Investigation of thermal protection systems for hybrid rocket motors

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Outline

- **Introduction**
  - Hybrid rocket motors
  - Thermal protection systems
- **Experimental analysis**
  - Materials choice
  - Experimental set-up
  - Test matrix
  - Test bench
- **Experimental results**
  - Graphite erosion
  - Cotton-phenolic erosion
  - Materials interaction
  - Temperature data
- **1D ablation model**
- **Future work**

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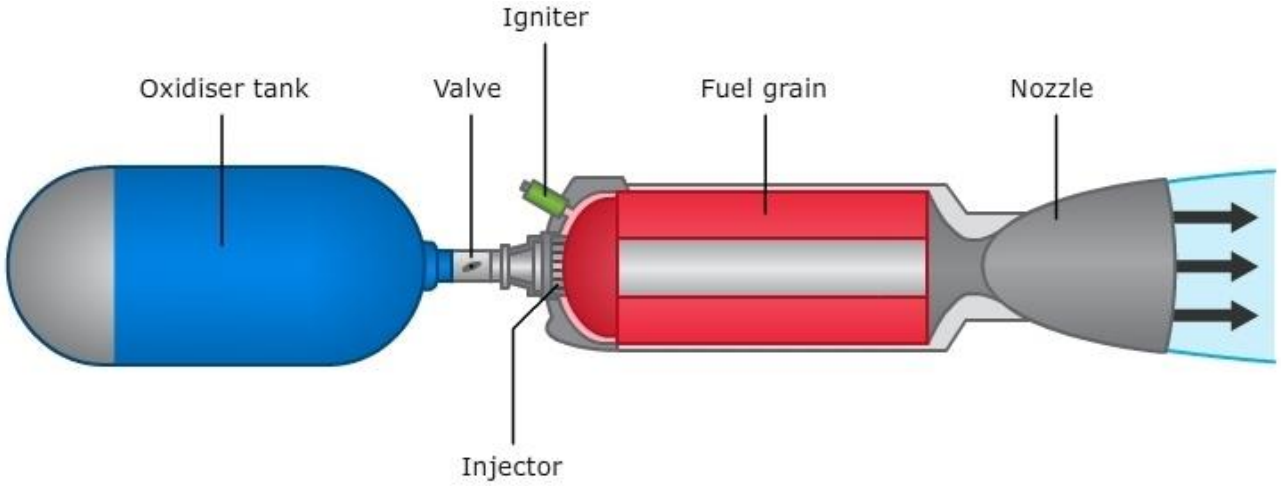
Hybrid Rocket Motors



Advantages

- Safety
- **Low costs**
- **Simplicity**
- Green propellants
- Oxidizer flow control

→ Mission abort and **throttlability**

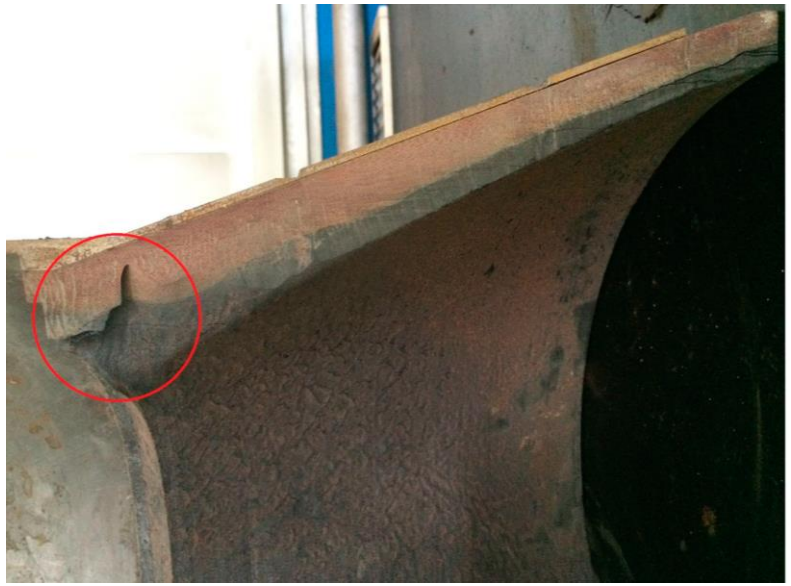
Disadvantages

- Low regression rates

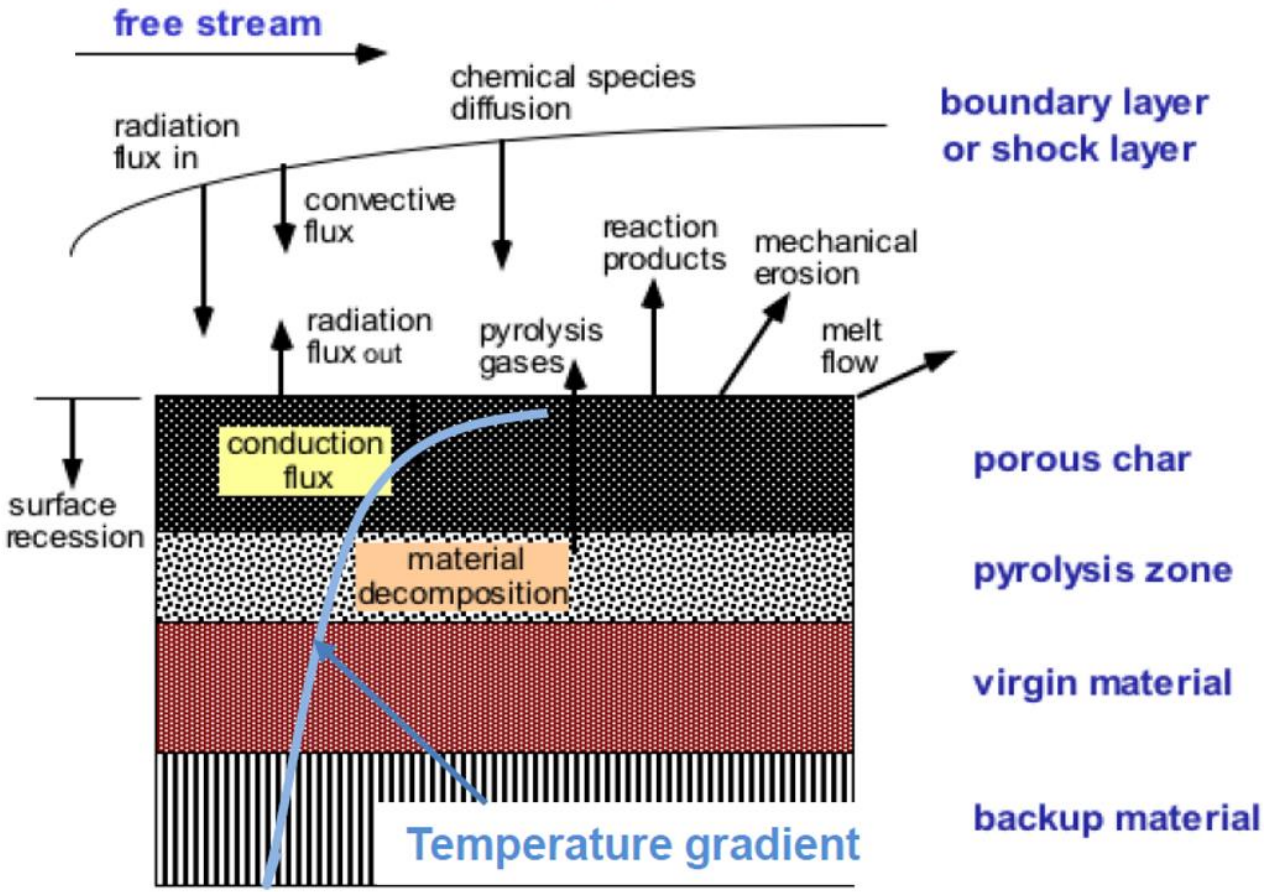
→ Low volumetric efficiency

- Combustion efficiency
- **High oxygen content**

Passive cooling systems



General concepts



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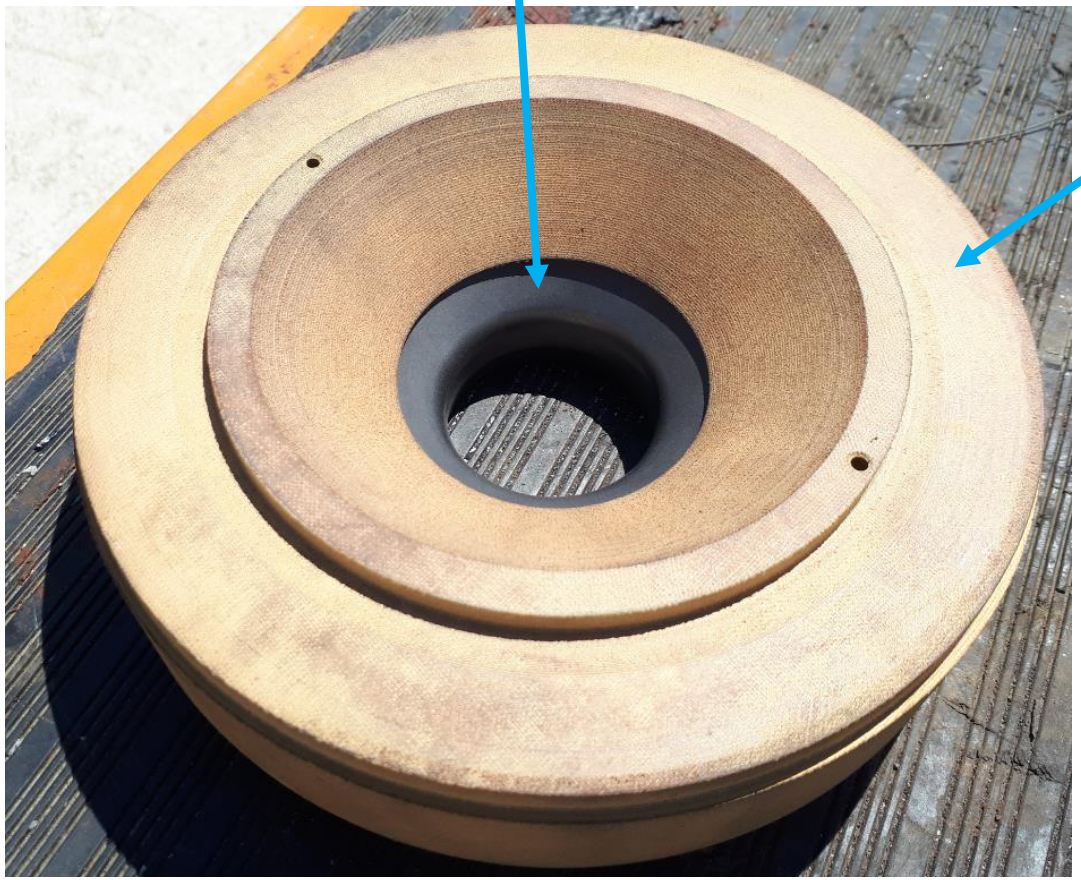
Materials choice

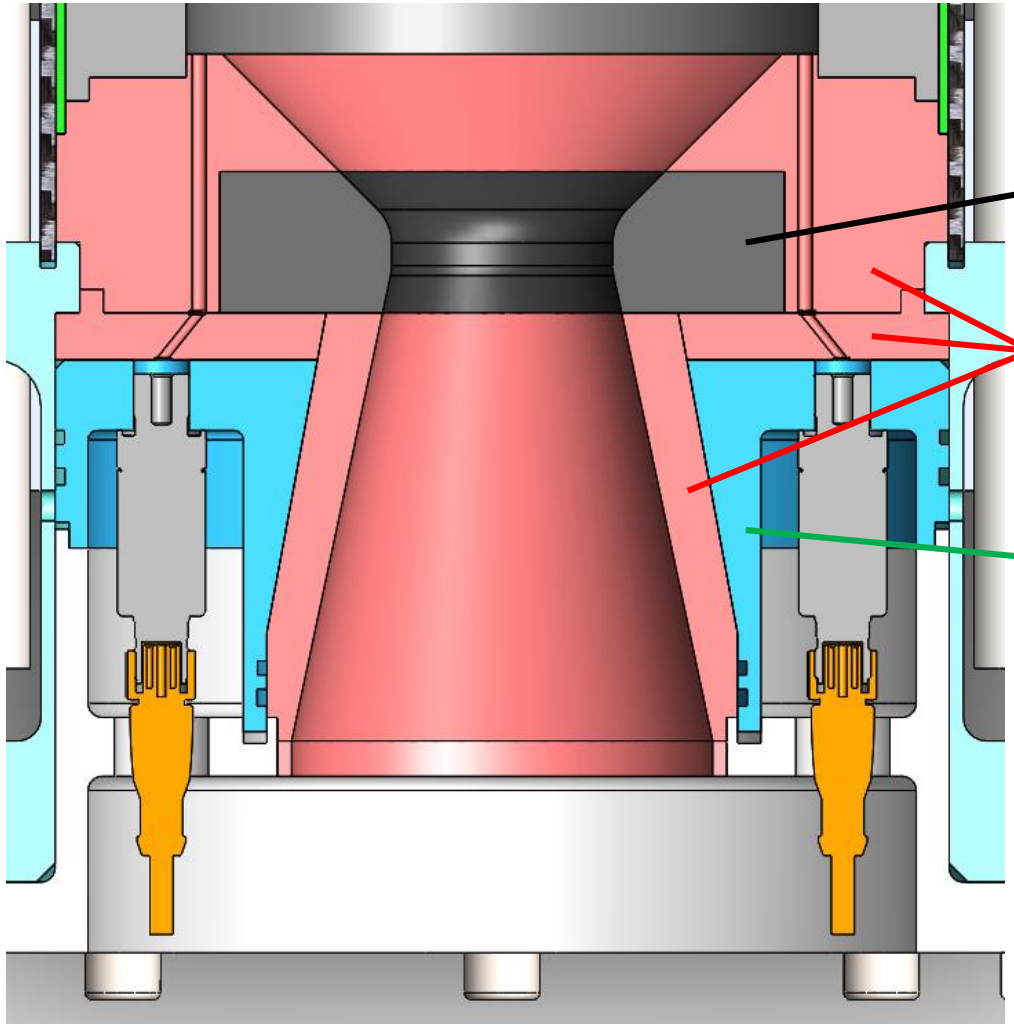
POLYCRISTALLINE GRAPHITE



COTTON PHENOLIC

Experimental set-up

Configuration 1



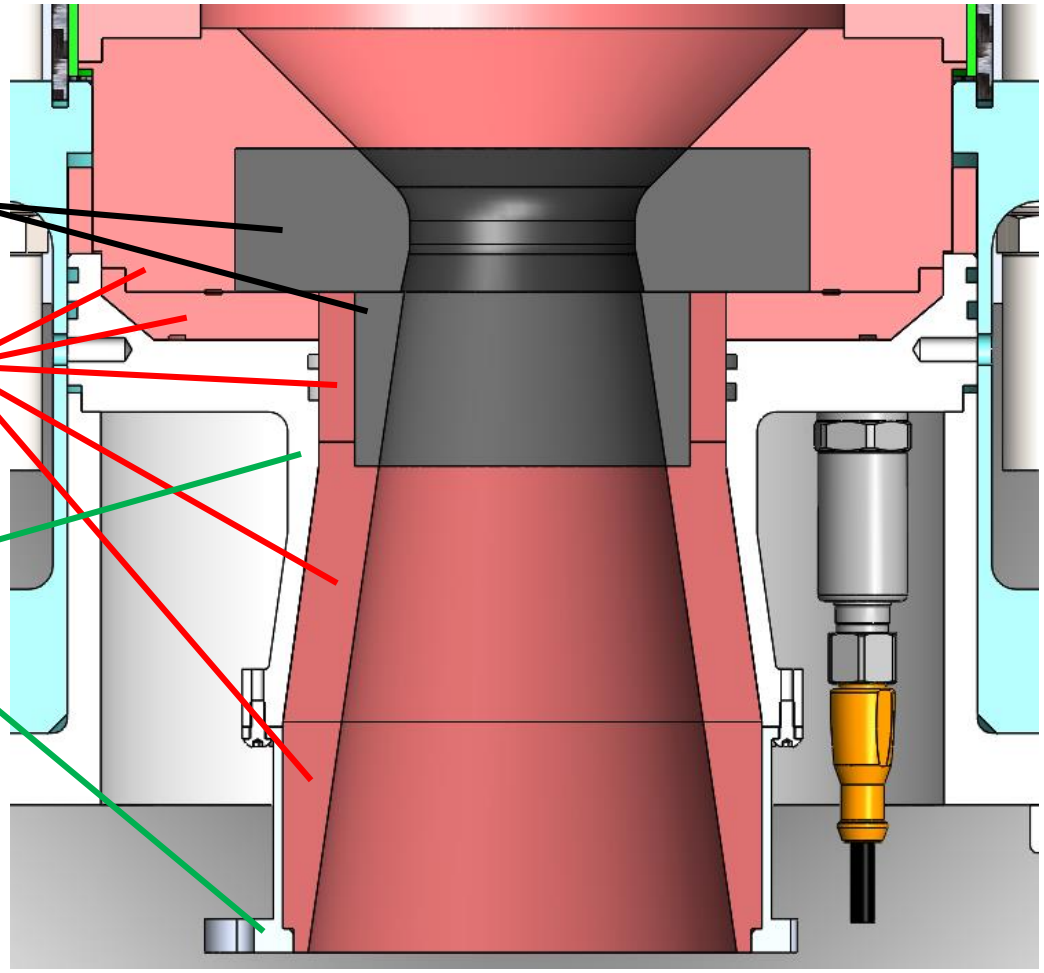
GRAPHITE

COTTON

PHENOLIC

C40

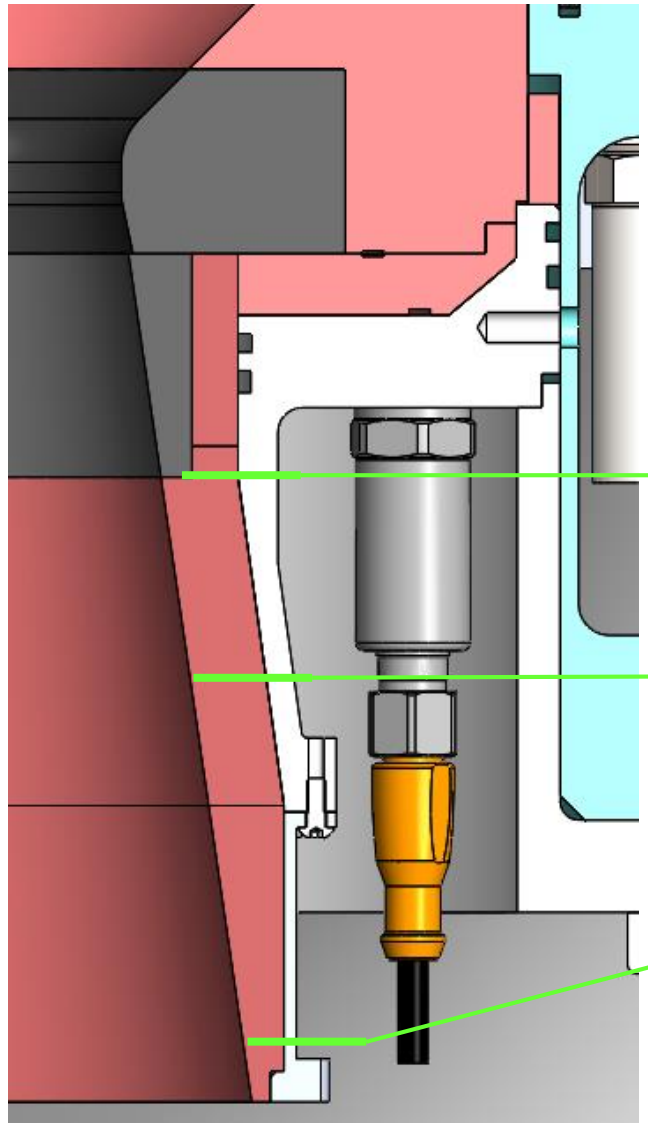
Configuration 2



Test matrix

Test number	configuration	burning time [s]
1	1	7
2	1	15
3	1	15
4	2	20
5	2	24.5

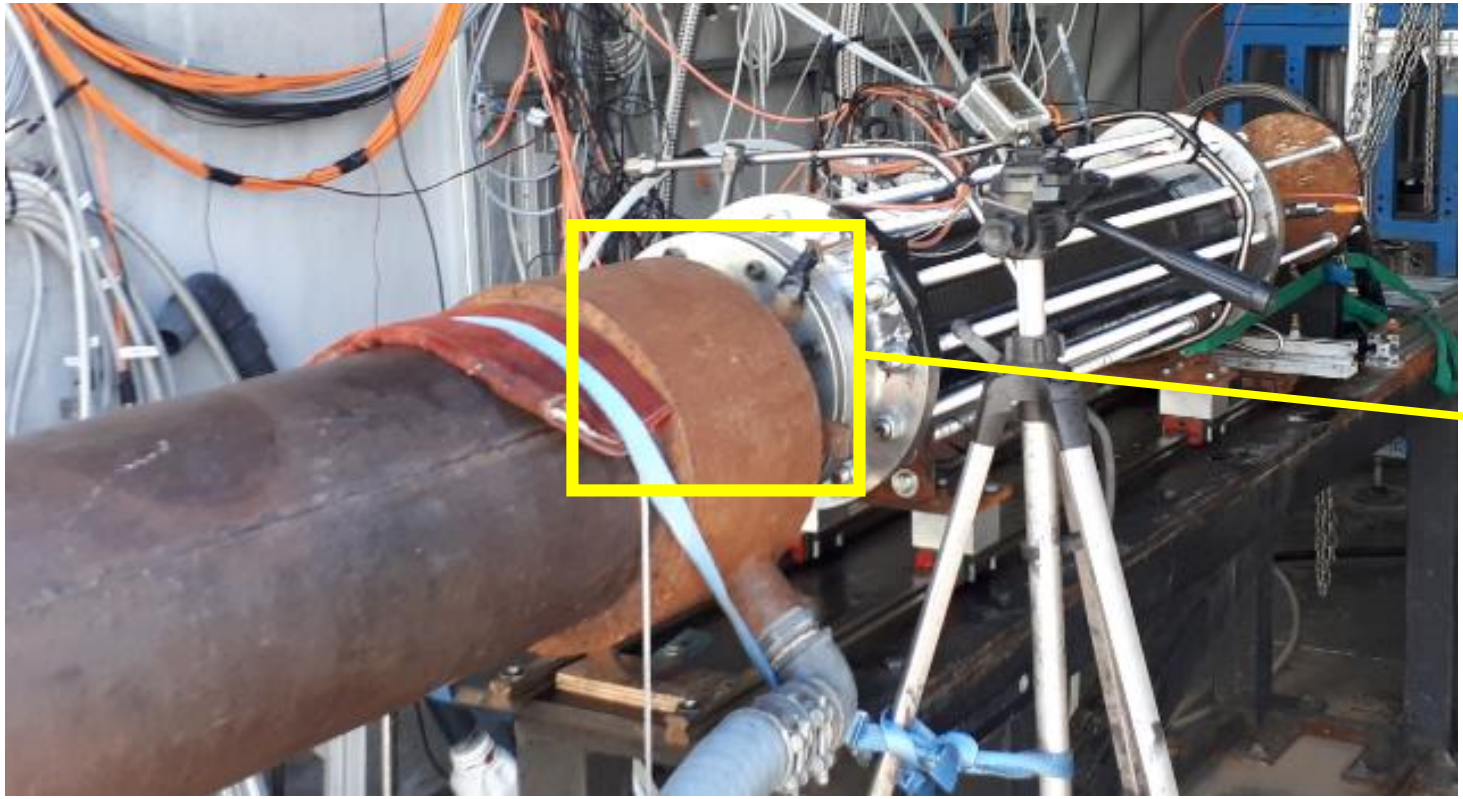
- Chamber pressure ≅ 20 bar
- Oxidizer mass flow rate = 2 kg/s
- O/F ≅ 6

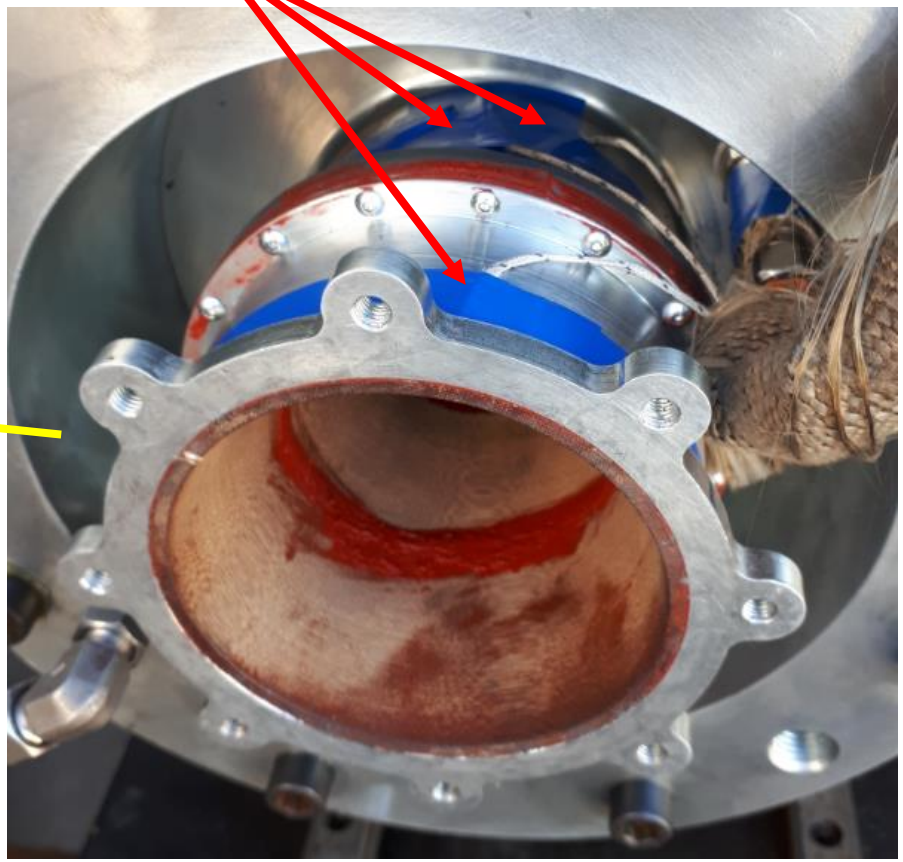


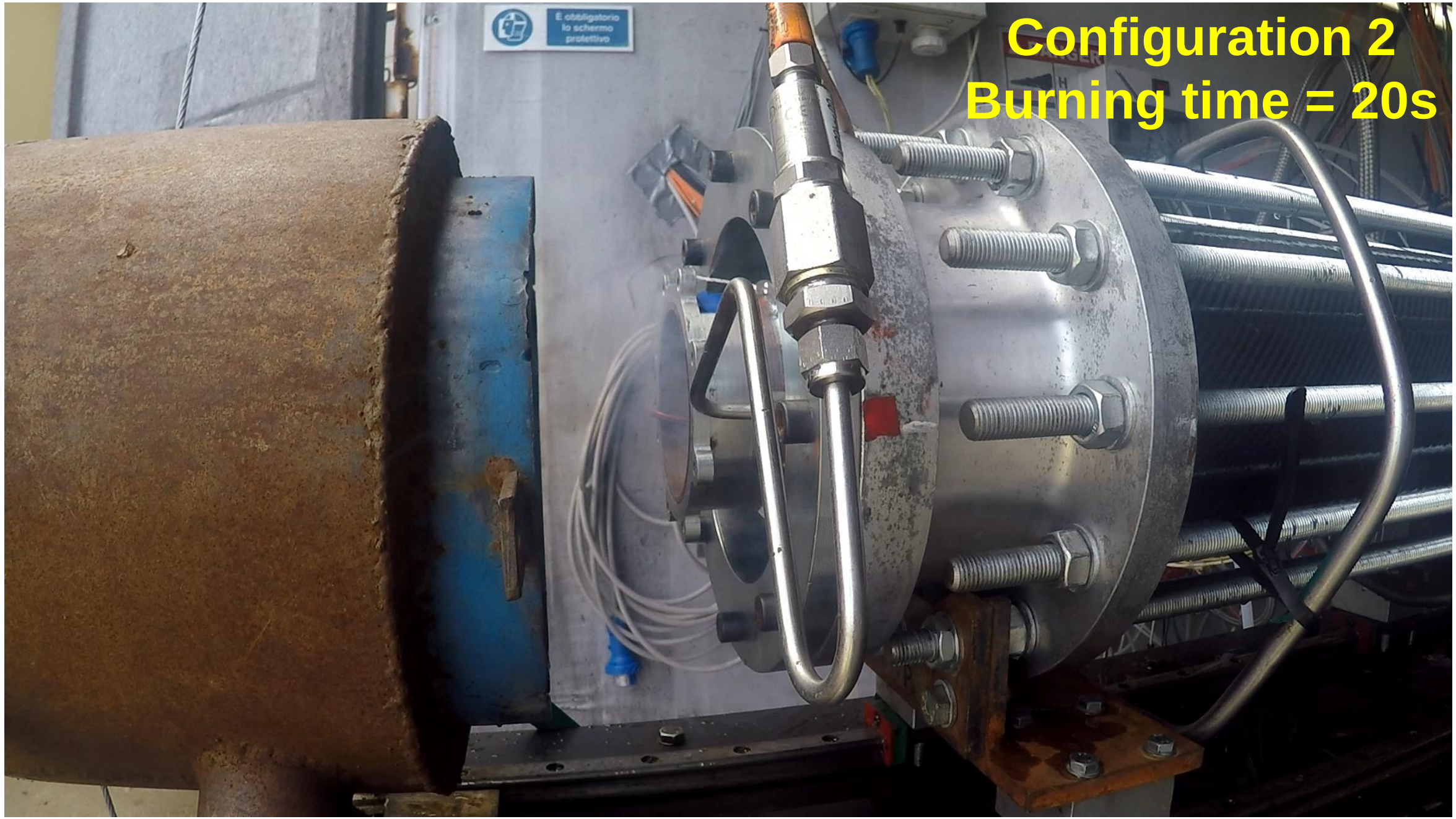
Thermocouples position

Test bench

Thermocouples






Configuration 2
Burning time = 20s

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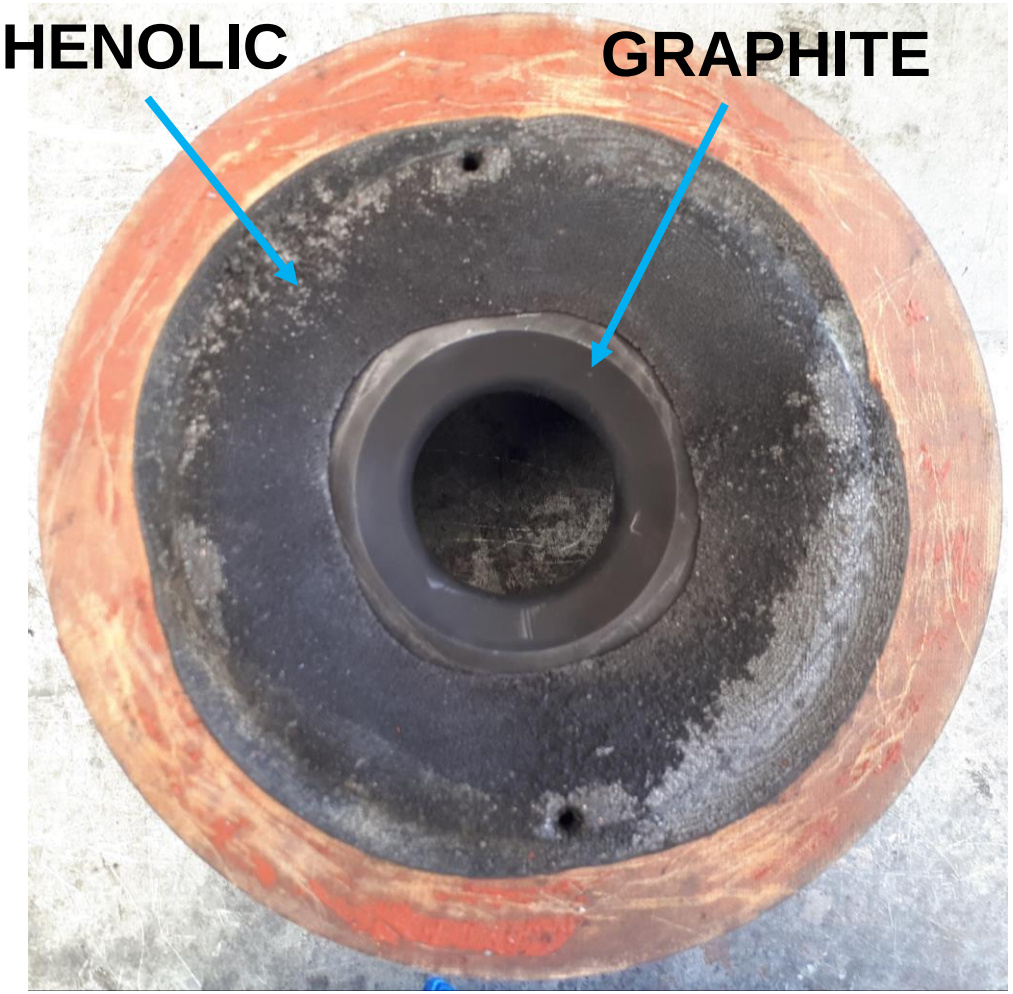
Experimental results



Graphite erosion

$TEST\ \#1, t_b = 7s$

$TEST\ \#2, t_b = 15s$

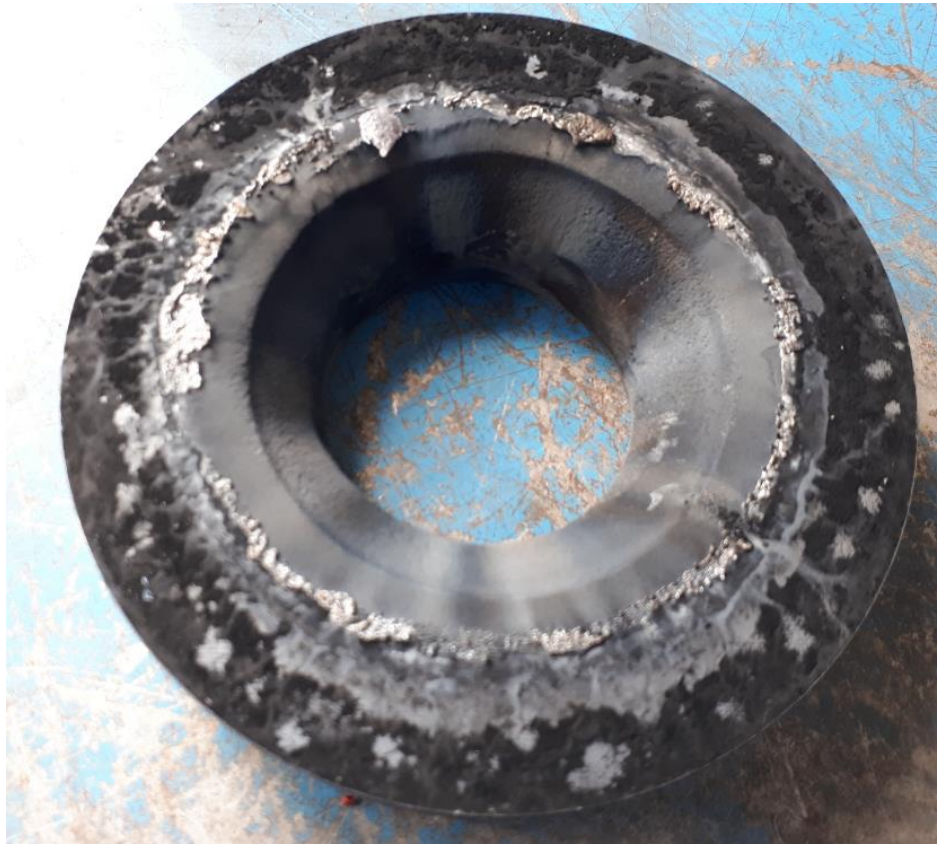
Graphite erosion

$TEST\ \#3, t_b = 15s$

$TEST\ \#4, t_b = 20s$

Graphite erosion

$TEST\ \#5, t_b = 24.5s$



$TEST\ \#5, t_b = 24.5s$

Graphite erosion

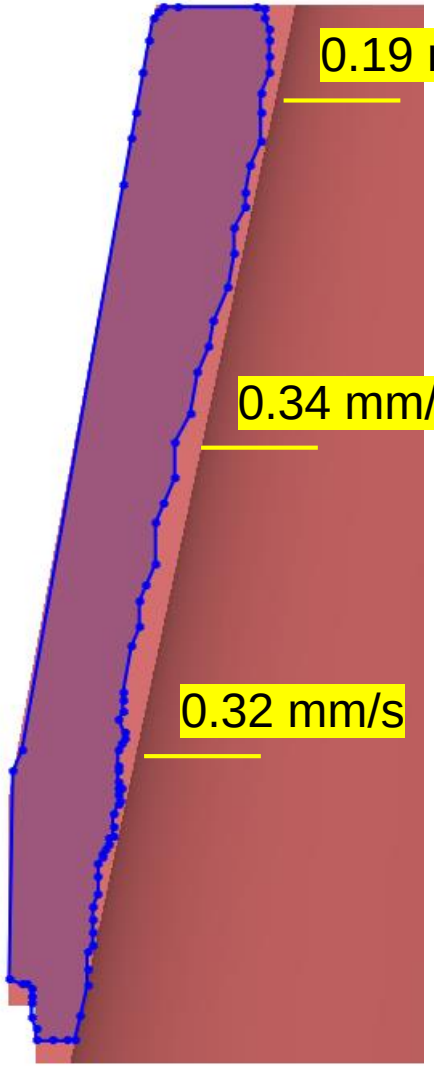
Test number	configuration	burning time [s]	Erosion rate [mm/s]	Pressure drop [bar]	
1	1	7	0	0	
2	1	15	0.0138	0.35	→ O/F = 4.83
3	1	15	0.0516	0.81	→ O/F = 5.68
4	2	20	0.0552	1.68	
5	2	24.5	0.0612	2.25	

Cotton phenolic erosion

General considerations

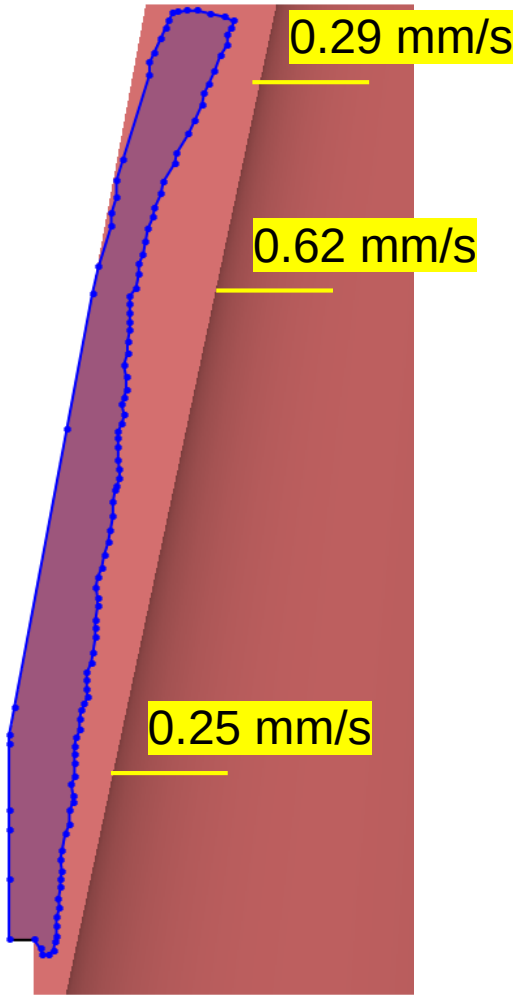
Cotton phenolic erosion

$$TEST\ 1, t_b = 7s$$
$$CONFIGURATION\ 1$$



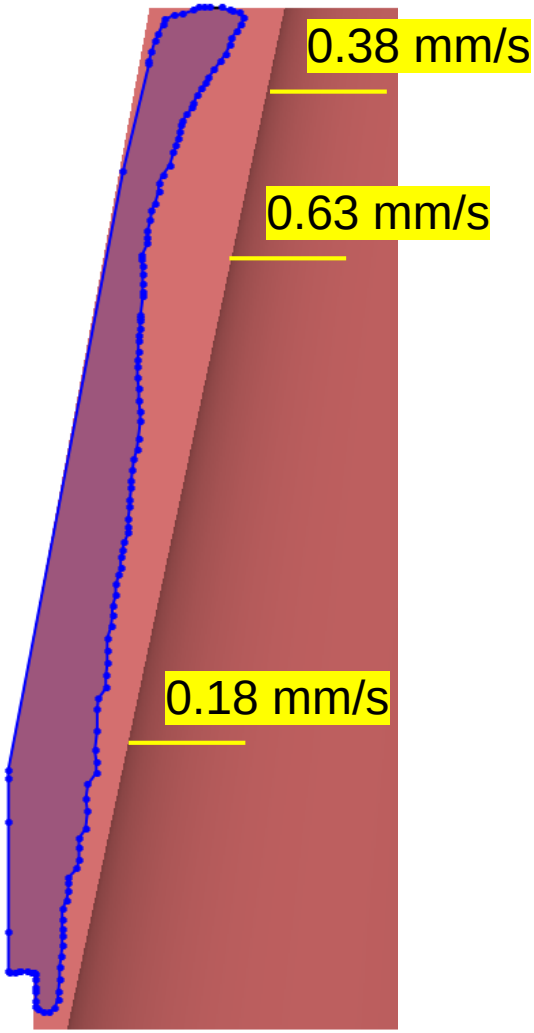
Cotton phenolic erosion

$$TEST\ 2, t_b = 15s$$
$$CONFIGURATION\ 1$$



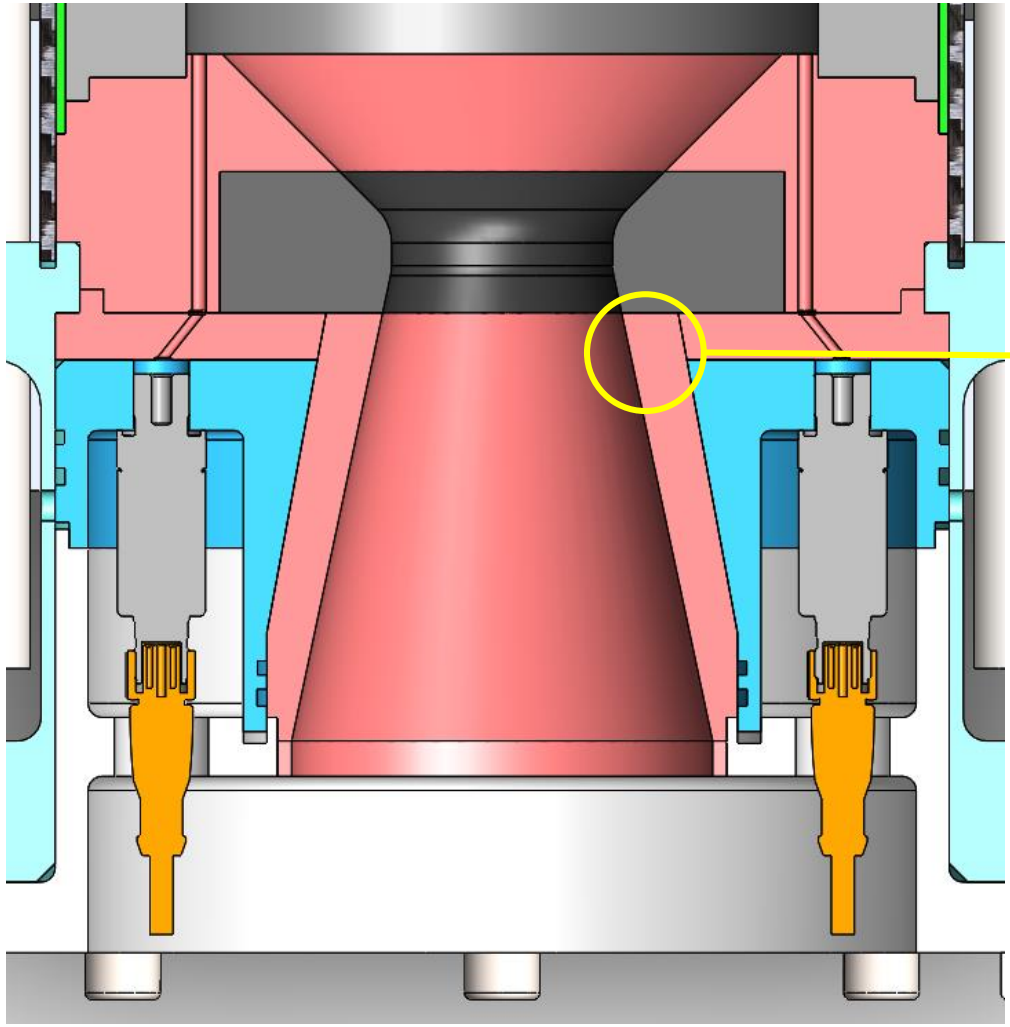
Cotton phenolic erosion

$$TEST\ 3, t_b = 15s$$
$$CONFIGURATION\ 1$$

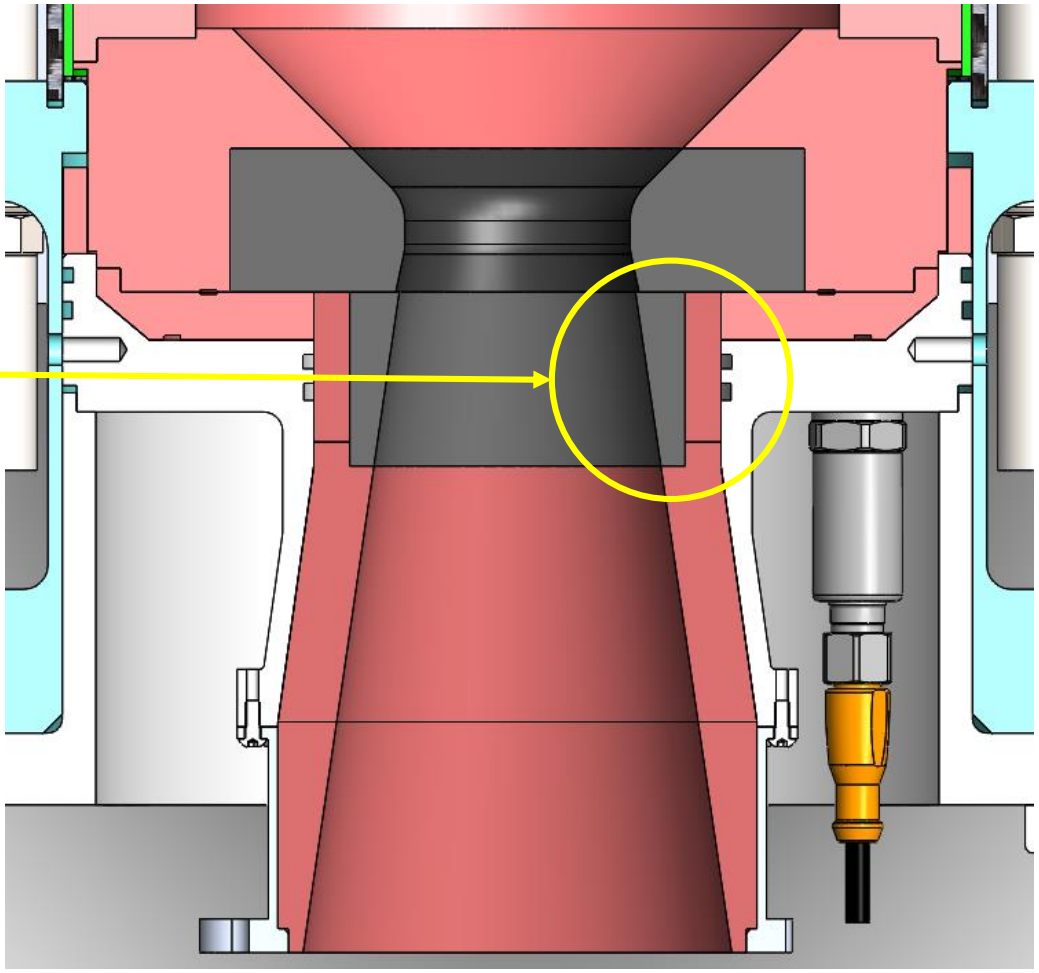


Cotton phenolic erosion

Configuration 1

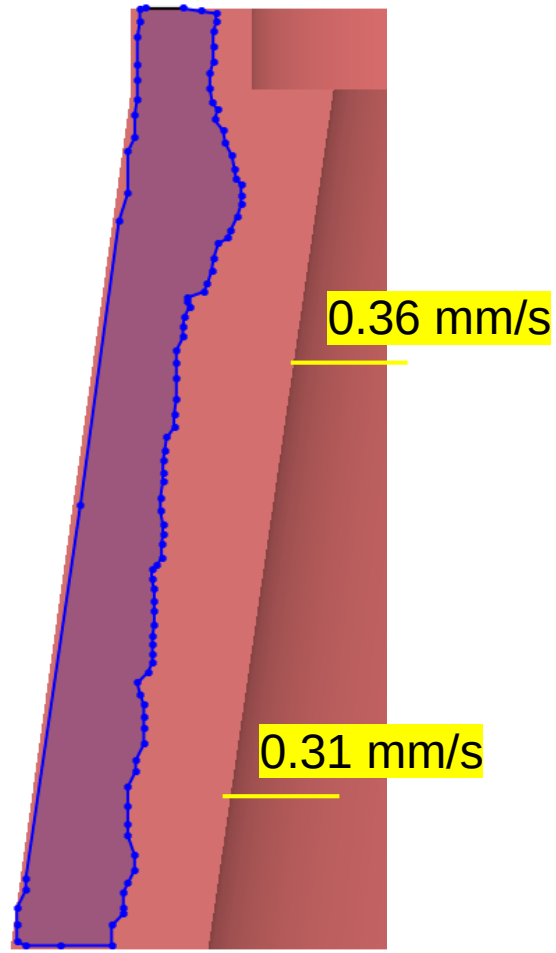


Configuration 2

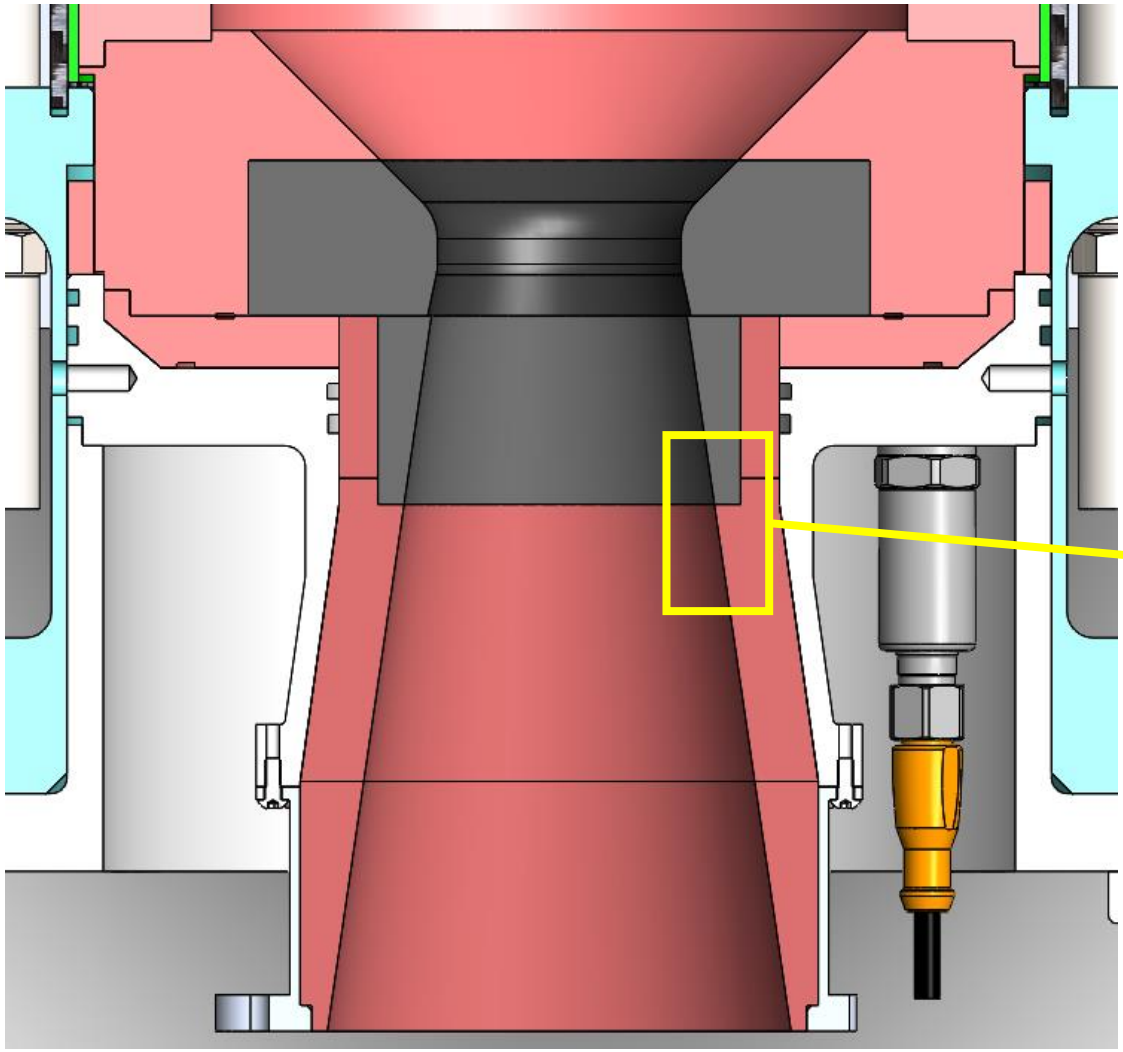


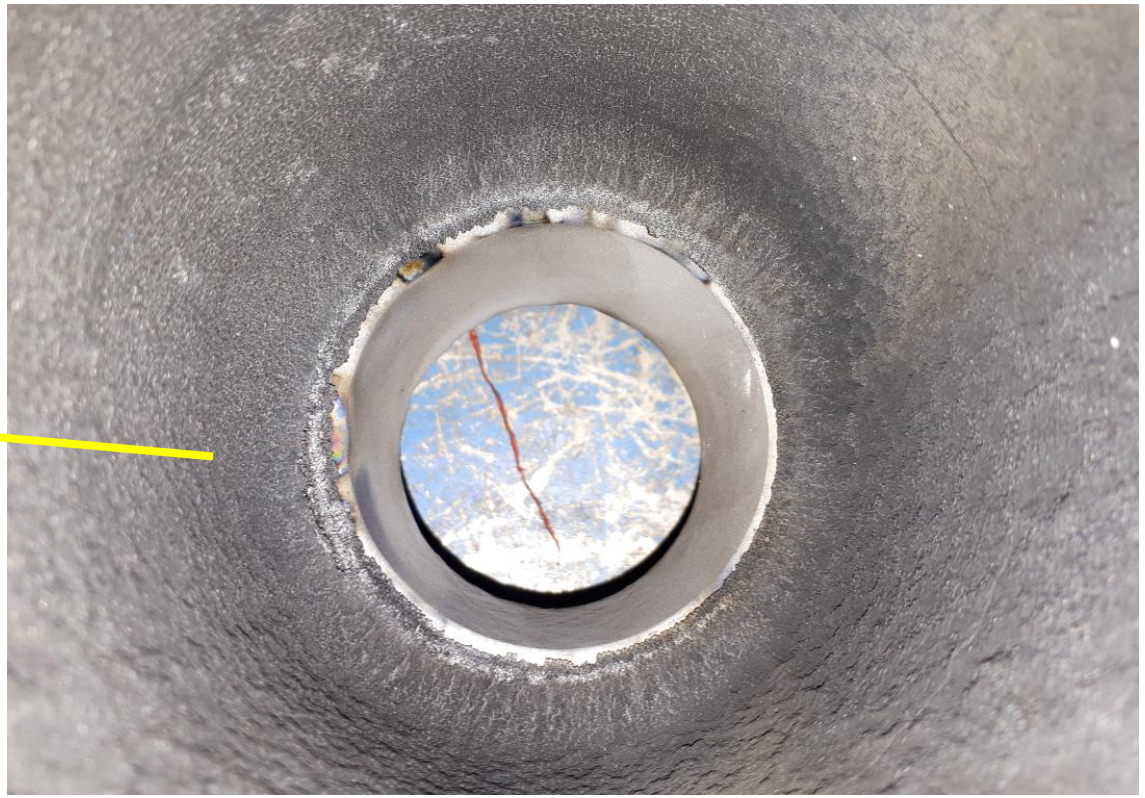
Cotton phenolic erosion

$$TEST\ 4, t_b = 20s$$
$$CONFIGURATION\ 2$$



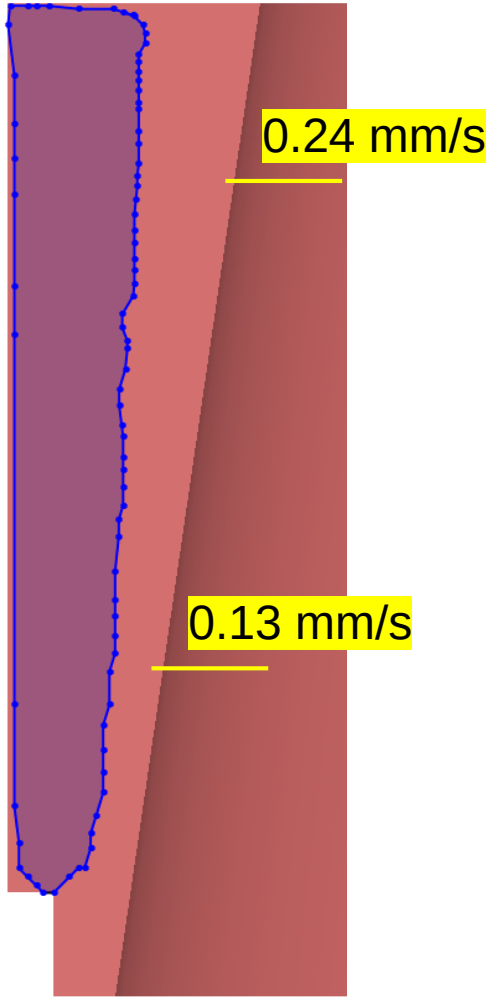
Materials interaction





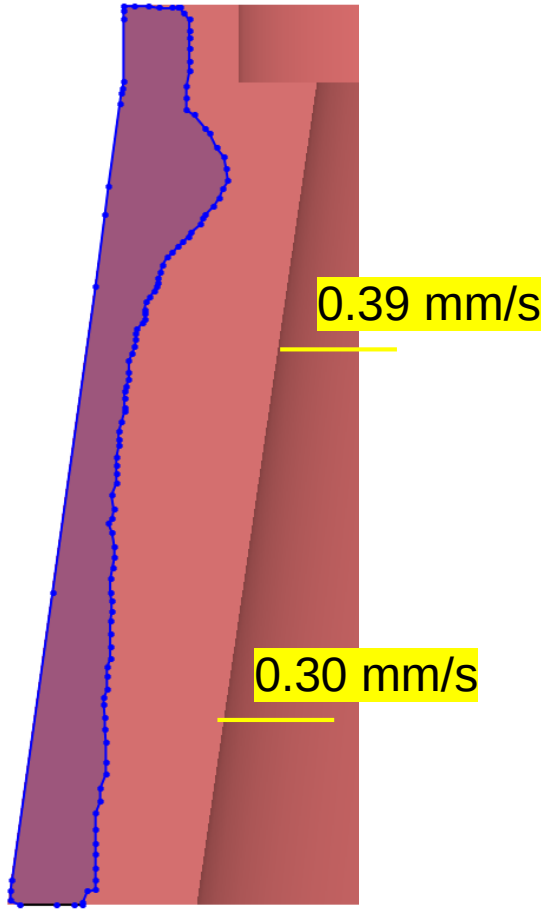
Cotton phenolic erosion

$$\boldsymbol{TEST\ 4, t_b = 20s}$$
$$\boldsymbol{CONFIGURATION\ 2}$$



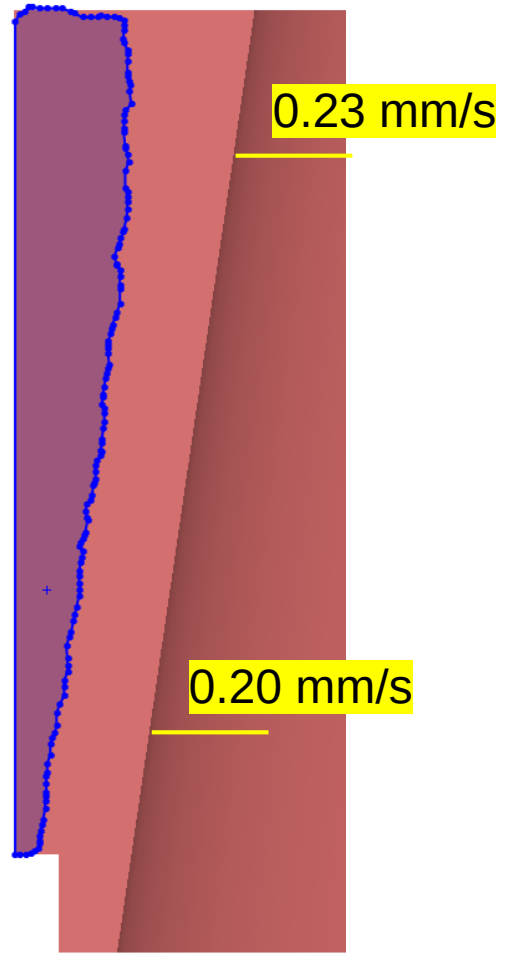
Cotton phenolic erosion

$$\boldsymbol{TEST\ 4, t_b = 24.5s}$$
$$\boldsymbol{CONFIGURATION\ 2}$$

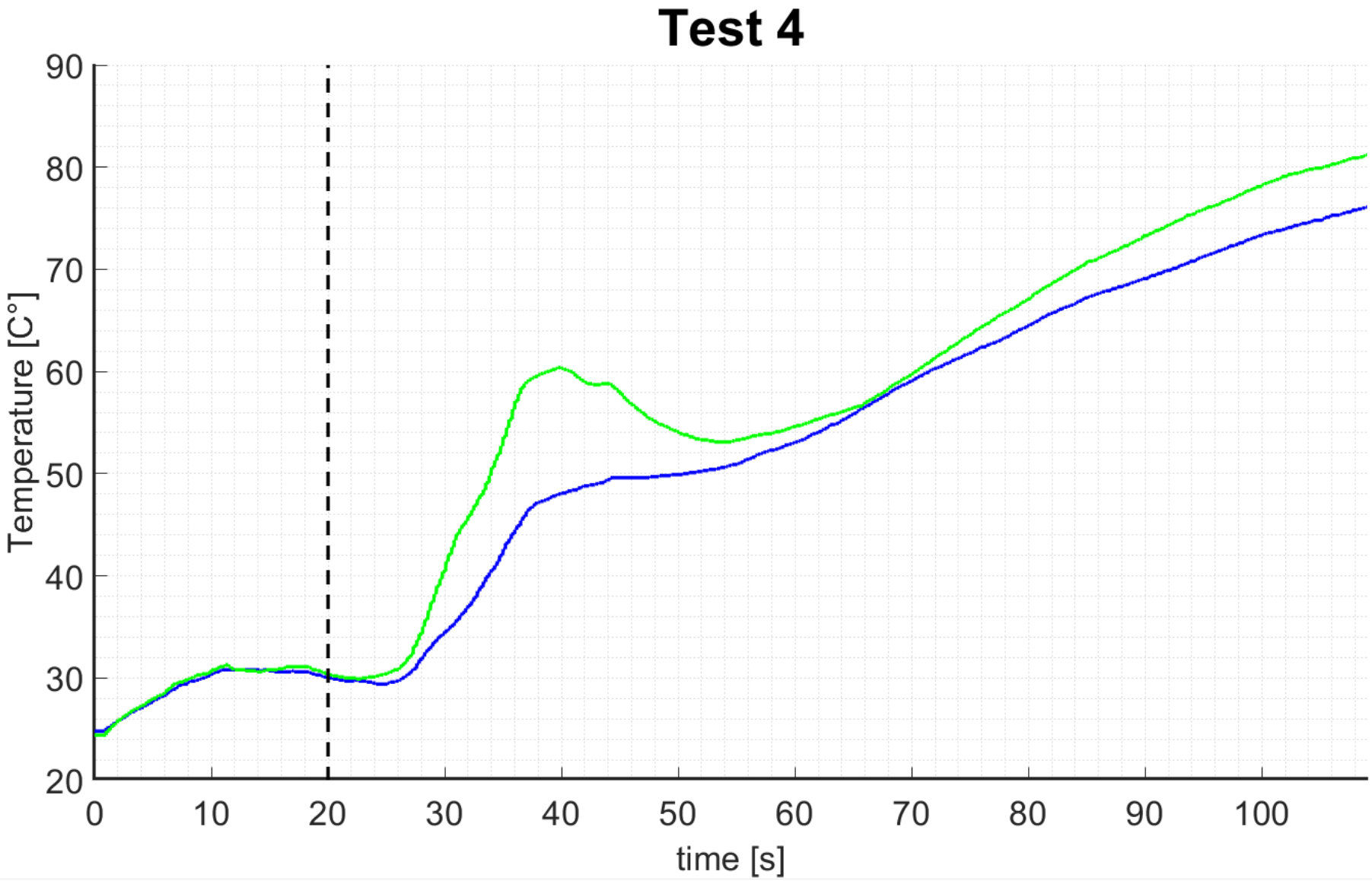


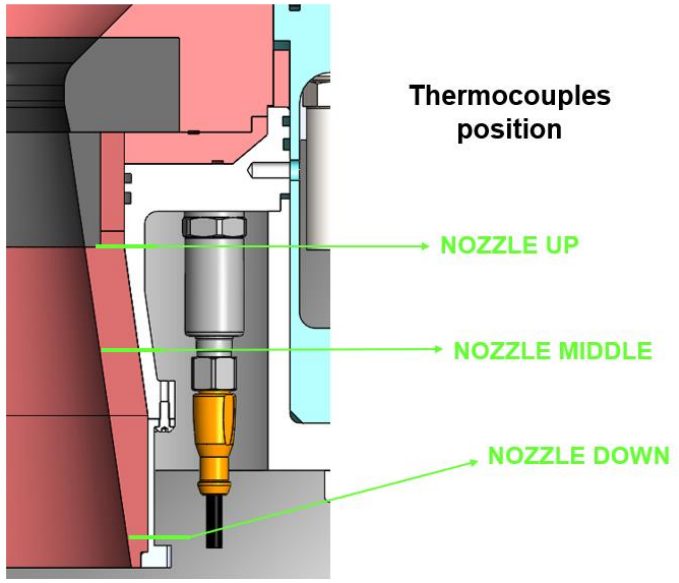
Cotton phenolic erosion

$$TEST\ 5, t_b = 24.5s$$
$$CONFIGURATION\ 2$$

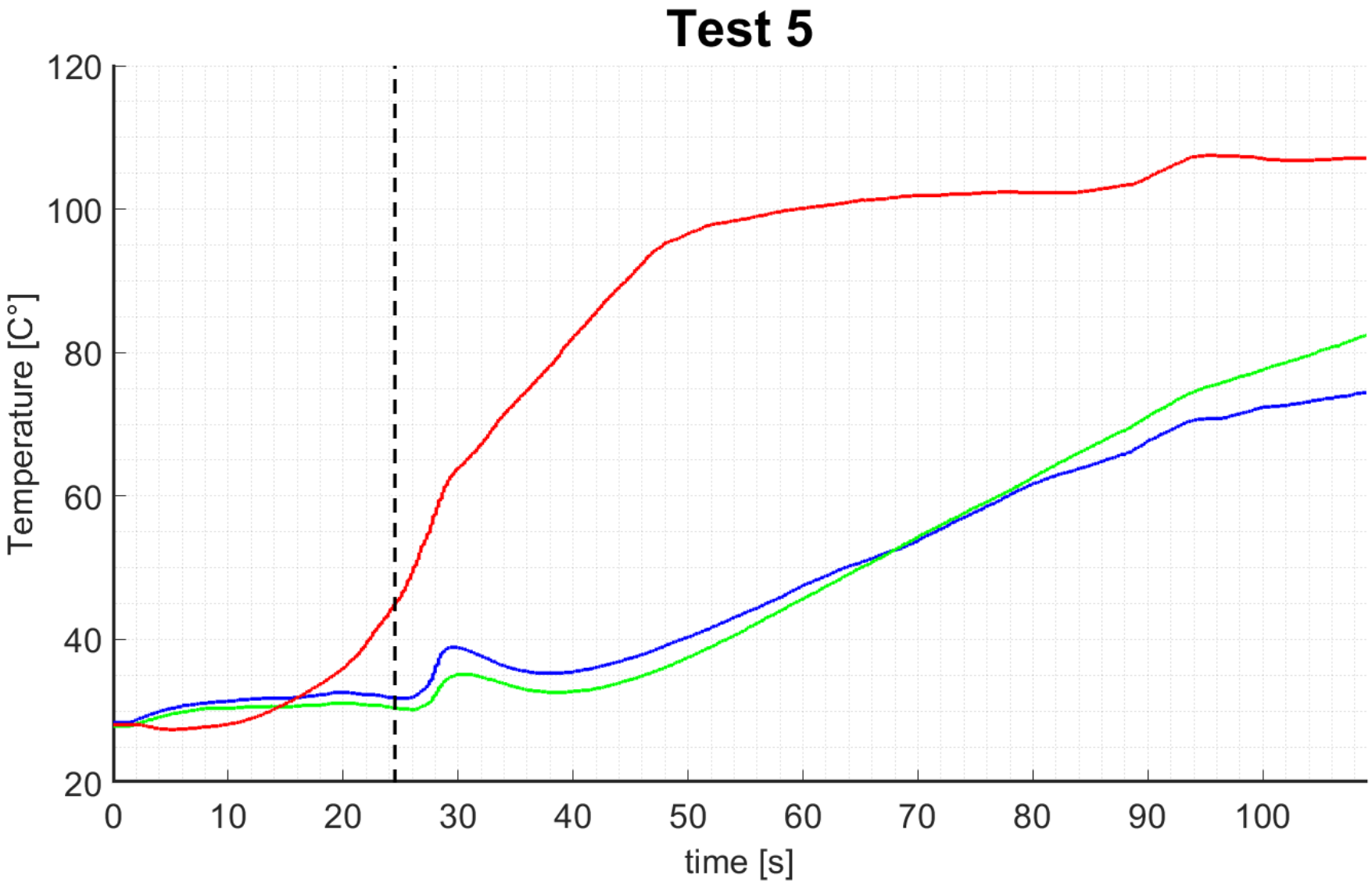


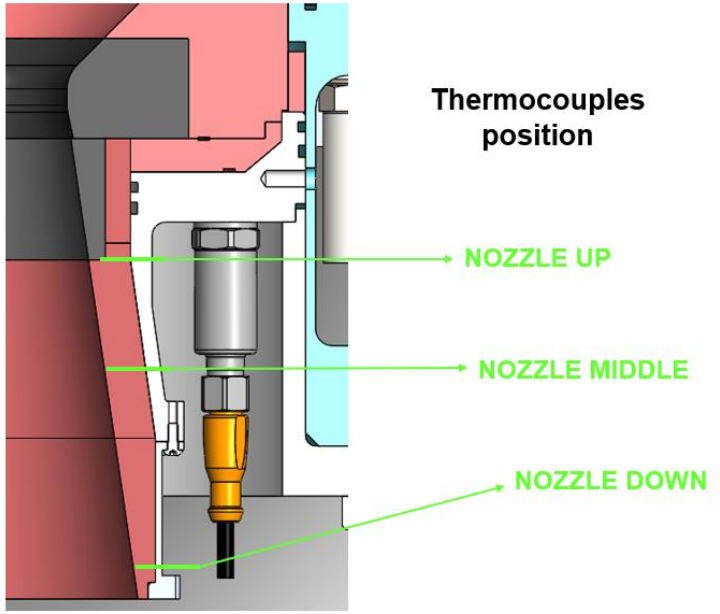
Temperature data





Temperature data





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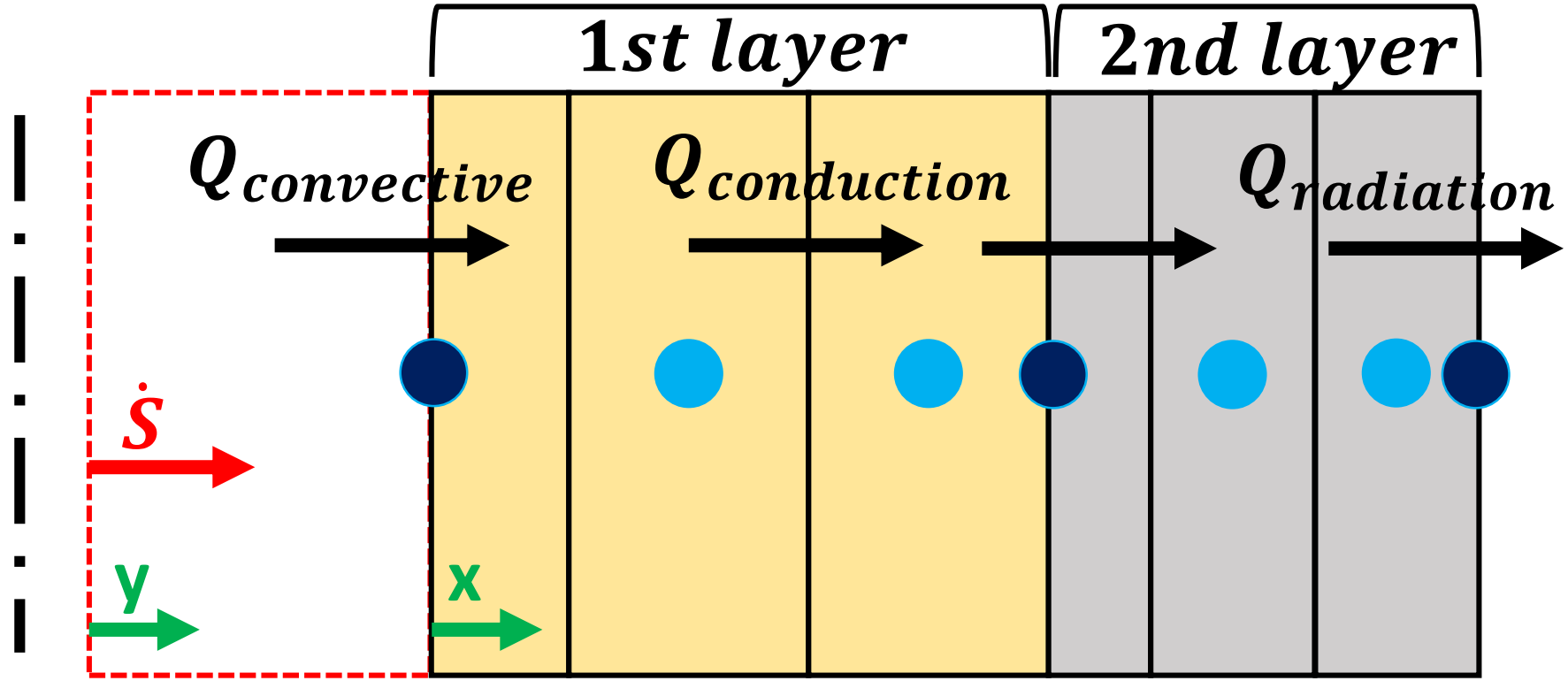
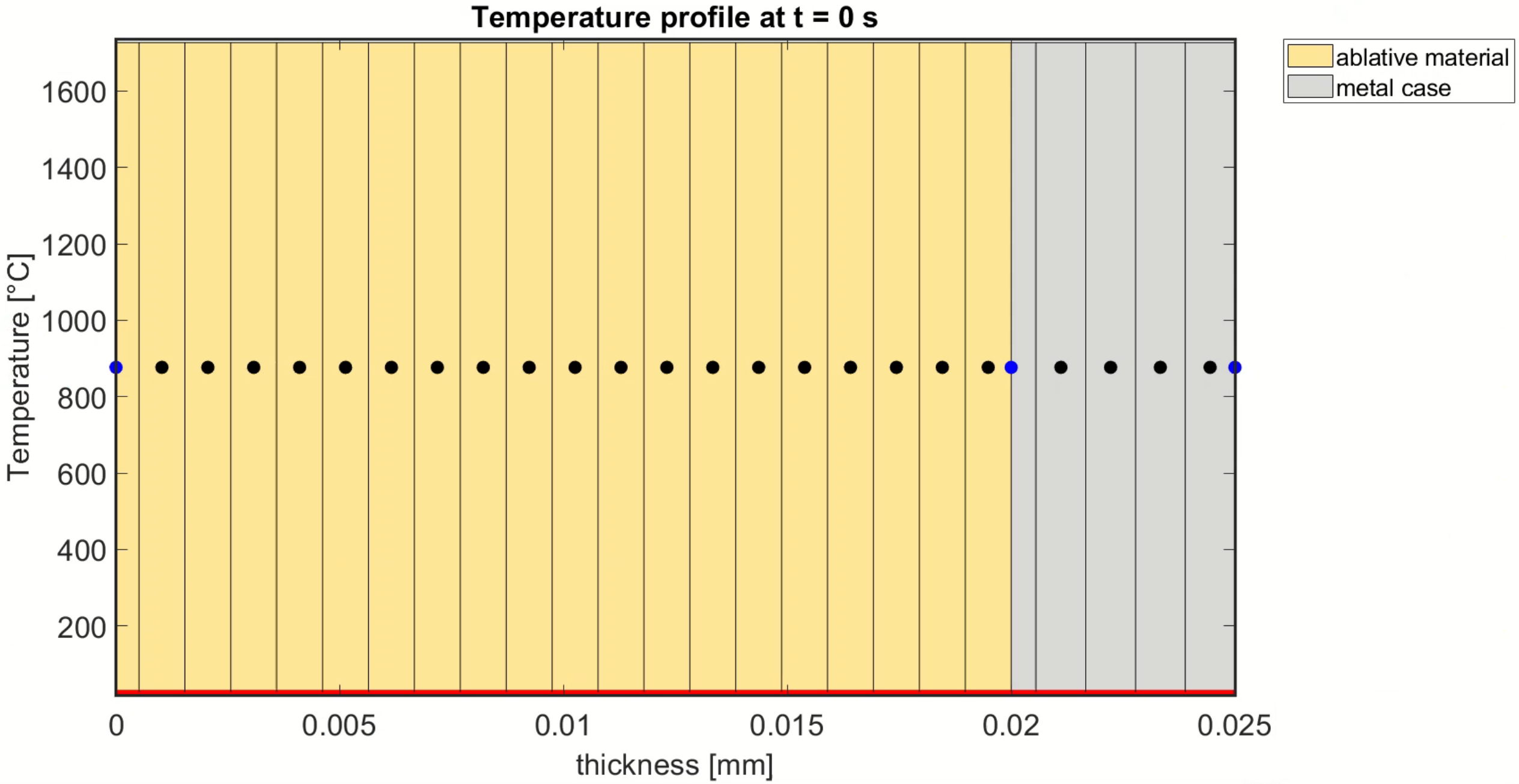
1D ablation model



$$\rho c_p \frac{\partial T}{\partial t}\Big)_x = \frac{1}{A}\frac{\partial}{\partial x}\left(kA\frac{\partial T}{\partial x}\right)_t + \left(h_g - \bar{h}\right)\frac{\partial \rho}{\partial t}\Big)_y + \dot{S}\rho c_p \frac{\partial T}{\partial x}\Big)_t + \frac{\dot{m}_g}{A}\frac{\partial h_g}{\partial x}\Big)_t$$


Temperature profile at t = 0 s
ablative material
metal case
Temperature [°C]
1600
1400
1200
1000
800
600
400
200
0
0.005
0.01
0.015
0.02
0.025
thickness [mm]

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  - Numerical results
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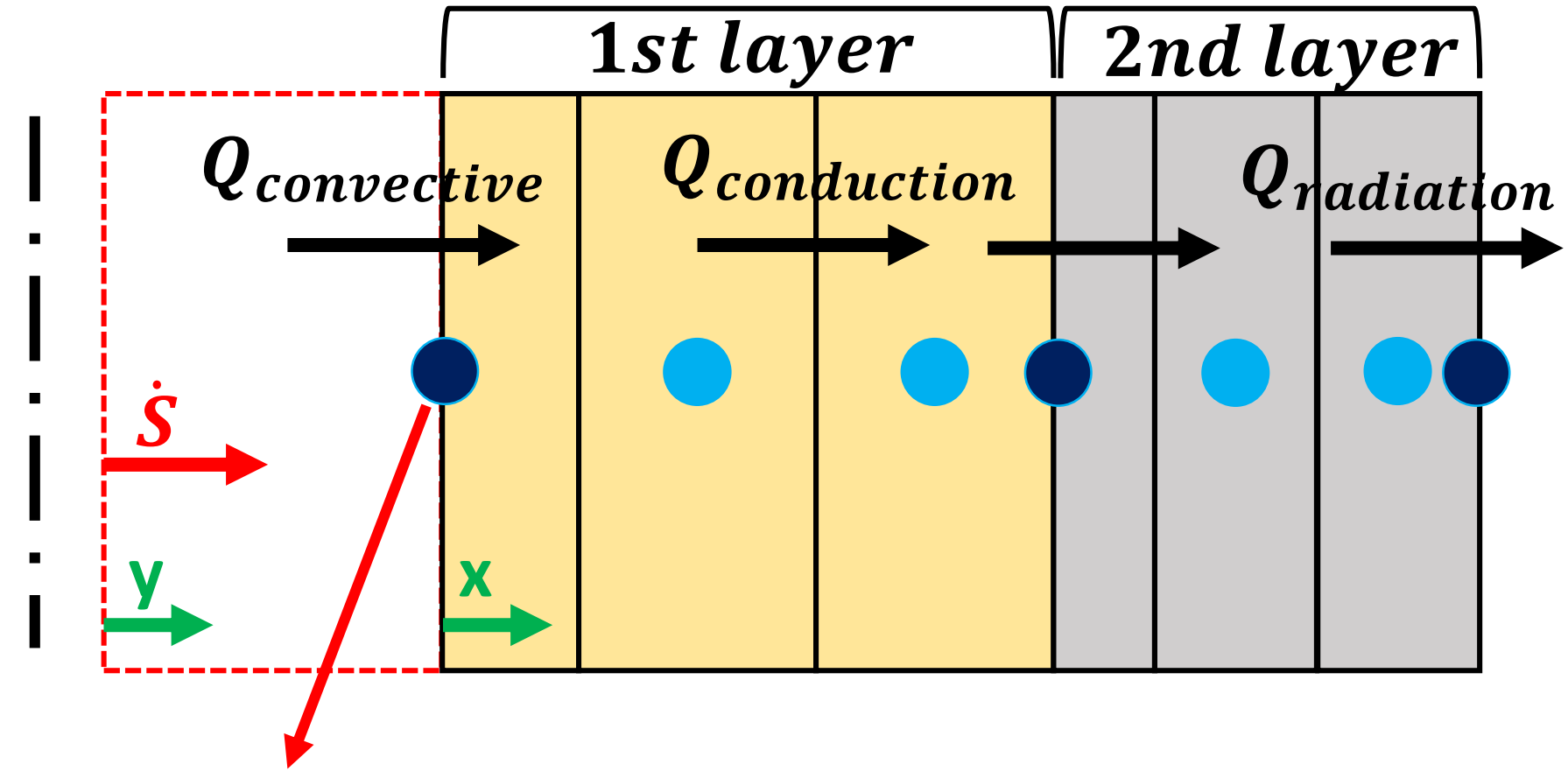
Future work



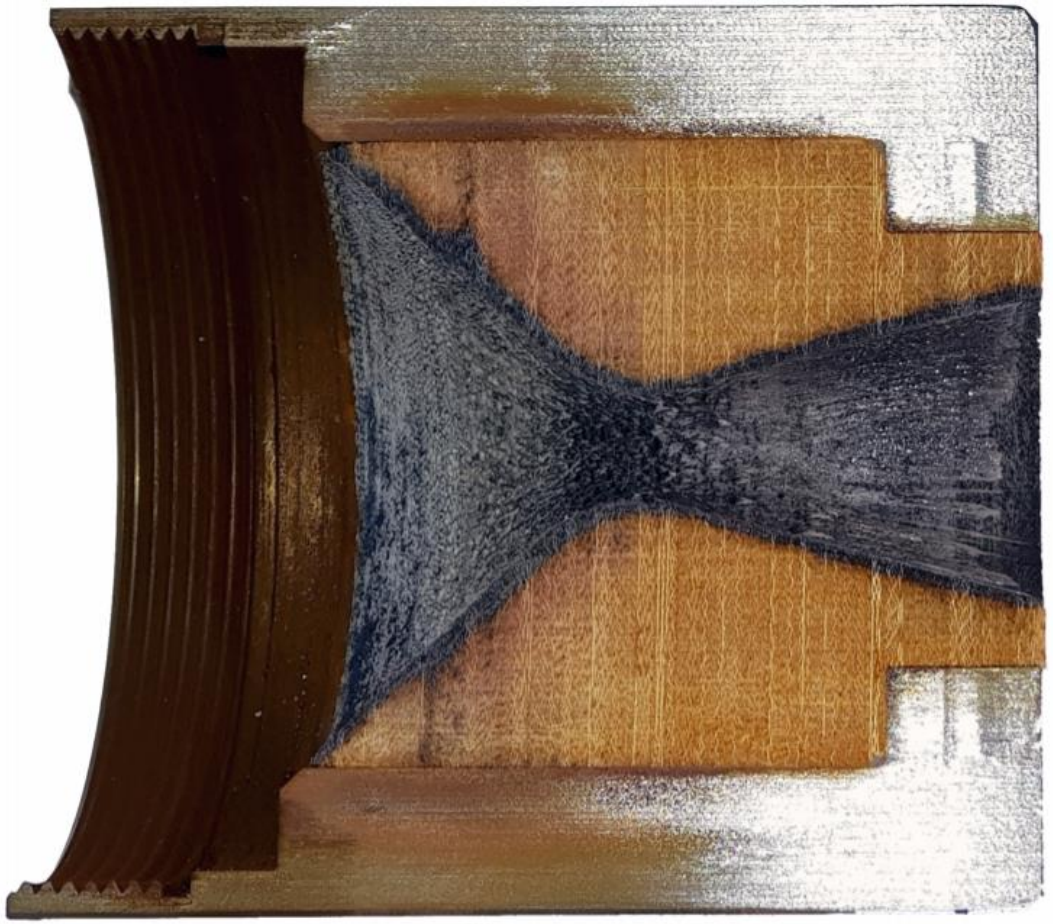
SURFACE ENERGY BALACE →thermochemical code (CEA)

Decomposition process & material properties

Future work

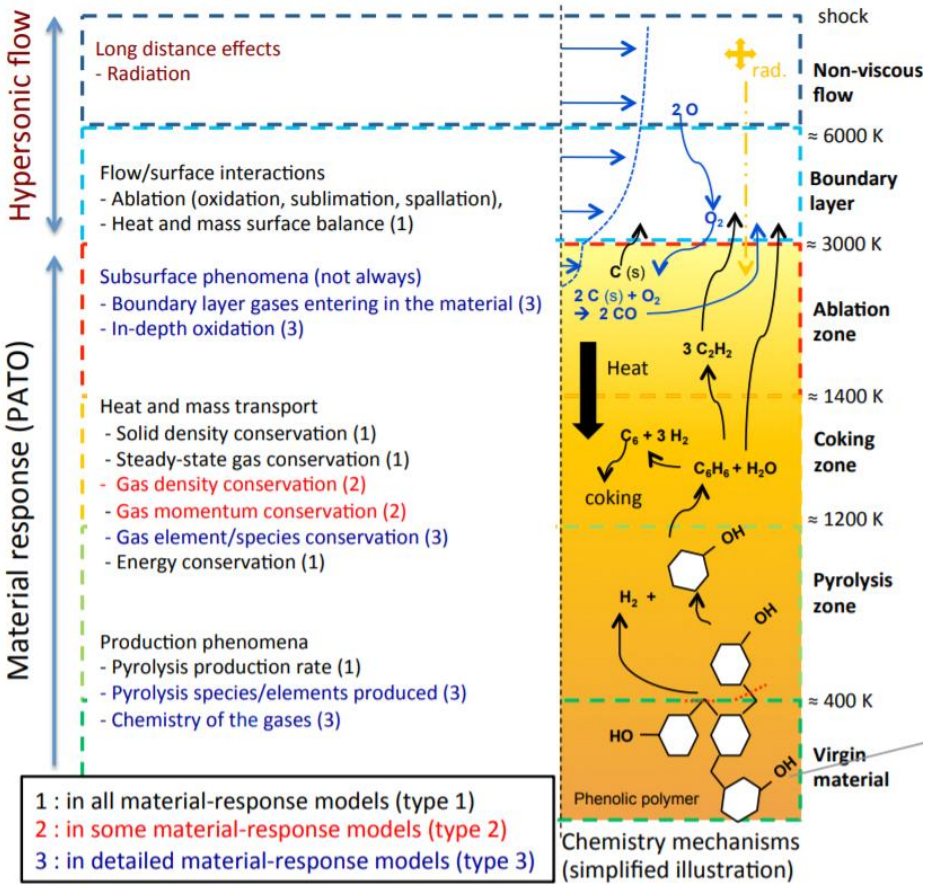
EXPERIMENTAL ANALYSIS

CARBON-PHENOLIC & SILICA PHENOLIC



NUMERICAL ANALYSIS

Porous material Analysis Toolbox (PATO)

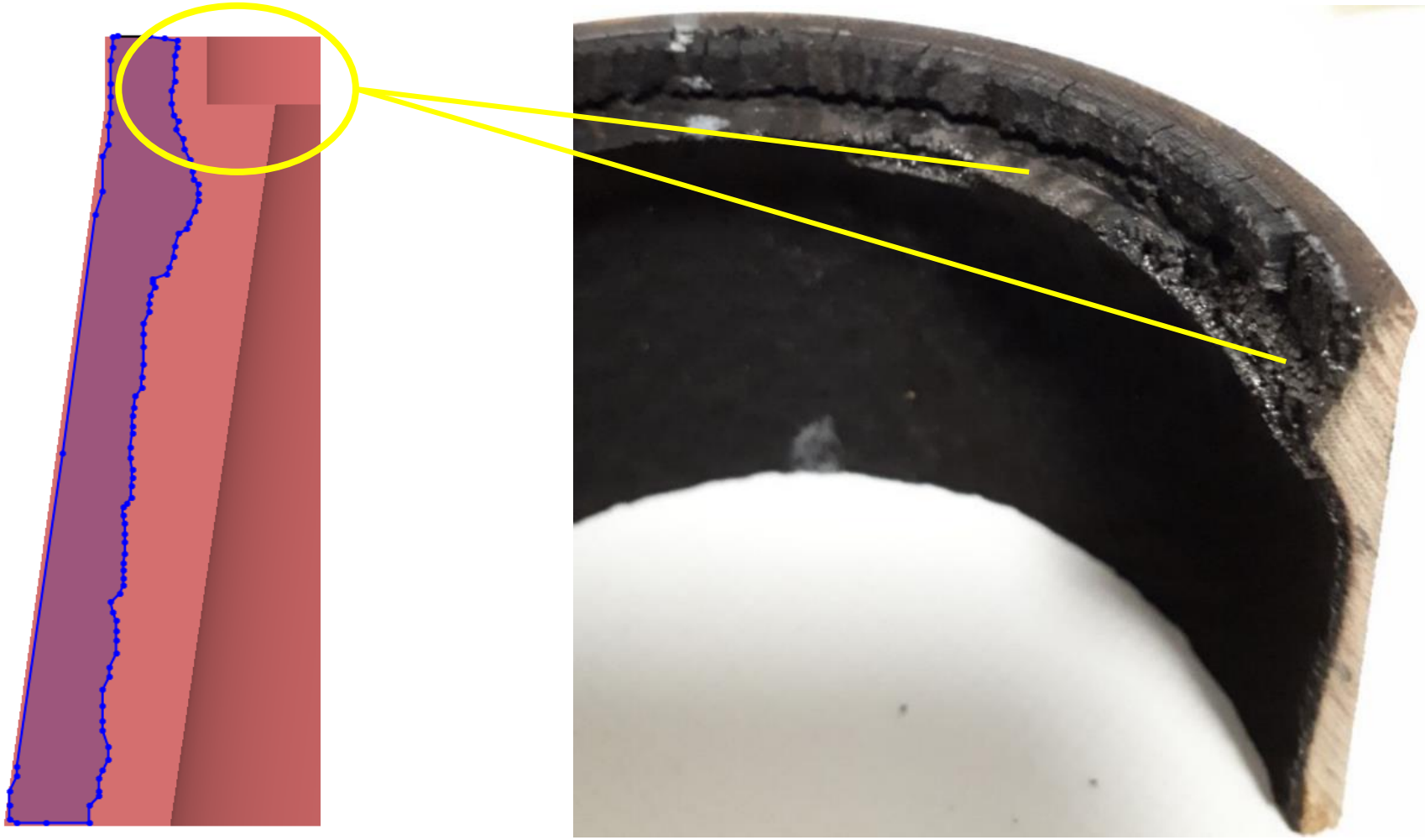


Thank you for your time! Any questions?

Extra

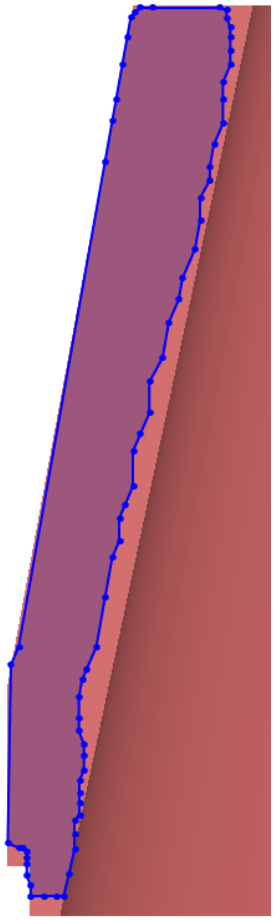
Materials interaction

Cotton phenolic erosion

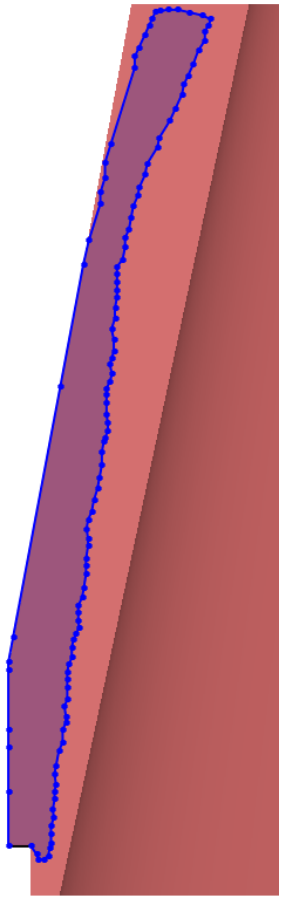


Cotton phenolic erosion

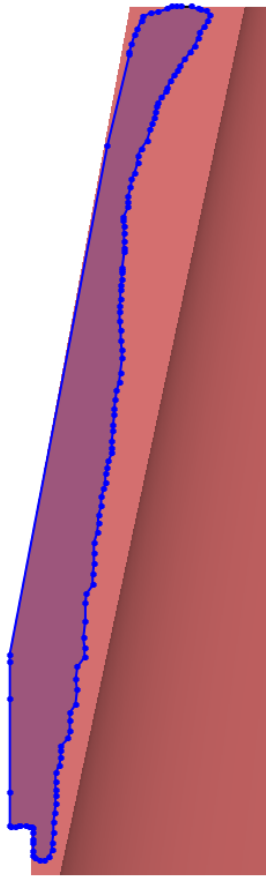
Configuration 1



$t_b = 7s$

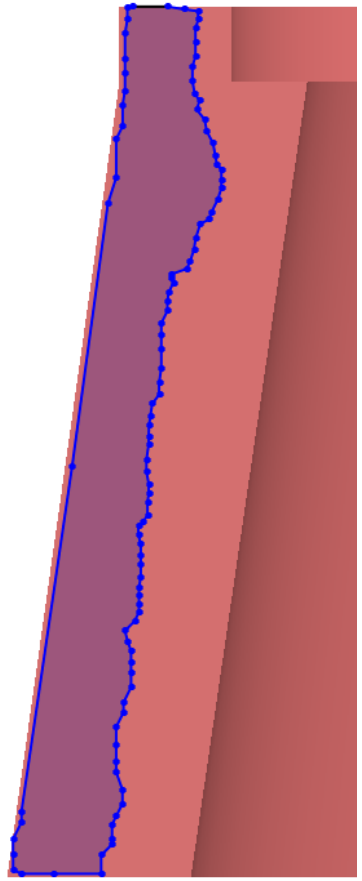


$t_b = 15s$

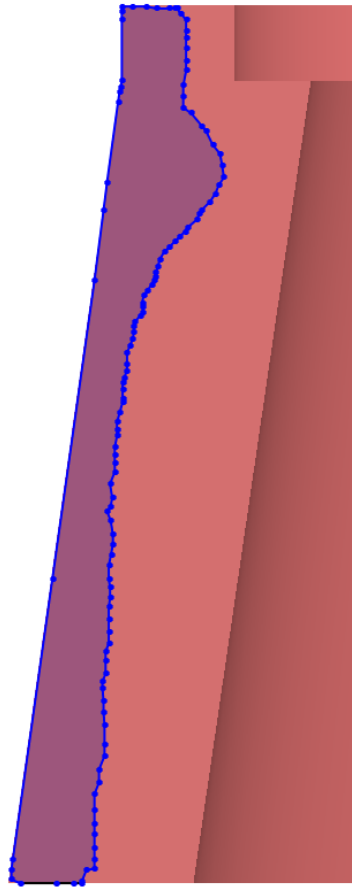


$t_b = 15s$

Configuration 2



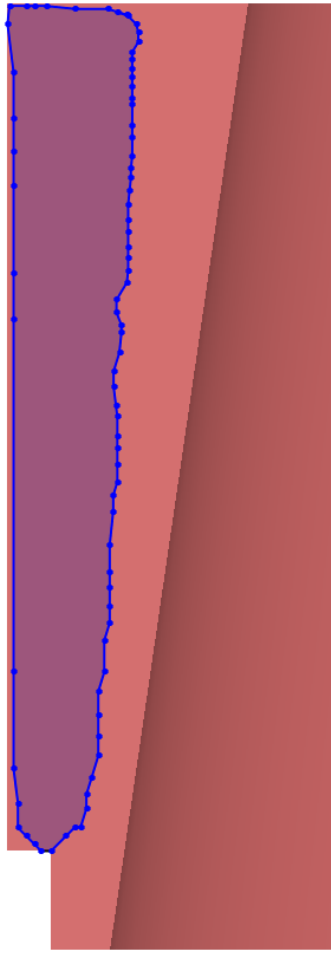
$t_b = 20s$



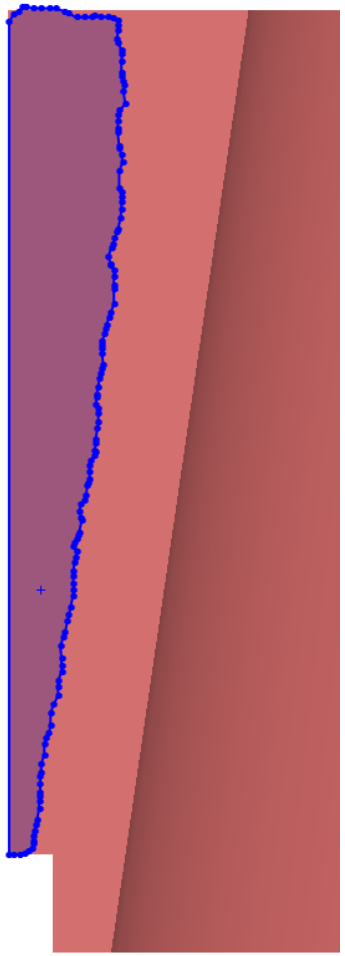
$t_b = 24.5s$

Cotton phenolic erosion

Configuration 2



$t_b = 20s$



$t_b = 24.5s$