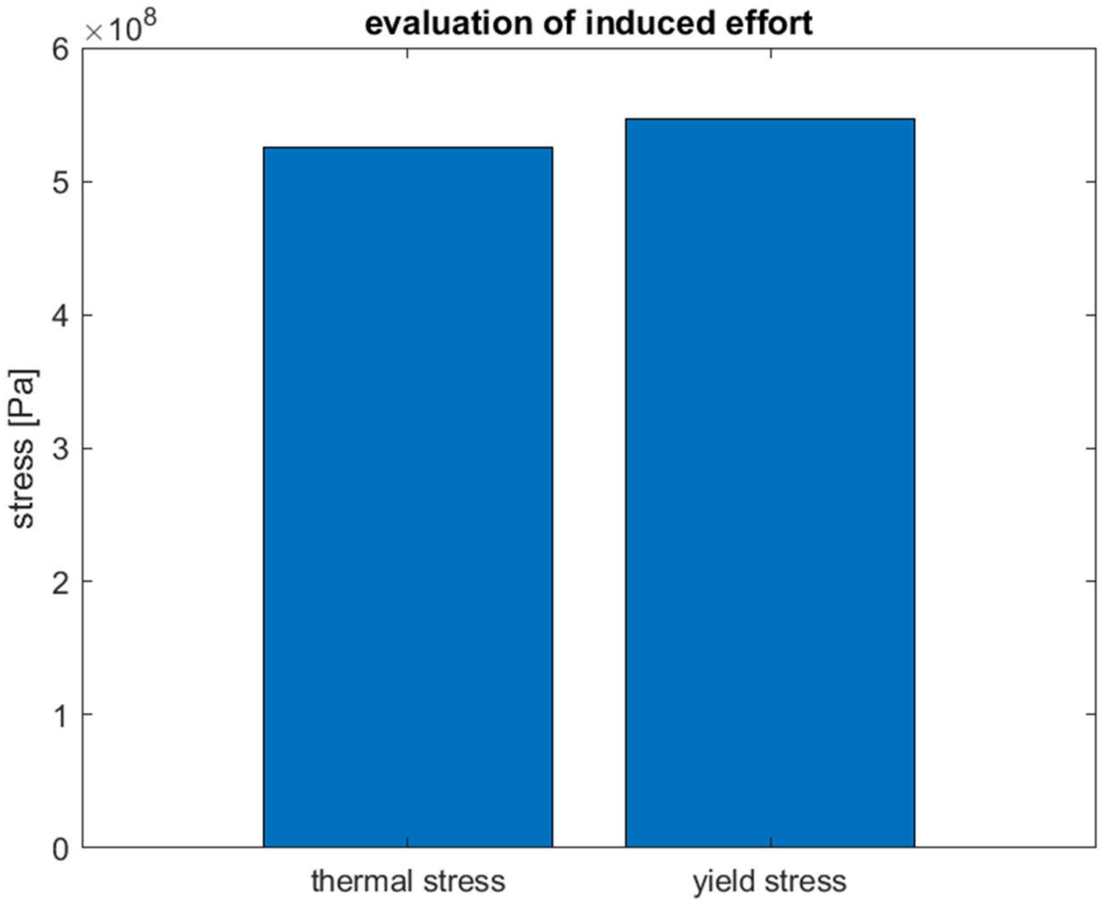
Haynes 230

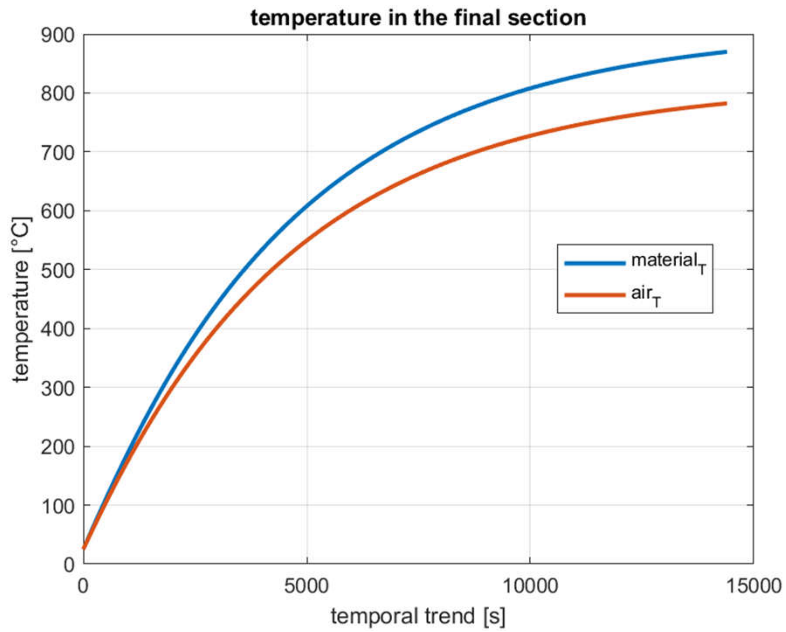




Biot = 0.0018

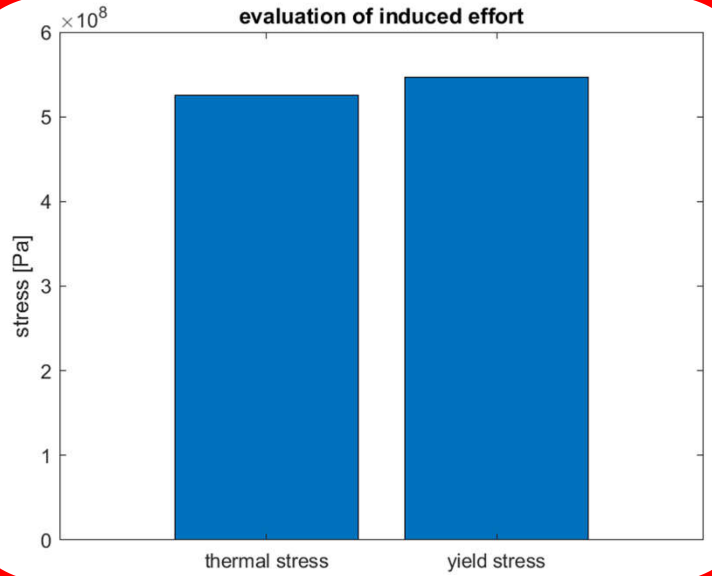
INCONEL 740H



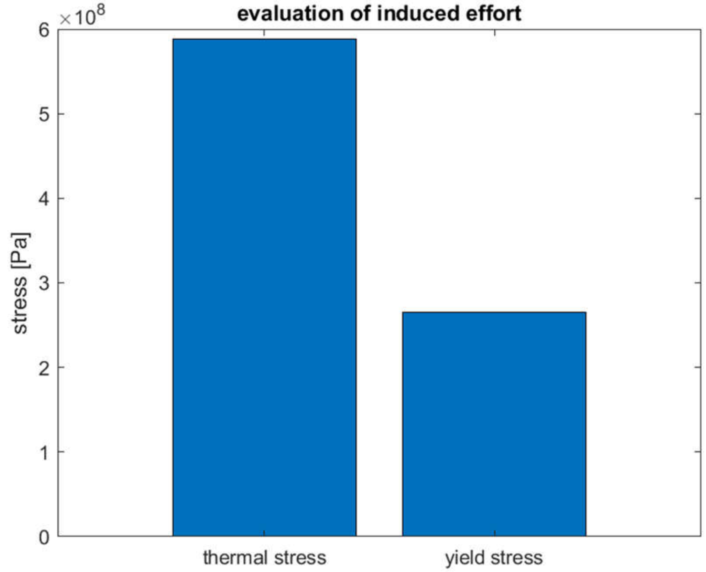


Biot = 0.0013

INCONEL 740H

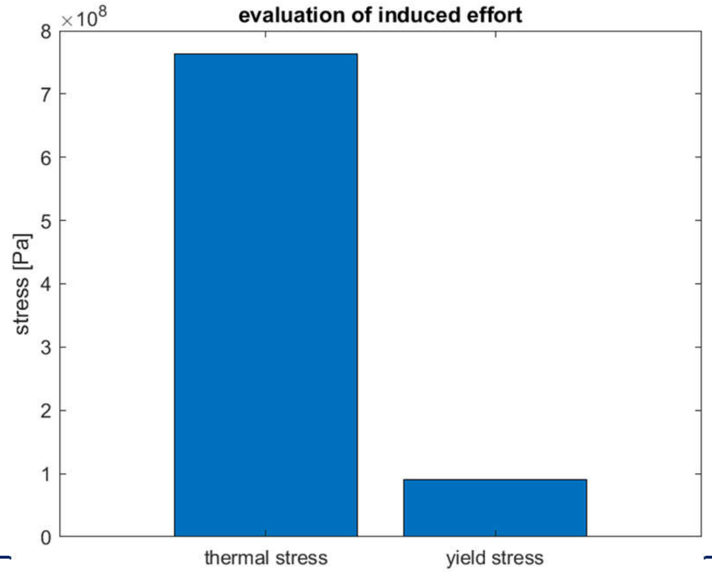


Haynes 230

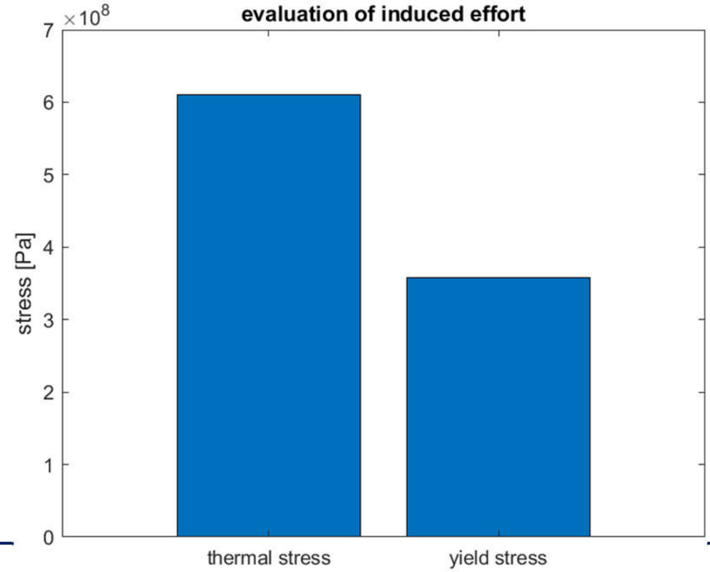


CONCLUSION

ALLOY 800H



ALLOY 625



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Thank you for the kind attention !!!