CR MeP

ECOLE DES MINES D'ALBI
C A R M A U X

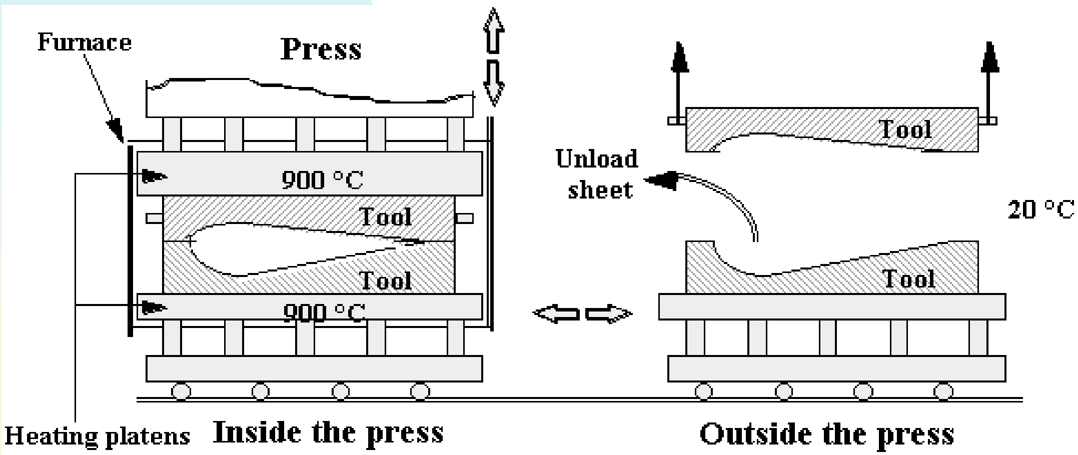
INSTITUT CARNOT M.I.N.E.S

Infra-Red sheet heating assisted Superplastic Forming (IR-SPF)

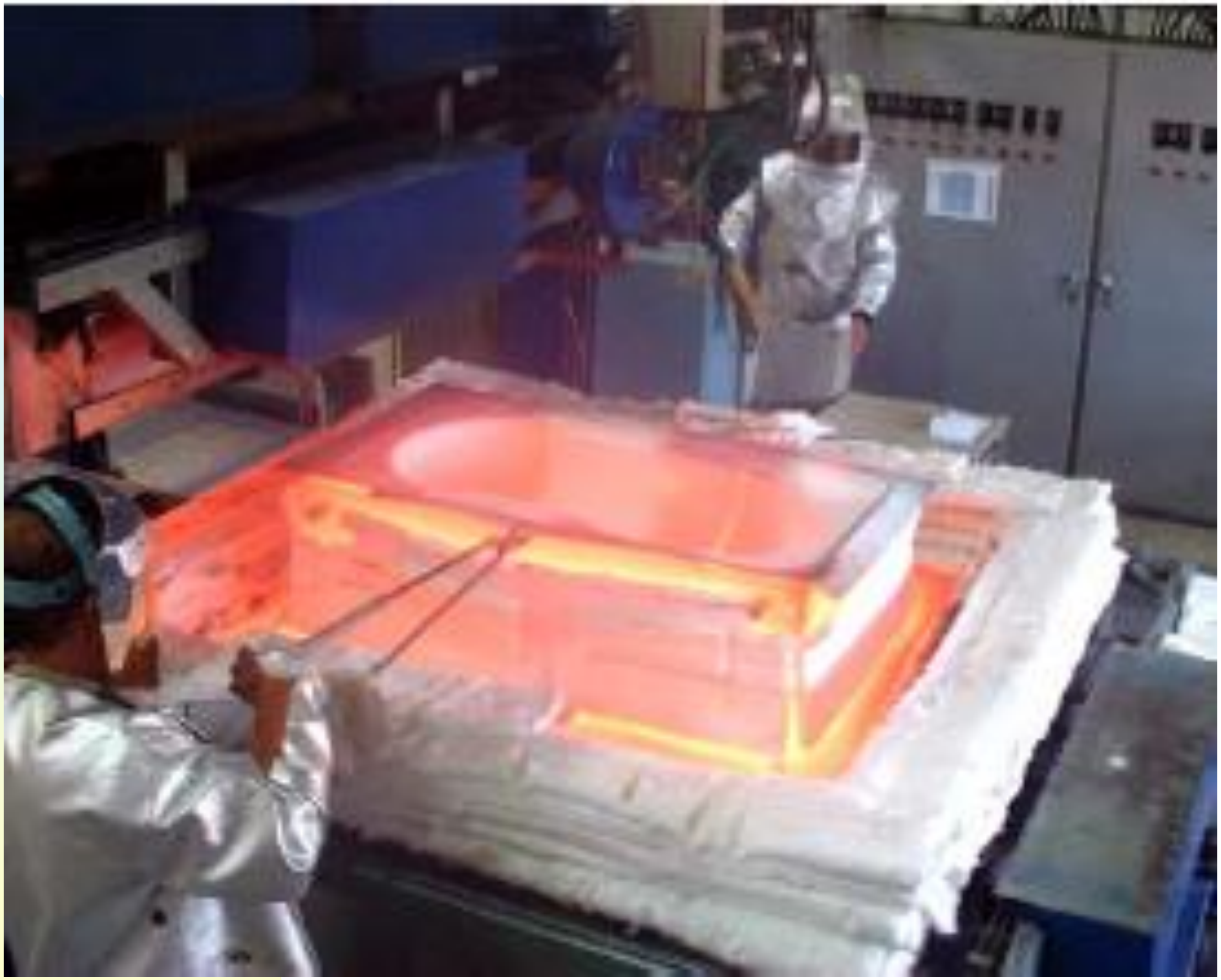
Gérard BERNHART , Thierry CUTARD, Yannick Le MAOULT, Fabrice SCHMIDT, Jean-Paul ARCENS

Background

- ✓ SPF energy consuming process
  - ➢ Press furnace technology

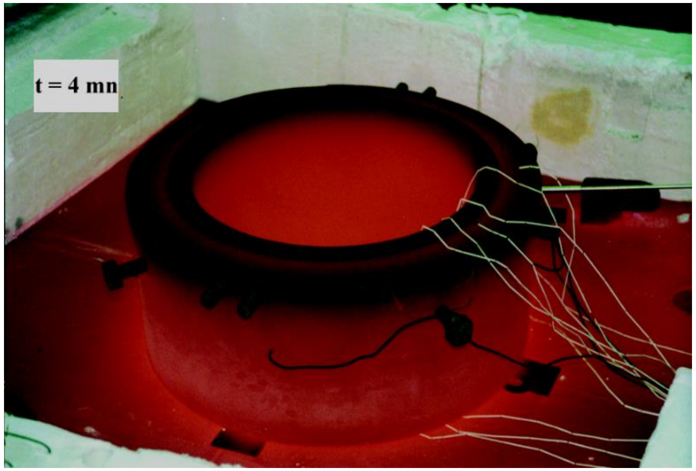


Loss of energy !!

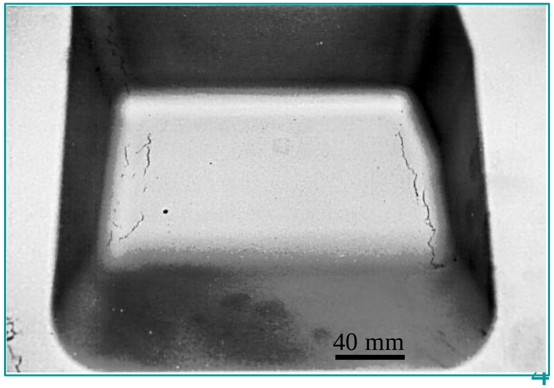


Background

- SPF a time consuming process (Titanium forming)
  - Initial heating (~24h to 48h)
  - Each cycle (~ 1h before forming)
  - Final cooling (~ 24 to 48 h



- SPF a damaging process
  - Damage of heating platen, heating elements
  - Damage of dies



CROMeP
ECOLE DES MINES D'ALBI CARMAUX

A need to decrease SPF process cost

INSTITUT CARNOT M.I.N.E.S

- ✓ Non recurent costs
  - Initial investment
  - Die investment
- ✓ Recurent costs
  - Energy consumption
  - Maintenance costs

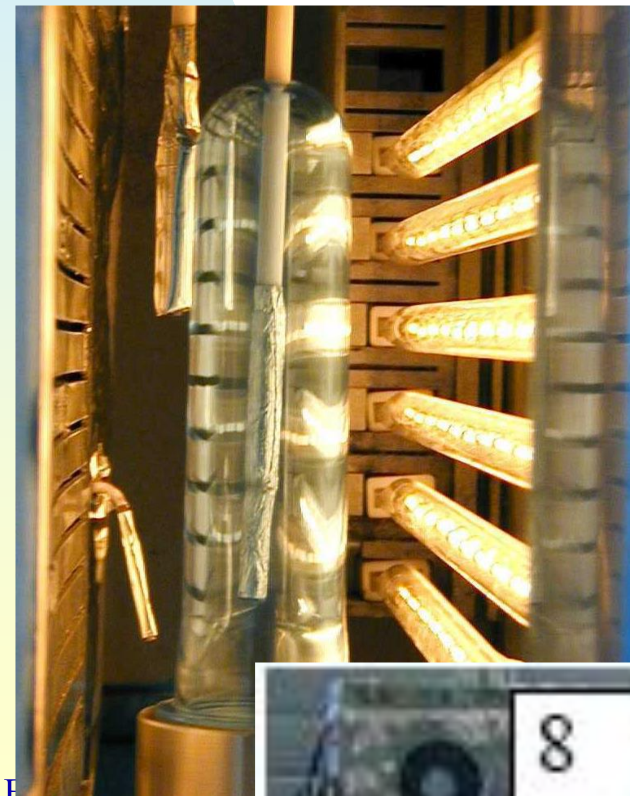
- ✓ Alternative technologies
  - SPLICE : SuperPlastic Laser Integrated Component Equiment (University of West England and LISTechnology Ltd)

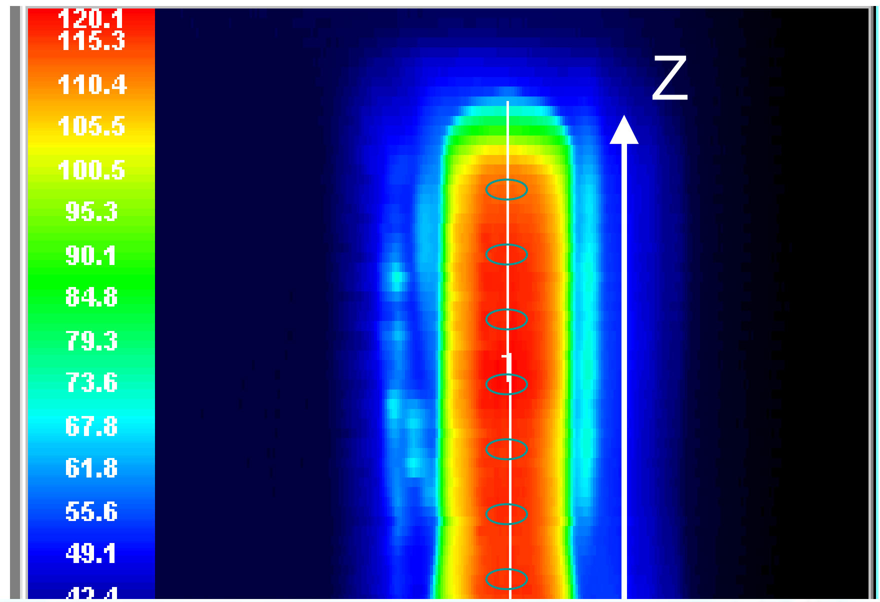
    ⇒ Cost reduction objectives questionable ?
  - IR-SPF : Infra-Read heating assisted SPF (CROMeP)

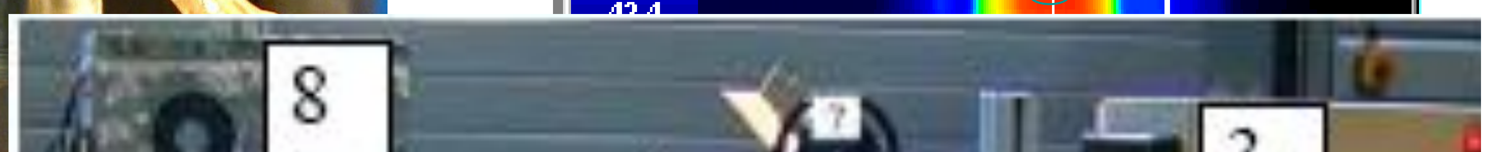
    ⇒ Limited to single sheet forming

CROMeP I-R heating background

- Three PhD thesis (1998-2006) on Infra-Read heating testing and simulation on polymer processes (Blow moulding and Thermo forming)
- Development of I-R pilot plants and in-house simulation codes (Plastirad® and ThermoRay®)



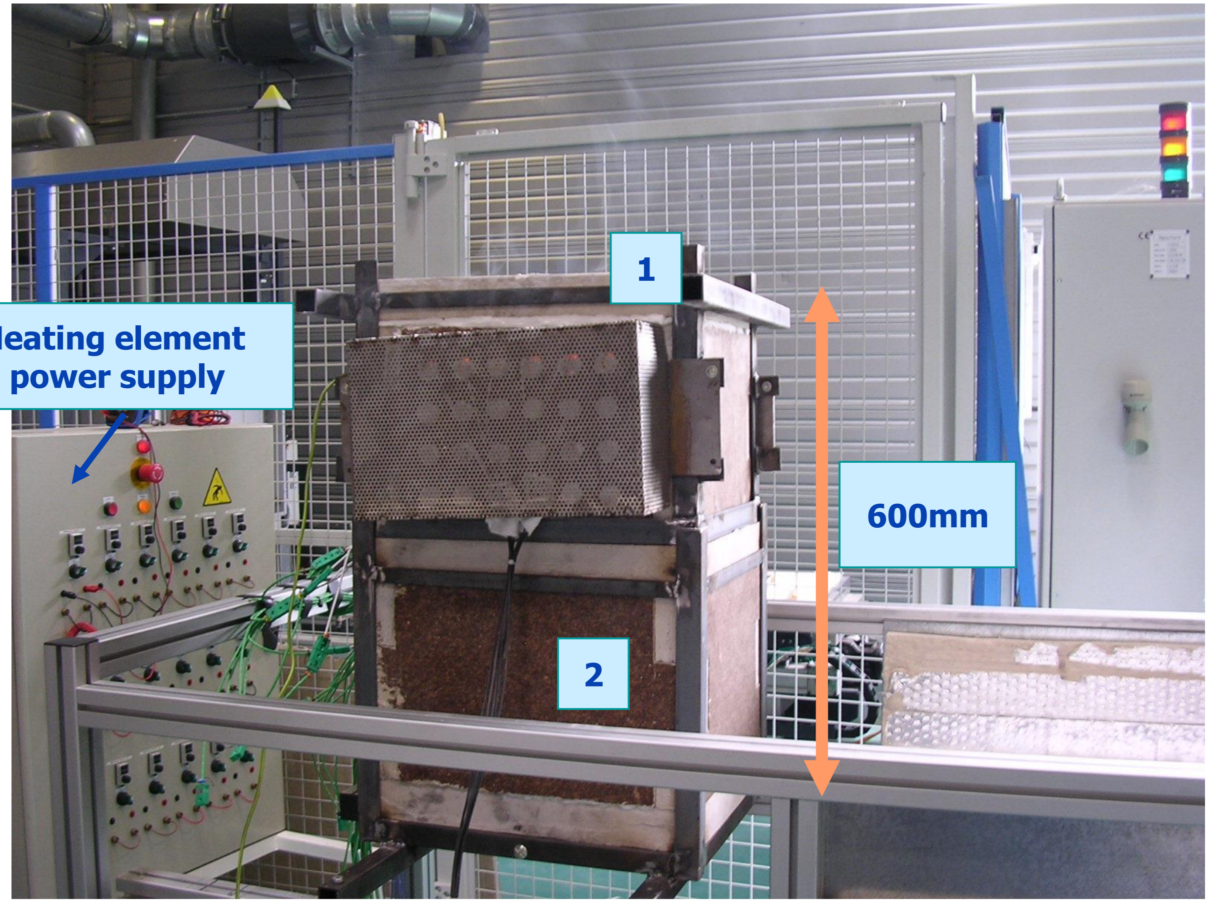




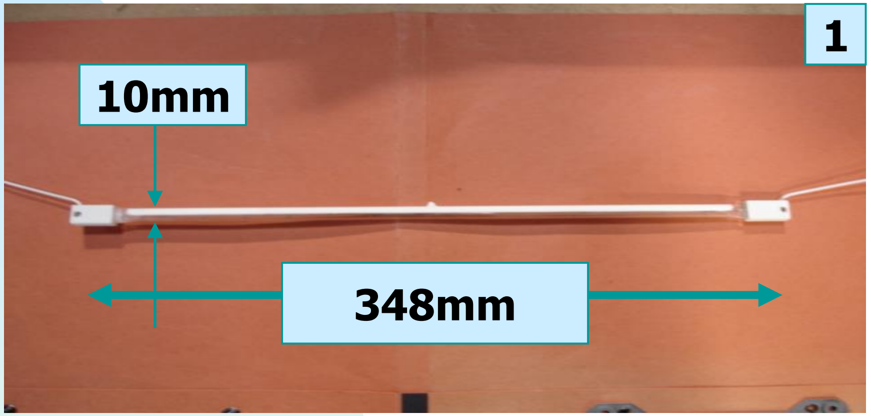
Summary

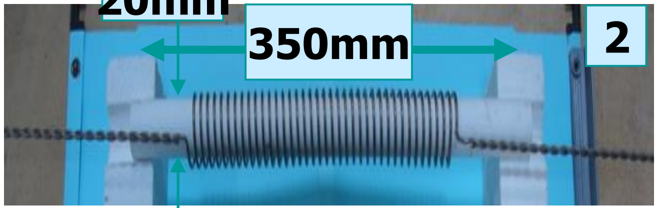
- ✓ TA6V Infra-Read heating experimental results
- ✓ Sheet Infra-Read heating simulation
- ✓ Die-sheet thermal contact evaluation
- ✓ Progress in Infra-Read SPF pilot equipment design

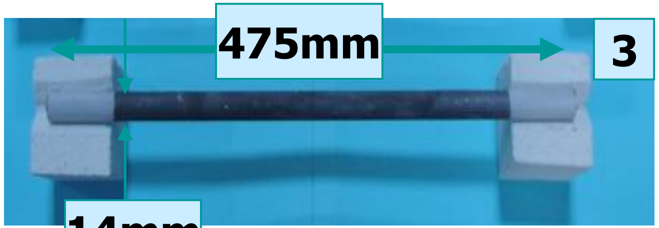
Experimental testing device



Infra-Read heating elements



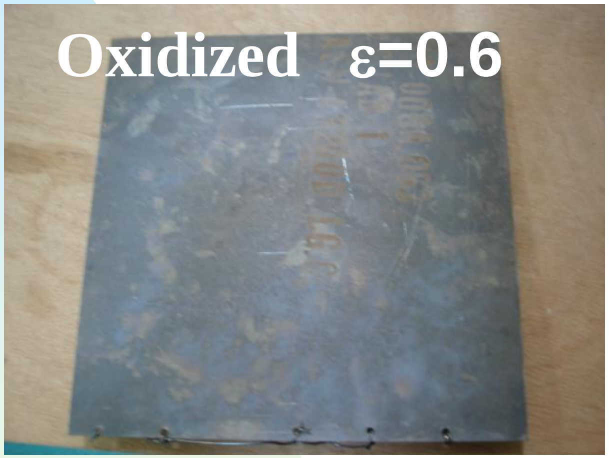


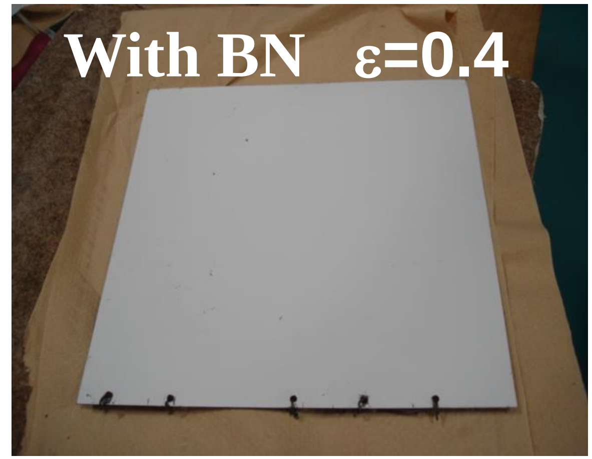


	Halogen lamps 1	Metallic wire heating elements 2	Silicon carbide heating rods 3
Maximal working temperature	2500 K	1698 K	1623 K
Maximal power	1000 W	1000 W	1000 W
Cost	25 €	120 €	60 €

Materials and test configuration

- ✓ TA6V sheets (200x200x 0.8 or 1.6 mm)



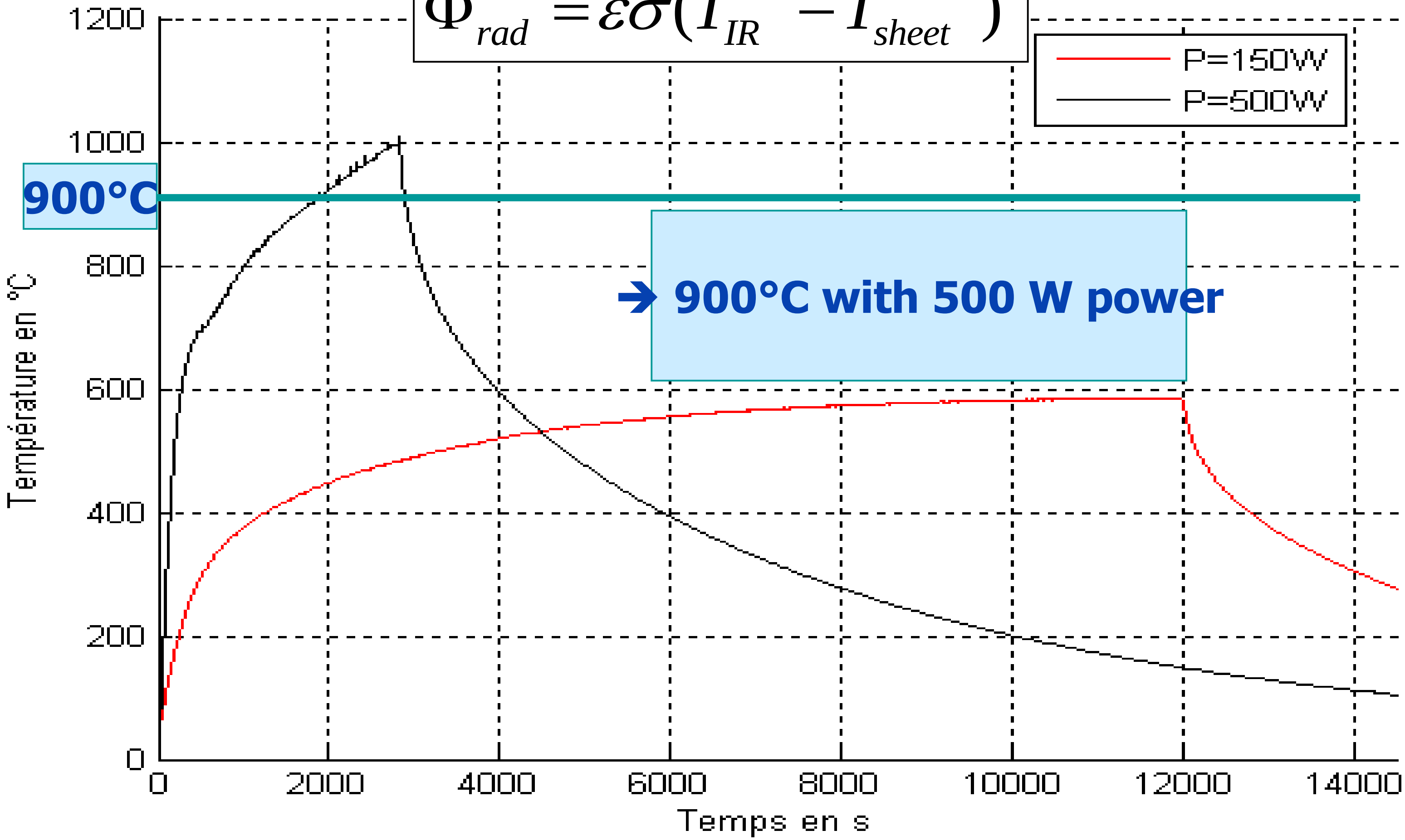


- ✓ Testing conditions
  - ➢ I-R heater/sheet distance : 200 mm
  - ➢ 6 Infra-Red heating elements
  - ➢ Power 150 W and 500 W

Welded K thermocouples

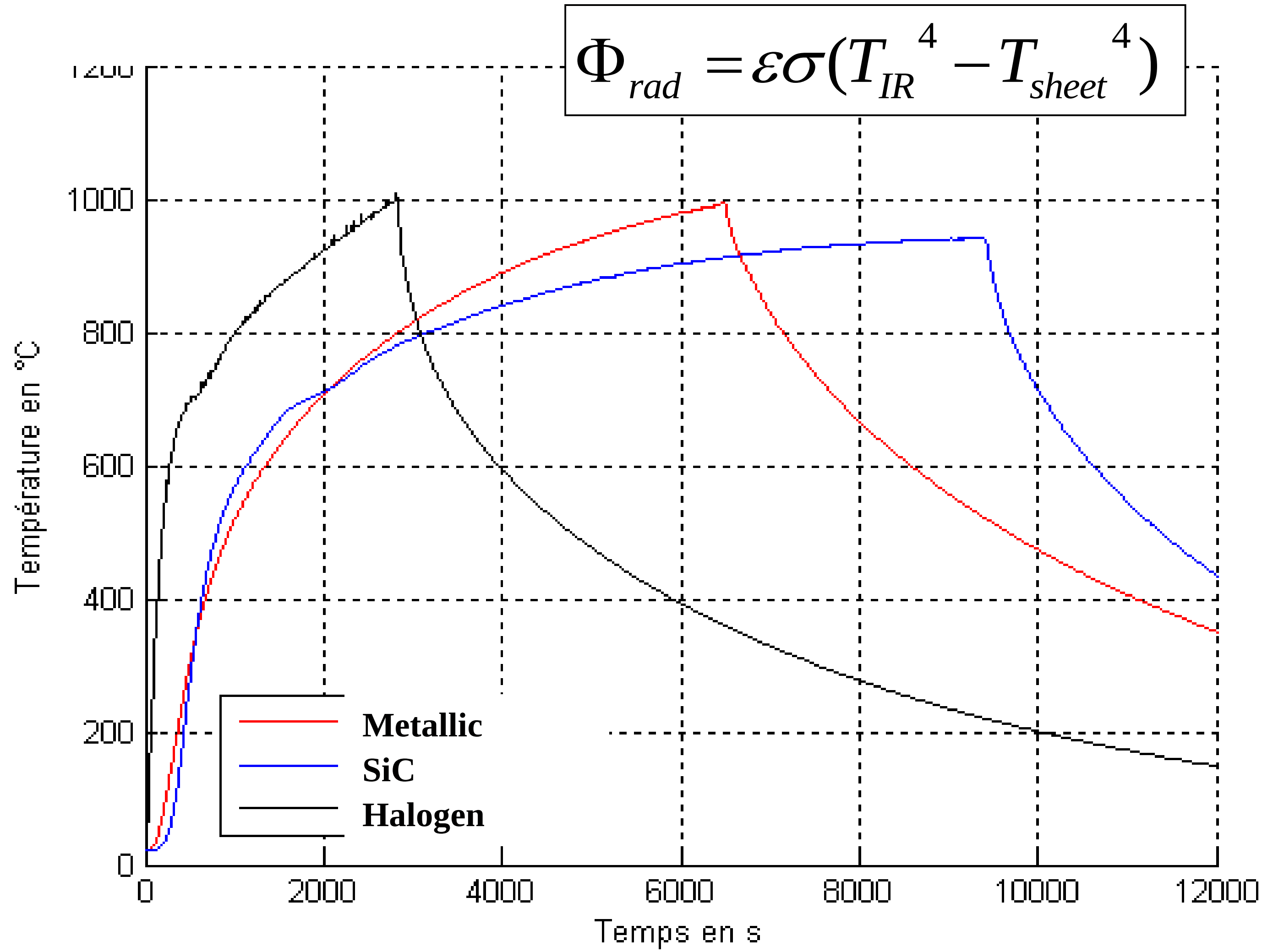
Test results : Halogen lamps

$$\Phi_{rad} = \varepsilon\sigma(T_{IR}{}^{4} - T_{sheet}{}^{4})$$



No significant difference between Oxidised and BN surface

Heating element comparison



- P=500W
- Halogen lamps are the best choise
- Time to reach 900°C :

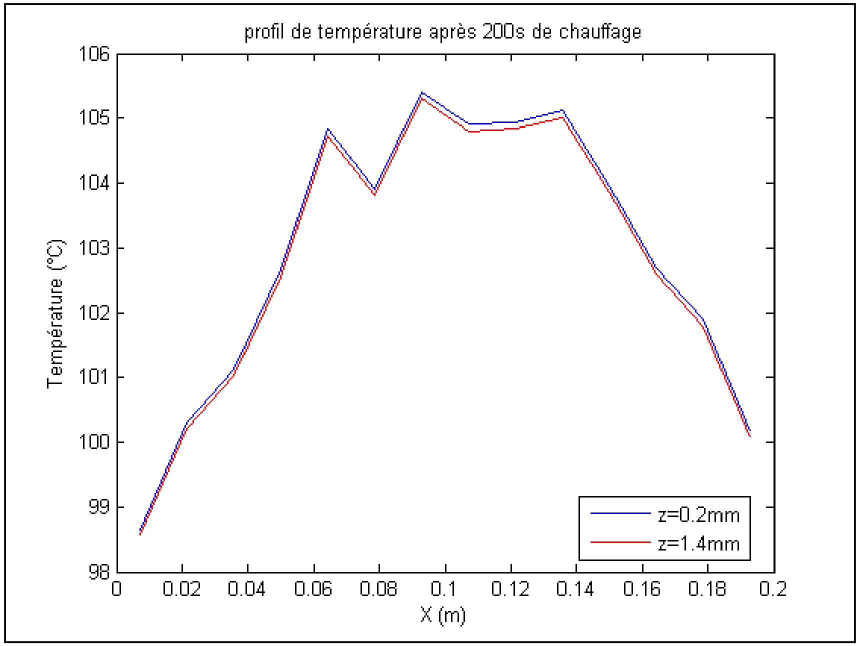
  30 minutes
- Very good surface temperature homogeneity (less 5%)

Through thickness temperature

- BIOT number analysis

$$Bi = \frac{Conduction}{Convection} = \left(\frac{h_g L}{\lambda_{sheet}} \right)$$

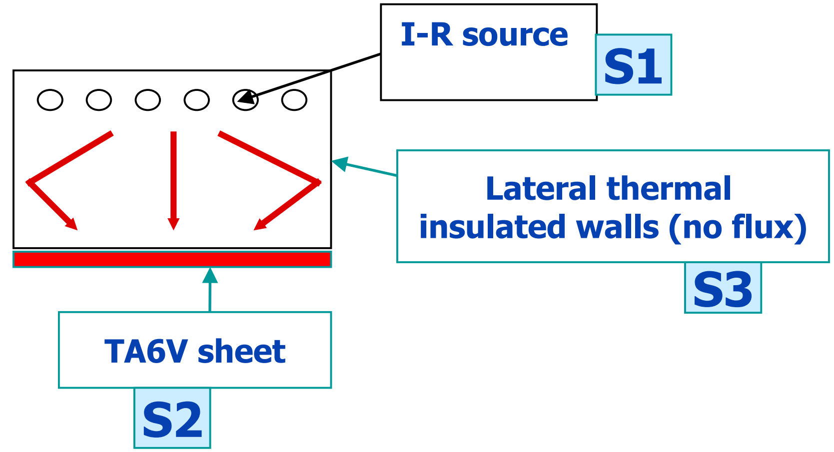
  - Values are below 1 : i.e there is no thermal gradient though the thickness
- Numerical simulation with THERMORAY®
  - Temp. profile after 200s
  - 0,2 mm and 1,4 mm
  - ΔT < 1°C



- Sheet is always isothermal

Transient thermal modeling

- ✓ Cavity transient "radiosity" model



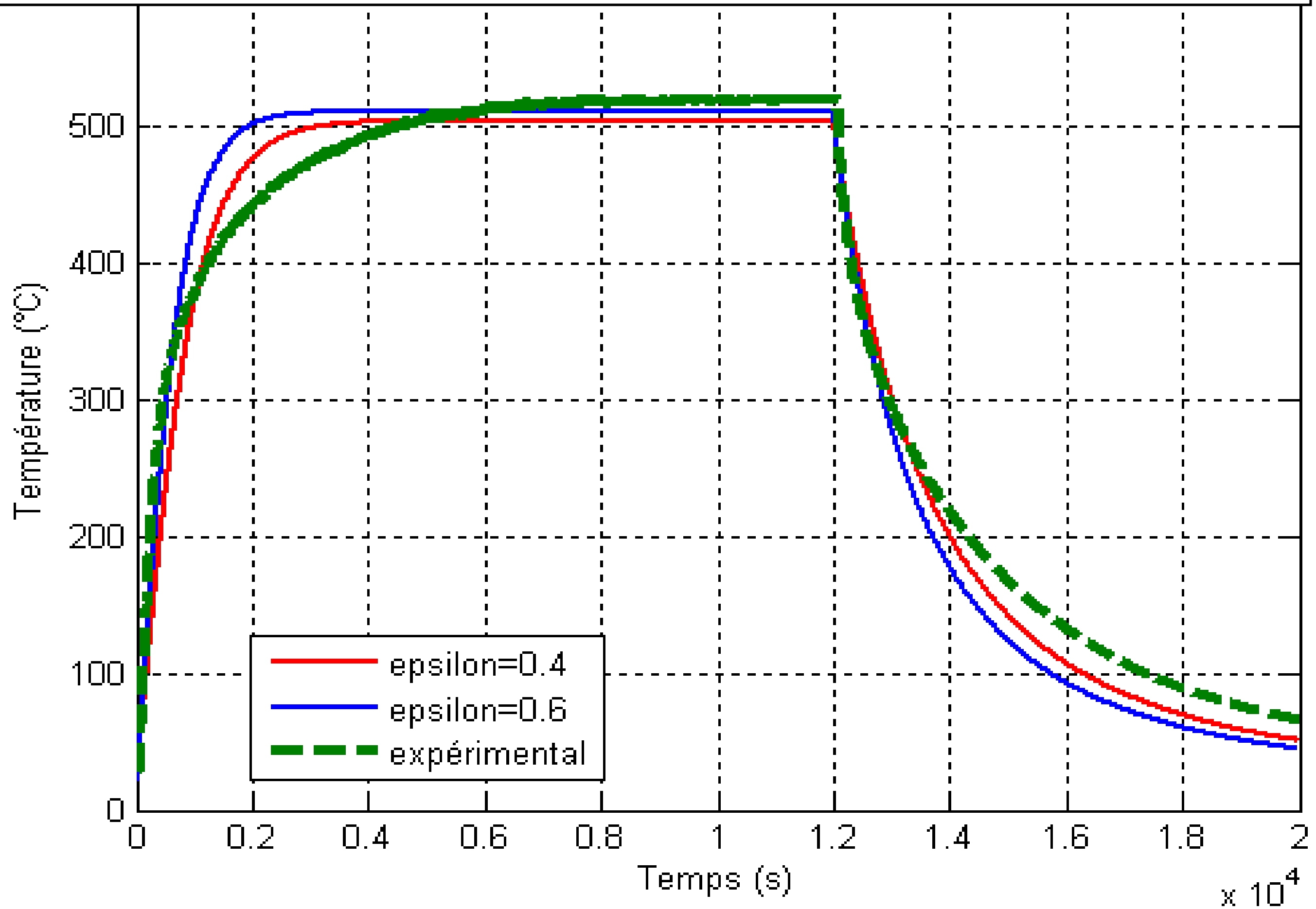
$$\rho V c_p(T_2)\frac{dT_2}{dt} = -h_c S_2(T_2 - T_a) - \varepsilon_2 S_2 \sigma (T_2^4 - T_a^4) + \phi_{12}(T_2)$$

$$\phi_{12}(T_2) = -\phi_{21}(T_2) = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 S_1} + \left(\frac{S_1 + S_2 - 2S_1F_{12}}{S_1S_2 - (S_1F_{12})^2}\right) + \frac{1-\varepsilon_2}{\varepsilon_2 S_2}}$$

[De Vriendt 1992]

Simulation results (P=150W)

Temperature evolution on the TA6V sheet



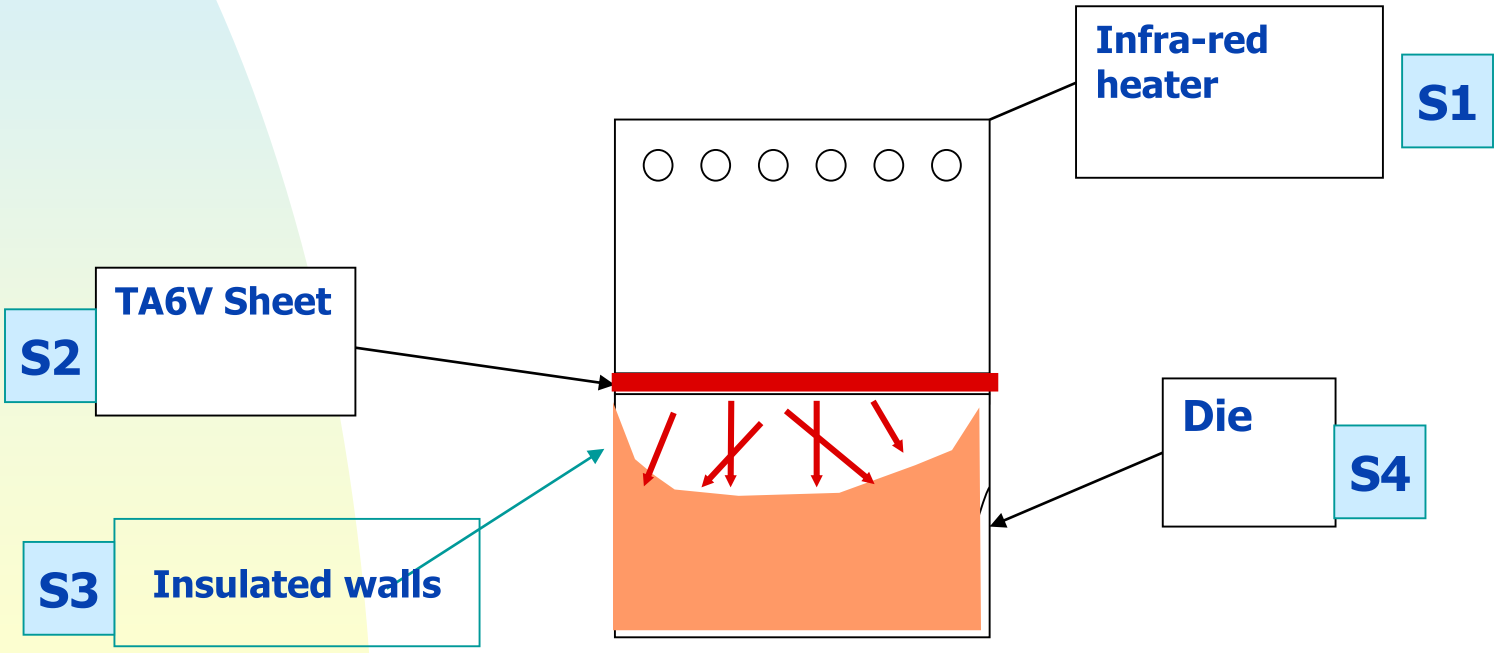
Initial temperature increase rate

$$\left(\frac{dT}{dt}\right)_{t=0} = \frac{\phi}{mc_p}$$

Explicit Euler Method with Matlab

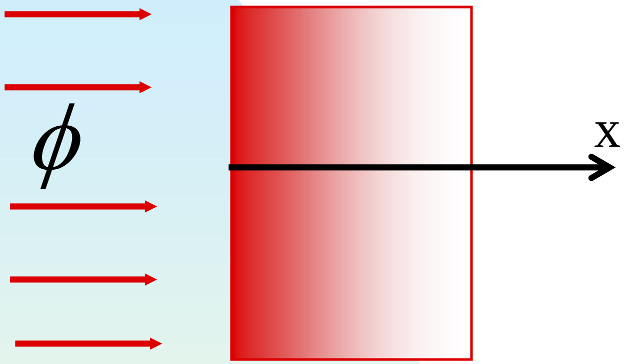
Sheet-die contact

- Sheet-Die contact may induce a drastic drop of sheet temperature ⇒ loss of SuperPlasticity domain
- During sheet heating die is heated by “cavity radiation”



Die surface temperature

- Simplified thermal analysis



$$\frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial x^2}$$

Transient heat equation

$$T(0,t) = \frac{2\phi}{b\sqrt{\pi}}\sqrt{t}$$

Surface temperature evolution

- b : thermal **effusivity** (thermal inertia m^2/s)
  - b low ➔ rapid surface temperature increase
  - b high ➔ heat sink effect

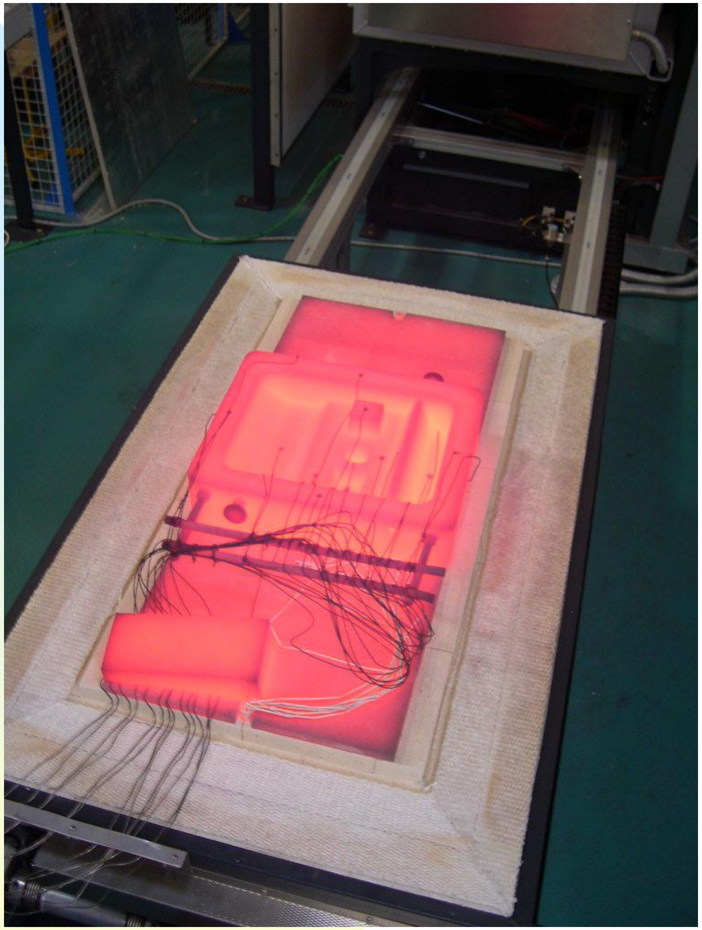
$$b = \sqrt{\lambda \rho C_p}$$

- Typical values at 900°C

Heat resistant steel : 10000
FRCC Concrete : 3200
Vitreous silica : 2400

- Preferential use of insulating materials

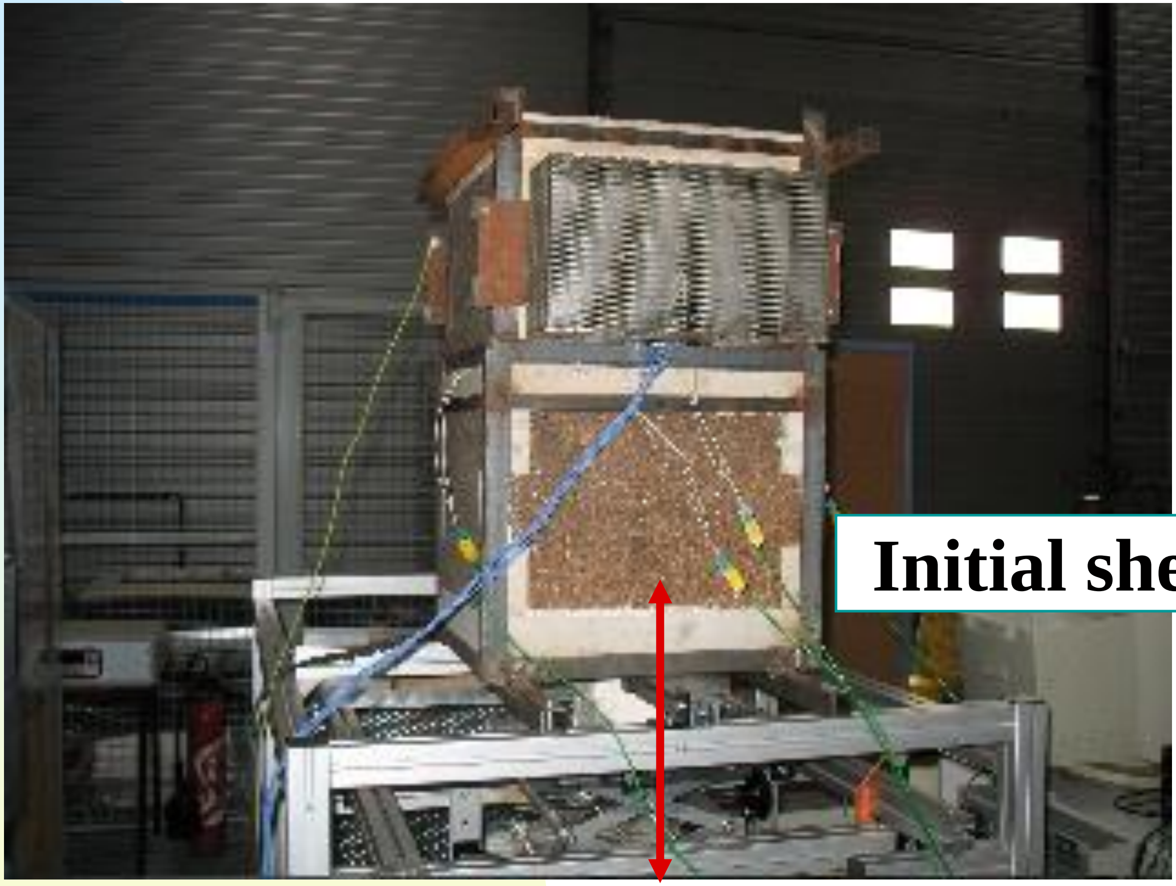
Thermal inertia evidence



Heat resistant die

Vitreous silica die

Sheet-Die contact experimental set up



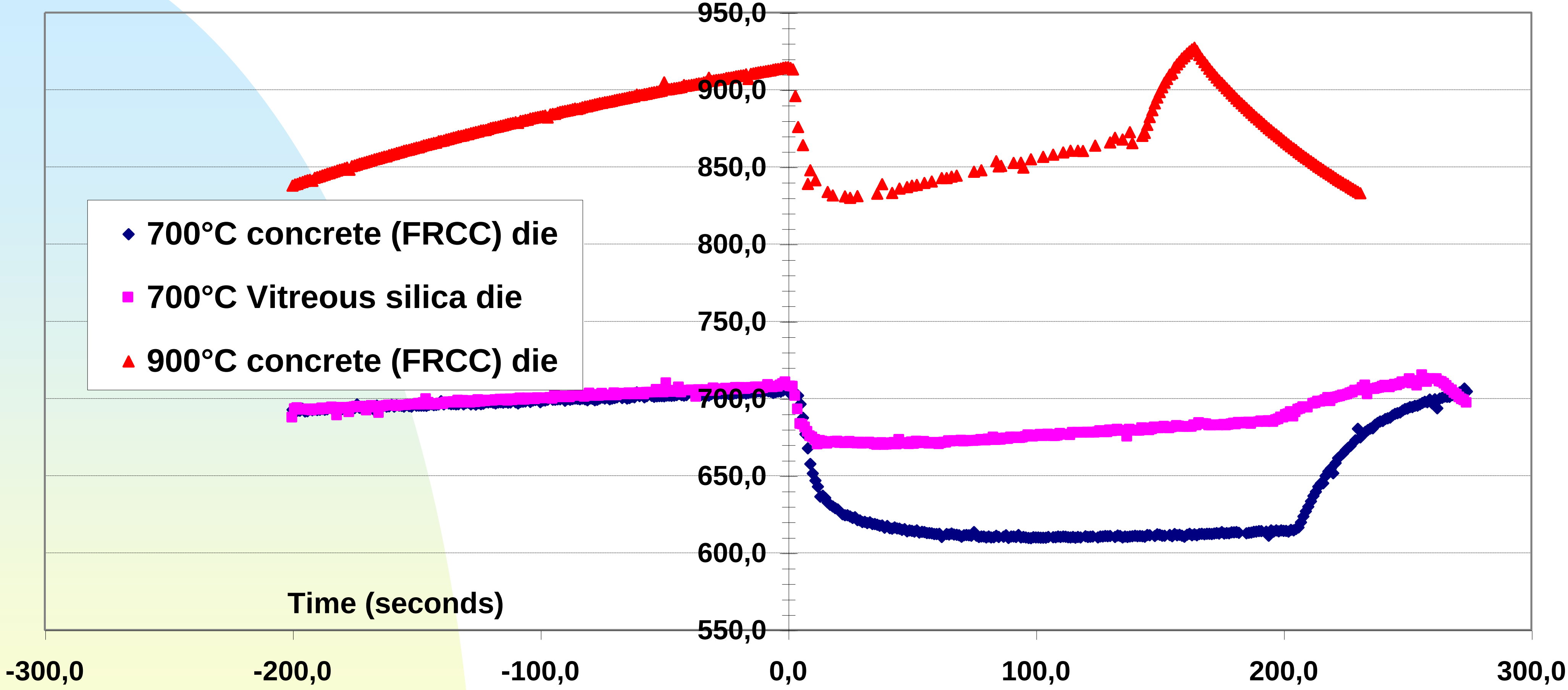
Initial sheet die gap : 35 mm

Die materials :

refractory reinforced concrete

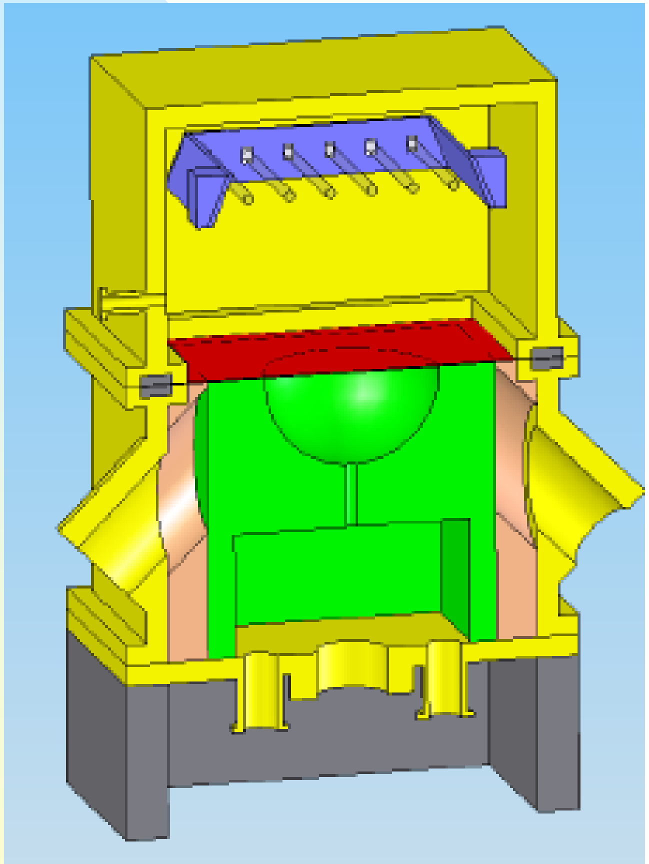
vitreous silica

Sheet temperature evolution during contact



- ✓ Mandatory : low conductivity material dies

IR-SPF Pilot preliminary design



- ✓ Individual heating element programming
- ✓ Exchangeable and removable die configurations
- ✓ CCD camera registration under free bulge forming
- ✓ IR camera sheet temperature measurement
- ✓ Clamping with mechanical presses
- ✓ Forming Pressure regulation

Conclusions

- IR-SPF seems a credible low cost forming route
  - Sheet heating with Infra-Red halogen lamps is realistic
    - Enough power available at maximum forming distances
    - Short heating times (lower than 30 min)
  - Using insulating dies, sheet temperature drop at die contact can be mastered
- In near future
  - Design and investment in a IR-SPF pilot equipment
  - Technological improvements (IR-Heating elements)
  - Research : heating optimization (numerical simulation)
- Open for collaborative research with industry
  - joint PhD work ? or other

Thank you for your attention