Fluid / solid heat transfers in the metallurgy cooling processes. Constellium approaches and issues

V. Duhoux,
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Constellium

Constellium At A Glance

Constellium is a **leader** in transforming aluminium into advanced solutions, and in **recycling**.

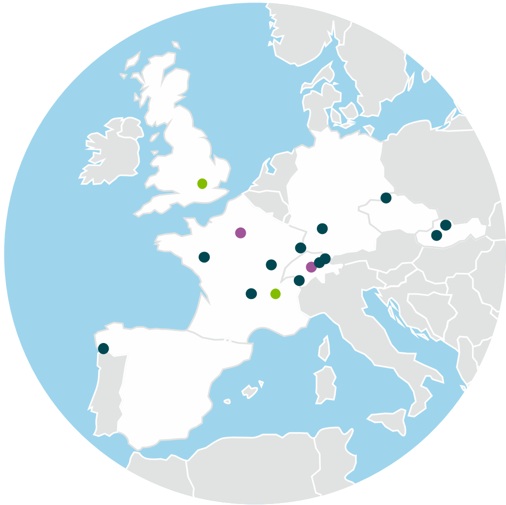
We manufacture **innovative**, lightweight, aluminium products in a responsible way, mostly for the **packaging**, **automotive**, and **aerospace** markets.

We are a **public company** listed on the **NYSE** (NYSE: CSTM).

100+	years of experience
~12,000	employees
25	production facilities
3	R&D centers
€7.2 bn	2023 revenue
32 bn	equivalent of used beverage cans (UBCs) recycled

Where We Operate

- Baltimore, MD
- Plymouth, Michigan, U.S.
- Bowling Green, Kentucky, U.S.
- Lakeshore, Ontario, Canada – JV
- Muscle Shoals, Alabama, U.S.
- Ravenswood, West Virginia, U.S.
- San Luis Potosí, Mexico
- Van Buren, Michigan, U.S.
- White, Georgia, U.S.



- Paris (HQ)
- Zurich
- C-TEC, Voreppe, France
- University Technology Center, Brunel University London

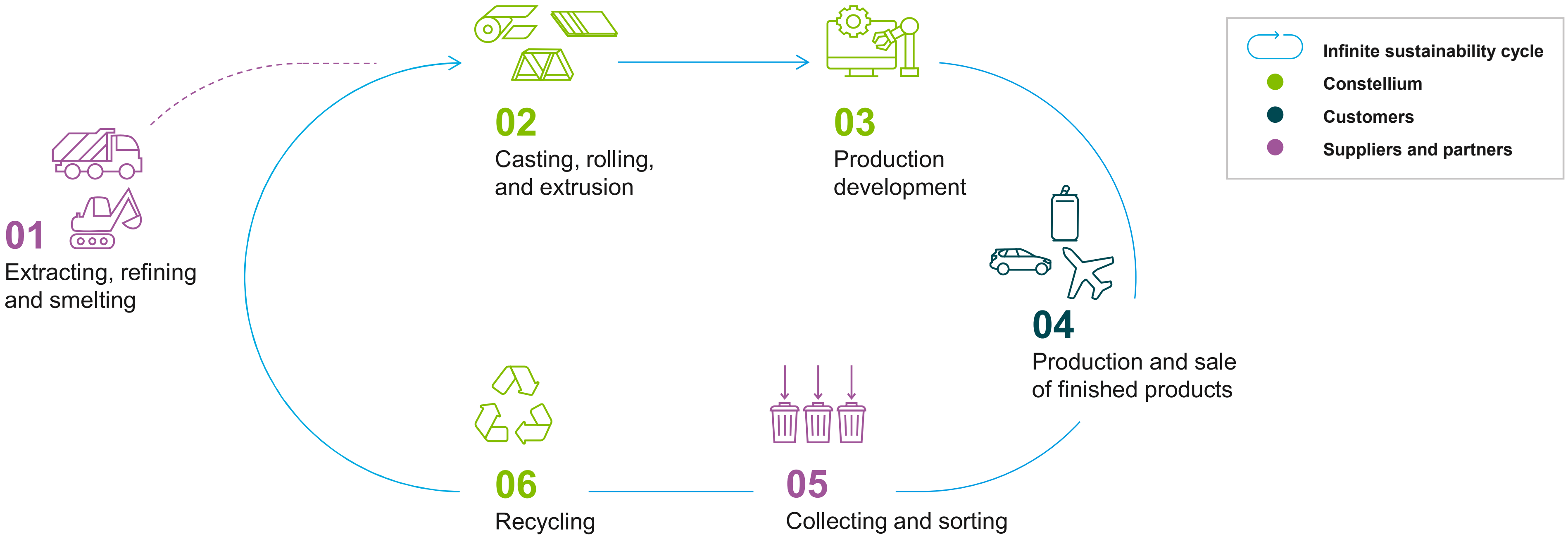
- Děčín, Czech Republic
- Dahenfeld, Neckarsulm, Germany
- Gottmadingen, Germany
- Issoire, France
- Levice, Slovakia
- Montreuil-Juigné, France
- Neuf-Brisach, France
- Nuits-Saint-Georges, France
- Singen, Germany
- Valais, Switzerland
- Vigo, Spain
- Žilina, Slovakia

- Changchun, China – JV
- Nanjing, China

- **3** Corporate Offices
- **3** R&D Centers
- **25** Manufacturing Plants

Our Contribution to the Aluminium Value Chain

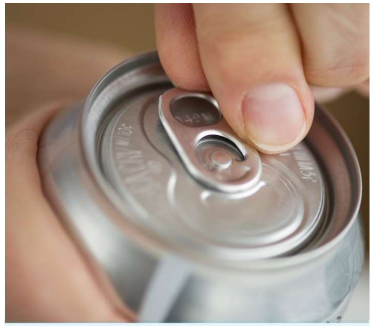
We transform aluminium into rolled and extruded products and automotive components, partnering with our customers to develop new and sustainable solutions. We recycle throughout the process to achieve **full circularity of the value chain**



Our Markets

Strong and **light**, and **fully recyclable**, **aluminium** is the **sustainable material of the future,** from soft drinks to cars and planes, and much more.

Packaging



Major global supplier of aluminium coils and sheets for beverage and food cans, wine and spirit closures, aerosols, luxury cosmetics and more

Automotive

Leading provider of aluminium rolled products and extrusion-based components, for lighter and safer cars

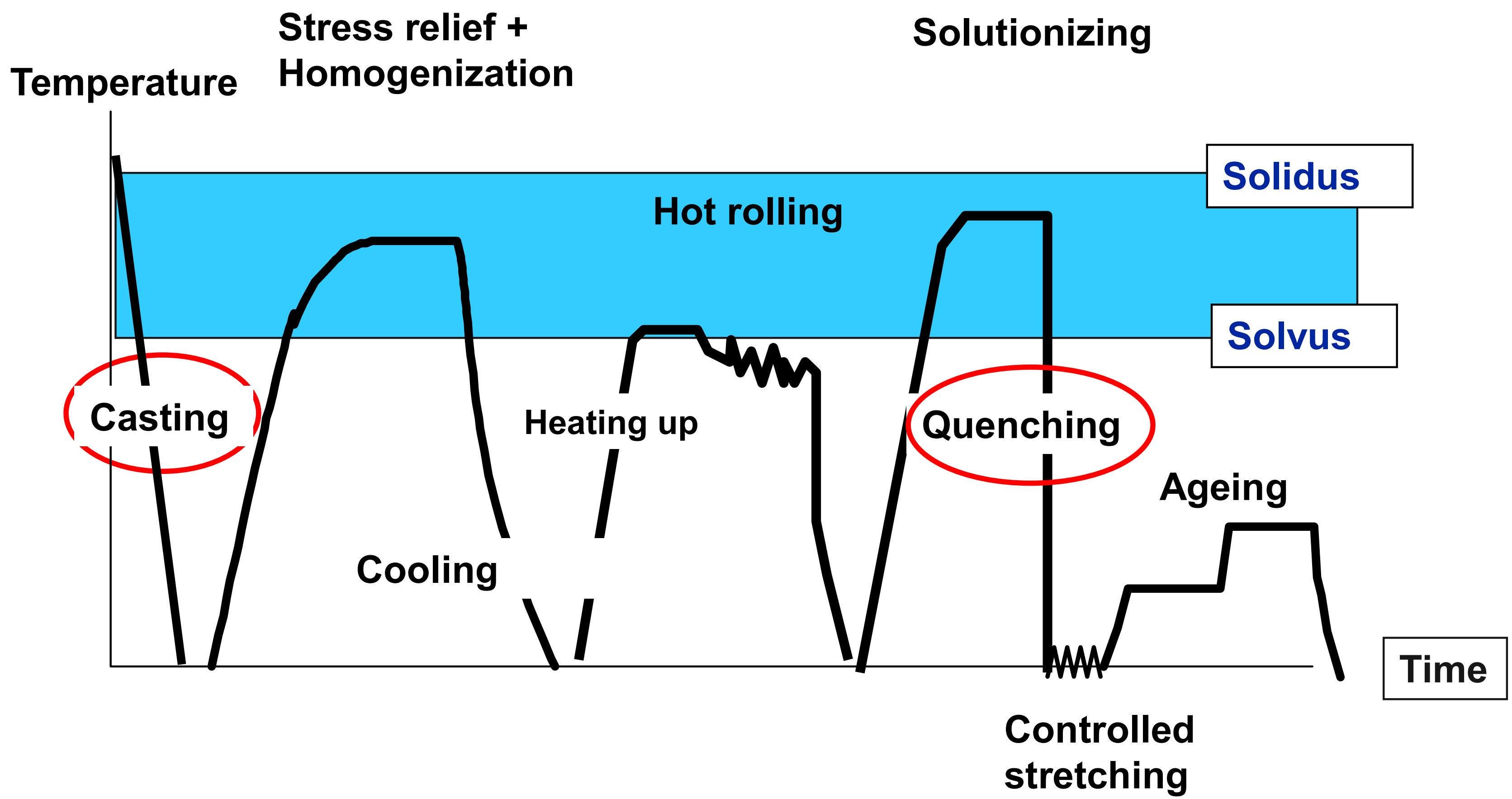
Aerospace

Key partner of aerospace manufacturers providing plates, sheets and extrusion solutions, and a leader in aluminium-lithium technology with Airware®

Specialties

Provider of **a wide range** of lightweight and high-performance solutions for the **transportation** and **industry** markets, and dedicated solutions for the **defense** market

Aerospace plate process
Many heats-up and cooling down



Cooling issues during semi-continuous Direct Chill Casting

Slab = cast product before rolling
Length 3.5 à 9 m
Width 1 à 2.5 m
Thickness 300 à 700 mm

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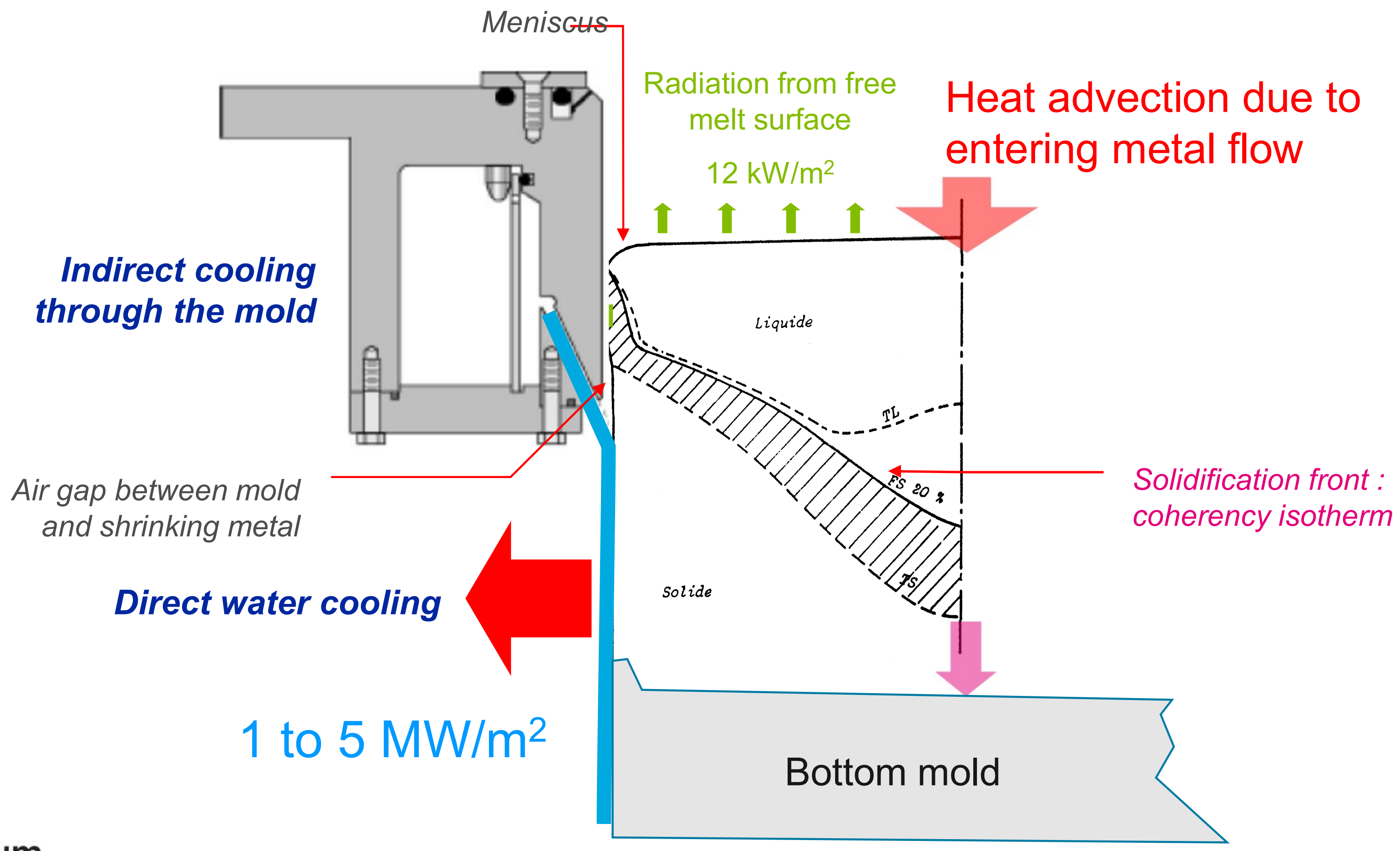
Casting process

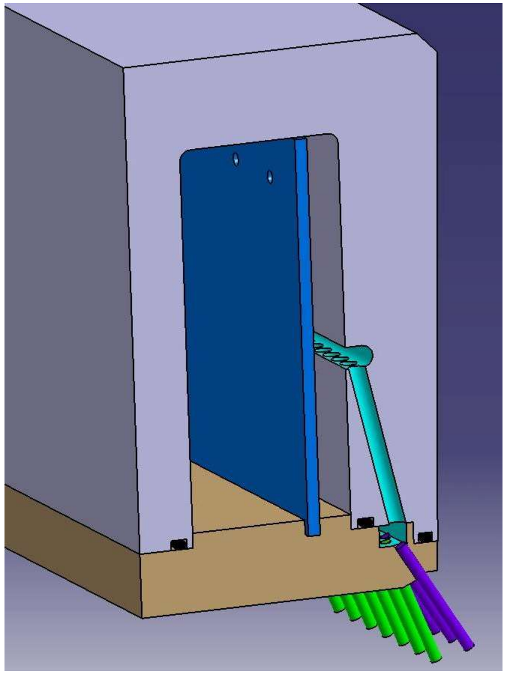


Thermo-mechanical distortion of the bottom of the slab during start-up: « butt camber »
[Ph. Jarry – TransInter 2019]

- High thermal gradient in the slab thickness during solidification when water cooling due to High HTC (high Biot number)
- Mechanical accommodation by distortion of the butt
- Potential issues : slab is blocked in the caster.
- **Solution : low cooling HTC during the start-up**
  - **Avoid boiling crisis regime (Leidenfrost temperature the lowest as possible)**
  - **Film boiling regime is requested**
  - **Low water flowrate**

Mold technologies for achieving film boiling cooling during casting start-up [Ph. Jarry – TransInter 2019]

- Aluminum industry uses water holes mold
- Water holes design should perform :
  - Low flowrates during start-up
    - → Low and constant extracted heat flux,
    - → Decrease Leidenfrost temperature, to maintain low heat flux as long as needed
  - High flowrates for steady state casting
  - Impact zone length sufficient to minimize vertical thermal gradient
    - Double line of holes
  - Jets angle should avoid rebounds, otherwise the cooling is not efficient in the streaming zone, especially during film boiling regime.



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Our ambition – our need:

We need to feed our transient numerical casting models (thermal – thermo-mechanical) with HTC boundary conditions so

We need to identify HTC laws, especially in film boiling regime.

HTC as a function of metal surface temperature

Taking into account:

- Water flowrate
- Jets angles
- Water temperature
- Water quality
  - Titre Hydrotimétrique (ions Ca^{2+} et Mg^{2+})
  - Titre Alcalimétrique Complet (ions OH^-, CO_3^{2-} et HCO_3^-)

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Experimental set-up at C-TEC quench test bench

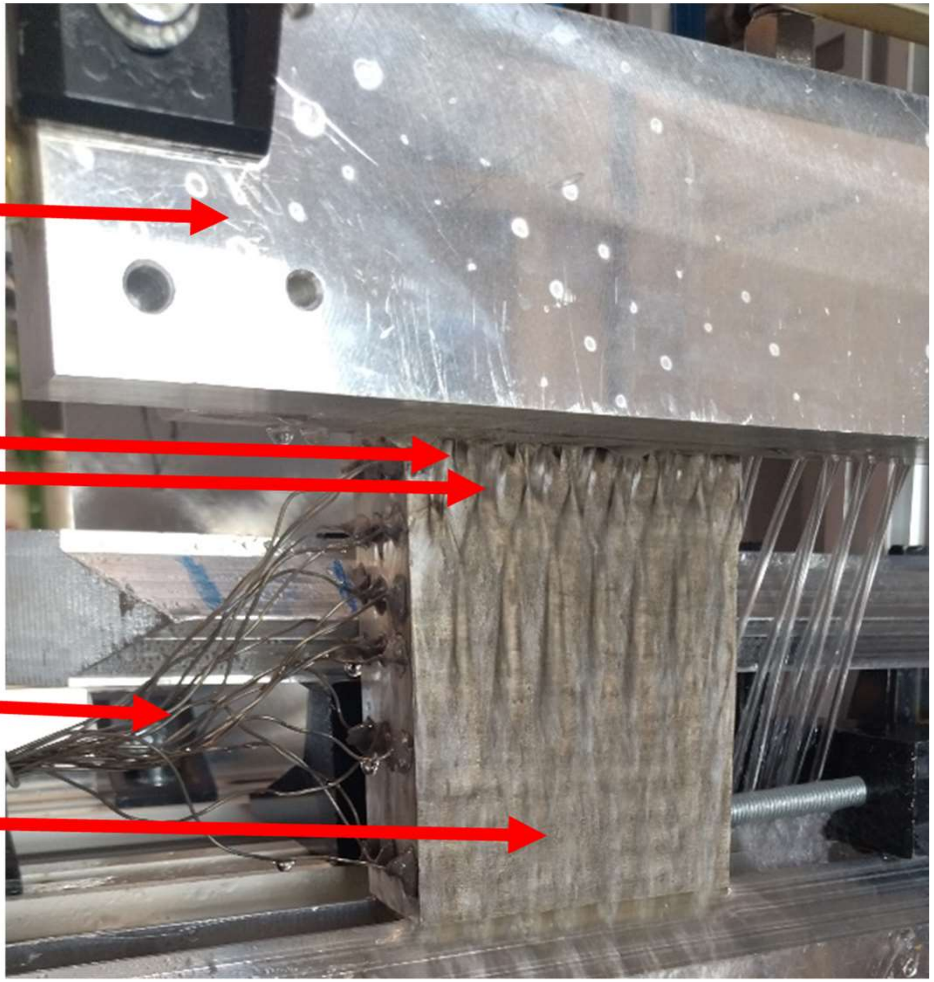
- Hot Al sample (500°C) is transferred from a furnace to the quench pilot:

Water cooling mold

Dual lines of water holes

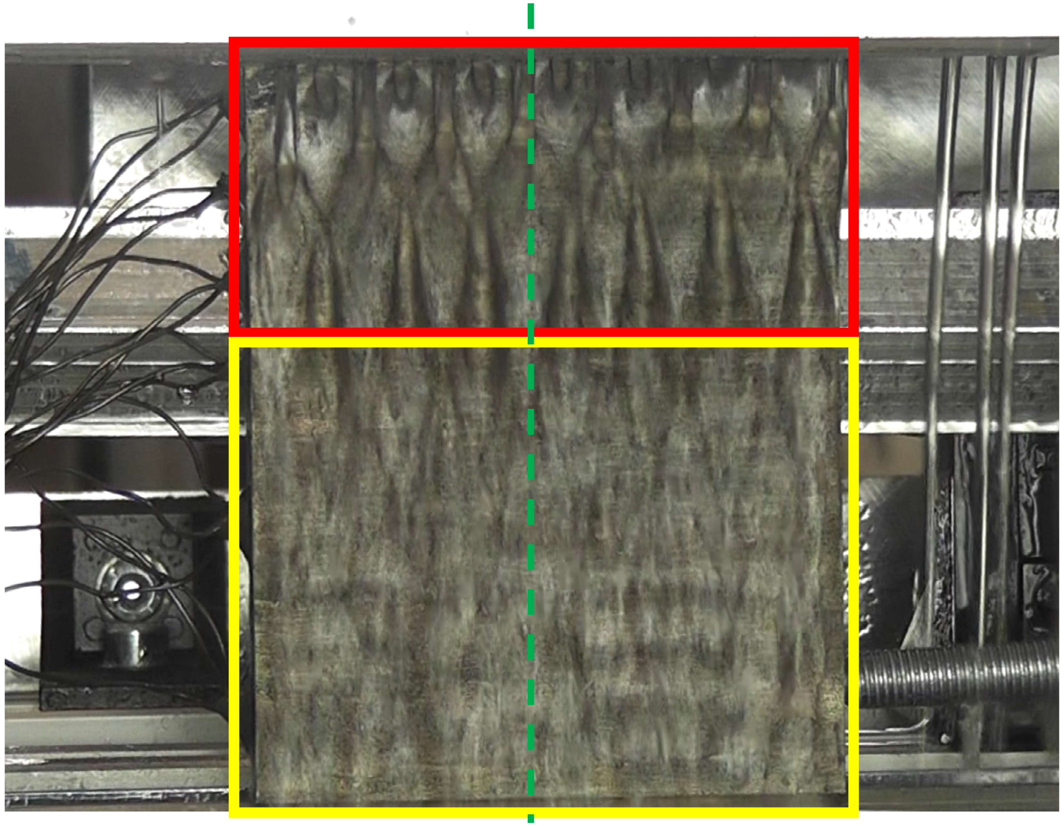
Thermocouples

Aluminum alloy sample
– As cast surface

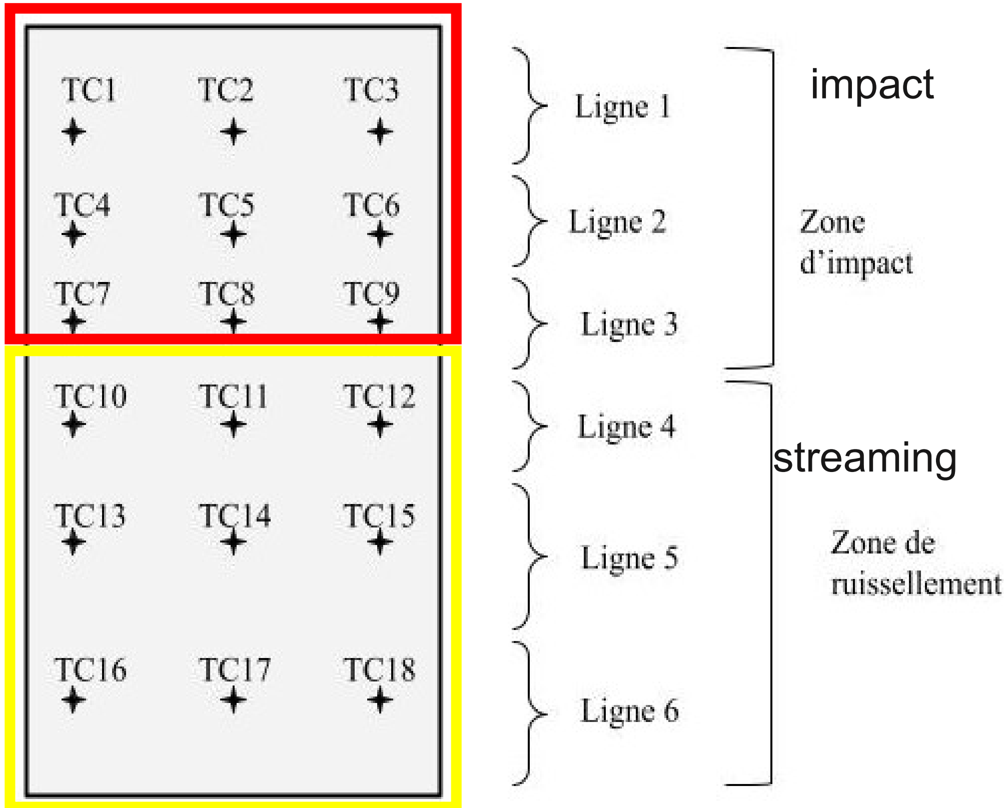


Protocole expérimental

- Thermocouples position, embedded in the sample



Front view of the sample in the quench test bench



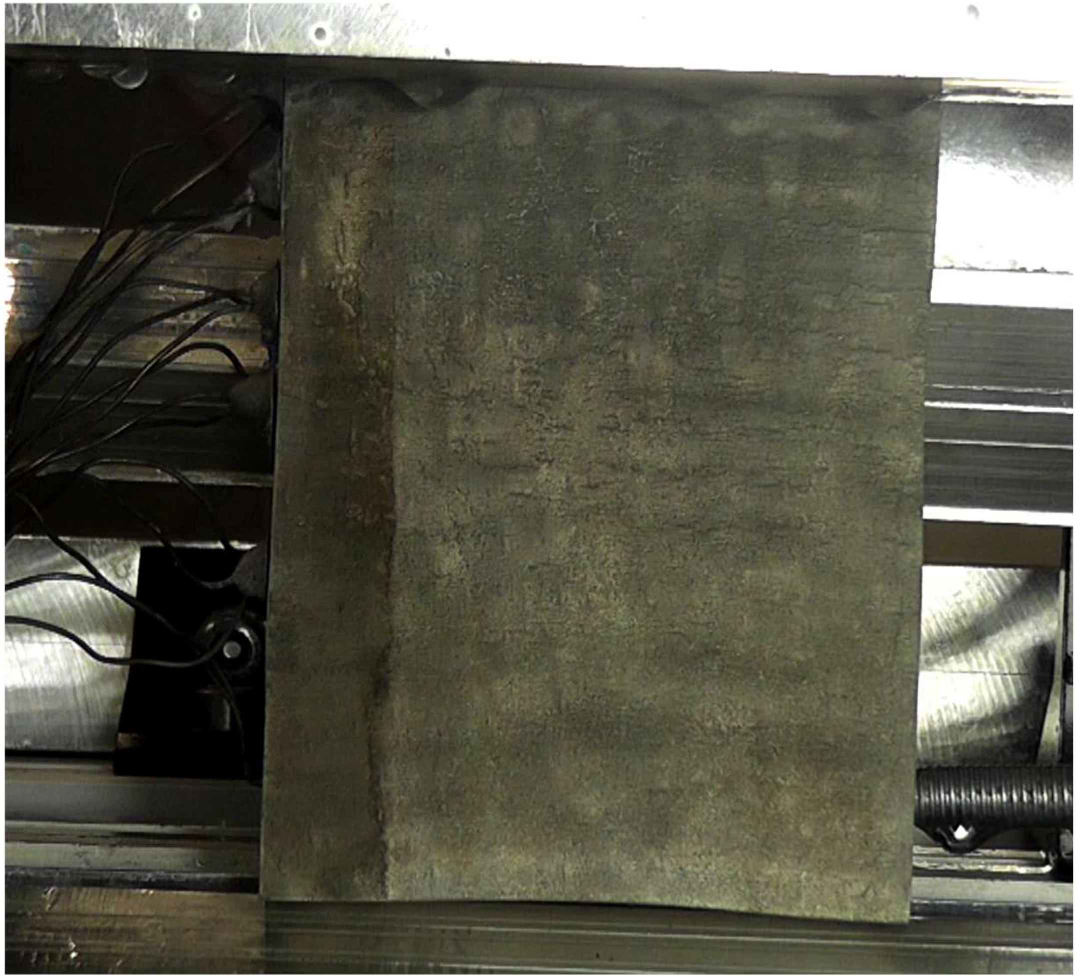
Left view of the sample with TC position

Rewetting front descent

Initial

+ 15s

Low flow rate – Influence of the surface aspect.
Oxidized surface due to quench repetition (Left), deoxidized (Right)



Inverse method

- 2D Direct resolution by finite differences, ADI solver

$$\rho C_p(T)\left(\frac{\partial T}{\partial t} + \vec{v}.\overrightarrow{grad}(T)\right) = div\left(\bar{\bar{\lambda}}\overrightarrow{grad}(T)\right) + P$$

- 2D Inverse by future steps méthod (« horizon glissant » / spécification de fonction) [1]

Minimisation de la fonction d'erreur J :

$$J(\varphi_1^{n+1}, \varphi_2^{n+1}, \ldots, \varphi_6^{n+1}) = \sum_{i=j}^{N} \sum_{j=1}^{ntf} (Y_i^{n+j} - T_i^{n+j})^2 + \alpha \sum_{l=2}^{6} (\varphi_{l-1}^{n+1} - \varphi_l^{n+1})^2$$

Avec :

- $\varphi_1^{n+1}, \varphi_2^{n+1}, \ldots, \varphi_6^{n+1}$: valeur du flux cherché au pas de temps n+1
- N : nombre de pas de temps
- ntf : nombre de pas de temps futurs
- Y_i^{n+j} : température mesurée par le capteur i au pas de temps n+j
- T_i^{n+j} : température calculée par le modèle direct à la position du capteur i au pas de temps n+j
- α : coefficient de régularisation spatiale permettant de pondérer l'écart entre deux flux voisins

[1] Techniques de l'Ingénieur BE 8.265, 2008, M. Raynaud

Our need (casting and quenching applications)

- Improve our ability to determine our cooling HTC laws with/w.o streaming, with a reduced confidence interval.

- Criteria : be able to discriminate the effect of water quality and metal surface aspect on HTC curves.

- Understand what are the physical and chemical levers at stake in the relationship between:
  - Water quality and extracted heat flux
  - Structure / shape / rugosity of the metal surface, and extracted heat flux

- Interaction of sprays (array of nozzles) ?